VALIDATION OF A SYSTEM FOR MONITORING WATER INTAKE AND RESTRICTING WATER INTAKE IN GROUP-HOUSED STEERS

By

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VALIDATION OF A SYSTEM FOR MONITORING WATER INTAKE AND RESTRICTING WATER INTAKE IN GROUP-HOUSED STEERS

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Abstract: The Insentec-RIC system was previously validated for the collection of water intake by Chapinal et al. (2007); however, this system has not been validated for the purposes of water restriction. The objective of this validation procedure was to evaluate the Insentec system as an appropriate tool for restricting water in beef cattle. A total of 239 crossbred steers were used in a 3 day validation trial which assessed intake values generated by the Insentec-RIC electronic intake monitoring system for both *ad libitum* water intake (n=122; BASE) and restricted water intake (n=117; RES). Direct human observations were collected on 4 Insentec water bins for 3 24-h periods and 3 12-h periods for BASE and RES, respectively. An intake event was noted by the observer when the electronic identification of the animal was read by the transponder and the gate lowered, and starting and ending bin weights were recorded for each intake event. Data from direct observations across each validation period were compared to total automated observations generated from the Insentec system. Missing beginning or ending weight values for visual observations occurred due to high bin activity and the observer was unable to capture the value before the monitor changed. To estimate the impact of these missing values, it was assumed that the missing beginning or ending weight was identical to that which was recorded by the Insentec system. Subsequent analyses will contain the data set containing missing values ($\mathrm{OBS}_{\mathrm{MISS}}$) and the data set with assumed missing values ($\mathrm{OBS}_{\mathrm{NOMISS}}$). Difference in mean total intake across BASE steers was 0.60 ± 0.11 kg $\mathrm{OBS}_{\mathrm{MISS}}$ (0.40 ± 0.09 kg $\mathrm{OBS}_{\mathrm{NOMISS}}$) greater for system observations than visual observations. The comparison of mean total intake across the three RES validation days was 0.84 ± 0.13 kg $\mathrm{OBS}_{\mathrm{MISS}}$ (0.44 ± 0.11 kg $\mathrm{OBS}_{\mathrm{NOMISS}}$) greater for system observations than direct observations ($P<0.001$). These results indicate that the system was capable of limiting water of individual animals with reasonable accuracy as compared to a restricted intake. The Insentec system is a suitable resource for monitoring individual water intake of growing, group-housed steers under *ad libitum* and restricted water conditions.

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CHAPTER I

INTRODUCTION TO LITERATURE

Water is arguably the most important nutrient a livestock producer can supply to an animal. Drinking water is often ignored in ration prediction and considered a readily available source. However, drought conditions throughout the United States have impacted water resources in some of the most influential beef producing states, and are encouraging further examination of water resources for agriculture. Furthermore, a growing world population has increased competition for water, forcing producers to evaluate water usage for their livestock.

The economic value of water is defined as the amount that a rational user is willing to pay, whether that be a publicly or privately supplied water source (Ward and Michelsen, 2002). Water gains economic value when the supply is limited and demand is high. Water scarcity results from an increase in market competition, typically exaggerated by population growth and urbanization. The global population is expected to increase to 9.6 billion people in the year 2050 (U.S Census Bureau, 2008) with a suggested increase in food production of 70% to satisfy the population increase (FAO, 2009). Competition for land and water supplies between urban development and agriculture production will likely increase. Beef cattle producers likely face an increase in accountability for water use as water scarcity continues to be a significant issue of debate.

Much of the foundational research on water intake and the effects of restriction on individual growing beef animals was conducted more than 60 years ago, and form the foundation for most of the general water intake guidelines in beef cattle. However, dramatic changes in genetic potential and management practices have occurred since the 1950s, and new technology for the measurement of water intake on large numbers of individual animals would suggest that these measures should be re-examined on a large scale.

Mechanized intake systems for cattle have been confirmed as effective and appropriate tools of measurement and therefore useful for studies collecting water intake data and redefining water intake prediction equations. It is crucial that producers are able to accurately estimate water requirements for their production system. Prediction equations currently in use to estimate water intake of beef cattle must fit the appropriate production stage, breed, and environmental conditions to assure the most accurate estimate. The information presented in this review of literature examines water intake of beef cattle, the interactional effects of abiotic factors influencing water consumption, and the validity of commonly used electronic systems for individual intake measurements.

CHAPTER II

REVIEW OF LITERATURE

WATER INTAKE ESTIMATES

Drinking water consumption and water in feed are the primary factors constituting water requirement as they comprise the largest portion of water demand. Body size, nutrition, and air temperature impact daily water requirement for an animal; therefore, understanding livestock water needs is crucial for effective management.

Prediction equations have been developed to estimate water intake (WI) in cattle. Numerous variables need to be incorporated in water prediction equations to best account for size, breed, and stage of production. For example, high-yield, lactating dairy cows have a higher water requirement due to the amount of water needed to produce milk (Winchester and Morris, 1956). Winchester and Morris (1956) are commonly credited with the first prediction equation for WI which utilized BW, ambient temperature and DM to predict intakes for cattle. Murphy et al. (1983) devised a prediction equation specifically for lactating dairy cattle which combined variables of dry matter intake (DMI), sodium intake (SODIN), milk produced (lb /day) (PROD), and weekly average minimum temperature (TMIN).

$$WI = 15.99 + 1.58\,(0.271) \times DMI + .90\,(0.157) \times PROD + .05\,(0.023) \times SODIN + 1.20\,(0.106) \times TMIN$$

The Murphy equation concluded that an additional 0.90 kg of water per kg of milk produced was consumed per lactating animal. This was similar to the preceding suggestion by Winchester and Morris (1956) of 0.87 kg of water per kg milk produced.

According to the equation developed by Winchester and Morris (1956), yearling feedlot cattle within a BW range of 363 to 498 kg were estimated to drink upwards of 81 kg per day when the ambient temperature is 32.2°C. Later, Hicks et al. (1988) expanded on the equation from Murphy et al. (1983) so that it was specific to feedlot cattle. This equation incorporated maximum temperature (MT) in place of mean minimum temperature, and also included precipitation (PP) and dietary salt (DS), as shown below:

$$WI\ (kg/d) = -18.67 + (0.3937 \times MT) + (2.432 \times DMI) - (3.870 \times PP) - (4.437 \times DS)$$

Although these equations are important in understanding variables that influence water intake, none are consistent across stages of production. For example, Meyer et al. (2006) observed that Na or K intake and mean MT did not impact water intake in growing bulls as was shown by Murphy et al. (1983) and Hicks et al. (1988). An evaluation of voluntary WI of 62 growing Holstein bulls determined average daily WI was 18 kg per animal and varied up to 78.7 kg per bull per day (Meyer et al., 2006). The comprised prediction equation for fattening bulls by Meyer et al. (2006) is as follows:

$$WI\ (kg/d) = -3.85 + (0.507 \times \text{Avg. ambient temp.}) + (1.494 * DMI) - (0.141 * \text{roughage of the diet, \%}) + (0.248 * \text{DM content of roughage, \%}) + (0.14 * BW)$$

The National Research Council (NRC) for beef cattle recommends the use of the Hicks et al. (1988) equation for individual predicted WI of feedlot steers. However, the NRC (2000) also suggests referencing tables constructed by Winchester and Morris (1956) for adjustments for production stage and gender (Table 2.1).

Total direct water consumption from beef cattle across all sectors has been estimated at 760 billion L of water per year (based on an inventory of 33.8 million beef cows and 5.7 million replacement heifers in breeding herds, 12 million animals on feed, and approximately 28 million animals fed on an annual basis). Beckett and Oltjen (1993) also estimated that 3,682 kg of water is required per kg of boneless meat for beef production. Furthermore, Beckett and Oltjen (1993) estimated that an increase in dressing percentage and boneless yield percentage from 62% to 67%, respectively, could result in a corresponding change in water requirement of the live feedlot animal due primarily by the physiological requirements needed for an animal of larger BW, frame size, or growth potential.

ABIOTIC FACTORS INFLUENCING WATER INTAKE

Factors that may impact maintenance, growth, reproduction, lactation, and respiration will subsequently alter an animal’s intake requirement and/or demand for water (Lardy et al., 2009). Winchester and Morris (1956) examined the effects of ambient temperature on water consumption. However, additional weather variables beyond ambient temperature have been examined to determine if their inclusion could increase the precision of water intake predictions. Hicks et al. (1988) observed that daily maximum temperature was positively related to WI and average daily precipitation was negatively related to WI. Because of the multitude of weather variables that appear to be important in predicting water intake, it may be more effective to examine indexes of weather variables. One such index is the temperature humidity index (THI) (Yousef, 1985). Temperature humidity index is calculated using air temperature and relative humidity, written as:

$$\text{THI} = (\text{Dry bulb temperature } ^\circ\text{C}) + (0.36 \times \text{dew point temperature } ^\circ\text{C}) + 41.2$$

Arias and Mader (2011) utilized data from 144 pen records across a 7 year period to assess the effects of environmental factors on total water intake (TWI) of cross-bred, finishing feedlot cattle. Daily water intake per animal was recorded using water meters and calculated by dividing the pen average water consumption by the number of animals per pen. Using simple and multiple regression analyses, Arias and Mader (2011) concluded that TWI increased in the summer months and cattle drank 87.3% more water when finished in the summer than compared to cattle finished in the winter. Trends between sexes were similar, so additional analyses were grouped among sexes. Arias and Mader (2011) also observed that the primary factors influencing TWI in feedlot cattle are mean ambient temperature, minimum temperature, and THI which contrasts the Hicks et al. (1988) prediction using daily max temperature. These results suggest that the response of cattle to dissimilar climatic conditions is highly variable and individualized (Arias and Mader, 2011).

In 2012, Sexson et al. utilized 8,209 individual animal records from 4 separate experiments to investigate the relationships between WI, DMI, and numerous weather variables. Daily WI averaged 37.14 ±11.58 kg per animal, which was recorded by water meters and determined by dividing the amount of water consumed per pen by the amount of animals present in each pen. Sea level pressure, humidity, and body weight (BW) were negatively related to WI while DMI, temperature, wind speed, and THI were positively related to WI. A multivariate model which evaluated the association between individual prediction variables and WI was also constructed. The results concluded that

BW, humidity, temperature, sea level pressure, and wind speed (with averages, high, low and squared values incorporated) impacted WI in yearling beef steers (Sexson et al., 2012). These results suggest that when predicting individual WI in feedlot cattle, multiple abiotic factors should be considered as potential prediction equation components.

Water Temperature

Water temperature can influence drinking behavior and intake volume (Lanham et al., 1986; Milam et al., 1986; Stermer et al., 1986; Baker et al., 1988; Huuskonen, Tuomisto, and Kauppinen, 2011). In warm climates where heat stress can be an issue, producer-regulated water temperature may be advantageous to performance of the animal (Andersson, 1985). Stermer et al. (1986) reported that volume of WI decreased as water temperature was decreased; however, water at 10°C had a greater reduction on overall body temperature and respiration rates when compared to water temperature at 28°C. Kelly et al. (1955) reported daily gains increased 0.15 kg when water was 18.3°C compared to 31.1°C in Hereford cattle. Research suggests that British breeds are more efficient and gain more weight when supplied water that has been cooled to 18.3°C rather than a non-controlled water temperature of 32.2°C (Lofgreen et al., 1975). Lofgreen et al. (1975) proposed that the mechanism for this increase in performance was a decrease in thermal heat load due to the cooler water, which lead to increased DMI and increased gain and efficiency. In cold environments, warm water intake (30 to 33°C) is greater than ambient water consumption (7 to 15°C), but there is no impact on feed intake or performance (Osbourne et al., 2002).

These results suggest that regulation of water temperature in hot environments can alleviate heat stress and positively impact animal performance. Regulation of ambient water temperature in cold weather environments resulted with an increase in WI by animals, but did not influence performance variables of DMI or ADG. Theoretically, it would be advantageous for a producer wishing to conserve water resources to shade water in the summer to decrease water consumption and increase performance level; however, this method may be more applicable to a small scale producer.

Water Quality

Water quality is an important factor that can affect voluntary intake, performance and animal health (Willms et al., 2002). Water quality analysis typically includes water properties such as salinity, hardness (calcium and magnesium levels), pH, algae, and nitrate and nitrite levels (Beede, 2005). When salinity is elevated, water intake increases until a point to which salinity level exceeds animal tolerance, and the desire to drink from the source will cease (Bagley, Amacher, and Poe, 1997). Numerous studies have been conducted which evaluate the effects of high-sulfate content in water on health and performance of cattle (Kandylis, 1984; Veenhuizen and Shurson, 1992; Drewnoski, Pogge, and Hansen, 2014), concluding that high- sulfate levels will result in decreased ADG and feed efficiency.

Furthermore, nitrate levels should be monitored but toxicity in drinking water is not common unless water sources have been contaminated by nitrogen fertilizer runoff (Wright, 2007). Recommended water quality measures are detailed in Table 2.2.

Beef cattle producers must frequently inspect water sources and evaluate water quality in order to reduce quality issues which can affect cattle health and performance. Poor quality drinking water decreases palatability and water intake, which ultimately decreases feed intake and subsequent performance (Lardy et al., 2009).

INFLUENCE OF HEAT STRESS ON WATER INTAKE

Thermal heat stress can significantly affect cattle performance and health (Mader et al., 2007; Koknanoglu et al., 2008) and ultimately decrease animal well-being. It has been reported that a combination of high temperature, high relative humidity, and low wind speed and high solar radiation can result in an increased cattle death loss. Feedlot cattle finished in the summer months are often subjected to periods of intense heat and humid conditions which impact individual water requirements (Hahn and Mader, 1997; Mader et al., 2006).

The metabolic activity needed to digest ingested feed can increase thermal stress by elevating the animal's metabolic heat load (Beede and Collier, 1986). An increase in total metabolic heat load is known to increase beef cattle water requirements and decrease DMI (NRC, 1996). In order to release body heat and decrease relative metabolic heat load, cattle utilize a mechanism known as evaporative cooling. Morrison (1983) found that cattle need to increase daily WI to compensate for the loss of water during the evaporative cooling process. Therefore monitoring animal well-being and alleviating heat-stress could assist in maintaining animal performance in environments which would typically have lower levels of performance and increased WI.

Mitigation Strategies for Heat Stress

Management strategies to decrease heat stress in feedlot cattle are often used in hot environments to prevent performance loss. Shade and sprinkling systems have shown to decrease respiration rates and body temperature, affirming the methods as appropriate mitigation strategies for decreasing heat stress in the animal (Morrison et al., 1973; Armstrong, 1994; Mader and Davis, 2004). In addition, limited or timed feeding methods prevent basal metabolic heat production during times of peak environmental stress (Carstens et al., 1989; Brosh et al., 1998). Mader and Davis (2004) examined the effects of combined and individual mitigation strategies on feedlot cattle and utilized water intake as a form of quantifying the effects of the strategies on the animals. Pen intakes were measured using a water meter and divided by the number of animals per pen. Treatments groups included a morning feeding regimen with no sprinkling (AMF/DRY), morning feeding regimen with sprinkling (AMF/WET), afternoon feeding regimen with no sprinkling (PMF/DRY), and afternoon feeding regimen with sprinkling (PMF/WET). Water intake for AMF/DRY was significantly higher and ranged from 26.95 to 38.79 kg/day throughout the 83 day trial. Treatment groups AMF/WET, PMF/DRY, and PMF/WET ranged from 26.99 to 36.17, 25.52 to 35.31, and 25.11 to 34.47 kg/day, respectively. Furthermore, there was higher gain to feed (G:F) efficiency and lower DMI from day 22 to 83 in heat stress mitigated treatment groups in comparison to traditionally managed cattle (Mader and Davis, 2004).

The ability to decrease or alleviate heat stress- related production loss lead to increased animal performance, reduced heat-induced mortality rates, and decreased water intake.

INFLUENCING WATER INTAKE THROUGH EXCRETION

Water is lost within the body through excretion of urine and feces, as well as through the lungs and skin as sweat. Water intake, ambient temperature, and physical activity will determine the volume of water excreted from the kidneys as urine. Urine production is partially controlled by vasopressin, an antidiuretic hormone which controls water reabsorption from the renal tubules and ducts. It has been observed that during water restriction, cattle will reduce urine volume and increase renal conservation (Balch et al., 1953; Weeth, Sawney, and Lesperance, 1967). When a diet is high in diuretic components like salt and protein, water requirement will increase (Weeth et al., 1965; NRC, 2001).

Water excreted through feces is determined by dietary composition of the ration. High- moisture feeds such as silage, green chop, or growing pasture will contribute more water to the body than low- moisture feeds (e.g., hay and dormant, winter pastures) and high-energy feeds will produce more metabolic water than low-energy feeds (NRC, 2001). Subsequently, energy dense diets will contribute more water in feces excretion. It has been reported that when allowed *ad libitum* access to water, heifers lost on average 6.8 kg more water per day in feces than in urine (Weeth et al., 1967). During periods of water restriction, it has been noted that reduction of water in fecal output was greater than compared to the water percentage reduction in urine (Horrocks and Phillips, 1961; Weeth, Sawhney, and Lesperance, 1967; Thornton and Yates, 1968). When heifers were deprived of water for four consecutive days, the amount of water lost in feces decreased more than the amount lost in urine (Weeth et al., 1967). This suggests that the regulation of fecal water output may be more variable than water loss in urine as a result of the diet of the animal.

WATER RESTRICTION EFFECTS ON DIGESTIBILITY

Bond et al. (1976) compared withdrawal of feed, water, and both feed and water for three different percent forage diets (0%, 33% and 88%) over 12, 24, 36, and 48 hour periods. Feed and water consumption varied between diets and water consumption was significantly reduced when steers were deprived of water when fed a high roughage diet (88%) but did not change when deprived of the high concentrate diet (0%). Overall, water deprivation caused a reduction in feed intake of approximately 47% across all diets.

Studies have shown that limited, or restricted water intake, of beef cattle can increase the digestibility of a ration (Larsen et al., 1917; Balch et al., 1953). When water is restricted, water economy adjustments (decreased rate of water excretion and reduced roughage intake) occur in the reticulo-rumen of the animal, favoring a water to DM ratio roughly equivalent to an animal that has unrestricted water intake (Balch et al., 1953). Balch et al. (1953) concluded that conditions in the ventral sac of the rumen are more favorable for the breakdown of crude fiber when water intake was restricted. Their results suggest that production of saliva increases with an absence of water, which results in favorable conditions for fermentation. Thornton and Yates (1968) further investigated the effects of water restriction on digestibility and confirmed that DM and acid detergent fiber breakdown increased when there was limited water intake. Their results also indicated that cellulose degradation in the ventral rumen increased during water restriction. This supports the findings of Balch et al.; however, it could not be concluded if the cause was due to an increase in production of saliva.

Burgos et al. (2001) investigated the ability of lactating dairy cows to cope with a sustained water restriction. Two experiments were conducted which compared *ad libitum* water intake to a 25% and 50% restriction of *ad libitum* water, over an 8- day duration. Daily feed intake was reduced, predominantly due to decreased meal size. Energy balance was not affected by restriction levels and higher digestibility of organic matter was noted. Although body weight declined at the onset of the restriction period, animals stabilized thereafter and feed intake became constant.

Water retention capacity of the rumen coupled with the suppression of food intake and increased digestibility allow ruminants to manage and survive periods of water restriction. Osmotic balance is stabilized when less feed is consumed during limited water intake, which demonstrates a balance between nutritional needs in the form of feed and osmotic regulation of bodily fluids. As suggested by Burgos et al. (2001), this homeostatic mechanism curtails the potential negative effects of dehydration to the animal.

Effects of Water Restriction on Carcass Characteristics

The effects of restricted feeding or fasting on carcass characteristics of feedlot steers has been thoroughly investigated (Hicks et al., 1990; Murphy and Loerch, 1994; Sainz et al., 1995; Rossi et al., 2001; Schmidt et al., 2005). Results suggest that restricted feeding of 5 to 15% below the prospective *ad libitum* feed intake during the finishing stage resulted in a reduced carcass quality grade of the animal (Gaylean, 1999). Programmed feeding methods which incorporate restricted feeding in the growth period and re-feeding strategies to optimize compensatory gain in the finishing stage have little effect on carcass quality grade (Gaylean, 1999). The impact of water restriction on carcass quality in beef cattle has not yet been explored. Jones, Rompala, and Haworth (1985) observed that pork color is slightly darker and carcass weight is decreased when swine are denied access to feed and water for 48 hours prior to harvest.

MEASURING INDIVIDUAL-ANIMAL WATER INTAKES

Early studies incorporated the use of individual pens for feed and water intake research. Feeding behavior and animal performance were negatively impacted when compared to animals housed in traditional management settings (De Haer and Mercks, 1992; Nielsen, 1995; Guiroy et al., 2001; Beatty et al., 2006). Lack of social interaction and competition for resources may induce irregular intake behavior. De Haer and De Vries (1993) reported that housing system had a significant impact on feed intake, and animals in individual settings had more frequent visits to the bin, which resulted in a larger number of smaller meals throughout the day. De Haer and De Vries (1993) suggested that boredom induced visits to the bin, whereas animals in group settings would be less prone to boredom due to social interactions with one another.

In the past, water intake studies which utilized pen-housed cattle which replicated industry practices were labor intensive or could only be done on a limited number of animals. Meyer et al. (2004) determined an average daily WI of lactating dairy cows to be 82 kg per cow with a range from 14 to 171 kg per day. Daily consumption rate was established by quantifying the mass of water in a tank before and after each individual drinking activity. This method of measuring was replicated by Meyer et al. (2006) using growing Holstein bulls, which also noted an extensive range between animals, 0 to 78.7 kg per day. Technology now exists which allows for monitoring of individual intakes under traditional management settings. Electronic feed and water intake systems such as the GrowSafe water intake system and the Insentec system allow for continuous data collection without subjecting an animal to individual housing or requiring intensive labor inputs.

Validation of Electronic Systems

The development of electronic systems utilizing radio frequency (RF) decreased labor intensity of bin monitoring and enabled the acquisition of feeding behavior information (Schwartzkopf-Genswein et al., 1999). The first formal validation of an RF system (GrowSafe Systems Ltd., Airdrie, AB) examined the duration frequency of feeding visits, feed bin attendance, and the relationship between feed bin attendance and feeding time (Schwartzkopf-Genswein et al., 1999). Data automatically collected from the system was compared to video surveillance data; determining a 6% error rate of the RF system for verifying presence of an animal. Of the 6% error rate, RF interference and antennae false readings were established as the principal causes.

DeVries et al. (2003) further examined the RF system for feeding behavior and summarized data as cow presence or absence as detected by both the automated system and video observations. Furthermore, they calculated predictability (likelihood a cow detected by the system was actually present), sensitivity (likelihood a cow present was actually detected by the system), and specificity (likelihood a cow that is absent was detected as absent from the system; Devries et al., 2003). Results indicated a highly correlated relationship between the GrowSafe system data and video recordings for meal measures and determined that predictability, sensitivity, and specificity were 96.5%, 87.4%, and 99.2%, respectively. As initially reported by Schwartzkopf-Genswein et al. (1999), external sources of RF interference accounted for the 12.6% variation in sensitivity and antennae read range accounted for the 3.5% decrease in predictability.

A similar electronic system (Insentec; Markenesse, Netherlands) can be utilized for continuous measurement of feed and water intake, and was initially validated by Chapinal et al. (2007). The water bins were programmed to fill to 40 kg and were automatically refilled after each animal visit, assuming the animal drank 1 kg or more of water. Chapinal et al. (2007) calculated sensitivity and specificity using direct observations and time- lapse video over a 2 day period and compared the number of visits to that recorded by the Insentec system. The electronic system and visual observations both recorded 819 animal visits to the feed bins and 274 animal visits to the water bins. Least-squares means for electronic observations and direct observations were identical for feeding visits and a 0.1 kg difference was reported for the water bins (5.6 ± 0.22 vs. 5.5 ± 0.22 per visit). Sensitivity was determined as 100% for the feed bins and 99.76% for the water bins. Incidents in which a cow displaced another at the bin without the barrier raising between cows, accounted for the slight decrease in sensitivity for the water bins. Specificity was determined as 100% for both feed and water bins. These values are higher than those previously reported of the GrowSafe system (Schwartzkopf-Genswein et al., 1999; DeVries et al., 2003).

The results from the system validations described determined electronic intake systems as useful tools for data collection of group-housed cattle. Electronic systems provide precise, individualized intakes which allow for the study of both feed and water intake and their associated behaviors.

Individual-Animal WI Estimates

To further the understanding of water consumption in cattle, studies have been conducted using the GrowSafe or Insentec system to measure individual water intake. Brew et al. (2011) examined the effects of sex on WI of growing beef cattle. Gross water intake per day and adjusted WI (WI/kg metabolic BW) were examined and reported that water consumption between growing bulls, heifers, and steers did not differ. Brew et al. (2011) reported a mean WI of 29.98 ± 8.56 kg/animal/day. Daily consumption reported by the GrowSafe system for growing beef cattle is close to or within range of values reported using pen data by Meyer et al. (2006) and Sexson et al. (2012). Additional studies examining WI in pre- and post-partum Holstein cows were studied by Huzzey et al. (2007) and Proudfoot et al. (2009) using the Insentec system. Huzzey et al. (2007) reported intake values of 37.8 ± 1.6 kg/cow/day one week pre-partum and values of 63.7 ± 2.9 and 82.4 ± 2.4 kg/cow/day at 1 and 3 weeks post-partum, respectively. Proudfoot et al. (2009) reported average daily water consumption per cow as 36.2 ± 4.4 kg at 24 hours pre-partum. In comparison to pen data of early lactating Holstein cows by Hicks et al. (1988), average daily WI was reported as 89.24 kg which is comparable to the 3 week post-partum value reported by Huzzey et al. (2007).

The comparison between electronic intake studies and previously reported estimates utilizing pen data demonstrate the value of technology in animal research. Individual animal variation was decreased using the electronic systems, as evident in the intake values listed.

CONCLUSION

Increasing water scarcity stimulated by prolonged drought conditions and an increasing population are necessitating better understanding of water intake and requirements in beef cattle. Water is used for every biological function in the body, and is influenced by multiple factors including stage of production, weather variables, water- temperature and water quality. Prediction equations have been established to estimate daily water intakes but much of the research in the scientific literature lacks large numbers of individual water intake records which would provide essential information on the variability of water intake in beef cattle. In addition, increased heat causes an increase in water requirements in cattle, which can create additional challenges for producers in water limited environments. The use of electronic intake systems could be utilized for generation of large numbers of water intake phenotypes and facilitate better understanding of the variation in water consumption between animals. Furthermore, restricted water intake studies serve as a proxy for reduced WI due to drought and climate change, as well as provide a way to study tolerance to environmental stressors in cattle.

Table 2.1. Estimated water intake levels for cattle from the NRC guidelines[a]

Water intake estimates, gallons

Temperature,°F

Weight,lb	**40**	**50**	**60**	**70**	**80**	**90**
Growing beef calves						
400	4.0	4.3	5.0	5.8	6.7	9.5
600	5.3	5.8	6.5	7.8	8.9	12.7
800	6.3	6.8	7.9	9.2	10.6	15
Finishing cattle						
600	6.0	6.5	7.4	8.7	10.0	14.3
800	7.3	7.9	9.1	10.7	12.3	17.4
1,000	8.7	9.4	10.8	12.6	14.5	20.6
Pregnant cows						
900	6.7	7.2	8.3	9.7	NA	NA
Lactating cows						
900	11.4	12.6	14.5	16.9	17.9	16.2
Mature bulls						
1,400	8.0	8.6	9.9	11.7	13.4	19.0
1,600+	8.7	9.4	10.8	12.6	14.5	20.6

[a] Winchester and Morris, 1956

Source: NRC, 2001. Adapted from NRC Nutrient Requirements of Beef Cattle, 7th revised edition.

Table 2.2. Recommended Water Quality Measurements for beef cattle.

Component	Range	Comments
Total Dissolved Solids (TDS), ppm	0-1,000	Animals which consume higher levels of salinity in water can experience diarrhea and refusal. Levels exceeding 7,000 ppm will result in health problems.
Nitrate, ppm	0-44	Values between 45 - 132 are safe if nitrate balance in feed is monitored. Values >132 ppm are potentially harmful and can result in death.
Sulfate, ppm	<600	Elevated levels can result in refusal and diarrhea
pH	5.0-9.0	Little is known about pH value on WI and cattle performance

CHAPTER III

VALIDATION OF A SYSTEM FOR MONITORING WATER INTAKE AND RESTRICTING WATER INTAKE IN GROUP-HOUSED STEERS

ABSTRACT

The Insentec-RIC system was previously validated for the collection of water intake by Chapinal et al. (2007); however, this system has not been validated for the purposes of water restriction. The objective of this validation procedure was to evaluate the Insentec system as an appropriate tool for restricting water in beef cattle. A total of 239 crossbred steers were used in a 3 day validation trial which assessed intake values generated by the Insentec-RIC electronic intake monitoring system for both ad libitum water intake (n=122; BASE) and restricted water intake (n=117; RES). Direct human observations were collected on 4 Insentec water bins for 3 24-h periods and 3 12-h periods for BASE and RES, respectively. An intake event was noted by the observer when the electronic identification of the animal was read by the transponder and the gate lowered, and starting and ending bin weights were recorded for each intake event. Data from direct observations across each validation period were compared to total automated observations generated from the Insentec system. Missing beginning or ending weight values for visual observations occurred due to high bin activity and the observer unable to capture the value before the monitor changed.

To estimate the impact of these missing values, it was assumed that the missing beginning or ending weight was identical to that which was recorded by the Insentec system. Subsequent analyses will contain the data set containing missing values ($\text{OBS}_{\text{MISS)}}$ and the data set with assumed missing values ($\text{OBS}_{\text{NOMISS)}}$. Difference in mean total intake across BASE steers was 0.60 ± 0.11 kg OBS_{MISS} (0.40 ± 0.09 kg $\text{OBS}_{\text{NOMISS}}$) greater for system observations than visual observations. The comparison of mean total intake across the three RES validation days was 0.84 ± 0.13 kg OBS_{MISS} (0.44 ± 0.11 kg $\text{OBS}_{\text{NOMISS}}$) greater for system observations than direct observations ($P<0.001$). These results indicate that the system was capable of limiting water of individual animals with reasonable accuracy as compared to a restricted intake. The Insentec system is a suitable resource for monitoring individual water intake of growing, group-housed steers under *ad libitum* and restricted water conditions.

INTRODUCTION

Livestock production covers approximately 45% of the earth's land surface, predominantly in environments too variable for other uses (Seijan et al., 2015). Climate change impacts agricultural productivity, specifically beef cattle production, due to its impact on vital natural resources. Water resources have become scarce in some regions due to periods of severe drought and elevated temperatures. These factors have increased pressure on existing water resources, and underscore the importance of evaluating water use efficiency in livestock production (Falkenmark and Widstrand, 1992). While drinking water for beef cattle is unimportant from a life cycle perspective (Ridoutt et al., 2012) it can be critical for an individual producer maintaining a cow herd under challenging environmental conditions. In addition, understanding water requirements of cattle during different stages of production will help improve animal production (NRC, 1996). Biological processes which maintain growth and performance of the animal are dependent on an adequate supply source of water (NRC, 1996). Water requirements of cattle are influenced by breed, size, and stage of production. Demand for water consumption can be influenced by milk production (Hicks et al., 1988), ration composition (Thornton and Yates, 1968; Utley et al.,1970; Brew et al., 201l), and environmental factors which include but are not limited to; numerous weather variables (Winchester and Morris, 1956; Arias and Mader, 2011; Sexson et al., 2012), heat stress ((Morrison, 1983; Hahn, 1995; Hahn and Mader, 1997; Mader and Davis, 2004; Mader et al., 2006; Koknanoglu et al., 2008); and water quality (Digesti and Weeth, 1976; Kandylis, 1984; Longeragan et al., 2001; Willms et al., 2002).

Previously, research examining water intake requirements of growing beef cattle has been limited to use of pen data or individually-housed research animals. However, group averages do not properly characterize the variability of intakes between animals, particularly those that may be due to genetics or are influenced by inter-pen dynamics and behavior such as bin competition. Furthermore, it has been reported that individual housing may induce irregular intake behavior and impact animal performance (De Haer and Mercks, 1992; De Haer and De Vries, 1993; Nielsen, 1995; Guiroy et al., 2001; Beatty et al., 2006).

Relative to feed intake trials, very few large-scale water intake studies for beef cattle have been performed. Early research has shown that limited, or restricted water intake, of cattle can increase dry matter digestibility (Larsen et al., 1917; Balch et al., 1953; Phillips, 1960; Thornton and Yates, 1968; Burgos et al., 2001). Burgos et al. (2001) examined the effect of chronic restriction of water over an eight day period and concluded that body weight and intake declined at the onset of the restriction period, but stabilized after day three. These findings suggest that cattle have the ability to acclimate to limited intake of water and stabilize performance under restricted conditions. The effects of water restriction on growth and performance over an extended period of time is unknown, as limitation of individual water intake was time and labor intensive.

The Insentec Roughage Intake Control (RIC) system (Insentec, Markenesse, the Netherlands) provides researchers with the ability to collect individual feed and water intakes in order to characterize water efficiency phenotypes in cattle. Chapinal et al. (2007) validated the electronic system using direct observations and time-lapse video data of *ad libitum* feed and water intake to confirm cow identification, presence at the bin and per visit intake values compared to data recorded by the system. The Insentec system was determined to be a useful instrument for monitoring individual intakes of group-housed cattle due to the strong correlation ($R^2 \geq 0.99$) between direct observations and automated data. Specificity for both feed and water bins (100%) and sensitivity for cow identification in the feed and water bins (100 and 99.76%, respectively) was also noted. However, to date there has been no data published which validate the system for monitoring restricted intake for feed or water.

The objective of this study was to validate water intake for animals provided water *ad libitum* and for animals which were restricted to a daily allotment of water utilizing direct human observations and automated intakes collected by the Insentec electronic RIC system.

MATERIALS AND METHODS

Observed intakes were collected for two separate validation periods that evaluated steers which had *ad libitum* access to water (BASE) and steers which had restricted access to water (RES). Animals were housed at Willard Sparks Beef Research Center (WSBRC) at Oklahoma State University (OSU) in Stillwater, OK. The Oklahoma State University Institutional Animal Care and Use Committee approved all procedures used in the study.

The BASE validation period utilized a subsequent group of 122 steers (mean body weight of 318.1 kg) which were enrolled in a 70 d *ad libitum* water intake trial during the time when visual observations were collected. Prior to the onset of the RES validation, RES steers underwent a 70 day period of *ad libitum* water intake to establish baseline measurements and a 35 day period of gradual step- down to restricted water intake. Validation observations were collected on three days within a 35 day period where water intake was restricted to 50% of each individual animal's baseline water intake. Daily restricted water allotment averaged across all steers was 16.3 kg during the validation period and average BW was 498.2 kg. Water content of the ration was not accounted for within this study.

Steers were fed a total mixed ration (TMR) consisting of 12.23% rolled corn, 60.12% sweet bran, 23.56% prairie hay, and 4.09% supplement mix on a DM basis. Feed was delivered daily at approximately 0730 and 1330 h and 0730, 1130, and 1330 h for BASE and RES cattle, respectively. Diet remained consistent between groups and feed was provided *ad libitum* throughout the duration of the experiment. Animals were owned by individual producers and managed within the feedlot by OSU personnel.

Study Design

All animals were blocked by body weight (low and high) and assigned to one of four pens (12.2 x 30.5 m). Each pen contained 186.5 m^2 of covered area which could be utilized for shade by the animals. Each pen contained six Insentec feed bins and one water bin which were equal in size and width. For the purposes of this study, visual observations were focused on the water bin within each pen.

An electronic identification (eID) tag (Allflex, Europe (UK)) was assigned to each animal and was programmed into the RIC system to allow each individual animal access to the feed and water bins. An electronic antenna detects the eID when an animal approaches, and the head gate lowers, allowing access to the bin. The system records eID number, bin ID, initial and ending weight of the bin, and the entry and exit times for each intake event. Duration and volume of intake is calculated for each visit. Visual identification was linked to eID number which permitted visual monitoring by individual observers.

Bin settings

Each water bin is 1.00 m wide, 0.75 m high, and has a depth of 0.84 m. The holding capacity of water for each bin ranges between 35 to 40 kg. Water bins were programmed to hold 35 kg of water during the baseline period, and total water level would exceed the programmed fill level slightly due to the flow rate of water at the facility. Each water bin was programmed to have a 40 second time delay and a differential (DIFF) setting of 0.5 in order to allow sufficient time for bins to refill and weights to stabilize before allowing another animal entry. Previous studies (Chapinal et al., 2007) have noted that water bins refilled when greater than 1 kg of water was consumed. However, we noted that water bins refilled only when the final weight was less than the programmed fill level for that bin.

Because the RIC system does not provide the ability to continuously monitor intakes and expel animals that have reached their allotment, each water bin was programmed to hold 5 kg of water during the RES period, which places an upper limit on potential over-consumption of water. This setting allowed tighter control over daily restriction intakes for each animal. Due to the flow rate of water at the facility, total water level in each bin would slightly exceed the programmed fill level by approximately 1-2 kg during the RES period. Bin settings were identical to those utilized during the baseline.

Data Collection

Program and bin settings were confirmed for each bin prior to each validation day. Visual intake observations were manually paired with automated intake events recorded by the RIC system for the same time period. The RIC system records IDs and can capture small bin weight fluctuations even if the gate has not descended, so visits recorded by the RIC system that did not have a corresponding visual observation were utilized.

During the baseline period, trained observers began monitoring each individual water bin immediately following the daily reset of the intake system at 0000. Observers recorded the visual ID tag of the animal each time the gate descended to allow the animal access to the bin. Initial and final weight of the bin was recorded using the display readout on the RIC monitor along with the time (to the nearest minute) that each animal entered and exited the system. One observer was utilized per set of adjacent water bins to record intake activity. Visual observations were conducted for 24 h for three separate days during the BASE period, with the exception of day two, where observations were only conducted for 23 h due to daylight savings time impacting the reset of the program one hour prior to the conclusion of the validation. There was a four day period between day one and two and a three day period between day two and three.

During the restriction period, trained observers recorded intakes under the same protocol followed during the baseline. From the hours of 0000 to 0200, one observer per bin was present to record intake activity as competition for water bin space was considerably higher than the BASE. Intake activity lessened after the first few hours of observation as cattle reached their daily water allotment and the number of observers was reduced to one observer for each pair of water bins. Visual observations continued until all animals reached their daily allotment (approximately 12 hours). Visual observations were recorded towards the end of the 35 day restriction period for three days, with a five day period between day one and two and a three day period between day two and three.

Data Analysis

All statistical analyses were conducted with SAS software (SAS Institute, 2004). Direct observations by day were analyzed for RES and BASE groups. Frequency of electronic system readings or ‘checks’ (which all have zero length and intake) were quantified using PROC FREQ and then removed from the data set. Daily total intake by animal for each three day observation period was computed using PROC MEANS. Significant differences between INS and OBS intakes were declared using a $P<0.05$. Total daily intake generated by the automated system across all animals for each three day period was compared with total daily intakes recorded by visual observation using PROC TTEST. Insentec total daily intake (INS) and observed total daily intake (OBS) were compared for each animal using PROC GLIMMIX in order to test whether significant differences were noted for specific animals. Difference between INS and OBS was used as the dependent variable within the model statement, which also included animal and day as fixed effects and residuals as the random effect. A regression, utilizing INS intake for each three day period as the dependent variable and OBS intakes as the independent variable was performed to evaluate the coefficient of determination. The strength of the relationship between INS and OBS intakes during RES and BASE periods were examined using a Pearson correlation, as well as the relationship between restriction intakes and the restriction intake goal.

RESULTS AND DISCUSSION

The Insentec system generated on average 604 and371 system checks for the BASE and RES validation periods, respectively. System checks were defined as records with eID of 0, visual ID of 0, and intake less than or equal to 0. Within the BASE data set, the system recorded 8 instances in which there was a visual ID of either ‘1’ or ‘999’ with a corresponding dummy eID attached to the recorded episode. These dummy IDs were programmed into the system for troubleshooting purposes, and were removed from the dataset. On four additional occasions during the RES validation, an erroneous EID (one that was not assigned to any steer) was attached to the system generated visual ID of ‘0’. There were an additional 9 instances in which the system recorded intake for visual ID 0, which ranged from 0.1 kg to 0.8 kg, but was not assigned to an animal in the dataset. Even though this erroneous information was recorded in the system, these records are not problematic from an analysis standpoint because they are generally zero and are not assigned to valid animals within the study, so these records can be easily filtered during data processing.

BASE period

The RIC system generated 984, 775, and 931 records for day one, two, and three, respectively. Of these observations, 54, 15, and 29 were associated with an intake of 0 kg, and did not pair with any recorded visual observations. When the 0 kg intake values without visual confirmation were removed from the observations, a total of 930,760, and 902 observations were noted for day one, two, and three, respectively, with a total of 2,592 observations for the entirety of the BASE period. Visual observation records totaled 920, 756, and 882 for day one, two and three, respectively. An overview of records generated by the system and those recorded by visual observers can be found in Table 3.1. Mean intake of unpaired observations across the three day period was 1.06 ± 0.24 kg. Approximately 0.3% of paired observations across all three days did not have a calculated OBS intake due to a missing observation for beginning weight or ending weight of the bin. This value is substantially lower than in the RES period, because bin demand at any given time was far lower. Because missing visual observations could not be verified with video recordings, the true number of unsubstantiated records is likely much lower. Because these missing values tended to be large, in subsequent analyses for the BASE period, the original values will be presented ($\mathrm{OBS}_{\mathrm{MISS}}$) and the values corrected for these known missing observations will be provided in parenthesis immediately following the original values and tagged as $\mathrm{OBS}_{\mathrm{NOMISS}}$.

We noted 11 instances in which a steer displaced another without the barrier rising or the system detecting the interruption. Sensitivity rate of the BASE period utilizing visual observations only was 99.6%, which was slightly higher than the sensitivity noted in the RES period and in agreement to what was reported by Chapinal et al. (2007); (99.8%).

During the BASE validation, 5 animals were removed from the study after completion of day one of the validation period. Comparison of INS and OBS intakes for each day are reported in Table 3.2. INS intakes were, on average, 0.60 ± 0.11 kg ($P<0.001$) (0.40 ± 0.09) greater than OBS intakes. Total average INS and OBS intakes were 25.2 ± 0.45 and 24.6 ± 0.46 kg $\mathrm{OBS}_{\mathrm{MISS}}$ (24.8 ± 0.45 kg $\mathrm{OBS}_{\mathrm{NOMISS}}$), respectively (Table 3.3). Daily total

OBS intakes were over estimated by a maximum value of 7.5 kg and underestimated at a maximum value of 11.7 kg $\mathrm{OBS}_{\mathrm{MISS}}$ (6.7 kg $\mathrm{OBS}_{\mathrm{NOMISS}}$). We did note one animal that did not have intakes recorded for day one of the BASE period, and this result was confirmed by the visual observations. The animal did access the water bin (the gate lowered) and it was confirmed by both the INS and OBS observations, but the animal did not drink.

There was no bias indicated by the difference in mean total intake for particular animals ($P>0.05$). The Pearson correlation coefficient between INS and OBS intakes was 0.99 ($P<0.001$). The coefficient of determination for INS and OBS intakes was $R^2=0.97$ $\mathrm{OBS}_{\mathrm{MISS}}$ ($R^2=0.99$ $\mathrm{OBS}_{\mathrm{NOMISS}}$) and the intercept was greater than zero ($P<0.001$) (Figure 3.1). These values are similar to results reported by Chapinal et al. (2007), which demonstrates that the systems were operating similarly in different locations and that reductions in accuracy of data collection during the restriction period are a result of changes in programming and animal behavior specific to water restriction, and not a bias in the system itself.

RES Period

The Insentec system generated 961, 1007, and 1081 records for day one, two, and three of the RES period, respectively. Of these observations, 405, 410, and 436 records for day one, two, and three were associated with an intake of 0 kg, and did not pair with any recorded visual observations. These values are likely a result of the system's ability to register a visit whenever the EID is read by the transponder, even if the gate does not allow entrance. These visits would not have a corresponding visual observation in our dataset, because only visits that resulted in the gate descending were recorded by observers. As expected, the frequency of this occurring is much greater in the RES period due to cattle visiting the water bin after their allotment had been reached in an attempt to access the bin. When the 0 kg intake values without visual confirmation were removed from the observations, a total of 556, 597, and 645 observations were noted for day one, two, and three respectively. Visual observation records totaled 414, 474, and 504 for day one, two and three, respectively. An overview of records generated by the system and those recorded by visual observers can be found in Table 3.2. Mean intake values of unpaired, missing observations during the RES observation period across the three d period was 0.35 ± 0.06 kg. The true intake values for missing observations is likely considerably less, because human observers were utilized and some intake events were likely missed, especially during times when bin demand was high. It should be noted that records for one pen during day two of the RES period were removed due to a mechanical malfunction with the water bin in that pen.

Visual observation totals were compared to those recorded for the entire 24 h period reported by the Insentec RIC system. Initially, mean differences between OBS and INS intakes showed INS intakes were 0.48 ± 0.18, 0.98 ± 0.26, and 1.10 ± 0.23 kg higher on day one, two, and three, respectively. When calculating the difference between individual visual intakes and total 24 h intakes (INS- OBS), differences in daily totals differed from 10.6 kg to -6.6 kg. OBS intakes were over-estimated a maximum of 6.6 kg and underestimated a maximum of 10.6 kg. Visual observations that were missing either a beginning or ending bin weight seemed to be a primary cause of the differences between OBS and INS intakes on individual animals. Approximately 3.0% of paired observations across all three days did not have a calculated visual intake due to a missing observation for beginning weight or ending weight of the bin by observers. To estimate the impact of human error on differences between INS and OBS intakes, observations missing beginning or ending weights in the OBS dataset that paired with a corresponding INS intake event were assumed to have a starting or ending weight equal to that recorded by the INS system and mean differences, by day, were re-calculated. Mean differences between INS and OBS intake values were greatly reduced to an average of 0.10 ± 0.11, 0.70 ± 0.26, and 0.45 ± 0.15 kg for day one, two, and three, respectively. The difference between total visual intakes for each animal and total 24 h intakes (INS- OBS) was reduced to 8.2 kg to -6.6 kg. Although some relatively large discrepancies exist between INS and OBS intakes, some of these are likely explained by additional human error for which we cannot account. When human error that can be accounted for was mitigated, we were successful in reducing the SE in two out of three of the days and mean differences decreased in all occurrences. Because these missing values had a large impact on the data, in subsequent analyses for the RES period, the original values will be presented (OBS_{MISS}) and the values corrected for these known missing observations will be provided in parenthesis immediately following the original values and denoted as OBS_{NOMISS}. A summary of these results can be found in Table 3.4.

The comparison of INS and OBS intakes (calculated as INS minus OBS intake) for each animal across the three day period showed that INS intakes were 0.84 ± 0.13 kg OBS_{MISS} ($P<0.001$; 0.44 ± 0.11 kg OBS_{NOMISS}, $P<0.001$) greater than the OBS intakes. Although INS intakes were higher than OBS intakes, steers were generally restricted slightly more than the intake goal (Figure 3.2.). Mean difference between intakes and the targeted restriction level showed that animals received 2.5 ± 0.54 kg and 3.0 ± 0.57 kg OBS_{MISS} (2.1 ± 0.6 kg OBS_{NOMISS}) less than the designated restriction amount for INS and OBS intakes, respectively (Figure 3.2). It should be noted that steers were initially programmed in the system between 2 to 3 kg lower (approximately half of the bin fill level) than their restriction intake goal because animals are not ejected from the system upon reaching their intake goal. Thus, an animal that has a goal restriction intake of 16 kg will still be allowed in the system one more time (and can drink the entire amount of water in the bin) if their previous intake events resulted in 15.9 kg of intake. We noted animals exceeded their allotment during the final visit to the water bin during the RES period for 10, 17, and 16 animals on day one, two, and three, respectively . Slight under-programming and decreasing the volume of water in the bin helps to control for these instances so that the mean intake across the 35 day restriction period should be approximately equal to the goal intake.

To quantify the number of INS records likely due to bin weight fluctuations when the gate was raised, daily intakes for RES animals until their daily allotment had been reached were calculated. Any remaining observations after the presumed allotment was obtained were totaled and counted as error. Total intakes after the time when an animal had met or exceeded the daily allotment showed additional mean total intakes per animal of 0.30, 0.43, and 0.79 kg for each day. Minimum and Maximum non-zero total daily intake for an individual animal after the animal’s allotment had been reached were 0.1 and 2.4 kg, respectively (Table 3.5). Chapinal et al. (2007) reported small negative values (-0.1 kg) recorded by the Insentec water bins which they posit may have been due to wave motion within the bin. In our study, we noted slightly higher discrepancies that seem to be due to fluctuations in the bin weights as a result of high levels of wind and animal contact rather than wave motion.

We noted 10 instances in which a steer displaced another without the barrier rising or the system detecting the interruption. Using the calculation outlined by Bach et al. (2004), sensitivity for steer presence during the RES validation for observed intake events was 99.4% (1-(10/1392). This amount of sensitivity is in agreement of that reported by DeVries et al. (2003) using the GrowSafe feeding system (99.2%), and Bach et al. (2004) when describing a computerized system for intake and feeding behavior (99.6%). As reported by Chapinal et al. (2007), the sensitivity rate as detection of animal presence of the Insentec water bins was 99.8%. Total average intake estimated by INS and OBS was 14.7±0.22 and 13.9±0.25 kg OBS_{MISS} (14.3±0.24 kg $\text{OBS}_{\text{NOMISS}}$), respectively (Table3.4).

There was no bias indicated by the difference in mean total intake for particular animals ($P>0.05$). Pearson correlation coefficients between INS and OBS observations were 0.91 OBS_{MISS} ($P<0.001$; 0.94 $\text{OBS}_{\text{NOMISS}}$, $P<0.001$) and the correlation between INS to restriction level and OBS to restriction level were 0.92 and 0.86 OBS_{MISS} (0.89 $\text{OBS}_{\text{NOMISS}}$), respectively ($P<0.001$). Because video recordings could not be used during the study, correlations would likely be much higher in the absence of human error. The coefficient of determination for INS and OBS intakes was $R^2=0.81$ OBS_{MISS} ($R^2=0.89$ $\text{OBS}_{\text{NOMISS}}$) and the intercept was greater than 0 ($P<0.001$; Figure 3.3.).

Summary

In summary, the comparison of mean differences of OBS observations to INS observations were greater for INS observations in a range of 0.60 (0.40 kg $\text{OBS}_{\text{NOMISS}}$) to 0.84 kg (0.44 kg $\text{OBS}_{\text{NOMISS}}$) in the validation periods. During restriction, total daily intakes classified as bin fluctuations averaged 0.51 kg across all days. Although these values contributed to the total INS intake for the animal, which needs to be considered when setting restriction levels, the total amount of error introduced was relatively low. Correlation and regression coefficients for BASE and RES were high, which demonstrated the strong relationship between INS observation intakes and OBS observation intakes.

Results from the BASE period were in agreement to those found by Chapinal et al. (2007) which demonstrates the ability of the system to operate similarly at different locations. After comparing the INS and OBS intake values of RES to the designated restriction level of each animal, results showed that steers were slightly more restricted than the targeted goal. We postulate this was due to the initial under-programming of the goal intake which curbed the ability of animals to over drink upon their final visit to the water bin. Several animals were observed exceeding their programmed intake values, so averaging intakes over a longer time period should alleviate some of the apparent over-restriction.

Although some of the differences noted between OBS and INS intakes are most likely caused by human error, it is also important to consider the biological relevance of the disparities between mean intake differences. Differences during the BASE period were approximately 0.60 kg (0.40 kg $\mathrm{OBS}_{\mathrm{NOMISS}}$), which is only approximately 2.38% (1.58% $\mathrm{OBS}_{\mathrm{NOMISS}}$) of the total average INS intake per day. Mean differences in the RES period were 0.84 kg (0.44 kg $\mathrm{OBS}_{\mathrm{NOMISS}}$), which is only 5.71% (3.0% $\mathrm{OBS}_{\mathrm{NOMISS}}$) of the total average INS intake per day. Although accuracy of data collection was lower in the RES period than the BASE period, we were able to restrict water intake near a target goal and obtain accurate data on water intake during water restriction.

Table 3.1. Overview of water intake records generated by the Insentec system and those recorded by visual observers during BASE.

	Original	Zero Values*	INS	OBS
d 1	984	54	930	920
d 2	775	15	760	756
d 3	931	29	902	882
Total	2690	98	2592	2558

*These values were results of the system defining an intake visit as whenever the transponder identified an eID, with/without gate descending.

Table 3.2. Overview of water intake records generated by the Insentec system and those recorded by visual observers during RES.

	Original	Zero Values*	INS	OBS
d 1	961	405	556	414
d 2	1007	410	597	474
d 3	1081	436	645	504
Total	3049	1251	1798	1392

*These values were results of the system defining an intake visit as whenever the transponder identified an eID, with/without gate descending

Table. 3.3 Mean ± SE, minimum and maximum for total intake (kg), by day for Insentec intakes and visually observed intakes during BASE.

	INS			OBS_{MISS}			OBS_{NOMISS}		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
d 1	25.7 ± 0.75	0	57.5	25 ± 0.76	0	54.6	25.4 ± 0.74	0	54.6
d 2	23.2 ± 0.72	8.6	50.3	22.8 ± 0.71	8.6	50.1	22.9 ± 0.71	8.6	50.1
d 3	26.6 ± 0.85	11.9	59.9	26 ± 0.88	9	58.9	26.1 ± 0.88	9	58.9
Total	25.2 ± 0.45	0	59.9	24.6 ± 0.46	0	58.9	24.8 ± 0.45	0	58.9

Table. 3.4 Mean ± SE, minimum and maximum for total intake (kg),by day for Insentec intakes and visually observed intakes during RES.

	INS			OBS_{MISS}			OBS_{NOMISS}		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
d 1	13.8 ± 0.38	5.3	30.3	13.3 ± 0.42	2.9	30.0	13.7 ± 0.40	6.4	30.0
d 2	15.8 ± 0.41	7.3	26.9	14.8 ± 0.44	2.7	26.2	15.1 ± 0.44	2.7	26.2
d 3	14.8 ± 0.34	6.8	26.1	13.7 ± 0.41	4.4	31.0	14.3 ± 0.40	4.4	31.0
Total	14.7 ± 0.22	5.3	30.3	13.9 ± 0.25	2.4	31.0	14.3 ± 0.24	2.7	31.0

Table. 3.5 Total intakes due to bin fluctuations after an animal had met or exceeded the daily RES allotment.

	Mean ± SE , (kg)	Minimum, (kg)	Maximum, (kg)
d 1	0.30 ± 0.15	0.1	0.6
d 2	0.43 ± 0.09	0.1	1.0
d 3	0.79 ± 0.15	0.1	2.4

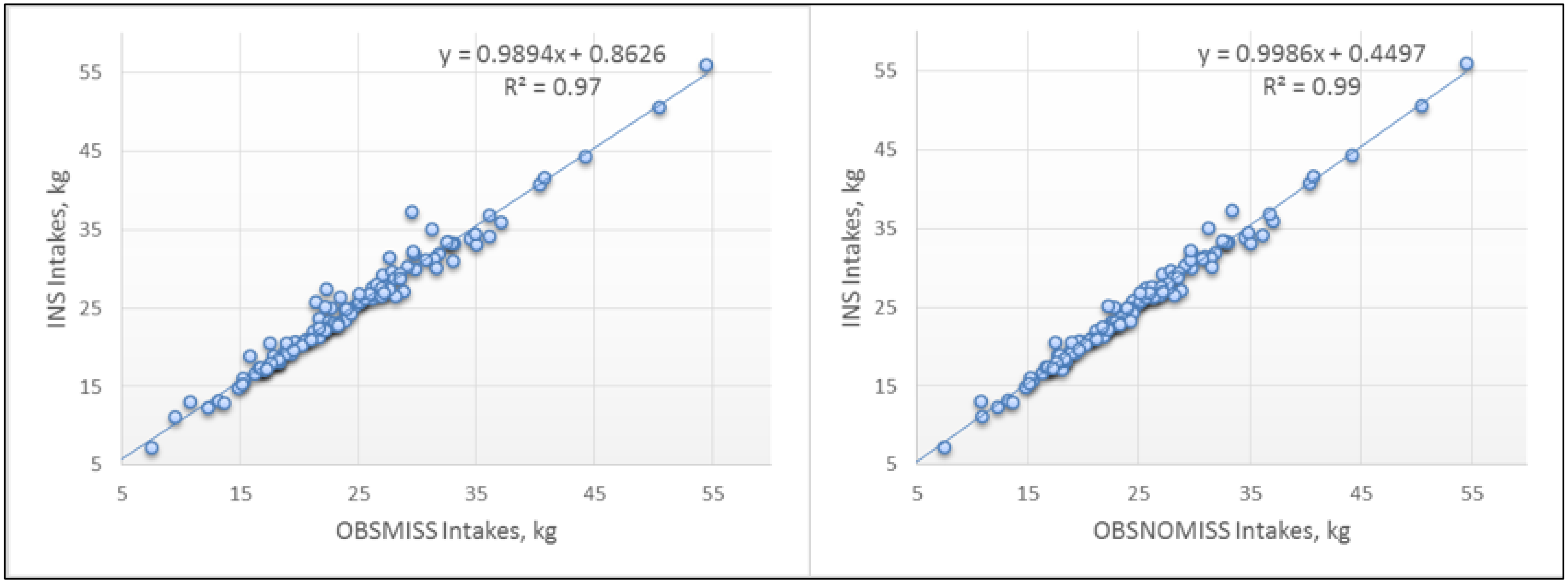

Figure 3.1 Relationship of intake values with Insentec generated intakes regressed onto visually observed intakes during BASE.

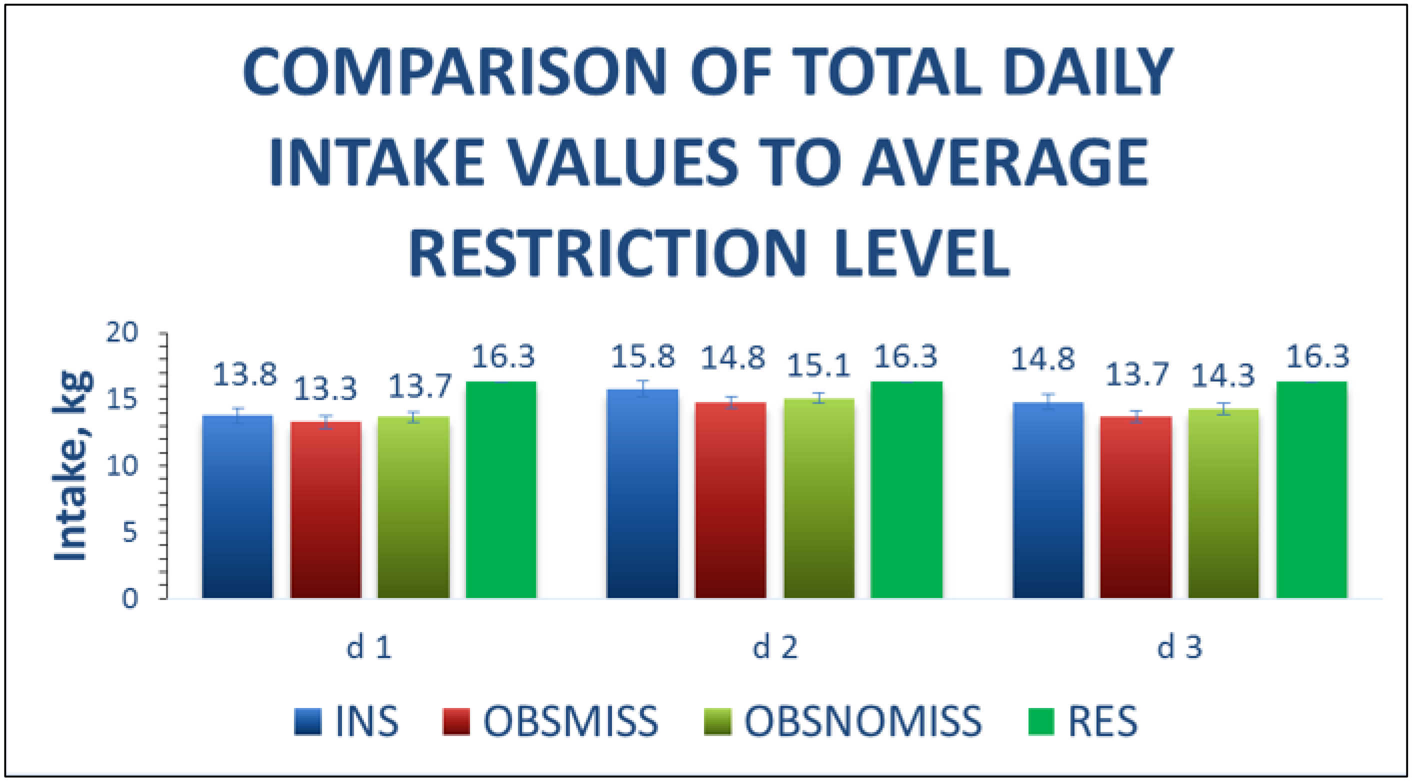

Figure 3.2 Total daily intake values during RES compared to the average daily restriction level across all animals.

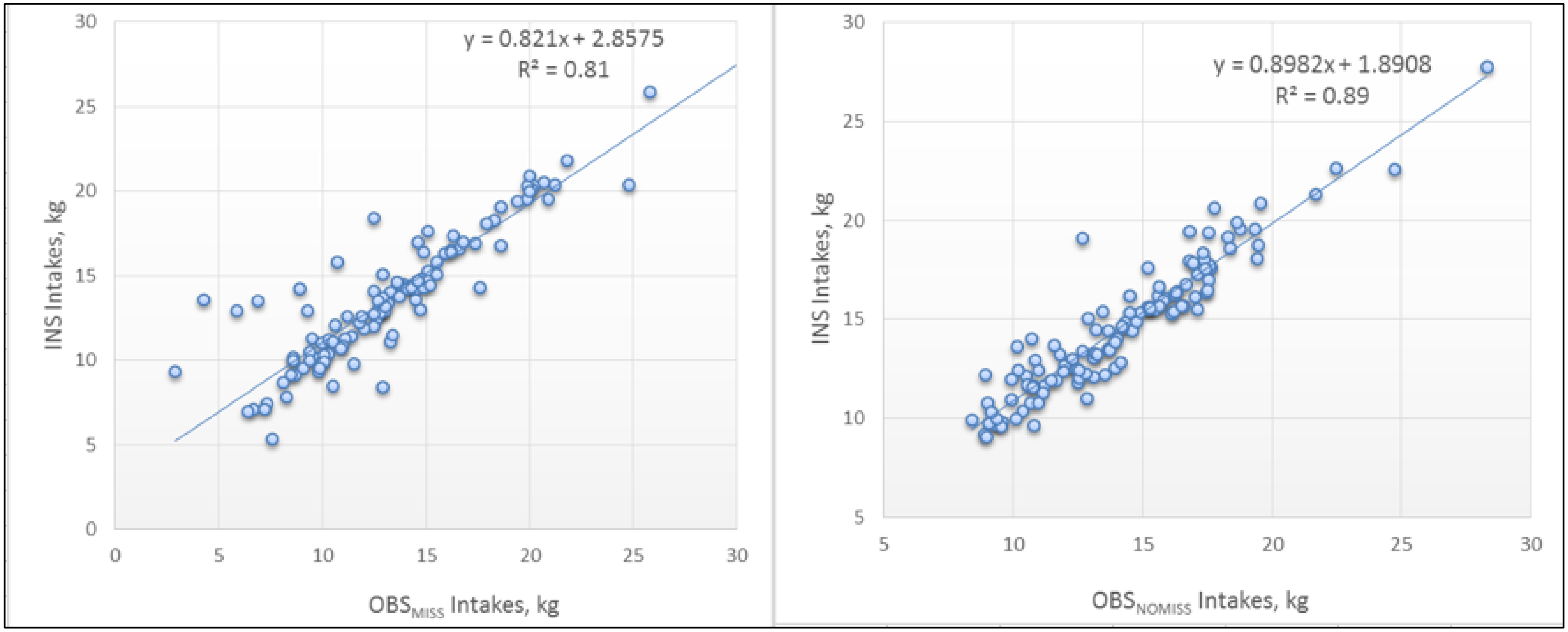

Figure 3.3 Relationship of intake values with Insentec generated intakes regressed onto visually observed intakes during RES.

CHAPTER IV

CONCLUSION

As a result of foundational research examining water intake in cattle, the use of electronic monitoring intake systems for water intake studies can be used to facilitate better understanding of the physiological response of cattle to adapt to water deprived conditions. Restricted water intake studies serve as a simulation of drought induced environments, and therefore the ability to acclimatize while maintaining efficiency would prove as an economically important trait to producers. The Insentec system is a useful tool for evaluating individual water intake of group-housed steers. The system provides appropriate estimates of intake during *ad libitum* water consumption and can be used to restrict cattle of water on an individual basis. The fill level of the water bin should be taken into consideration prior to limiting cattle, as a sudden decrease in fill could disrupt typical drinking behavior. Furthermore, under programming of cattle below the desired restriction amount coincides with the fill level of the water bin and must be done in order to alleviate the likelihood of over drinking during the final bin visit. System generated intake can vary between 0.60 kg (0.40 kg OBS_{NOMISS}) and 0.84 kg (0.44 kg OBS_{NOMISS}) greater than the actual intake of the animal, depending on the programmed functions of the monitoring system. This study clearly demonstrated that during periods of high activity and bin competition, data can be generated as a result of scale variation. These intake values were incorporated into the daily total value for each animal but can be mitigated by use of under- programming or data editing using the average value of 0.51 kg.   Nonetheless, cattle maintained a higher than expected level of restriction which demonstrated the appropriateness of using the system to limit water intake in growing feedlot steers.

REFERENCES

Andersson, M. 1985. Effects of drinking water temperatures on water intake and milk yield of tied-up dairy cows. Liv. Prod. Sci .12:329–338.

Arias, R. A., & Mader, T. L. 2011. Environmental factors affecting daily water intake on cattle finishedin feedlots. J. Anim. Sci. 89(1): 245-251.

Bach, A., Iglesias, C., & Busto, I. 2004. Technical note: A computerized system for monitoring feeding behavior and individual feed intake of dairy cattle. Journal of dairy science. *87*(12): 4207-4209.

Bagley, C. V., Amacher, J. K., & Poe, K. F. 1997. Analysis of water quality for livestock. AH/Beef. 28: 1.

Baker, C. C., Coppock, C. E., Lanham, J. K., Nave, D. H., Labore, J. M., Brasington, C. F., & Stermer, R.A. 1988. Chilled drinking water effects on lactating Holstein cows in summer. J. Dairy Sci. 71(10): 2699-2708.

Balch, C. C., Balch, D. A., Johnson, V. W., & Turner, J. 1953. Factors Affecting the Utilization of Food by Dairy Cows. British J. Nutr. 7(03): 212-224.

Beatty, D. T., Barnes, A., Taylor, E., Pethick, D., McCarthy, M., & Maloney, S. K. 2006. Physiological responses of and cattle to prolonged, continuous heat and humidity. J. Anim. Sci. 84(4): 972-985.

Beckett, J. L., & Oltjen, J. W. 1993. Estimation of the water requirement for beef production in the United States. J. Anim. Sci. 71(4): 818-826.

Beede, D. K. 2005. Assessment of water quality and nutrition for dairy cattle. Proc. Mid-south Ruminant Nutrition Conf. p. 1-19.

Beede, D. K., & Collier, R. J. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. J. Anim. Sci. 62(2): 543-554.

BIF, 2012. Beef Improvement Federation. BIF 9th edition guidelines. Available www.beefimprovement.org. Accessed: June 23, 2015.

Bond, J., Rumsey, T. S., & Weinland, B. T. (1976). Effect of deprivation and reintroduction of feed and water on the feed and water intake behavior of beef cattle. J. Anim. Sci. 43(4):873-878.Brew, M. N., Myer, R. O., Hersom, M. J., Carter, J. N., Elzo, M. A.,

Hansen, G. R., & Riley, D.G. 2011.Water intake and factors affecting water intake of growing beef cattle. Liv. Sci.140 (1):297-300.

Burgos, M. S., Senn, M., Sutter, F., Kreuzer, M., & Langhans, W. 2001. Effect of water restriction on feeding and metabolism in dairy cows. Amer. J. Phys.-Regulatory, Integrative and Comparative Phys. 280(2): 418-427.

Chapinal, N., Veira, D. M., Weary, D. M., & Von Keyserlingk, M. A. G. 2007. Technical note: Validation of a system for monitoring individual feeding and drinking behavior and intake in group-housed cattle. J. Dairy Sci. 90(12): 5732-5736.

De Haer, L. C. M., & De Vries, A. G. 1993. Feed intake patterns of and feed digestibility in growing pigs housed individually or in groups. Liv. Prod. Sci: 33(3): 277-292.

De Haer, L. C. M., & Merks, J. W. M. 1992. Patterns of daily food intake in growing pigs. Anim. Prod. 54(01): 95-104.

DeVries, T. J., Von Keyserlingk, M. A. G., Weary, D. M., & Beauchemin, K. A. 2003. Technical note: Validation of a system for monitoring feeding behavior of dairy cows. J. Dairy Sci. 86(11): 3571-3574.

Drewnoski, M. E., Pogge, D. J., & Hansen, S. L. 2014. High-sulfur in beef cattle diets: A review. J. Anim Sci. 92(9): 3763-3780.

FAO, 2009. Food and Agriculture Organization of the United Nations. How to Feed the World I 2050. Available:http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_t _Feed_the_Word_in_200.pdf. Accessed: June 27, 2015.

Gaughan, J. B., Mader, T. L., Holt, S. M., Sullivan, M. L., & Hahn, G. L. 2010. Assessing the heat tolerance of 17 beef cattle genotypes. Inter. J. Biometeorology. 54(6): 617-627.

Guiroy, P. J., Fox, D. G., Tedeschi, L. O., Baker, M. J., & Cravey, M. D. 2001. Predicting individual feed requirements of cattle fed in groups. J. of Anim. Sci. 79 (8): 1983-1995.

Hahn, G. L., & Mader, T. L. 1997. Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. Proc. Fifth Inter. Liv. Envir. Sym., Bloomington, Minnesota. ASAE, St Joseph, MI.

Hicks, R. B., Owens, F. N., Gill, D. R., Martin, J. J., & Strasia, C. A. 1988. Water intake by feedlot steers. Misc. publication-Agricultural Experiment Station, Oklahoma State University, Oklahoma.

Hicks, R. B., Owens, F. N., Gill, D. R., Oltjen, J. W., & Lake, R. P. 1990. Daily dry matter intake by feedlot cattle: influence of breed and gender. J. Anim Sci. 68(1): 245-253.

Horrocks, D., & Phillips, G. D. 1961. Factors affecting the water and food intakes of European and zebu type cattle. J. Agri. Sci. 56(03): 379-381.

Huuskonen, A., Tuomisto, L., & Kauppinen, R. 2011. Effect of drinking water temperature on water intake and performance of dairy calves. J. Dairy Sci. 94(5):2475-2480.

Ittner, N.R., Kelly, C.F., and H.R. Guilbert. 1951. Water Consumption of Hereford and Brahman Cattle and the Effect of Cooled Drinking Water in a Hot Climate. J. Anim. Sci. 10(3): 742-751.

Jones, S. D. M., Rompala, R. E., & Haworth, C. R. 1985. Effects of fasting and water restriction on carcass shrink and pork quality. Can. J. Anim. Sci. *65*(3): 613-618.

Kandylis, K. 1984. The role of sulphur in ruminant nutrition. A review. Liv. Prod. Sci. 11(6): 611-624.

Kelly, C. F., Bond, T. E., and Ittner, N. R. 1955. Water cooling for livestock in hot climates. Agricultural Engineering 36: 173-80.

Lanham, J. K., Coppock, C. E., Milam, K. Z., Labore, J. M., Nave, D. H., Stermer, R. A., & Brasington, C.F. 1986. Effects of drinking water temperature on physiological responses of lactating Holstein cows in summer. J. Dairy Sci. 69(4): 1004-1012.

Lardy, G., Stoltenow, C., Johnson, R., Boyles, S., Fisher, G., Wohlgemuth, K., & Lundstrom, D. 2009. Livestock and water.

Larsen, C., Bailey, D. E., & Hungerford, E. H. 1917. The role of water in a dairy cow's ration (No.175). Agricultural Experiment Station, South Dakota State College of Agriculture and Mechanic Arts.

Lofgreen, G. P., Givens, R. L., Morrison, S. R., & Bond, T. E. 1975. Effect of drinking water temperature on beef cattle performance. J. Anim. Sci. 40(2): 223-229.

Mader, T. L., & Davis, M. S. 2004. Effect of management strategies on reducing heat stress of feedlot cattle: feed and water intake. J. Anim. Sci. 82(10): 3077-3087.

Mader, T. L., Davis, M. S., & Brown-Brandl, T. 2006. Environmental factors influencing heat stress infeedlot cattle. J. Anim. Sci. 84(3): 712-719.

Mader, T. L., Davis, M. S., & Gaughan, J. B. 2007. Effect of sprinkling on feedlot microclimate and cattle behavior. Inter. J. Biometeorology. 51(6): 541-551.

Meyer, U., Everinghoff, M., Gädeken, D., & Flachowsky, G. 2004. Investigations on the water intake of lactating dairy cows. Livestock production science. 90(2): 117-121.

Meyer, U., Stahl, W., & Flachowsky, G. 2006. Investigations on the water intake of growing bulls. Livestock Science. 103(1): 186-191.

Milam, K. Z., Coppock, C. E., West, J. W., Lanham, J. K., Nave, D. H., Labore, J. M.,& Brasington, C.F. 1986. Effects of drinking water temperature on production responses in lactating Holstein cows in summer. J. Dairy Sci. 69(4): 1013-1019.

Morrison, S. R. 1983. Ruminant heat stress: effect on production and means of alleviation. J. Anim. Sci. *57*(6): 1594-1600.

Murphy, M. R., Davis, C. L., & McCoy, G. C. (1983). Factors affecting water consumption by Holstein cows in early lactation. J. Dairy Sci. 66(1): 35-38.

Murphy, T. A., & Loerch, S. C. 1994. Effects of restricted feeding of growing steers on performance, carcass characteristics, and composition. J. Anim. Sci.72 (9): 2497-2507.

Nielsen, B. L., Lawrence, A. B., & Whittemore, C. T. 1995. Effect of group size on feeding behavior, social behavior, and performance of growing pigs using single-space feeders. Liv. Prod. Sci. 44(1): 73-85.

National Research Council. 1974. Nutrients and toxic substances in water for livestock and poultry. National Academy of Sciences. Washington D.C., USA.

NRC, 1996. National Research Council. Nutrient requirements of dairy cattle, 7th edition. NRC, National Academy Press, Washington, DC, USA.

NRC, 2001.National Research Council. Nutrient requirements of dairy cattle, 7th rev. edition. NRC, National Academy Press, Washington, DC, USA.

Osborne, V.R., R.R. Hacker, and B.W. McBride. 2002. Effects of heated drinking water on the production responses of lactating Holstein and Jersey cows. Can. J. Anim. Sci. 82: 267 273.

Paula-Lopes, F. F., Chase, C. C., Al-Katanani, Y. M., Krininger, C. E., Rivera, R. M., Tekin, S., & Hansen, P. J. 2003. Genetic divergence in cellular resistance to heat shock in cattle: differences between breeds developed in temperate versus hot climates in responses of preimplantation embryos, reproductive tract tissues and lymphocytes to increased culture temperatures. Reproduction. 125(2): 285-294.

Ridoutt, B. G., Sanguansri, P., Freer, M., & Harper, G. S. 2012. Water footprint of livestock: comparison of six geographically defined beef production systems. The International Journal of Life Cycle Assessment. 17(2): 165-175.

Rollins, W. C., Carroll, F. D., & Ittner, N. R. 1964. Comparison of the performances of f-Hereford—J Brahman calves with Hereford calves in a variable climate. J. Agri. Sci., Camb. 62: 83.

Rossi, J. E., Loerch, S. C., Moeller, S. J., & Schoonmaker, J. P. 2001. Effects of programmed growth rate and days fed on performance and carcass characteristics of feedlot steers. J. Anim. Sci. 79(6): 1394-1401.

Sainz, R. D., De la Torre, F., & Oltjen, J. W. 1995. Compensatory growth and carcass quality in growth restricted and refed beef steers. J. Anim. Sci. 73(10): 2971-2979.

Schmidt, T. B., Olson, K. C., Linville, M. L., Clark, J. H., Meyer, D. L., Brandt, M. M., & Berg, E. P. 2005. Effects of dry matter intake restriction on growth performance and carcass merit offinishing steers. The Prof. Anim. Sci. 21(4): 332-338.

Schwartzkopf-Genswein, K. S., Huisma, C., & McAllister, T. A. 1999. Validation of a radio frequency identification system for monitoring the feeding patterns of feedlot cattle. Livestock Production Science. 60(1): 27-31.

Sexson, J. L., Wagner, J. J., Engle, T. E., & Eickhoff, J. 2012. Predicting water intake by yearling feedlot steers. J. Anim. Sci. 90(6): 1920-1928.

Stermer, R. A., Brasington, C. F., Coppock, C. E., Lanham, J. K., & Milam, K. Z. 1986. Effect of drinking water temperature on heat stress of dairy cows. J. Dairy Sci. 69(2): 546-551.

Thornton, R. F., & Yates, N. G. 1968. Some effects of water restriction on apparent digestibility and water excretion of cattle. Crop and Pasture Science. 19(4): 665-672.

Turner, J. W. 1980. Genetic and biological aspects of Zebu adaptability. J. Anim. Sci. 50(6): 1201-1205.

United States Census Bureau. 2015. http://www.census.gov/population/international/data/worldpop/table_population.p hp. Accessed June 27, 2015.

Veenhuizen, M. F., & Shurson, G. C. 1992. Effects of sulfate in drinking water for livestock. J. American Vet. Med. Assoc (United States). 201:3.

Ward, F. A., & Michelsen, A. 2002. The economic value of water in agriculture: concepts and policy applications. Water policy. 4(5): 423-446.

Weeth, H. J., & Lesperance, A. L. 1965. Renal function of cattle under various water and salt loads. J. Anim. Sci. 24(2): 441-447.

Weeth, H. J., Sawhney, D. S., & Lesperance, A. L. 1967. Changes in body fluids, excreta and kidney function of cattle deprived of water. J. Anim. Sci. 26(2): 418-423.

Willms, W. D., Kenzie, O. R., McAllister, T. A., Colwell, D., Veira, D., Wilmshurst, J. F., & Olson, M. E. 2002. Effects of water quality on cattle performance. J. Range Mgmt., 452 460.

Winchester, C. F., & Morris, M. J. 1956. Water intake rates of cattle. J. Anim. Sci. 15(3): 722 740.

Wright, C. L. 2007. Management of water quality for beef cattle. Veterinary Clinics of North America: Food Animal Practice. *23*(1): 91-103.

Yousef, M. K. 1985. Stress physiology in livestock. Volume III. Poultry. CRC Press Inc.

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