THE INFLUENCE OF DRINKER WATER PRESSURE ON BROILER WATER USAGE AND PERFORMANCE

by

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(Under the Direction of Brian Fairchild)

ABSTRACT

Advancements in technology used to monitor water usage has opened the door to studying some of the management practices used by growers. Drinker water pressure has little research with most of the information available coming from the manufacturer. Studies were conducted to monitor the effect that different drinker water pressures had on water usage in a commercial house. It was then followed up with a pen trial to evaluate the influence that drinker water pressure has on broiler performance along with the water usage. The results in both the commercial and pen trial showed that increased drinker pressure increased the daily water usage by 10-18%. The pen trial resulted in a body weight that was 125g heavier at 49 days of age and a 0.34 better feed conversion in the treatment group receiving a higher drinker pressure but they also had a higher litter moisture throughout the trial.

INDEX WORDS: Drinker Pressure, Drinker Line Management, Water Usage, Broiler Performance

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DEDICATION

This thesis is dedicated to my parents, Ron Brown and Debbie Brown. Without them this would not have been possible.

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CHAPTER 1

Literature Review

Water is a vital nutrient to all animals and is a key component to digestion (Jafari et al., 2006). It is an important nutrient to birds and aids in maintaining the body's homeostasis along with helping with digestion, lubrication of joints and organs and transportation of nutrients (Ross and Hurnik et al., 1983; Fairchild et al., 2006). The importance of water is often overlooked especially when compared to feed. Birds would survive longer when withheld from feed rather than water, but most of the time it is not given much attention as long as it is a steady supply and relatively clean (Fairchild et al., 2006). A reason for wanting to monitor water usage in a commercial poultry house is it can signal issues with bird health. Water usage may decrease as bird health declines, so monitoring the daily usage will often give the grower the ability to detect a problem before other symptoms are evident (Manning et al., 2007).

The Relationship between Water and Feed

The amount of water a bird consumes has a strong relationship with the amount of feed it will eat (Czarick et al., 2001). With this information the grower can get a good estimate of how much feed their birds are consuming by tracking the daily water usage in the house. Pesti et al., (1985) showed that flocks grown in commercial conditions had on average a water to feed ratio (W:F) that was 1.77 gram of water to every gram of feed consumed. They stated that ratio began to approach 2:1 during the warmest months of the study. Williams et al., (2013) compared W:F ratios generated from commercial flocks in 1991, 2001, and 2011. The average W:F for broilers 7 to 42 days of age for the 1991, 2001, and 2011 flocks showed that the water-to-feed ratio increased through the years (1.90 vs 1.98 and 2.02 respectively). While the feed consumption has a close relationship with water there are several other factors that affect water usage such as drinker type, bird density, environmental temperature, relative humidity, and drinking behavior to name a few.

Drinker Type

The delivery method of the water to the birds is important. There are many different types of drinker systems used to deliver water to birds in a commercial house ranging from an open system, such as a trough or bell shaped drinker, to a totally enclosed system, such as a nipple drinker system. The drinker most commonly found in the broiler industry today is a totally enclosed nipple system which has a trigger pin that has to be activated for the water to release (Miles et al., 2004). Drinker types used in the past were the open system drinkers. Andrews (1980) had conflicting results when comparing Hart water cup to Plasson fountain drinker where in one trial the Hart cup resulted in heavier broilers at eight weeks while in a second trial the Plasson drinker resulted in heavier birds at eight weeks of age. A Hart water cup is made up of a bowl shaped cup that allows a small level of water to remain for the bird to consume. Water is released into the cup when the bird pecks the end of a plunger opening a valve releasing water into the cup. The author suggested that the different bird densities could have caused the differences between trials. Some of the trials in the Andrews (1980) study monitored litter moisture and all of those found that litter was wetter when using the Hart water cup system. A study done by McMasters et al., (1970) compared trough and nipple drinker systems in two trials. Broiler body weights from the nipple drinker group were significantly lower than that those in the trough drinker group. This work showed that decreasing the bird to nipple ratio improved bird body weight at eight weeks of age. The litter moisture was significantly higher in the pens containing nipple drinkers in both of the experiments but the author suggests that this could be attributed to more wastage of the water with the nipple drinkers. From the information provided in this paper it is not clear why the nipple drinkers had a higher litter moisture content but it may have been due to the design of the drinker system which was not explained.

Drinking Method

The drinker systems used in modern commercial broiler houses have been designed to provide unlimited water, reduce water contamination and minimize water wastage. The modern drinker system is an enclosed nipple system which reduced the labor required for cleaning since the previous equipment was open source that could be contaminated by the birds and particulates from the environment. The open waterer were prone to increased chances of contamination and more labor with cleaning the system between and throughout the flock. The systems used prior to the enclosed drinker system were trough and bell shaped drinkers. The trough, like the bell shaped drinker, was an open water source and gave birds a more “natural” delivery method (Lott et al., 2001). It has been described that the “natural” way of drinking for a bird is for it to scoop down into the water and then raise its head to allow the water to flow down the esophagus. Houldcroft et al. (2008) reported no significant initial preference for one drinker system over the other by broiler chickens when first exposed to different drinker options but over the course of the testing period the birds spent significantly more time at the bell and bowl drinker compared to the nipple drinker. However there were no significant differences for preference between the bell and bowl drinkers. The author suggested that the reason for the broilers preference in the bell and bowl over the nipple drinker is that birds cannot consume water the ‘natural’ way with the nipple drinker system.

Water Restriction

Studies where broilers or broiler breeders were water restricted provide interesting insight into the relationship between feed and water consumption. Ross et al., (1981) ran a trial where skip-a-day feeding program was compared to water restriction as a method to control feed consumption. The treatments in the first trial consisted of a group of birds that received ad libitum feed and water, a group that received the skip-a-day (SAD) feeding program, a group that received a twenty-three hour water restriction each day. The second trial replaced the SAD treatment group with a three hour water restriction group. These birds were grown out to eight weeks and the body weight, feed and water consumption was analyzed. The results in the first trial showed that the birds in the SAD treatment group had the lowest body weight while the ad libitum group had the highest body weight. The ad libitum group had the lowest FCR while the SAD and the twenty-three hour restricted group had the same FCR. In the second trial the three hour restricted group and the ad libitum group had similar body weights while all three treatment groups had similar FCR. They suggest that 23 hour water restriction can be compared favorably to SAD feed programs. A similar study where birds were given different levels of water restriction ranging from 0-50% out to eight weeks showed that there is an inverse relationship between water restriction and body weight (Kellerup et al., 1965). Miller and Morgan (1988) ran two trials where broiler cockerels were raised in pens where the control group received feed and water ad libitum and the treatment group only received feed ad libitum. The treatment group received water for 15min. every three hours in trial one while they received water for 30min. every four hours in trial two. The trial one results showed that in trial one the treatment group had a significantly lower body weight to the control group by 41g. The second trial yielded inconsistent results as there were no differences in body weight between the control and the treatment groups. There were no differences in FCR between the treatment and control in either trial. This suggests that broilers can consume the water they need in a short period of time regardless of whether they have unlimited access to it. A similar study was done by Bennett and Leeson (1989) where a comparison of broiler breeders given restricted access to water within a SAD feeding program was performed. They reported no differences in water consumption between treatments in the first trial when 18 week old birds had restricted access to water either on feed days or off-feed days or when they had free access to feed and water. When 13 week old pullets were used in the second trial, body weight and water consumption was significantly greater in the full fed treatment when compared to the SAD treatment. There was not a significant difference between the water restricted and free access to water treatment groups within the SAD treatment for both water consumption and body weight. Gerry (1980) conducted a study comparing different water restriction time periods on broilers in finisher cages. Only one of the four trials produced significantly different body weights. When birds given water continuously, increased body weight was observed when compared to birds given water at 30 minutes per hour while the 15 minutes per hour treatment group was not significantly different from the group receiving water continuously. The drinker system in the group receiving water 30 minutes/hour had a problem and may have resulted in the decreased body weights. Viola et al., (2005) exposed broilers to different levels of restricted water availability ranging from 10% to 40% during the first three weeks. They were then provided ad libitum access to water at twenty-one days of age and experienced compensatory water consumption that normalized to be the same as the control group that was given unlimited access to water the entire study by twenty-eight days of age.

Water Consumption vs. Bird Age

A study by Brake et al., (1992) measured the amount of water and feed consumed by commercial broiler chickens through 21 days of age. Birds were fed a starter diet during the study. The data were used to develop equations to estimate daily and cumulative feed and water consumption.

$$\text{Daily water usage} = 9.73+6.142X$$

$$\text{Cumulative water usage} = 21.41+9.064X+3.193X^2$$

$$X = \text{Day of age}$$

This formula can be used to predict the water consumed for birds under similar conditions to that of the experiment but may not accurately represent the modern broiler since the birds have changed over the years due to selective breeding for economically important traits such as growth and feed conversion. Pesti et al., (1985) analyzed the water usage of 24 commercial broiler flocks over a three year period from two houses on one farm. The study generated a regression equation from the water usage data to estimate the amount of water a bird would consume at a given age by multiplying the birds age by 5.284. The birds have changed since the time of this study and as a result, the water consumption equation may not be an accurate representation of modern broilers. A similar study was done by Xin et al., (1994) where male broilers were raised in a similar house design as those in Pesti et al., (1985) study. Two of the houses were conventional broiler housing (with no tunnel ventilation) while the other two houses had tunnel ventilation for better cooling of the birds during hot weather. The data that was collected was used to create equations that can be used to estimate the amount of water a broiler would use on a daily basis for any day of age between 1 and 56 days of age.

$$\text{Daily water usage} = -2.78 + 4.70\,X + .128\,X^2 - 2.17\times10^{-3}\,X^3$$

$$X = \text{Day of age}$$

This equation is different from Brake et al., (1992) since this equation was generated from flocks grown out to 56 days rather than just 21. This work revealed that the broiler water consumption has doubled since 1991 (Williams et al., 2013). This study compared flocks from 1991 to 2011 on their water consumption and feed consumption. The authors illustrated that the modern broilers are consuming more water than the broiler chickens did back in 1991 and in 2001. The birds in 2011 consumed approximately 7.59 gal of water/1000 birds per day more than the 2001 flocks and 13.25 gal of water/1000 birds more per day than the 1991 flocks. This shows water consumption by broiler chickens has increased through selection for heavier body weights and shorter market age. The average daily gain (ADG) was calculated and showed that the 2011 flocks were significantly higher than the 2001 flocks at 0.12 lb./day and 0.11 lb./day respectively. The 2001 flocks ADG were significantly higher than the 1991 flocks at 0.11 lb./day and 0.10 lb./day respectively. While the birds did have a higher ADG in more recent years the author points out that there were no interactions between water usage and ADG which they suggest indicates more than just the ADG playing a role in changing the water usage.

Genetic Differences of Water Consumption in Broilers.

Birds grow at different rates between different strains and even within the strains the males grow to be larger than females (Cobb-Vantress 2012). Marks et al. (1985) conducted a study on different strains of birds given free access to food and water and found there is a different point at which the sexual dimorphism in water usage began between a commercially available genetically selected stock and the Athens-Canadian/Athens random bred non-selected strain. The results from this study showed that males of the selected and non-selected strains consumed more water around 4 and 10 days of age respectively. This difference between selected and non-selected birds is likely attributed to the faster growth rate seen in the selected strain due to breeding for commercially important traits such as breast meat yield, growth rate, feed conversion and livability. Once the sexual dimorphism in water consumption begins, the difference between males and females continues to increase during the remainder of the grow-out period. When males are feed and water restricted to a level equal to what the females consume, restricted males grew at a slower rate than the non-restricted males and were similar to the females (Marks et al., 1986). The non-restricted treatment groups supported the previous study by Marks et al. (1985), where males given feed and water ad libitum, drank more water than the females after 10 days of age. Since the males consume more water than females, this research shows that bird gender has to be taken into consideration when studying water consumption.

Bird Density and Water Consumption

While broiler genetics has had an impact on broiler performance, one has to consider the changes in bird management as well. In an effort to make poultry farms cash flow, bird densities have increased over time and as a result could be a factor in water usage. Feddes et al. (2002) showed a significant difference in water consumption between densities of 23.8, 17.9, and 14.3 birds/m^2 vs. 11.9 birds/m^2 with water usage per bird increasing as birds/m^2 increased. Broilers were significantly heavier at a density of 14.3 birds/m^2 along with a higher feed consumption when compared to the other densities. The author found that as the number of birds per nipple increased there tended to be a decrease in water consumed per bird but this decreased water consumption was not statistically significant. This indicates that even though the nipple density decreases it does not necessarily decrease the amount of water consumed by individual birds on average.

Environmental Temperature Effect on Water Consumed

Bruno et al. (2011) compared high (34°C) and low (25˚C) environmental temperature with bell and nipple drinkers. Bird activity was monitored by the number of trips made to either drinker type at the two temperatures in a ten minute time period after the birds had been water restricted for two hours. These data were collected weekly through forty-nine days of age. The results showed that birds visited the nipple drinkers significantly more than they did the bell drinkers (148 and 94 more times at 25˚C and 34˚C respectively). They reported that the birds consumed less water at each visit along with lower water consumption over the ten minute time samples at both temperature levels of 0.93 ml/visit and 0.75 ml/visit at 25˚C and 34˚C respectively. One result that stood out was that the birds made fewer trips to the nipple drinkers at the higher temperature as compared to the lower temperature, 136 vs. 176 respectively, but they did consume more water upon each trip based on the total water usage. This might explain the reason for fewer trips. In contrast, birds visited the bell drinker more in the higher temperature treatment group. Both the bell and nipple drinkers consumed more water at higher temperatures when compared to the low temperature group but birds consumed significantly more water from the bell drinker when compared to the nipple drinker regardless of the ambient temperature. Lott et al. (1991) examined the idea that a bird acclimated to higher ambient temperatures may be able to handle heat stress better than one not exposed to heat stressed. They reported that birds given an acclimation period, which was a heat cycle throughout the day starting at 24˚C, rising to 35˚C, and then ending back at 24˚C for three days prior to the trial, consumed more water than non-acclimated broilers following a heat stress cycle after the acclimation period. The heat stress during the trial consisted of starting the temperature at 24˚C then increasing to 41˚C and was maintained until bird rectal temperature approached 45˚C. The acclimated group drank more water per bird during the heat stress cycle as compared to the non-acclimated group when feed was withheld one hour prior to the heat stress cycle. When birds had access to feed prior to the heat stress cycle the birds that had been acclimated had a peak in water usage one hour earlier than the non-acclimated group. While the body temperatures were similar between groups when birds were given feed, the birds in the acclimated group had lower body temperatures than the non-acclimated group. The author proposes that water was used to maintain the bird's body temperature which they suggest is supported by the higher water usage of the acclimated group in the trial when the birds were withheld from feed one hour prior to the heat stress cycle. May and Lott et al. (1992) reported similar results of higher water consumption in birds when they were acclimated to high temperature. This supports the findings of the previous study (Lott et al., 1991) where birds acclimated to high temperatures use some of the water to regulate body temperature. As a result, they drink more water during the heat stress periods than control birds. May et al. (1997) placed broilers in pens with either nipple or bell drinkers and then exposed them to high cyclical temperatures. The birds drinking from bell drinkers consumed more water as the temperature increased and used less water as temperatures decreased while the birds using nipple drinkers decreased water consumption before the peak temperature was reached. In a different trial within this same paper the birds were either given one of two different height nipple drinkers or a bell drinker. The birds drank more water through the high temperature cycle with the low nipple drinker when compared to the high nipple drinker system but water consumption with the low nipple drinker was less when compared to the bell drinker. May et al. (1997) suggest that these results show that the birds may have a difficulty when drinking from a nipple drinker as compared to the bell drinker since the nipple drinker does not follow the natural way of drinking. Even though the nipple drinker system is unnatural when compared to the bell drinker, the decreased grower labor involved with the nipple drinker system, reduced water wastage, better littler quality, and a decrease in condemnations at the processing plant led to wide use of the nipple drinker system (Lott et al., 2001).

Effects of Air Speed on Water Consumption

May et al. (2000) examined the effect of cyclical temperature and a constant temperature on water consumption with different air speeds over the birds. They showed that birds exposed to cyclical temperatures had an inverse relationship between temperature and water consumption and this response was similar with both groups receiving <15 m/min and 120 m/min air speed. This inverse relationship was most evident between 47 to 49 days of age. It was suggested that birds may have consumed less water from the nipple drinker due to panting at the high environmental temperature. The authors suggest that the act of drinking is coordinated with breathing and that drinking from a nipple drinker system may be unnatural to the birds, interrupting the drinking procedure. When the birds were given a constant temperature they consumed less water in the higher air velocity group when compared to the low air velocity group.

Water Temperatures and Bird Performance

Abioja et al. (2011) showed that drinking water temperature can affect performance. Eight week old broilers were significantly heavier when they were given 8˚C water instead of ambient water at a temperature of 29.5˚C. It was suggested that the cooler water aids the birds in handling heat stress better so that they can grow to a heavier body weight. Harris et al. (1975)

showed that bird body weight gain and feed consumption from day of hatch to three weeks of age significantly increased as drinking water temperature decreased from 35.0°C to 23.9°C. These birds were exposed to different brood temperatures in the first three weeks and when taken past that out to eight weeks of age showed that birds receiving 23.9°C had an increase in body weight gain with a decrease in temperature while the opposite results were seen for birds receiving 35.0°C water. The significant results from the first three weeks were not seen when birds were taken out to seven weeks of age. Similar results were seen with a study where birds that were heat stressed at 37.0°C had decreasing rectal temperature when drinking water temperature decreased (43.3°C, 26.7°C, and 10.0°C). The daily weight gain and feed consumption significantly increased as the temperature of the drinking water decrease but when a 0.5% KCL supplement was added to the water the results from the 26.7°C group had similar results to those at 10°C. A similar study done with commercial layers exposed to a cyclic heat stress that ranged from 27˚C to 35˚C while supplying different water temperatures ranging from 15˚C to 27˚C showed that the water temperature of 23˚C enhanced feed and water intake of the birds (Xin et al., 2002). A large variation was noted among birds within treatment groups and suggested that further work needed to be done using a larger sample size than just 24 birds so that there would be a better opportunity of determining the optimal water temperature to provide the layers.

Water Line Height of Drinking Systems

Chicks may get some water as they metabolize the residual yolk during the first few days. From a bird performance standpoint, it is critical that birds get water once they are placed in the grow-out house so that they do not become dehydrated and will begin to consume feed. The birds that cannot access the water due to improper drinker line height may resort to consuming the wet bedding material below the drinker system in an effort to satisfy their thirst (Branton et al., 2001). This can lead to the bedding material getting lodged in the mouth blocking the opening to the larynx causing the bird to choke and die. This means that drinker lines need to be set to a height where chicks can access to the water as soon as they are placed in the house to discourage eating bedding material. The height of the drinker system needs to be adjusted throughout the flock. As the birds grow, the optimum angle for water consumption from nipple drinker systems changes (Ross and Hurnik et al., 1983). The results of this study illustrates that when birds drink water from a bowl, they throw their head back to a 70˚ angle to swallow the water. Now that nipple drinkers are used in commercial poultry houses this information can be used to show that the upward angle makes it easier for birds to swallow water from these systems. This means to maintain this method of delivery the drinker line height needs to be maintained as the birds grow so that they activate the pin at a 70° angle. Drinker lines that are too high affects both chicks and older birds. It has been shown that birds have better performance with nipple drinkers kept at a lower height rather than a higher one. At two different environmental temperatures it was shown by Lott et al., (2001) that a lower drinker line height increased body weight of broilers. Similar results by Ipek et al., (2002) showed that birds kept with lines at a height that the birds drank from the side of their beak without stretching their necks had higher body weights than birds kept with lines where they had to stretch their necks or where they had to lift their breast and then stretch their neck to drink. These studies show that proper management practices of water line height should be put in place to ensure that birds are being provided adequate water supply so that they can perform at their highest potential.

Effect of Flow Rate on Water Consumption

Another factor that affects poultry water consumption from nipple drinker systems is water emitted when the trigger pin is activated by the bird. Drinker water pressure and nipple flow rate are positively correlated. Birds drinking from a line with high pressure, get more water when they activate the nipple than drinker lines with low water pressure. While this may seem like a good idea there are several negative aspects to having the water pressure in the drinker line too high. An increased water pressure during the first two weeks will make it more difficult for the chicks to activate the trigger pin and could lead to dehydration. Older and larger birds, which require more water, might not get enough water to meet their requirements if the water pressure, and thus water flow rate, is too low. This was illustrated by Carpenter et al. (1992) where male birds that were given a higher flow rate of 2.3 ml/s had a higher body weight than birds that were provided a flow rate of 0.4 ml/s. Surprisingly, this difference was not observed in females given different flow rates. The different flow rates also appeared to affect mortality when the large birds were heat stressed. Birds drinking from water lines with a higher water flow rate had a lower mortality than the birds supplied water with the lower flow rate (Carpenter et al., 1992). When straight run birds were subjected to different flow rates no significant difference was seen in body weight but litter moisture was shown to be significantly higher with increasing flow rates (Quilumba et al., 2015). Miles et al., (2004) used three flow rates and observed broiler performance. While there were no differences in feed conversion, the lower flow rate of 25 ml/min decreased growth when compared to higher flow rates of 50 and 75 ml/min.

Summary

The limited research that exists regarding water usage and how it is affected by environmental and management factors is becoming dated. While the concepts that have been researched before can be applied to birds today, it should be understood that the broiler genetics and housing conditions have changed greatly over the last three decades. Most of the current information that is available pertaining to drinker height and water pressure management comes from the manufacturers. While this information may work, it tends to lack any supporting data and is mostly made up of general concepts. This gap in drinker management information needs to be addressed to ensure that birds get optimal water for growth and development. Innovations in technology have made it more affordable and possible to monitor water usage at low flow rates. This has created the opportunity to obtain more precise data on drinker management practices and their influence on water usage. Additional research in the area of water management on today's larger and faster growing broiler will certainly be useful to poultry producers.

CHAPTER 2

Statement of Purpose

Advances in technology used to monitor water usage in a poultry house have continued to improve. As the technology has improved, the sensors have become more accurate with an increased level of sensitivity. This allows for a more accurate representation of the water usage by broilers in either field or pen research. Mechanical water meters typically used in commercial broiler houses usually generate one pulse/gallon while the digital water meters that are available today generate an output of 20,000 pulses/gallon. This technology allows a significantly higher level of precision than in the past.

Water consumption is frequently taken for granted. Very little research has been conducted on water usage with poultry compared to other areas of bird nutrition. There are several management areas that need additional research to understand the impact they have on modern broiler breeds. They include but are not limited to lighting programs, drinker line height, drinker water pressure, drinker management and air quality. The purpose of the current research project was to study the influence of drinker water pressure management on bird performance and water usage. The goals of this research were (1) to observe the effects of different drinker water pressures on broiler water usage in a commercial house and (2) to determine the effect that different drinker water pressure has on broiler performance and litter conditions under more environmentally controlled conditions in a pen trial. The pen trial was conducted to provide supporting data to that obtained from the commercial trial on bird performance aspects which are difficult to determine in field studies.

CHAPTER 3

Materials and Methods

Commercial Trial

This study was conducted in a 40' x 500' tunnel ventilated broiler house on a farm in Northeast Georgia over the course of three consecutive flocks between the months of December to May. All three flocks were half house brooded for the first seven to ten days. The water flow meters were installed one day prior to bird placement. Water pressure sensors were installed around five days of age when the drinker lines were high enough to provide the clearance needed to get the sensor under the line without touching the ground. The equipment remained in the house throughout the flock and was removed the day that the birds were caught for processing. This broiler house used Lubing drinkers (Floor-watering system without cup, Lubing, Barnstorf, Germany). Drinker line heights were measured and kept the same throughout the grow out period with adjustments being made by the grower as needed with regards to bird size until 20 days of age when all lines were adjusted to the same height. The water pressure was kept the same in all the lines within the house at a water column (WC) height of 10", which was the WC typically used by this particular grower.

The treatments were set up so that two rows of drinkers that shared a common feed line were treated as a group (Figure 1). The treatments were grouped in this way based on previous work that demonstrated that drinker lines that are adjacent to a common feed line are related to each other (Fairchild and Czarick 2006). For example, if water usage in one water line decreases due to a drinker management decision, it is often associated with an increase in water usage in an immediately adjacent water line. In the 40' wide broiler houses used in this study, there were two rows of feeders and four rows of drinkers. As is the case with most broiler houses, these feeder and drinker lines were divided at the middle of the house. Thus, four different groups with two in the front and two in the back of the houses were monitored.

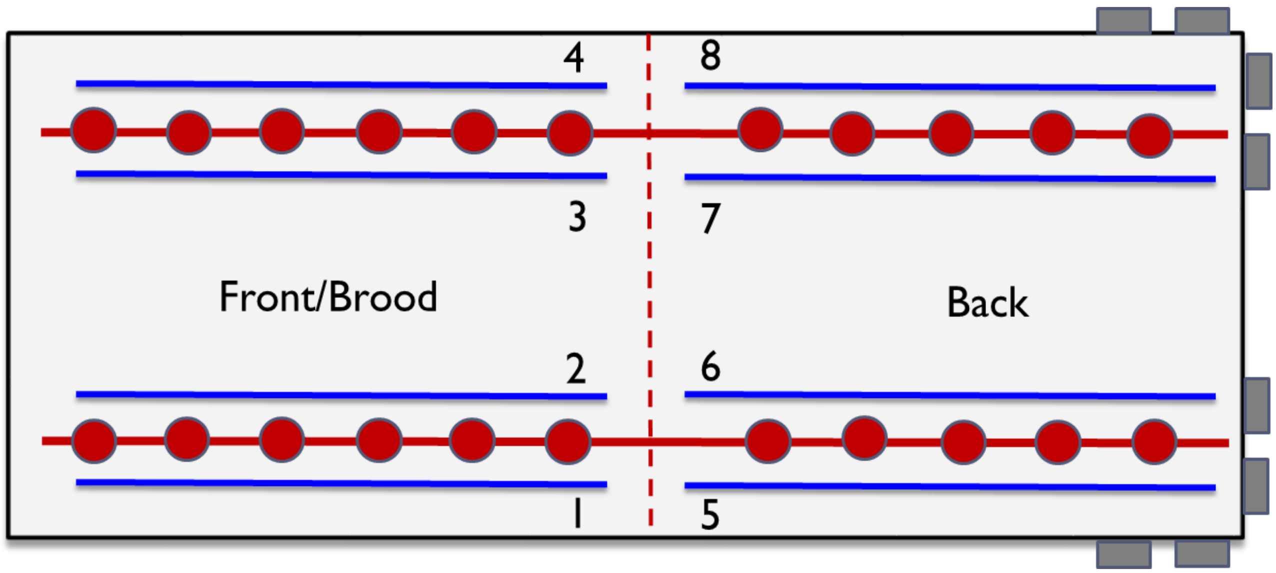

Figure 1. The layout of the commercial research house showing the numbering of the drinker lines in the house.

At 20 days of age, the water pressure was adjusted on Lines 1, 3, 6 and 8 (control), (Figure 1) to be 7" of WC for Flock 1 and 6" WC for Flocks 2 and 3, while Lines 2, 4, 5 and 7 (treatment) (Figure 1) were kept at the original pressure of 10" WC This pressure was kept the same for the next 6 days until 26 days of age when the water pressure was adjusted to 14" WC in all 8 lines. At 32 days of age the drinker water pressure was adjusted to 11" WC in Flock 1 and 10" WC in Flocks 2 & 3 for lines 1, 3, 6 and 8 (control), while lines 2, 4, 5 and 7 (treatment) were kept at a water pressure of 14" WC. All water pressure adjustments can be seen in Tables 1 and 2.

Table 1. Times at which pressures were changed in terms of bird age for Flock 1. Drinker lines 1, 3, 6, and 8 were the control drinker lines while 2, 4, 5, and 7 were the treatment drinker lines

Bird age	Time Period		Water pressure (WC Height)	Drinker lines
20	1	Control	7"	1, 3, 6, 8
		Treatment	10"	2, 4, 5, 7
26	2	Control/Equalized	14"	1 - 8
32	3	Control	11"	1, 3, 6, 8
		Treatment	14"	2, 4, 5, 7

Table 2. Times at which pressures were changed in terms of bird age for Flock 2 and 3. Drinker lines 1, 3, 6, and 8 were the control drinker lines while 2, 4, 5, and 7 were the treatment drinker lines

Bird age	Time Period		Water pressure (WC Height)	Drinker lines
20	1	Control	6"	1, 3, 6, 8
		Treatment	10"	2, 4, 5, 7
26	2	Control/Equalized	14"	1 - 8
32	3	Control	10"	1, 3, 6, 8
		Treatment	14"	2, 4, 5, 7

Drinker line height was adjusted for bird age but kept the same between all drinker lines during the trial. These settings were kept the same until the birds reached market age. Water usage per line, water pressure and outside temperature were recorded on one minute intervals each day throughout the flock. The house temperature was recorded on 15 minute intervals and was collected using a computer connected to the house environmental controller using CHORE-

TRONICS C-CENTRAL Professional Management Software (Chore-Time, Milford, Indiana) which recorded the temperature data generated by the controller system.

Water usage data per minute was compared in Microsoft Excel for differences in trends and patterns between the water pressure treatments. With the current set up, all water pressure treatments were replicated four times within each of the three flocks in the study. The daily total water usage averaged for each time period was analyzed in R Core Team (2015) using a two sample t-test to determine if there was a difference between the control and high treatment group. Means were determined to be different if $P \leq 0.05$.

Pen Trial

This study was conducted in a research room at the University of Georgia Poultry Research Center. The room was 30' by 100' with four rows containing 18 pens. Each row had a single Ziggity drinker line running through each pen. Birds had access to two nipples (Ziggity TLMax3, Ziggity Systems, Inc., Middlebury, IN) in each of the pens. The light was provided by four rows of LED lights. This facility has four exhaust fans which included one 24", two 36", and one 48" fans. Heat was provided by two furnace heaters and was distributed by two rows of six circulation fans running the length of the house. The circulation fans were operated constantly to keep the room environmental conditions uniform. The room environment was controlled by a Choretronics 2 environmental controller and had a Choretronics Programmable Back-up Box system (Chore-Time, Milford, Indiana).

At the start of the study, 1,800 Cobb 500 parent line male chicks were placed into 72 pens (25 birds/pen) with 3 inches of fresh pine shavings. The pens measured 3.5' by 5' giving a density of 0.7 ft^2/bird. Pens were arranged into four rows with 18 pens per row (Figure 2).

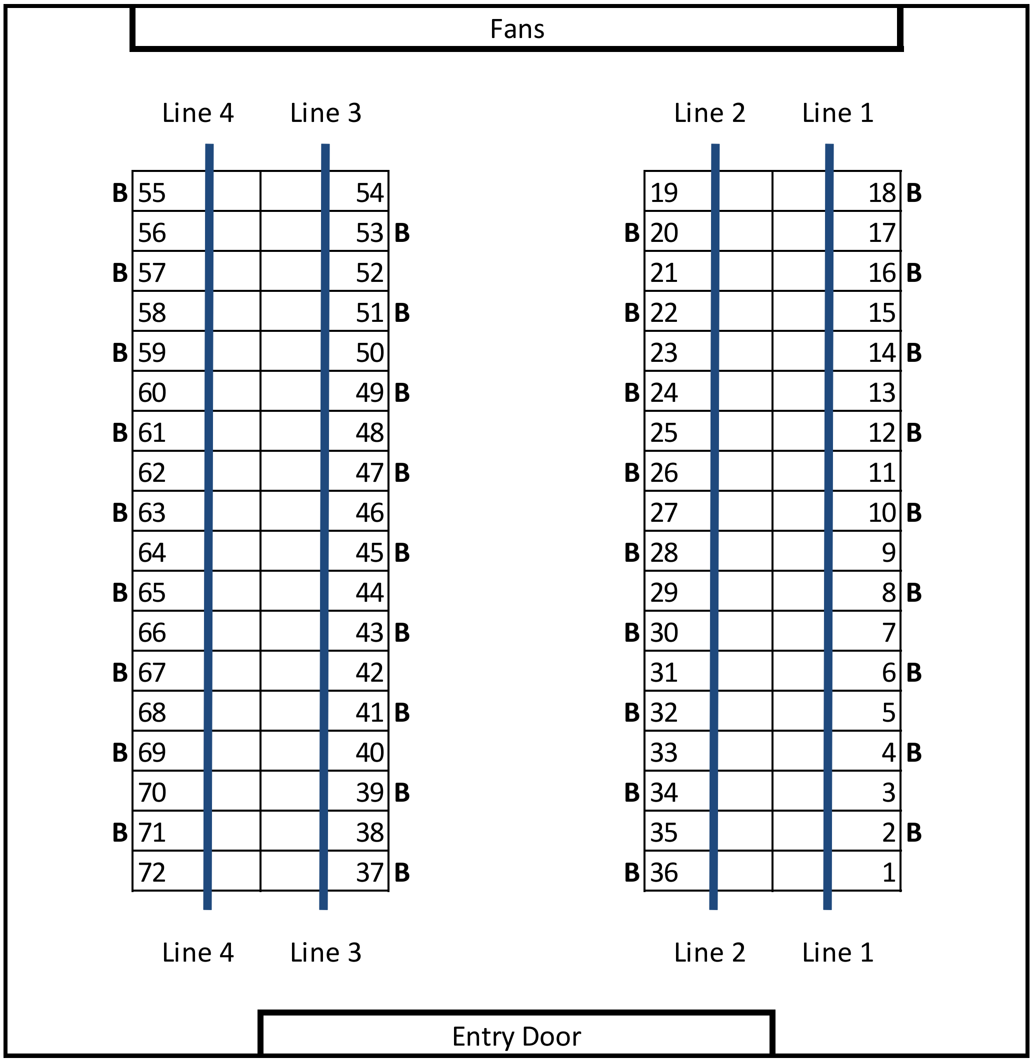

Figure 2. The layout of the research facility where the blue line indicates a continuous water line and the “B” represents pens used for litter moisture evaluation.

The two groups consisted of different drinker line pressures of a control and high water pressure applied from 21 days of age to the end of the study. Both treatments were managed the same for the first 20 days of the study. The control level of 6” WC was selected to follow the water pressure recommendations of the drinker manufacturer at 4 weeks of age (Ziggity, 2012) and the treatment group was set to 12” WC. The treatment drinker pressure was selected to be double that of the control group. Each drinker line was equipped with a low flow water meter (Omega FTB334D, OMEGA Engineering, INC., Stamford, CT) at the incoming water source along with a water pressure sensor (Omega MMG001V5W4C0T1A1, OMEGA Engineering, INC., Stamford, CT) at the end of the line. The water meter and water pressure sensors were connected to Hobo U-30 (Onset U30-GSM, Onset Computer Corp., Bourne, MA) data logging units set to record data each minute. Feed and water was provided *ad libitum* throughout the study. The birds were fed standard starter crumble and grower pellet diets that met or exceeded NRC requirements (National Research Council, 1994) and the diet can be seen in Table 3.

Table 3. Starter and grower diets showing the % composition that each ingredient makes up of the feed used

Ingredient	**Starter Diet**	**Grower Diet**
	%	
Corn	56.07	60.74
Soybean meal	37.47	32.59
Soybean Oil	3.07	3.43
Salt	0.29	0.32
Limestone	0.73	0.78
Def. Phos.	1.75	1.56
Trace mineral	0.07	0.07
Vitamin	0.25	0.25
DL-Meth.	0.20	0.17
Amprol 25	0.05	0.05
Total	100	100
Calculated analysis		
ME (kcal/kg)	3050	3117
Crude Protein (%)	23	21
Lys (%)	1.25	1.12
Met (%)	0.55	0.49
Cys (%)	0.37	0.34
TSAA (%)	0.92	0.84
Threonine (%)	0.90	0.82
Available Phosphorus (%)	0.15	0.14
Calcium (%)	0.95	0.90

Environmental conditions were maintained according to the Cobb broiler guidelines (Cobb-Vantress, Inc. 2016). The lighting program used 22 hours of light at an intensity of 45 lux with 2 hours of dark until Day 12 after which the lighting program was changed to 20 hours light and 4 hours dark and the intensity reduced to 5 lux. At Day 15, the light intensity was maintained at 5 lux while the light period was changed to 16 hours light and 8 hours of darkness through the remainder of the study.

The water pressure in the treatment rows was increased on Day 21 from 6” to 12” WC Prior to 21 days of age the control and treatment water line height was the same and adjusted according to bird size based on manufacturer’s guidelines (Ziggity Systems Inc. 2016). Bird performance (body weight and feed consumption) were monitored weekly starting at 21 days of age until the end of the trial at 49 days while mortality was recorded daily. On Day 21 BW was analyzed and birds were redistributed to ensure that there were no differences in BW between the treatments when the water pressure adjustments were applied. Bird body weight and feed were weighed at 28, 35, 42 and 49 days of age.

Litter Moisture Analysis

On Day 21 alternating pens (18 per treatment) (Figure 2), were equipped with two plastic containers with dimensions of 14.6”L x 11.0”W x 5.1”H, under each nipple. Fresh pine shavings were placed in each box and then weighed individually. The boxes were weighed each week and the shavings from both boxes within a pen were combined and thoroughly mixed in a container. A composite sample was then taken from the mixed material in the container for litter moisture analysis. The boxes were then filled again with fresh pine shavings, weighed, and then placed back in the pen. This procedure was repeated each week until the end of the trial. The samples were placed in pans and put in a drying oven at 75°C for 24 hours. Samples were weighed before and after drying (Shepherd 2010). The percent litter moisture was then calculated by taking the difference between the dried samples weight from the pre-dried weight and then dividing that value by the pre-dried weight of the sample before the drying process.

Data Analysis

There were some pens that had lower body weights, prior to the start of the study, for unknown reasons and these outliers (outside of three standard deviations from the mean) were removed from the data set prior to analysis. This resulted in two pens being excluded from analysis which left 35 pens per treatment. The water usage and water to feed ratio data was analyzed in R Core Team (2015) using a two-sample t-test to compare between the control and treatment. The body weight, body weight gain, feed consumption, feed conversion ratio, and litter moisture between the control and treatment groups was analyzed for differences using a One-way ANOVA. The means were determined to be significantly different if $P \leq 0.05$. All outliers (outside of three standard deviations from the mean) were removed prior to data analysis.

CHAPTER 4

Results and Discussion

Field Trial

Equipment Accuracy

The low flow meters that were used to monitor water usage had a stated accuracy range of 300 to 3000ml/min. Two calibration curves of pulses vs flow (ml/min) was generated for each water meter and it was found that the accuracy range could be expanded to 150 to 3,500 ml/min since two equations were used instead of one. The data were considered to be accurately representing the water usage when the flow no longer went below the lower range limit during the day, not including the dark period, which tended to occur at 4 to 6 days of age (Figure 3). The water meters would temporarily fall below accuracy range between 7-10 days of age which corresponded with the time the grower gave the bird's access to the whole house and water flow per line decreased. Once the birds had spread out evenly between the brood area (front of house) and non-brood area (back of house) the water flow in the drinkers became high enough to register accurately on the water meters between 12 and 14 days of age.

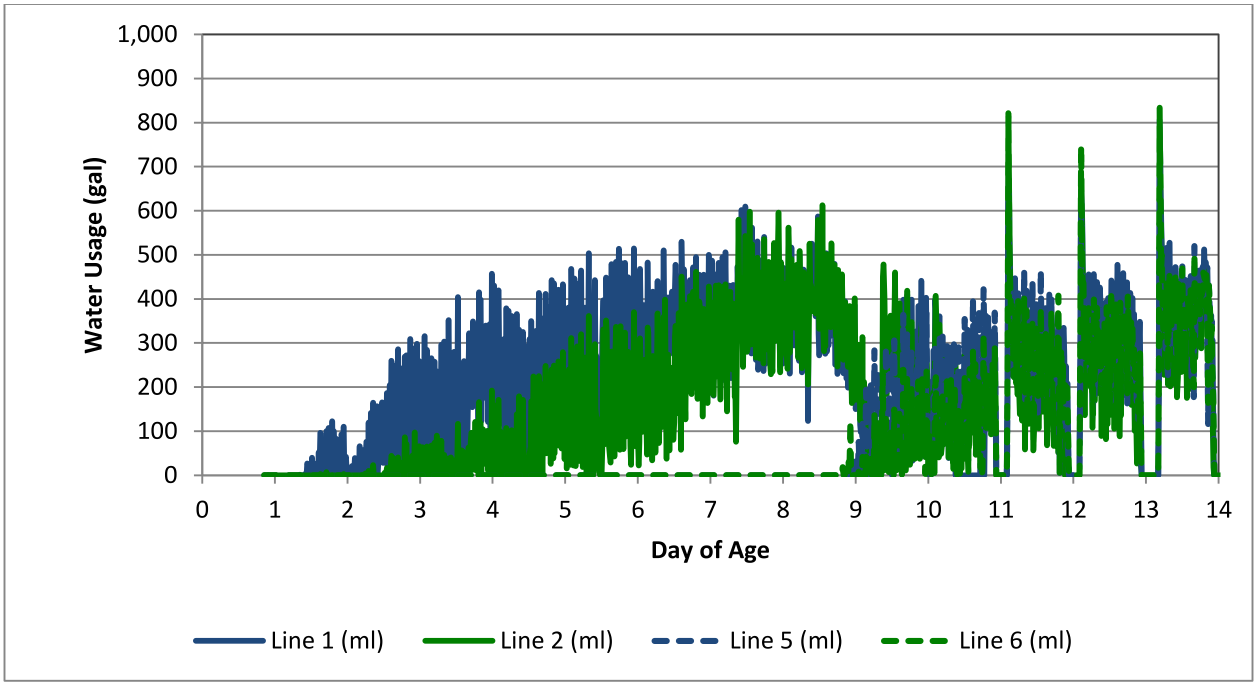

Figure 3. Average water usage over the course of 15 minutes illustrating when the water meters reach a flow rate at which the unit flow did not drop below the lower detection limit (day 6, 7, 8, 14) while also showing the effect of moving birds from half house to full house (day 9)

Flock 1

Trial 1 was conducted on a flock of commercial broilers grown during the months of December 2014 through February 2015. The data logger that measured the water usage failed to start on Day 24 and as a result, the water usage during this time was excluded (Figure 4). The water usage between the treatment and control was not significantly different during any of the three time periods. This may be due to the difference in drinker water pressure only being 3” WC difference and for this reason in the next two flocks the difference in drinker water pressure was increased to 4” WC. It may be that 3” WC difference is not enough to create a benefit for the birds to where one line uses significantly more water than the other.

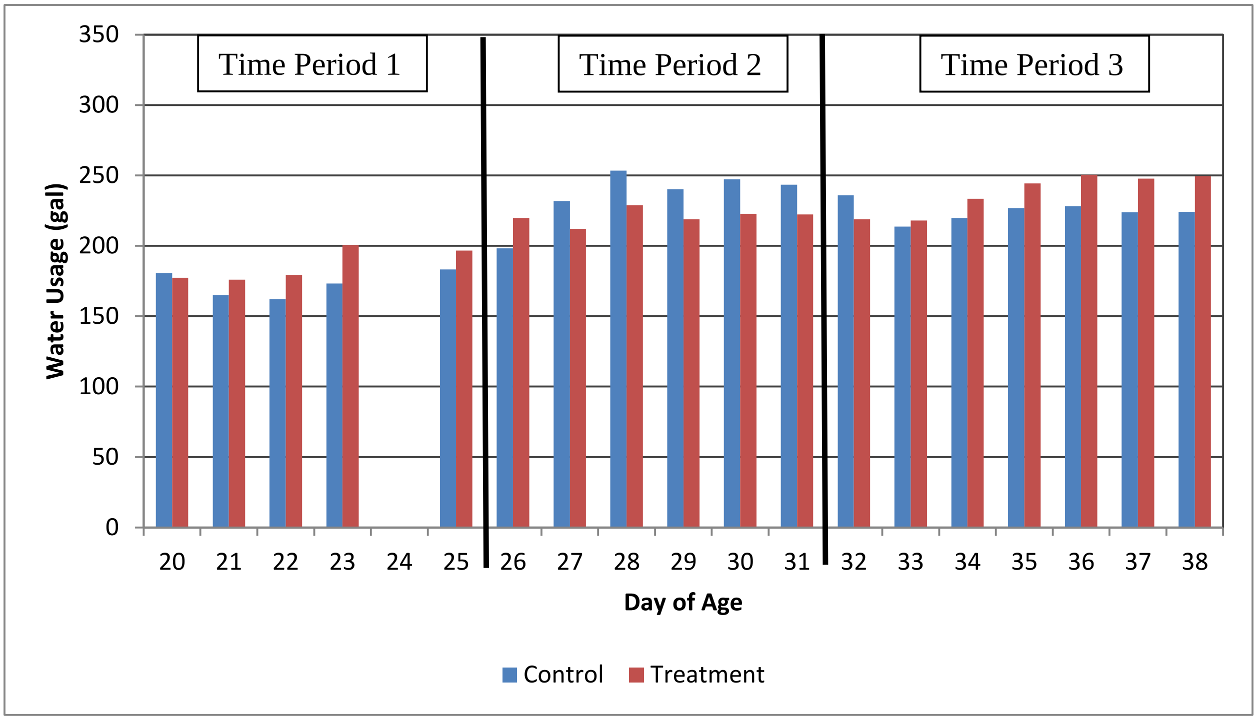

Figure 4. The difference between treatment and control water usage for each time period. (Time Period 1 and 3 = 3” water pressure difference, Time Period 2 = 0” water pressure difference)

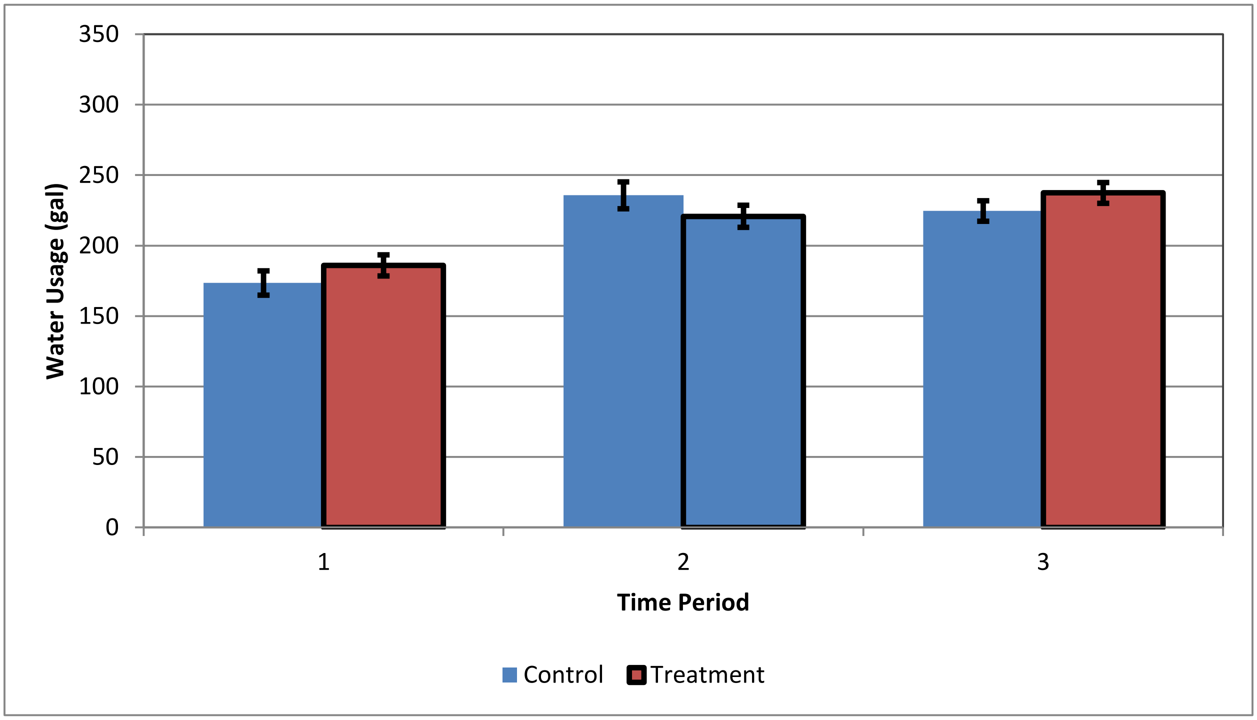

Figure 5. The average water usage during each time period (period 1 and 3 = 3” water pressure difference, period = 0” water pressure difference) between control and treatment drinker lines for Flock 1. Values are means ± SEM. n = 4 drinkers per treatment

Flock 2

Trial 2 was conducted during the months of February and March 2015. There was not a consistent trend in drinker line usage prior to when the water pressure was changed (Day 20). After the pressure was changed the treatment lines began to exhibit a higher water usage in all sections compared to the control lines (Figure 6). The water usage 43.8 gallons/day (25% difference) for Time Period 1 (20 to 25 days) was higher in the treatment drinkers compared to the control drinkers (Figure 7). This was also seen in the Third Time Period (32 to 39 days) where the water usage was 44.5 gallons/day (18% difference) higher for the treatment compared to the control drinkers. When all three time periods were summarized, the data indicated that the treatment had a higher water usage than the control group. However, during the time period where the drinker water pressure was equalized, the water usage was similar being 13.1 gallons/day (6% difference) between treatment and control (Figure 7). The difference between control and treatment drinkers was higher in Flock 2 compared to Flock 1 but this is most likely due to the change to increase the difference in WC height (Flock 2 = 4" WC vs Flock 1 = 3" WC).

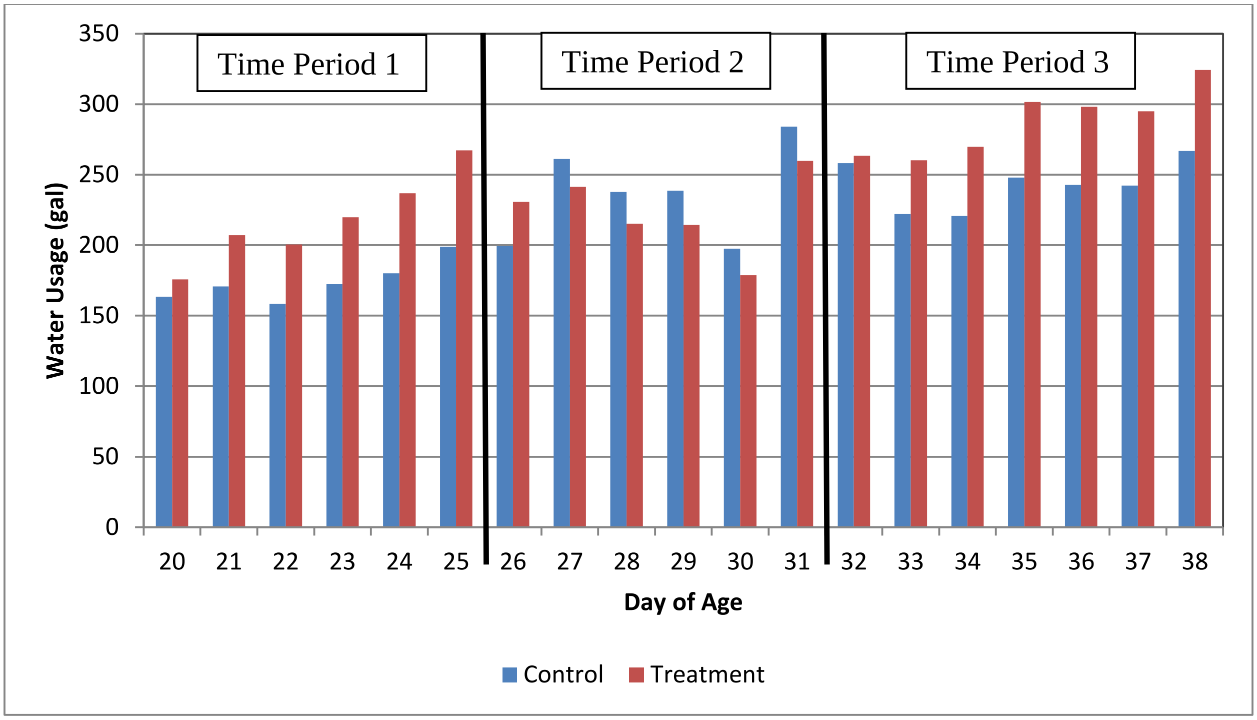

Figure 6. The difference between treatment and control water usage for each time period. (Time Period 1 and 3 = 4” water pressure difference, Time Period 2 = 0” water pressure difference)

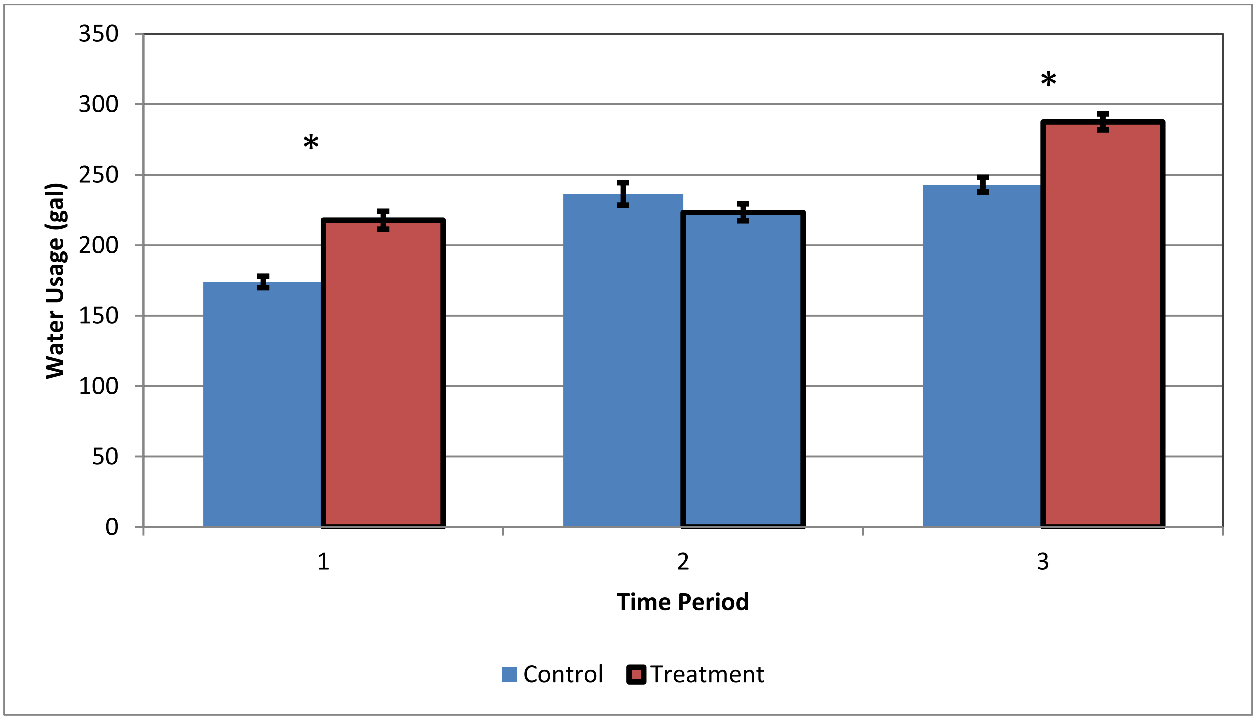

Figure 7. The average water usage during each time period (period 1 and 3 = 4” water pressure difference, period = 0” water pressure difference) between control and treatment drinker lines for Flock 2. * indicates a difference in water usage between treatment group within a time period (P-value<0.05). Values are means ± SEM. n = 4 drinkers per treatment

Flock 3

Trial 3 was conducted in the months of April and May 2015. The water usage trend during the first period (day 20 to 25) was similar to Flock 2 though the results in Flock 3 were not significant. Once the water pressure was equalized to 14 inches WC in the second period (day 26 to 31), the water usage between the lines became similar between treatment and control groups. When the water pressure was changed in the third period (day 32 to 39), where the control lines was changed from 14 to 10 inches WC, the pattern began to follow a similar pattern seen in Flock 2 during Time Period 3 (Figure 8). A trend in water usage was observed in all three flocks where change in bird water usage, when the drinker water pressure was changed, gradually changed over a period of 1-2 days. The lack of significant differences between treatment and control may be due to daily management factors such as walking through the broiler house moving the birds around.

No differences in litter moisture were observed due to the high moisture content under all of the lines being so great. Unfortunately this does not mean that there was no wastage but indicates that the grower tended to operate the drinkers at a water pressure on the high side leading to wet litter under both the control and treatment drinker lines (Figure 10).

Flock 2 and 3 Combined

Since Flock 2 and 3 had similar patterns along with similar bird numbers and rearing conditions the water usage was combined and analyzed for differences between control and treatment drinker lines for each time period. This was done to increase the evidence that there is an increase in water usage with an increase of drinker water pressure. The results showed that there was not a flock effect between the two flocks' data so the data was analyzed by looking at the main effects of drinker water pressure. The water usage was higher in the treatment group during the first time period being 23% higher than the control group or 41.6 gal/day (Figure 11). The water usage was similar between control and treatment during Time Period 2. Once the drinker water pressure was changed in Time Period 3 the treatment water usage was higher by 17% or roughly 41.2 gal/day. These result from combining the two flocks together support the findings in Flock 2 that there is a higher water usage in the treatment group when given a higher water pressure.

Summary of Commercial Trial

Since the drinker water pressure treatments were changed to provide a difference of 4" rather than 3" W.C height after Flock 1, the water usage cannot be directly compared to that of Flocks 2 and 3. Flock 1 can be considered a preliminary trial while the trends in water usage were being determined. During Flocks 2 and 3 water usage on the treatment lines was greater than the control lines (44 and 39 gallons/day for Flocks 2 and 3 respectively, 18% and 16% difference respectively). While a similar trend was seen in Flock 1, the difference between the treatment and control water usage was smaller (13 gallons/day, 6% difference) which could possibly be attributed to the change from 3" WC height difference between control and treatment to the 4" W.C height difference in Flocks 2 and 3. Birds could move freely between lines. Thus the higher water usage on the treatment drinker lines may have been the result of birds having a preference for the treatment lines.

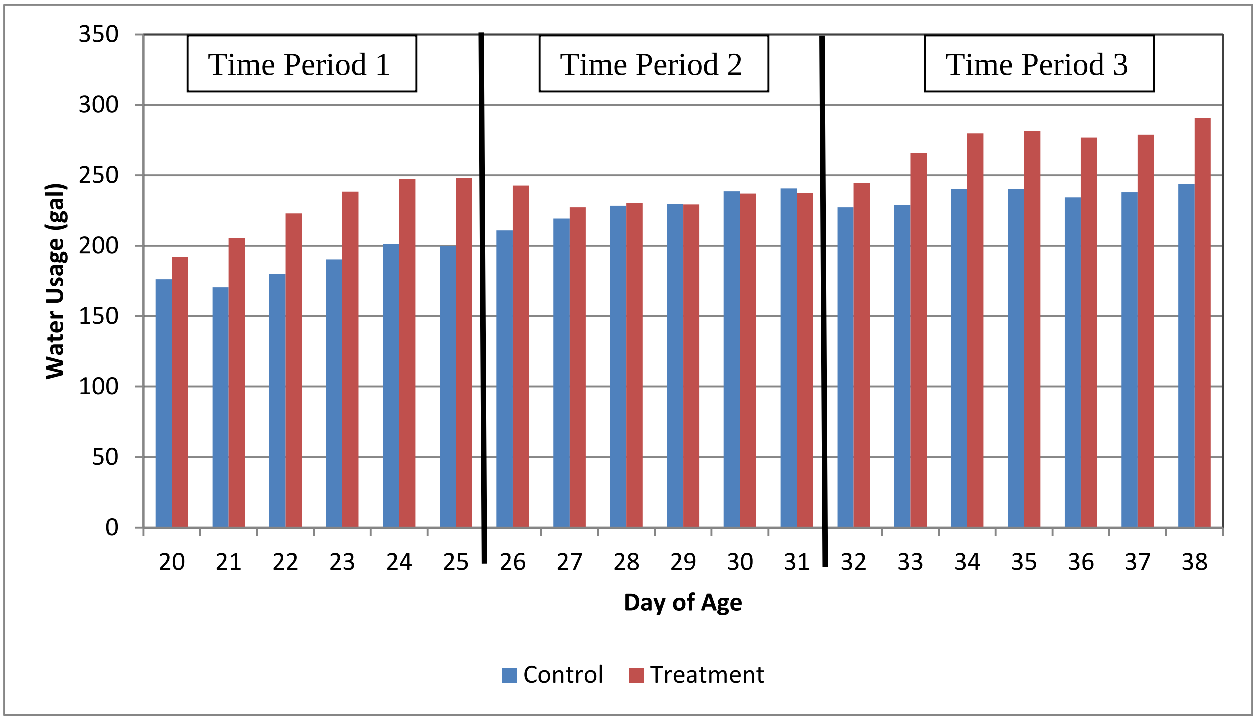

Figure 8. The difference between treatment and control water usage for each time period. (Time Period 1 and 3 = 4” water pressure difference, Time Period 2 = 0” water pressure difference)

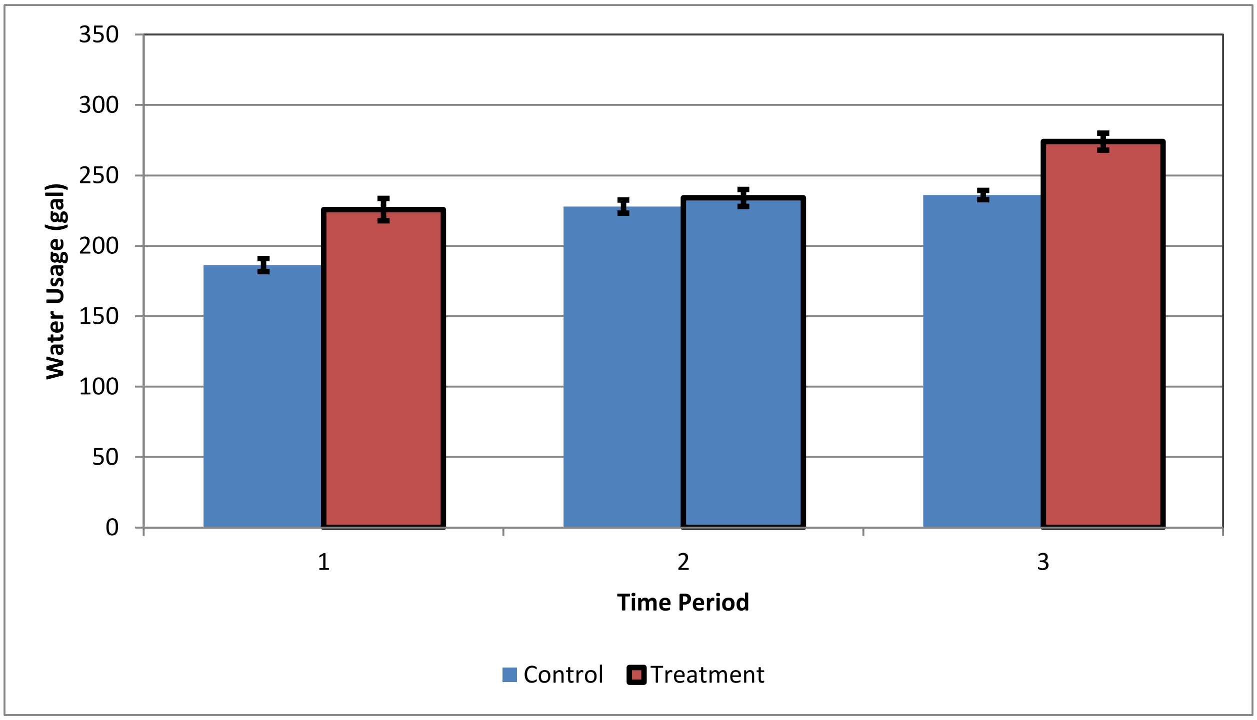

Figure 9. The average water usage during each time period (period 1 and 3 = 4” water pressure difference, period = 0” water pressure difference) between control and treatment drinker lines for Flock 3. Values are means ± SEM. n = 4 drinkers per treatment

Figure 10. Picture showing the condition of the litter underneath the drinker lines in the commercial broiler house indicating the wet litter that inhibited the ability to show a difference between control and treatment litter moisture

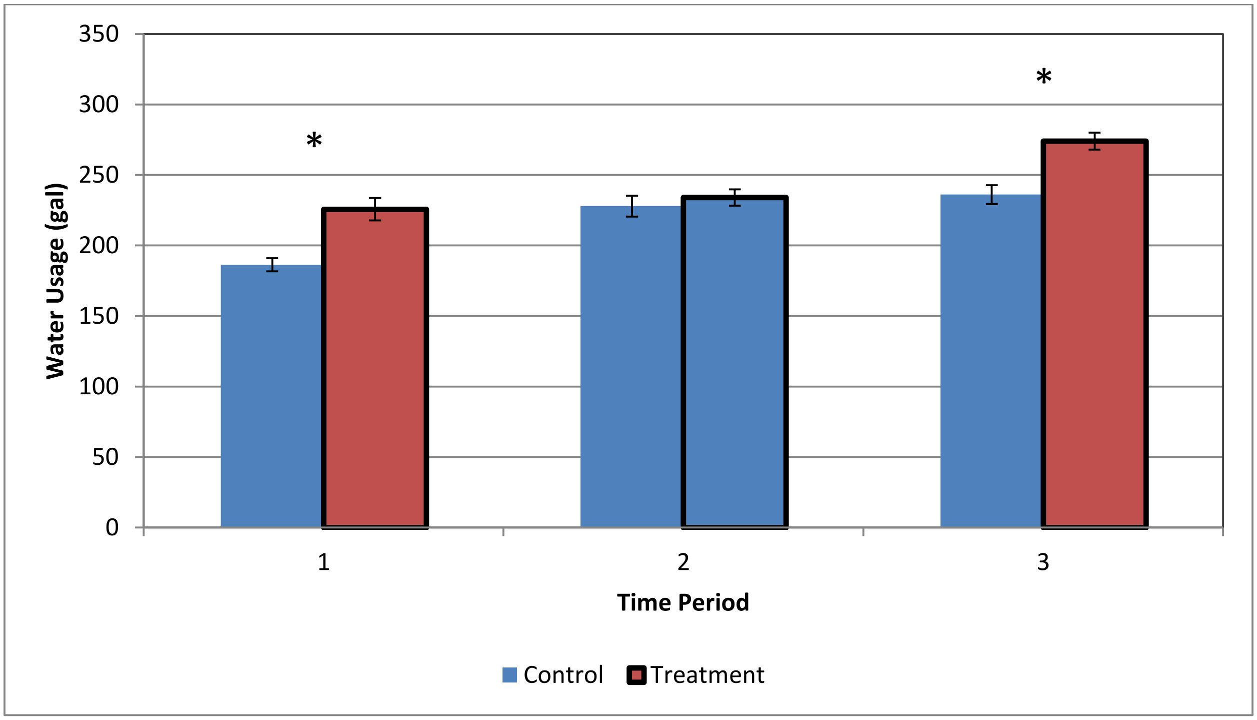

Figure 11. The average water usage during each time period (period 1 and 3 = 4” water pressure difference, period = 0” water pressure difference) between control and treatment drinker lines for Flocks 2 and 3 combined. * indicates a difference in water usage between treatment group within a time period (P-value<0.05). Values are means ± SEM. n = 8 drinkers per treatment

Pen Trial

Bird Body Weight

Birds in the treatment group had significantly heavier body weights compared to the control birds at 42 and 49 days of age ($P < 0.05$) (Figure 12). The birds were 52g and 125g heavier on day 42 and 49 respectively (Table 4). Similar results were seen by Miles et al., (2004) and Carpenter et al., (1992) where birds given a higher nipple flow rate had higher BW, however the flow rates were increased by using nipples of difference design and not by increasing drinker water pressure as done in the current study.

The body weight gain (BWG) was significantly different between the treatment and control group on days 35, 42, and 49 (Figure 13). On day 35 and 42 the difference in BWG was 16g and 23g higher in the treatment group respectively with the largest difference in BWG happening on day 49 with the treatment group being 73g higher (Table 4). The data shows that the higher drinker pressure becomes more beneficial to birds as the age of the birds increases with the best benefit coming in the last week of the study due to the larger difference in BWG. These results along with the results seen in the BW suggest that higher water pressure would be most beneficial to the birds later in the flock with the best results in the last week.

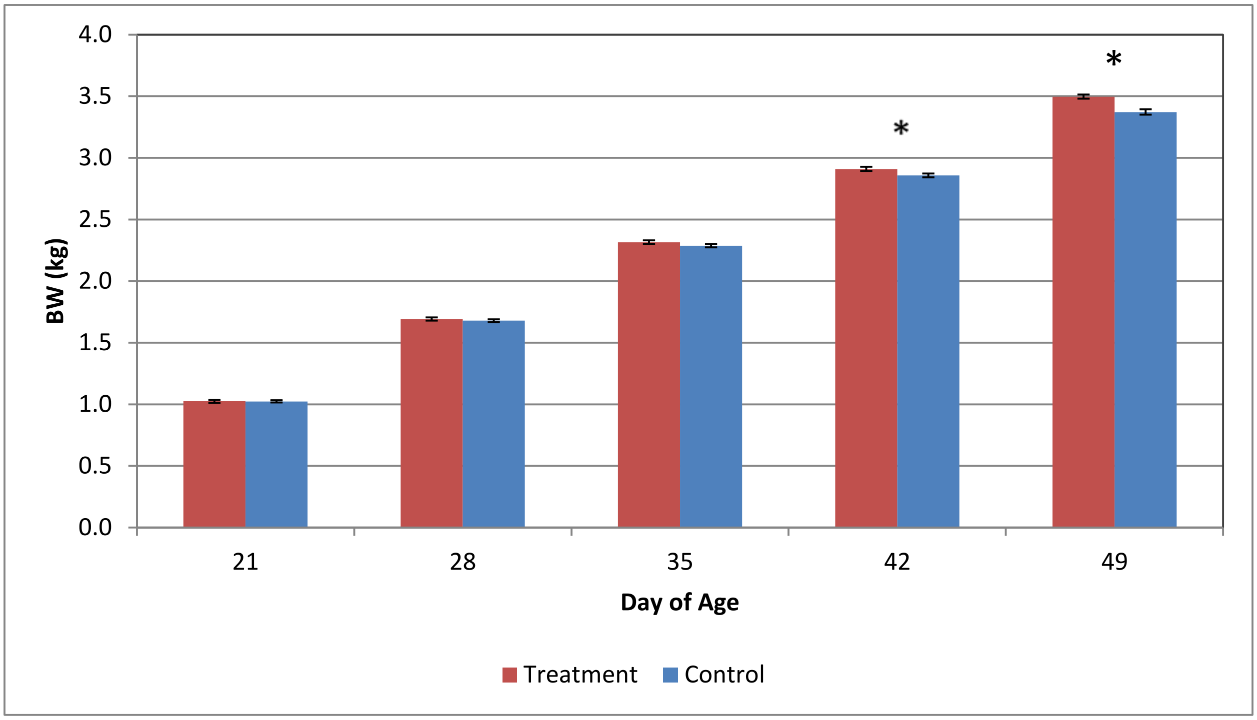

Figure 12. The BW for both the treatment and control group for each weigh date during the entire study. * indicates a difference in water usage between treatments within a time period (P-value<0.05) Values are means ± SEM. n = 35 pens per treatment

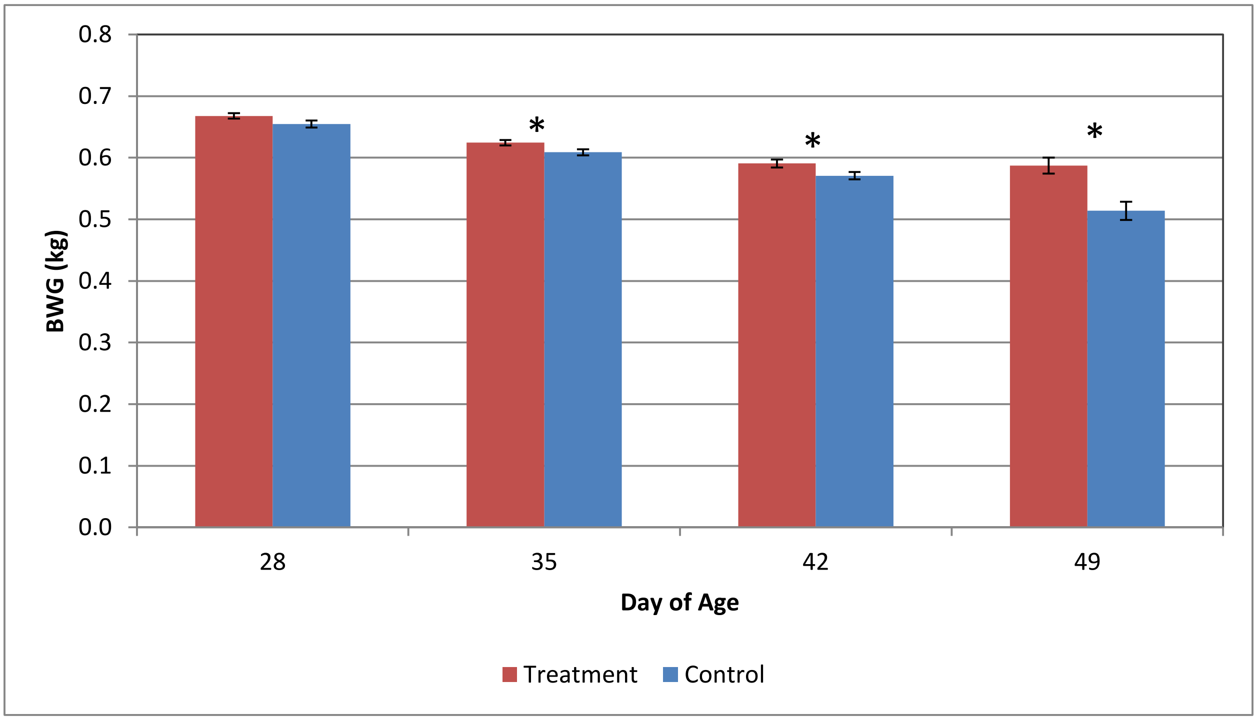

Figure 13. The BWG for both the treatment and control group for each weigh date during the entire study. * indicates a difference in water usage between treatments within a time period (P-value<0.05). Values are means ± SEM. n = 35 pens per treatment

Feed consumption, Feed Conversion Ratio and Water to Feed Ratio

The feed consumption was significantly higher in the treatment group on days 35, 42 and 49 (Figure 14). This is similar to what was seen with the BWG being higher during these times making the increased drinker water pressure beneficial. The feed conversion ratio (FCR) was only significantly different between the groups on day 49 (Figure 15). During the last week, the treatment group had a better FCR compared to the control group (2.26 vs 2.60 respectively) that was 0.34 lower FCR (Table 4). This supports the results seen with the BW and BWG with the best improvement that increased drinker water pressure happening in the last week of the trial.

The water to feed ratio (W:F) was significantly different on Day 42 with the treatment group having a higher W:F value of 2.15 compared to the control group with 2.07. No other differences in W:F were noted during the trial. Since the treatment group would have a higher flow rate out of the nipple this difference could be the result of increased water wastage indicated by the higher litter moisture observed (Figure 16).

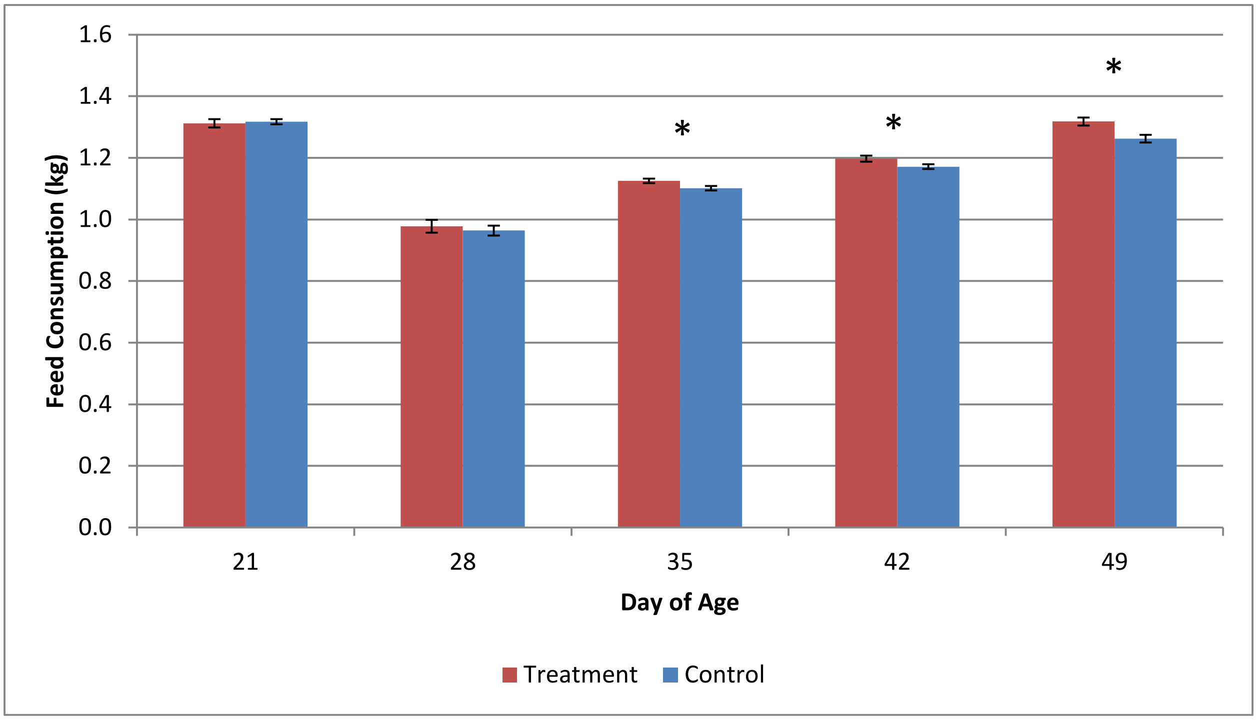

Figure 14. The feed consumption for the treatment and control group for each week of the study. * indicates a difference in water usage between treatments within a time period (P-value<0.05). Values are means ± SEM. n = 35 pens per treatment

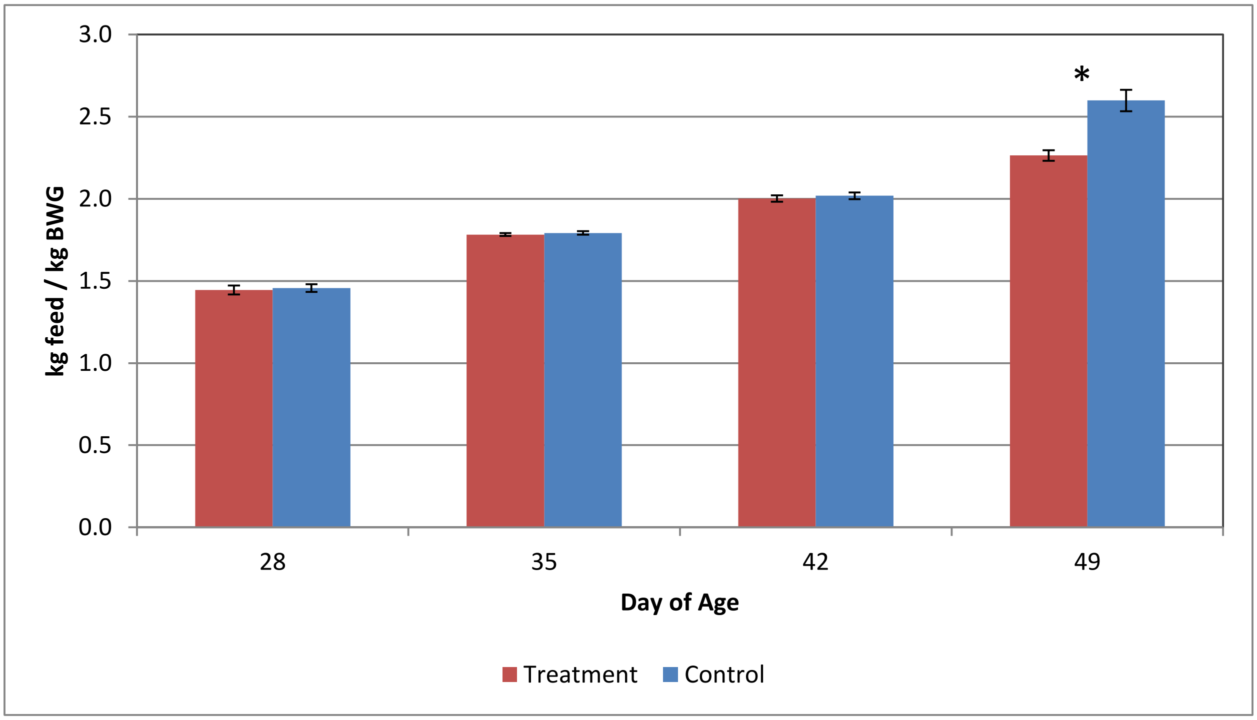

Figure 15. The FCR for the treatment and control group for each week of the study. * indicates a difference in water usage between treatments within a time period (P-value<0.05). Values are means ± SEM. n = 35 pens per treatment

Litter moisture

The litter moisture was significantly different on all sample days of the trial. It was 6%, 6.8%, 9.3%, and 4.8% higher in treatment group than the control group on days 28, 35, 42, and 49 respectively (Figure 16). This was supported by the treatment pens being visually wetter than the control pens. These results are similar to those found by Quilumba et al., (2015) and Carpenter et al., (1992) where greater levels of litter moisture under the drinker were observed as nipple flow rate increased. Since this is a novel method for analyzing litter moisture it should be noted that it was observed that the broilers sometimes used the containers under the drinkers that were used to estimate the water wastage, as nest boxes. The birds spent considerable amounts of time sitting in them. It is not known whether the birds in each pen spent equal amounts of time in the container which could increase variation between pens, both within and between treatments. The birds also defecated in the boxes so that the values observed are a combination of moisture and manure added and does not represent just the wastage from the drinker. Even though fresh shavings were used in the containers each week, the birds introduced some of the pen bedding material into the boxes as they scratched and worked the bedding around the edges of the container.

The percent difference between the treatment and control water usage in pounds and BWG in pounds are compared for each week (Figure 17). The difference in the water usage tended to be higher than the BWG which could back up the results seen with the higher litter moisture in the treatment pens. This may suggest that the birds are not taking advantage of the higher water pressure until the last week of the trial and as a result would have a higher level of water wastage.

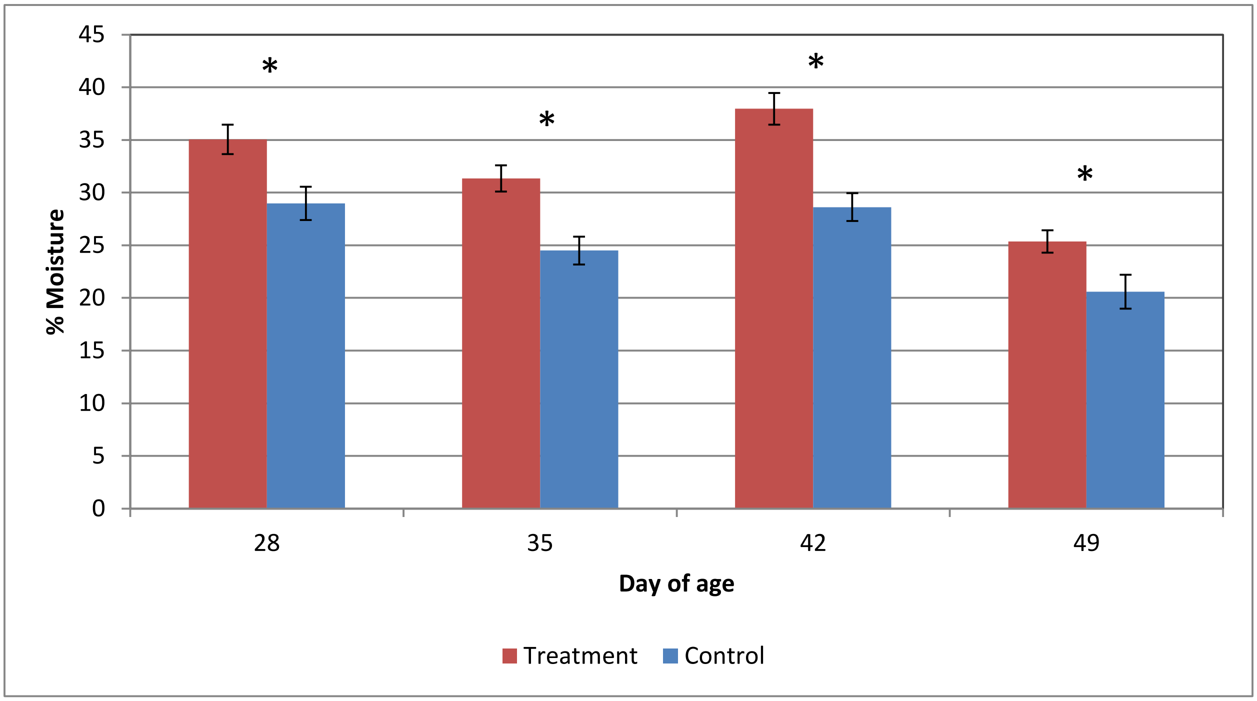

Figure 16. The litter moisture level (%) at each week beginning at 28 days of age. * indicates a difference in water usage between treatments within a time period (P-value<0.05). Values are means ± SEM. n = 18 pens per treatment

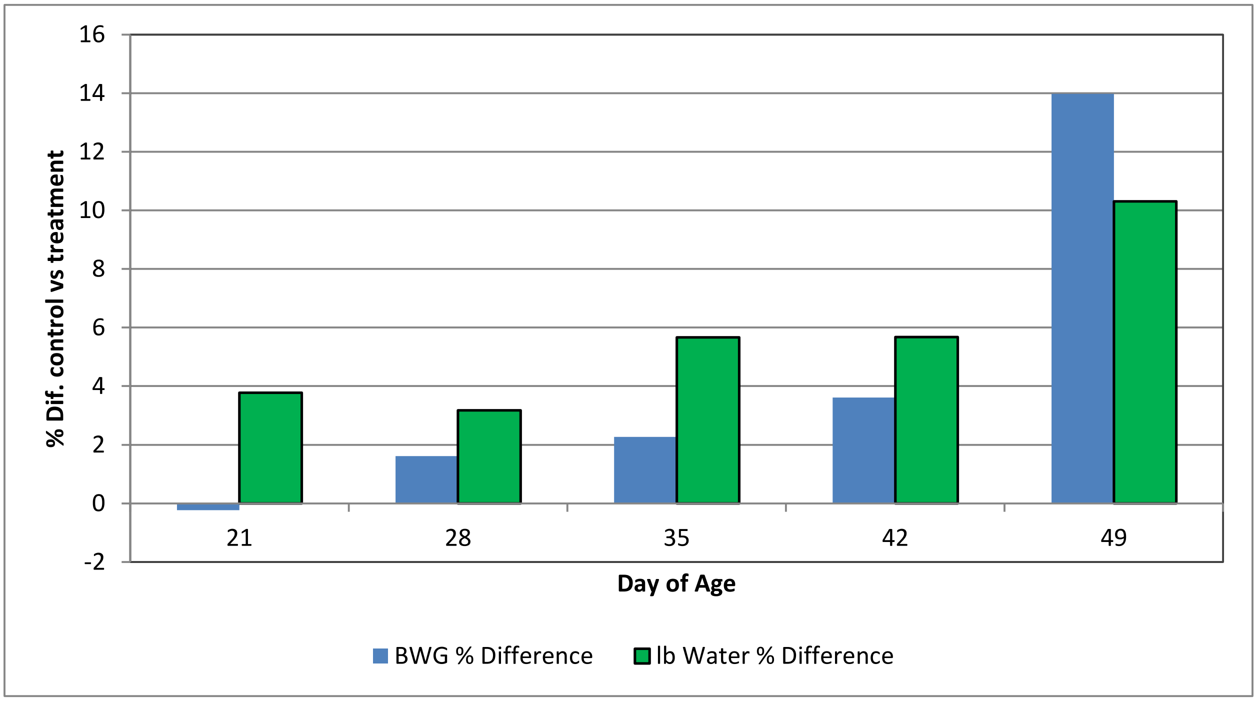

Figure 17. Percentage difference between the treatment and control comparing pounds of water usage and the BWG in pounds to show that the amount of water used by the birds surpassed the BWG until the last week of the trial which may point to the utilization of the extra water in the last week of the trial

Water Usage

The water usage was significantly different between the treatment and control in the last two weeks of the study (Figure 18). The treatment group had a higher water usage of 16.5 (6% difference) and 30.7 (10% difference) gallons during the sixth (Day 36 to 42) and seventh week (Day 43 to 49) respectively. Since feed consumption is tightly related to water usage the increase in W:F could be associated with more feed consumption and therefore could result in heaver BW. These results are similar to those seen by Quilumba et al., 2015 where bird water usage increased as nipple water flow rates increased. The 15 minute average water usage pattern over the course of the day throughout the flock can be seen in Figures 19, 20, 21 and 22. The pattern in water usage is similar between treatment and control earlier in the trial but as the birds get older the pattern begins to change during the highest demand periods of the day, when the lights first come on and just prior to the lights turning off. This pattern may show that the time that birds may be able to take advantage of the higher water pressure could be during the highest peaks in water usage during the day.

Summary of Pen Trial

The birds in the treatment group showed a significantly heavier BW in the last two weeks of the study when compared to the control group. The BWG was significantly higher with the treatment group in the last three weeks of the flock with the largest increase in BWG in the last week. The FCR was only significantly different in the last week with the treatment group having a better FCR by 0.34. While there are performance benefits from the higher water pressure, mostly toward the end of the flock, the downside is an increased litter moisture.

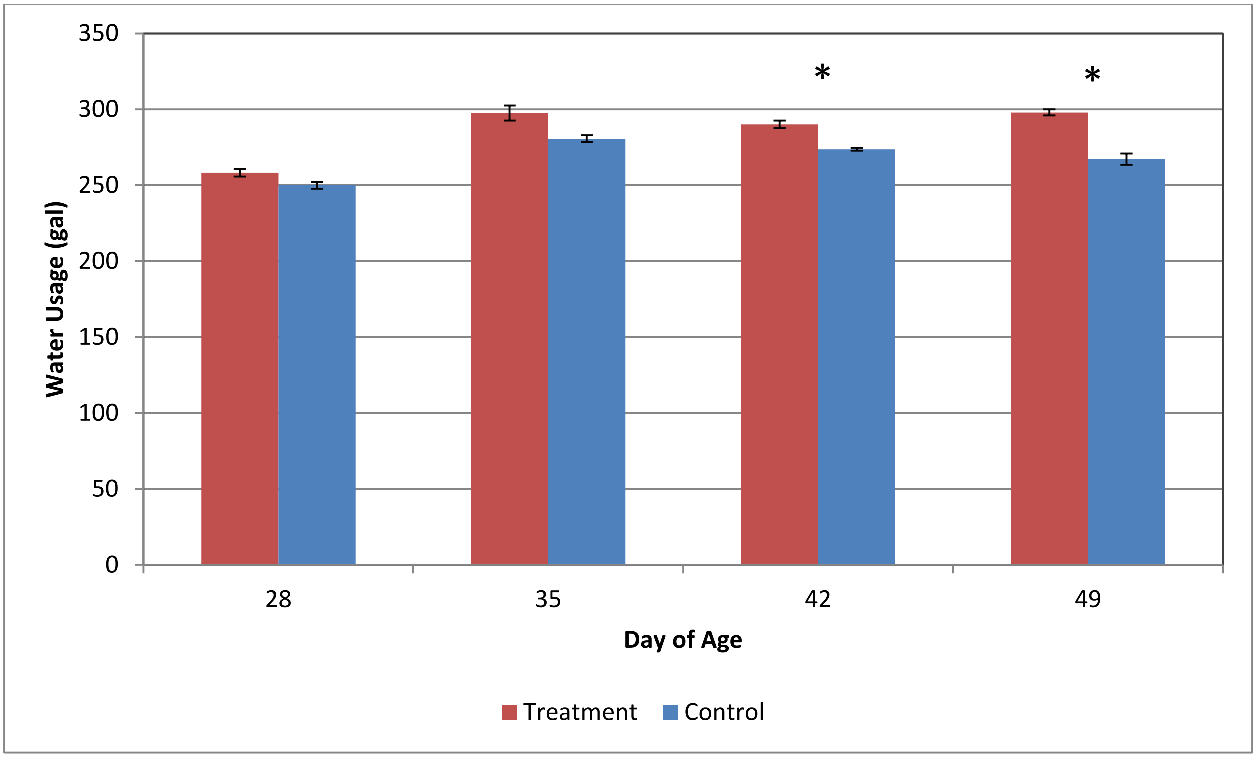

Figure 18. Weekly average water usage for the treatment and control group. * indicates a difference in water usage between treatments within a time period (P-value<0.05). Values are means ± SEM. n = 2 drinkers per treatment

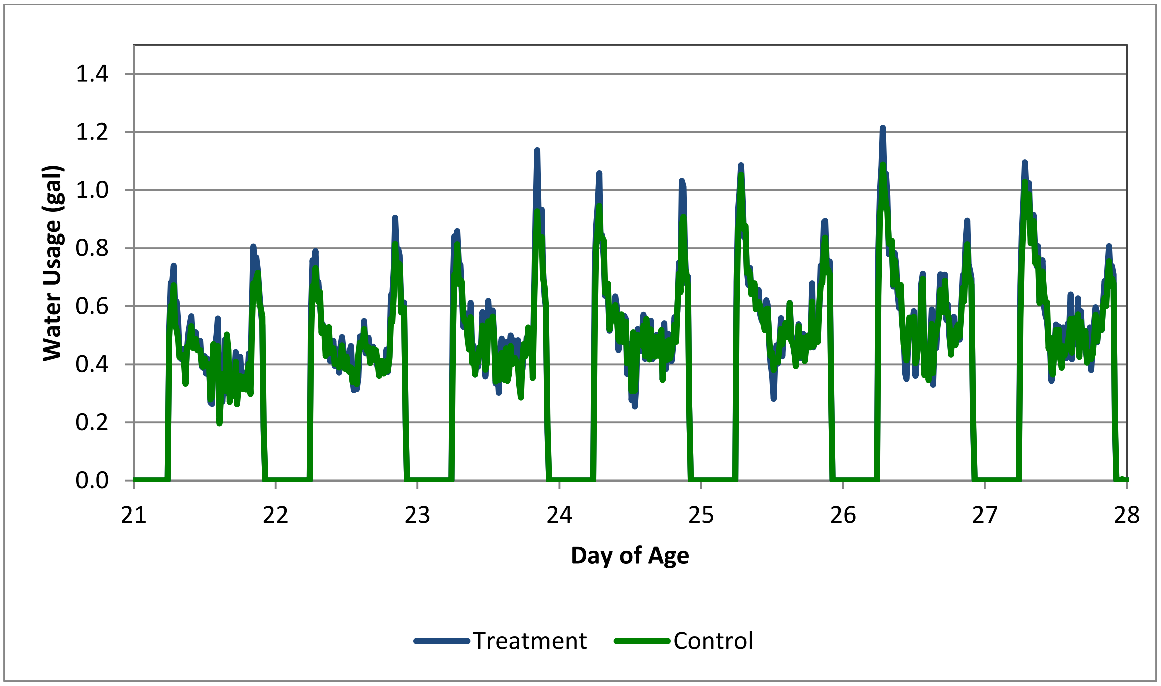

Figure 19. Week 4 (Day 21 to 28) 15 minute average water usage per group showing a similar level of water usage throughout the day

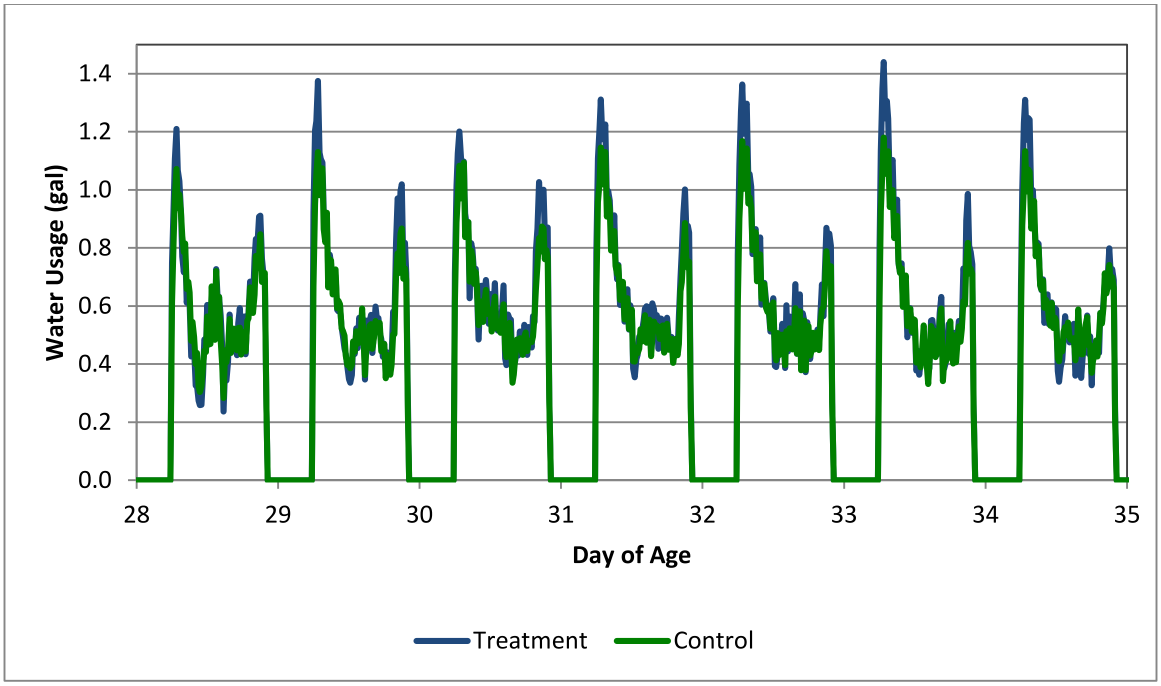

Figure 20. Week 5 (Day 28 to 35) 15 minute average water usage per group showing that the treatment group is starting to show a higher water usage in the morning peak

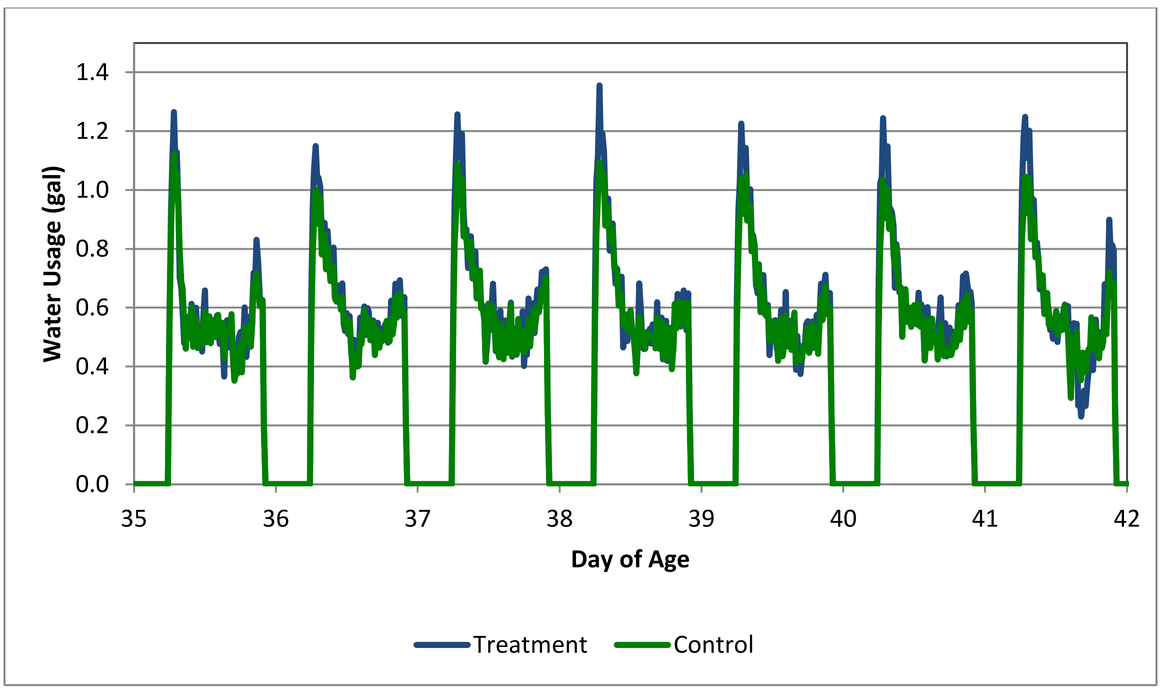

Figure 21. Week 6 (Day 35 to 42) 15 minute average water usage per group showing that the treatment group is starting to show a higher water usage in the morning peak

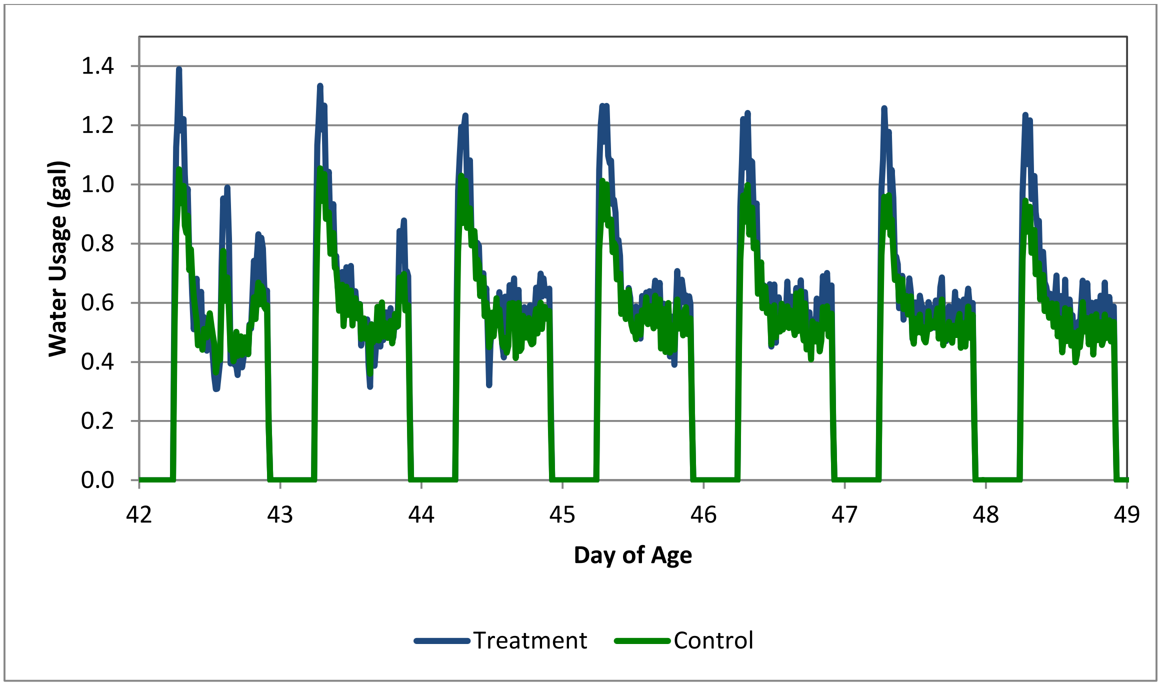

Figure 22. Week 7 (Day 42 to 49) 15 minute average water usage per group shows that there is a higher water usage in both the morning and afternoon peaks

Table 4. Influence of drinker water pressure on bird body weight (g), bird body weight gain (g), and feed conversion ratio (g/g) for each week

	Bird Body Weight		**Bird Body Weight Gain**		**Feed Conversion Ratio**	
Age	(grams)				(g/g)	
(day)	treatment	control	treatment	control	treatment	control
21	1,023 ± 11	1,023 ± 9	-	-	-	-
28	1,691 ± 13	1,678 ± 12	668 ± 4	655 ± 6	1.44 ± 0.027	1.46 ± 0.023
35	2,316 ± 15	2,287 ± 14	624^{a} ± 4	609^{b} ± 5	1.78 ± 0.008	1.80 ± 0.011
42	$2{,}909^{a}$ ± 17	$2{,}858^{b}$ ± 15	594^{a} ± 6	571^{b} ± 6	2.00 ± 0.019	2.02 ± 0.021
49	$3{,}496^{A}$ ± 17	$3{,}371^{B}$ ± 21	587^{A} ± 13	514^{B} ± 15	2.26^{B} ± 0.032	2.59^{A} ± 0.066

^{a,b} Means within a row without a common superscript are different (P-value<0.05)
^{A,B} Means within a row without a common superscript are different (P-value<0.01)
Values are means ± SEM
n = 35 pens per treatment

CHAPTER 5

Conclusion

The objective was to determine the influence that a difference in drinker water pressure had on bird water usage and performance. The results found that;

1. An increase in drinker water pressure resulted in increased water usage
2. Birds had a higher BW on days 42 and 49
3. BWG was higher in the treatment group on day 35, 42 and 49 with the largest difference of 70 grams happening in the last week (Day 49)
4. Feed consumption was significantly higher in the treatment group starting at Day 35 and continued throughout the remainder of the trial
5. FCR was improved by 0.34 in the last week of the trial (Day 49)
6. Litter moisture was increased in the treatment group throughout the entire study (Days 28, 35, 42 and 49)

While these results show that birds have better performance in the treatment group compared to the control group it also has to be taken into account the increased litter moisture. Increased litter moisture can have a negative impact on broilers due to increased footpad dermatitis or through increased ammonia generation. Increased litter moisture can be detrimental but if the litter is kept dry until the end of the flock and the drinker water pressure is then increased, the increase in litter moisture right before the birds go to market may not have the detrimental effects to the birds. While the BWG had the largest difference in the last week of the trial this is not to say that birds sold at a younger age wouldn't benefit from increased water pressure at the end of the flock since there was an increased BWG of 16g and 23g on Days 35 and 42 respectively.

The results of the pen trial shows that the birds in the control pen may actually become water restricted as they get older since the lower drinker water pressure would lead to less water being delivered out of the nipple. This can be indicated by the decreased BW and BWG toward the end of the trial. Similar results were seen by Kellerup et al. (1965) where birds that had restricted access to water had depressed body weights. This may show that in some instances birds are actually being water restricted when low levels of drinker water pressures are given to birds at a certain age. While the water restriction in this trial may not have been the level that was done to the birds in the previous paper it does shed some light on how important proper drinker management is to get the best performance out of the broilers. Further research would be needed to determine the drinker water pressure for the birds to reach their optimal growth potential but the litter quality would need to be considered.

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APPENDIX

Water Meter Calibration

Each water meter had a calibration curve created so the pulses that were generated by the unit could be converted to a flow rate in milliliters per minute which could then be converted into gallons per minute. This curve was created by first attaching each unit to a water source with a flow rate controller in line to control the flow of the water passing through the water meter (Figure 23). The water meter was then hooked up to a Hobo U-30 unit that collected the pulses generated each minute. The water source was then activated and the flow controller was set to 300ml/min. The water being discharged was then collected initially to determine the true flow rate going through the water meter. Once this flow rate was determined the time was documented for reference to the data file being created in the Hobo U-30 unit. This flow rate was then passed through the water meter for 5 minutes to collect multiple data points for the calibration curve. Once the 5 collection period was completed the flow regulator was then increased ~ 100ml/min flow rate and the process was repeated until reaching a flow rate of 3,000ml/min. After data points were collected for the range of flow rates for the water meter, the information was then imported into excel where the pulses at each 5 minute time interval per flow rate were averaged together and plotted as a line. Once the line was plotted two regression lines were created, one for less than 300 ml/min and the other for greater than 300 ml/min flow rates. These equations were then applied to the corresponding water meter when data was collected. This process was repeated for each water meter until each one had its own individual equations to be applied to the data collected when in use.

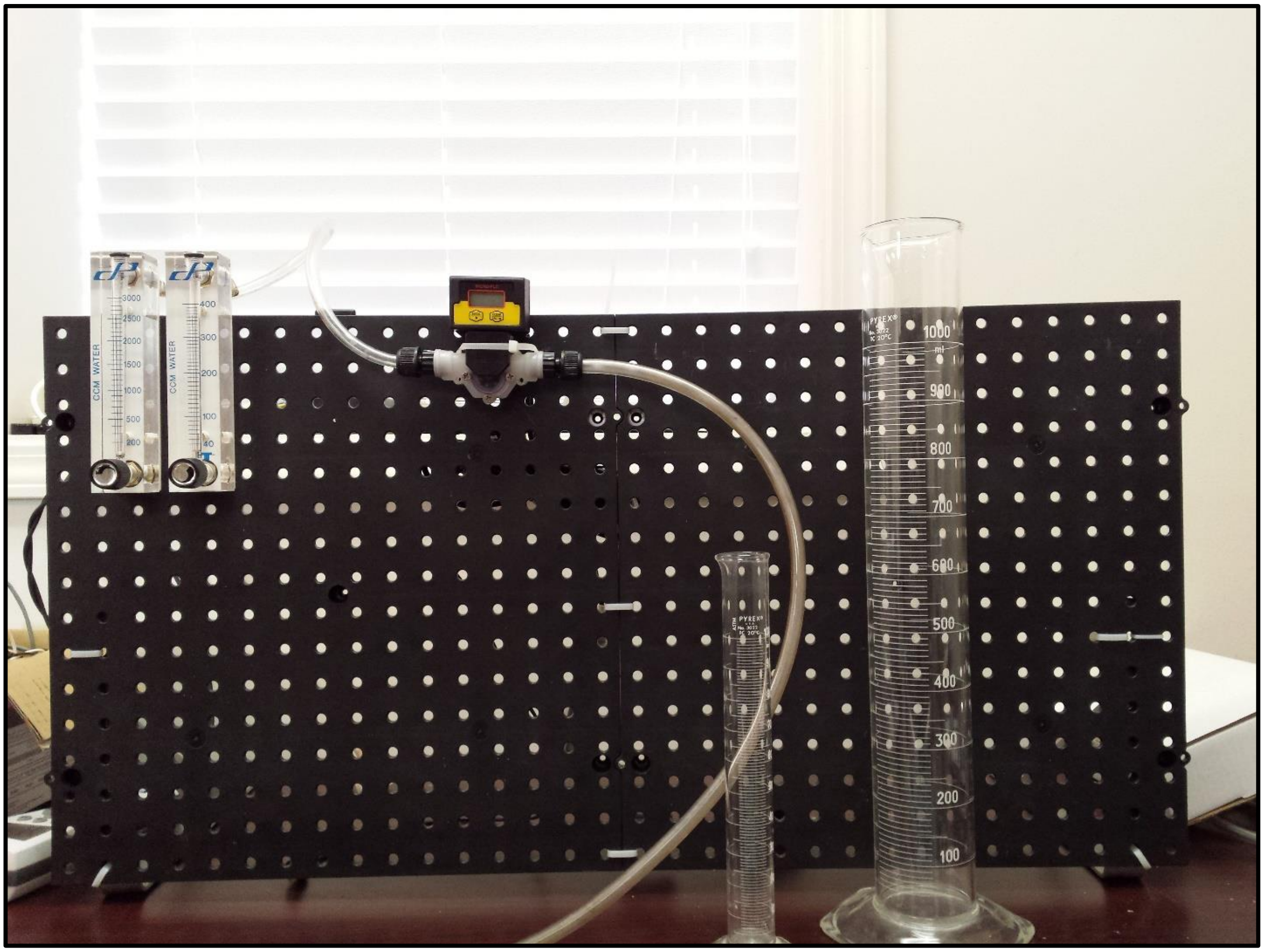

Figure 23. A picture showing the setup for the generation of calibration curves for each low flow water meter