Fall 2018

Effects of Irrigation on Forage Growth Rates on Rotational Grazing Dairies

Zachary Davis
Missouri State University, Davis66@live.missouristate.edu

Recommended Citation
Davis, Zachary, "Effects of Irrigation on Forage Growth Rates on Rotational Grazing Dairies" (2018). *MSU Graduate Theses*. 3336.
https://bearworks.missouristate.edu/theses/3336

EFFECTS OF IRRIGATION ON FORAGE GROWTH RATES ON ROTATIONAL GRAZING DAIRIES

A Master's Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Plant Science

By

Zachary Davis

December 2018

EFFECTS OF IRRIGATION ON FORGE GROWTH RATES ON ROTATIONAL GRAZING DAIRIES

Environmental Plant Science and Natural Resources

Missouri State University, December 2018

Master of Science

Zachary Davis

ABSTRACT

The amount and timing of rainfall in Missouri can be very irregular. This causes issues for producers of agronomic products in the state who rely on forages for income. The most sensible approach to the problem is the use of irrigation. But there is little useful information to reference when implementing this management decision. By studying three different styles of irrigation (center pivot, spider, and k-line) on 4 species of forages native to Missouri (alfalfa, crabgrass, perennial ryegrass, and tall fescue/clover), this study provides valuable insight as to the cost and benefit of irrigation. The main goal is to produce information that will allow owners to develop systems that increase their profitability as well as remain sustainable. This includes measuring forage effects from irrigation, the type of irrigation, forage species response and the associated cost with irrigation. To accomplish this, measurements were taken from paddocks scattered throughout these dairies on the forage height using an ultrasonic sensor mounted to an allterrain vehicle (atv). Calibration cuttings were assigned throughout the year to give relative pounds per acre for each crop at associated heights. The readings were then passed through the neural network which performs replications based on the original raw data to provide growth rates. Irrigation rates will be determined by farm managers on a per farm per paddock basis.

KEYWORDS: forages, rotational grazing dairies, irrigation, ultrasonic sensor, pasture

EFFECTS OF IRRIGATION ON FORAGE GROWTH RATES ON ROTATIONAL GRAZING DAIRIES

By

Zachary Davis

A Master's Thesis
Submitted to the Graduate College
Of Missouri State University
In Partial Fulfillment of the Requirements
For the Degree of Master's of Science, Plant Science

December 2018

Approved:

William McClain, Ph.D., Thesis Committee Chair

Melissa Remley, Ph.D., Committee Member

Micheal Gorndt, Ph.D., Committee Member

Julie Masterson, Ph.D., Dean of the Graduate College

TABLE OF CONTENTS

Introduction Page 1

- Industry Trends Page 1
- Rotational Grazing Dairies Page 2
- Water Page 3
- Forages Page 3
- Sonic Sensor Technology Page 5

Materials and Methods Page 8

- Overview Page 8
- Irrigation Types Page 8
- Weather Page 9
- Individually Owned Dairies Page 9
- Grassland LLC. Dairies Page 10
- Height Measurements Page 11
- Calibration Harvest Page 12
- Statistical Analysis Page 12

Results and Discussion Page 14

- Ryegrass Page 15
- Alfalfa Page 16
- Tall Fescue Page 16

References Page 18

LIST OF TABLES

Table 1. ANOVA for Pasture Growth Rates of All Species on All Farms for 2016-17 Page 21

Table 2. ANOVA for Pasture Growth Rates of Ryegrass on the White Oak Farm for 2016-17 Page 21

Table 3. ANOVA for Pasture Growth Rates of Ryegrass on the Thomlinson Farm for 2016-17 Page 21

Table 4. ANOVA for Pasture Growth Rates of Ryegrass on the Mariposa Farm for 2016-17 Page 22

Table 5. ANOVA for Pasture Growth Rates of Alfalfa on the Fletcher Farm for 2016-17 Page 22

Table 6. ANOVA for Pasture Growth Rates of Tall Fescue on the Fletcher Farm for 2016-17 Page 22

Table 7. ANOVA for Pasture Growth Rates of Tall Fescue on the Bernie Farm for 2016-17 Page 23

LIST OF FIGURES

Figure 1. Location map of five pasture-based dairies in southwest Missouri for both study years 2016 and 2017. Page 24

Figure 2. Pivot irrigation system located on Bernie farm over a paddock of tall fescue in October of 2016. Page 25

Figure 3. Low pressure traveling gun irrigation system located at Fletcher farm deployed on alfalfa paddock shortly after grazing event in September of 2016. Page 26

Figure 4. Rainfall amounts for the year of 2016 and 2017 and the 30 year average. Recorded by the weather station at the University of Missouri Southwest Research Center in Mount Vernon, Missouri. Page 27

Figure 5. Evapotranspiration rates for the year of 2016 and 2017. Recorded by the weather station at the University of Missouri Southwest Research Center in Mount Vernon, Missouri. Page 28

Figure 6. Average daily air temperatures (˚C) for the year of 2016 and 2017 and the 30 year average. Recorded by the weather station at the University of Missouri Southwest Research Center in Mount Vernon, Missouri. Page 29

Figure 7. Plot map of the Fletcher farm for the first year of the study. Paddocks of alfalfa and tall fescue were flagged to allow for treatment area designation without disrupting grazing behavior or other paddock management. Page 30

Figure 8. Plot map of the Bernie farm for 2017. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation system coverage of paddocks of tall fescue and a perennial ryegrass. Page 31

Figure 9. Plot map of the White Oak farm. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation coverage over perennial ryegrass paddocks. Page 32

Figure 10. Plot map of the Mariposa farm for 2016. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation coverage over paddocks of perennial ryegrass. Page 33

Figure 11. Plot map of the Thomlinson farm for 2016. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation coverage over perennial ryegrass paddocks. Page 34

Figure 12. Calibration harvester mounted behind a tractor and allterrain vehicle equipped with ultrasonic sensor. Page 35

Figure 13. Linear regression of calibration harvest dry matter yields of perennial ryegrass to height measurements obtained using the ultrasonic sensor. Page 36

Figure 14. Linear regression of calibration harvest dry matter yields of alfalfa to height measurements obtained using the ultrasonic sensor. Page 37

Figure 15. Linear regression of calibration harvest dry matter yields of tall fescue to height measurements obtained using the ultrasonic sensor. Page 38

Figure 16. Irrigation of perennial ryegrass in paddock on the White Oak farm during 2017. Vertical lines represent irrigation events of 2.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 39

Figure 17. Irrigation of perennial ryegrass on the Thomlinson farm in 2017. Vertical lines represent irrigation events of 2.5 cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 40

Figure 18. Irrigation of perennial ryegrass on the Mariposa farm during the summer of 2017. Vertical lines represent irrigation events of 2.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 41

Figure 19. Irrigation of perennial ryegrass paddock on the Thomlinson farm during 2016. Vertical lines represent irrigation events of 2.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 42

Figure 20. Irrigation of alfalfa paddock on the Fletcher farm during 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 43

Figure 21. Irrigation of alfalfa paddock on the Fletcher farm in 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 44

Figure 22. Irrigation of tall fescue paddock on the Fletcher farm during 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 45

Figure 23. Irrigation of tall fescue paddock on the Fletcher farm during 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 46

Figure 24. Irrigation of tall fescue paddock on the Bernie farm in 2017. Vertical lines represent irrigation events of varied amounts of applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 47

Figure 25. Irrigation of tall fescue on the Bernie farm in 2017. Vertical lines represent irrigation events of varied amounts of applied water. Height measurements at each date are an average of 500 to 2,000 readings. Page 48

INTRODUCTION

Industry Trends

Missouri ranks 25th nationwide in terms of number of milk cattle with a total of 85,000 cows. This number has been on a steady decline for the last few decades before the census. With falling prices and higher feed costs hurting the economic feasibility of dairies, it is important now more than ever to make improvements to the efficiency of milk production. American dairy production has shifted from small family-owned dairies into fewer larger farms (MacDonald, McBride, O'Donoghue, 2007a; MacDonald et al., 2007b), and southwest Missouri shows the same pattern. With this consolidation there have been a few key changes. Although cattle numbers have fallen to half of what they were prior to the 21st century, the market has seen a 1% increase in cattle numbers since 2008. In conjunction with the slight increase in total numbers, the milk production per cow has increased sharply since 2008 rising by 12% to around 2,300lbs of milk per year on average. This increase in per cow production is attributed to increasing technology and better management practices in areas such as facilities, nutrition and health. It is important to note that with our growing population, milk consumption has grown as well. The average American eats approximately 645 pounds of milk fat per capita as of 2016 opposed to 591 pounds just 15 years earlier (USDA ERS, 2014). With a population growth of 16 million people in the United States alone over that time, this is an astronomical increased demand put on the market.

Rotational Grazing Dairies

Grass-based dairies are built to run on a lower operational and keeping a consistent level of production (Elbehri and Ford, 1995; Hanson, 1998). This idea is centered around a smaller portion of the budget being lost into feedstuffs. Dairies that use confinement methods typically operate using total mixed ration (TMR). TMR's are a great way to combine all the nutrients that are needed for milk production. Harvested forages, grains, and other fiber products are often used in TMR's. One problem associated with this method is that harvested products demand a higher price due to the inputs of collecting and processing as well as large amounts of machinery involved. By feeding cattle forages straight from the field there is less money lost in combining, baling, or ensiling. In addition, harvested forage systems look to maximize yield because they are taken only once or twice a year this can compromise the nutritive value. Under grazing conditions however plants are more likely to be consumed when they are more nutritious because they are grazed earlier in the growth stage. Grazing dairies can reduce feed costs by 30% to 50% when using forages rather than stored feeds (Parker, 1992; Hanson, 1998).

These lower feed costs, along with less labor hours (due to decreased milking times) lead to lower operating costs, thus allowing a producer to become more sustainable even with a smaller operation. For example, in a study of small dairies in the mid-Atlantic region of the U.S., rotational grazing dairies showed average incomes the same as confinement dairies (Hanson et al., 2011). In addition to these financial benefits, cattle in a rotational grazing system experience many health and milk quality benefits. Less incidence of hoof and eye problems were reported by Parker et al. (1993) compared to confinement cattle. Veterinary expenses were reduced by 54% at rotational grazing dairies (Hanson et al., 2011), and the mortality rate was reduced by 46-75% (Burow, 2011). For these reasons grazing dairies in the Midwest region of the U.S. had increased in number significantly since 1998. (Pierce et al., 2002)

Water

Approximately 70% of global water use is dedicated to agriculture (World Water Assessment Programme, 2009). Due to the limited nature of this resource and the growing population, there will be increased regulation of fresh water (International Water Management Institute, 2007; Wani, 2009). In particular, the dairy industry between stock drinking water, milking parlor water, and irrigation water, consumes a large portion of agricultural water so confining these uses to their most efficient methods is crucial. In Missouri, there are 260,000 irrigated farms, but of this, only 23% of the farms are irrigating forage for pasturing the rest are cropland (USDA NASS, 2012). Missouri has a continental climate with strong seasonal differences averaging between 40 and 45 inches of precipitation a year. Rainfall averages however fall below 4 inches a month during July and August. Temperatures for 50-60 days of the summer can surpass 90°F thus potentially causing a period of drought stress. Therefore, irrigation of forage may be a useful tool to sustain reasonable forage production when rainfall is infrequent.

Forages

Milk production in the United States follows a specific yearly pattern with much of the production occurring between the months of March and August after calving in February. Due to this increase in production there is a much higher nutrient requirement for the cattle during the late spring and summer months. To meet these under a rotational grazing system optimal forage growth is a must.

Forage production is the primary agriculture land use for southwest Missouri, ranking in the top 10% when compared to other congressional districts in the U.S. (USDA NASS, 2012). The interaction of climate, topography and infrastructure all make this region a major producer of hay, grass-silage and pasture. While much of the area is not considered ideal cropland it can support adequate forage growth. Southern Missouri is well adapted forages that prefer warm weather as well as those favoring cooler temperatures because of its diverse climate an advantage which is lost when moving much north or south on the equator.

Grass-based dairy farms in the area often make use of several types of forage to provide adequate feed supply for milking cows throughout the year and reduce the need for stored feeds. Among the options available for production are alfalfa (Medicago sativa), tall fescue (Lolium arundinaceum), and perennial ryegrass (Lolium perenne).

Alfalfa. Alfalfa, a warm season legume is a very nutritional forage source for dairy cattle. Crude protein levels of about 18% in mid-bloom alfalfa (Southern Forages,) are more than adequate to provide for milk production. Along with the better quality of the forage, it has high palatability and lower neutral detergent fiber (Ball, Hoveland & Lacefield, 2015) which increases consumption when compared to other forages in the area. These two factors make alfalfa an ideal candidate for meeting the high requirements of milk producing cows. Cattle grazing grass pastures mixed with legumes, such as alfalfa, had a higher yield and milk fat percentage than those grazing a ryegrass monoculture (Pembleton, 2015). The majority of alfalfa growth is concentrated in the summer months and it tolerates drought better than many grasses because of its strong taproot and ability to perform osmotic adjustments (Jefferson & Cutforth, 2005).

Irrigation considerations rely primarily on frequency and not necessarily water depth as noted in a study showing an 80% decrease in yield when no irrigation was applied (Auckly & Guitjens, 1995). Rotational grazing can be a suitable use of alfalfa management when done intensively in an attempt to preserve plant densities because over grazing can result in poor stand persistence (Brummer & Moore, 2000).

Cool season grasses. Tall fescue and Perennial ryegrass are very similar forages, both producing most of their growth in the spring as well as decent yields during the fall. These cool season grasses are lower in crude protein at approximately 14%-10%, declining as the plant becomes reproductive (Ball et al., 2015). Tall fescue has a higher water use efficiency than perennial ryegrass under optimal irrigation, and a deficit irrigation of 66% field capacity (Neal, Fulkerson, Sutton, 2011). Although tall fescue used more water in each of the treatments, average yield was higher thus making it more efficient.

Sonic Sensor Technology

Sampling of pastures is a tough endeavor to accomplish. The reason for this is due to the fact that to get an accurate measurement of growth of forage the sampling area must be left void of animals until mature height is reached. This can cut down on the available area for grazing and decrease producer resources. In addition, research plots can often be ruined during experimentation when livestock destroy fencing or can be subjected to small plot effects which reduce the chance for accurate representation. Finally, pasture composition is a very dynamic system changing throughout the growing season and from one year to the next and requires sampling at regular intervals (Kallenbach, 2015). History has presented many types of tools used to collect samples of “harvestable forage” including sward sticks, rising plate meters (RPM) and visual estimates. A sward stick consists of a 2 by 1 cm ruler with a clear viewing window which is lowered vertically until it reaches the vegetation. This type of measurement is developed along the positive relationship of uncompressed forage height to field biomass. RPM are most commonly a plastic or metal disk centered around a pole which can freely slide through. The forage can be measured by the height at which the disk is supported when the center rod is lowered into the forage canopy until contacting the ground. These rapid measurements can be recorded internally or manually depending on the model being used. These data points are calculated using the size of the disc and the disc weight in a compressed forage height system. These systems are calibrated by mechanically harvesting smaller subplots from within the sample area to provide weights that are available at each given height measurement. Number of cuttings to gain a representative sample is a widely debatable topic and is often different from one experiment to the next (Eckblad, 1991). Using this approach cuttings can be done less often, and nondestructive readings can be repeated throughout the year. Such methods have been found to be reasonably accurate in experiments such as Bransby (1977) and Kallenbach et al. (2012).

Ultrasonic sensors described in the following section are currently undergoing research to be assessed on how they can be used to fill the gap in forage estimation. By being mobilized on systems such as golf carts and all-terrain vehicle these systems allow for users to obtain large datasets over bigger sample areas in a timelier manner thus cutting down on labor expenses. In addition, these methods have potential to be as accurate in pasture measurement as previously studied practices (Pittman, 2015)

This study looks to address the effect of irrigation type, amount, and timing across different species of forages. This information can be used to help producers make better management decisions and increase farm viability. The null hypothesis is irrigation of perennial ryegrass, tall fescue, and alfalfa, will not increase the dry matter (DM) production.

MATERIALS AND METHODS

Overview

This study was conducted on five pasture-based dairies in southwest Missouri during the 2016 and 2017 growing seasons (Figure 1). Dairy producers in the counties of Barry, Jasper, and Newton allotted 4 to 10 paddocks from each farm to the study. Paddocks were flagged to distinguish irrigated portions from non-irrigated areas without interrupting the grazing behavior of the cattle. These flags were placed beyond irrigation areas or on pre-agreed upon locations decided by the producers and were maintained throughout both years of the study. Two of the five pasture-based dairies in this experiment were individually owned and operated. The other three dairies are operated by Grasslands LLC, members of the New Zealand Grassland Association and all follow a set of management practices, species selection and utilize the same type of irrigation system. Due to the variability of individual farms in this study, each location, soil characterization, number of paddocks, species selected, and type of irrigation used is discussed below.

Irrigation Types

Two different irrigation systems were included in this experiment. Four of the five farms utilize central pivot irrigation systems (Figure 2) and one utilized a low pressure traveling gun (Figure 3). Central pivot irrigation systems require the least amount of labor after setting up and are often controlled electronically by smart phones and even automated soil moisture probes. These systems travel across the farm in large arcs while distributing water in even bands along the length of the pivot arm. Although central pivots are easily used, they do require the largest amount of starting capitol and are less adaptable to a changing fencing system and farm shape. Low pressure traveling guns are easily compared to large lawn sprinklers. This type of system requires the gun be attached to a winch, which pulls the unit across a single paddock distributing water along its path. While this system is a more affordable option for producers, it requires more time and labor to utilize.

Weather

Environmental data is presented as monthly averages for air temperature, precipitation, and evapotranspiration for both years of the study and are summarized in Figures 4-6. Monthly averages and 30-year average data were collected from the Mount Vernon weather station located Lat: 37.077000°, Lon: -93.879000°. Available soil water was calculated using each paddocks soil type water holding capacity minus the evapotranspiration from short crop totals from the University of Missouri Southwest Research center website for each day and any precipitation or irrigation event was added back to the value for each day from the first of May through the last paddock reading for each year.

Individually Owned Dairies

Fletcher farm. In 2016 three paddocks of alfalfa and three paddocks of tall fescue were evaluated and 2017 an additional four alfalfa paddocks were added to the study (Figure 7). All paddocks at this farm were located on a Scholten-Tonti complex 3-8 percent slope (Loamyskeletal, siliceous, active, mesic Typic Fragiudults) at 36°50'36.21"N & 93°53'43.20"W. This farm utilizes a low pressure traveling gun irrigation system.

Bernie farm. In 2016 three paddocks of tall fescue and one paddock of perennial ryegrass were evaluated, in 2017 there was an addition of one paddock of tall fescue at this location (Figure 8). Two paddocks were located on a Hepler Silt Loam 0-2 percent, occasionally flooded (Fine-silty, mixed, superactive, thermic Mollic Endoaqualfs). Three paddocks were located on Bearthicket silt loam, 0-1 percent slope, occasionally flooded (Fine-silty, mixed, active, mesic Ultic Hapludalfs) at 37°10'4.03"N & 94°10'44.33"W. All paddocks at this farm were irrigated utilizing a central pivot system.

Grassland LLC. Dairies

White oak farm. In 2016 three paddocks of perennial ryegrass were evaluated and in 2017 one additional paddocks of perennial ryegrass (Figure 9). Three paddocks were located on Newtonia-Eldorado silt loam 1-3 percent slope moderately eroded (Fine-silty, mixed, superactive, thermic Typic Paleudolls) and one paddock was on a Maplegrove silt loam 1-3 percent slope (Fine, mixed, active, thermic Oxyaquic Argiudolls) at 37°13'31.31"N & 94° 4'3.65"W. All paddocks at this farm were irrigated utilizing a central pivot system.

Mariposa farm. In 2016 three paddocks of perennial ryegrass were evaluated and in 2017 three additional paddocks of perennial ryegrass (Figure 10). One paddock was located on a Keeno gravely silt loam (Loamy-skeletal, siliceous, active, mesic Oxyaquic Fragiudalfs) and the rest of the paddocks were Hoberg silt loam 2-5 percent slope (Fine-loamy, siliceous, active, mesic Oxyaquic Fragiudalfs) at 36°53'52.35"N & 94°12'0.81"W. All paddocks at this farm were irrigated utilizing a central pivot system.

Thomlinson farm. In 2016 four paddocks of perennial ryegrass were evaluated and in 2017 three additional paddocks of perennial ryegrass (Figure 11). Five paddocks were located on a Creldon silt loam 1-3 percent slope (Fine, mixed, active, mesic Oxyaquic Fragiudalfs), one paddock was located on a Secesh-Cedargap complex, 1 to 3 percent slopes, frequently flooded (Fine-loamy, siliceous, active, mesic Ultic Hapludalfs), and one paddock was on a Hoberg silt loam 2-5 percent slope (Fine-loamy, siliceous, active, mesic Oxyaquic Fragiudalfs) at 36°52'0.99"N & 94°13'47.37"W. All paddocks at this farm were irrigated utilizing a central pivot system.

Height Measurements

Readings were taken using an ultrasonic sensor mounted to the front cargo rack of an allterrain vehicle (Figure 12). The sensor used was a single headed system with a distance sensing transducer acting as both the emitter and the receiver. The sensor was connected to a GPS and a Data Limited dli 8500P, shock proof computer. Height readings were taken each week from the month of May to November for both 2016 and 2017 using paddock trac software to organize and log data. Seven-day intervals were used when possible to maximize time for forage growth between readings, but weather conditions and technical issues sometimes forced intervals of different lengths. Measurements were collected with a 120 Mhz sensor. The senor’s output rate was set to 20Hz with a sound cone projected at a 15° angle recording at a 645mm tare height (set to a mowed grass height similar to a lawn setting). Paddocks were sampled at a rate of 20 readings per second and at speeds between 11-14km/hr resulting in different total readings for each pasture based on size and route taken. Approximately 1500 individual height measurements were made for each paddock at each farm and averaged. Paddock routes were driven to provide a good representation of the whole paddock and avoided areas of high traffic or weed populations when possible.

Calibration Harvest

To assess pasture biomass, calibration harvests were done three time in 2016 (6/14, 7/28, 9/21) and two times in 2017 (6/22, 7/19) for each of the different species. Areas of forages with differing heights were selected for harvest. These plots were marked with flags then measured with the ultrasonic sensor. Next, a flail mower on a three-point attachment was used to cut each path (Figure 12). The harvester recorded distance measurements and weighed each sample for a fresh weight. After each sample was cut and dumped a subsample was taken and bagged to be dried. By doing this, heights from the ultrasonic sensor were assigned with relative kilograms of dry matter per hectare (DM kg/Ha) for each species. Regression analysis was used to develop cross-calibration equations between forage height and dry matter weight (Figures 13-15). Only regression coefficients significant at $P \leq 0.05$ were retained in equations. The growth rates were then estimated using the change in height of forage divided by the number of days between readings.

Statistical Analysis

Due to the highly variable nature of the management methods and sites used in this experiment, data was analyzed in a way to accommodate these changes. Individual farms were analyzed by species by paddocks over two growing seasons. The experiment was considered a completely randomized design analyzed as a split plot in time model with repeated measures for each farm. This model was used to test for statistical significance of irrigation effects as well as interactions with harvest date and year using PROC MIXED in SAS version 9.4 (ref). The main plot consisted of irrigation treatment and harvest date (year) was considered the split plot.

Irrigation treatment and harvest date were fixed effect factors and paddock and year were considered random factors. All effects and interactions were considered significant when $P<0.05$. When F test indicated significance ($P<0.05$), means were separated using Fisher's protected LSD ($\alpha = 0.05$). Experimental years are presented separately due to significant interactions for treatment effects.

RESULTS AND DISCUSSION

For both years of the study monthly precipitation values were below the 30-year average rainfall for each month except May and August of 2017(Figure 4). Evapotranspiration values were highest in June and July for both years (Figure 5). Average air temperatures were higher in 2016 than 2017 for all months except May and both years experienced air temperatures higher than the 30-year average (Figure 6).

Across all dates for both years there was no significant effect of irrigation treatment on forage growth rates (Table 1). There was a significant difference between farms, species and individual paddocks across all dates for both years. Since irrigation events rarely occurred at the same time and in the same amount across different farms for the same species comparing the results as though they are equal would be an inaccurate assumption. To better assess the results of irrigation, data sets were compared only within species and farm for both years so that conditions were as close to the same as possible. In addition, there was more consistent rainfall throughout the 2016 growing season and this caused less dependence on irrigation during the first year of the study.

Pasture characteristics were widely varied between the different management strategies and species involved in the study which can be witnessed through the large range of height measurements in the data set (Figures 16 - 25). Sensor height readings across both years ranged from 34mm to 312mm with a mean reading of 98mm in perennial ryegrass, 41 to 415 with a mean of 200 in alfalfa and 20 to 285 with a mean of 68 in tall fescue. Dry matter availability of 531 to 4858, 1427 to 4092, and 682 to 3205kg/Ha for perennial ryegrass, alfalfa, and tall fescue respectively.

Ryegrass

Ryegrass is the primary forage species located on the most paddocks across all farms and showed differing results across farms. When looking at individual farms and paddocks over a short period of time increase in growth rates is easily noticed. For the White Oak farm there was a significant effect of irrigation on ryegrass growth rates across all paddocks (Table 2). Ryegrass growth rates of non-irrigated paddocks plateaus sooner than the irrigated treatments therefor never reaching the same amount of dry matter per hectare (Figure 16). The Thomlinson farm also showed a significant effect of irrigation on ryegrass growth rates but also had a significant effect of paddock (Table 3). The increase in ryegrass growth rates occurred mainly in the fall of both years (Figure 17). The effect of irrigation on ryegrass growth rates was not significant at the Mariposa farm over both years (Table 4). The lack of significant effect on ryegrass growth rates is most likely due to the highly significant differences in individual paddock growth rates.

At times when irrigation was not being used and soil moisture levels were similar in the two treatments the yield is very similar between them. This was not the case in all paddocks presented in the study. In some situations, paddock conditions played a role in changing the effect of irrigation. Mariposa paddock 30 (Figure 9) was situated on a hill with irrigation occurring at the top. Excess water applied to the irrigated portion would then runoff onto the non-irrigated plot and confound the results (Figure 19). Weed pressure also caused issues with data collection. Thomlinson paddock 7 (Figure 11) contained a non-irrigated portion that was sparsely populated with ryegrass plants allowing an invasion of johnsongrass in the summer months during the study. The johnsongrass contamination led to much higher growth rates than the ryegrass, even without the additional water supplied though irrigation events (Figure 19).

The Bernie farm only had one paddock of perennial ryegrass for both years of the study. There was no effect of irrigation on the growth rates of ryegrass for either year (data no shown). This farm is situated on a flood plain and multiple reading dates were missed as the paddocks were under water.

Alfalfa

The entire population of alfalfa utilized in this study was located on the Fletcher farm which was irrigated using low pressure traveling gun system. No paddocks showed a significant effect of irrigation on the growth rates of alfalfa across both years of the study (Table 5). In the second year of the study late summer irrigation of alfalfa did indicate a slight increase of growth rates in irrigated plots over unirrigated plots (Figure 20 - 21). It is possible that well-timed irrigation of alfalfa in late summer and early fall could increase the production potential of paddocks. In some cases, the non-irrigated portion of the paddocks were skipped in the farms grazing rotation leading to uneven forage growth throughout the year and confounding the results of these paddocks. Although there was no significant effect of year in the overall model, the effect of irrigation in 2017 is most likely due to the increased amount of rainfall over the first year of the study and alfalfa's ability to tolerate drought more so then the cool season grasses in the experiment.

Tall Fescue

Tall fescue paddocks included in this experiment were found on two individually owned farms over both years of the study and varied in stand composition as some paddocks were over seeded with clovers especially at the Fletcher farm location. On the Fletcher farm, no paddocks showed a significant effect of irrigation on the growth rates of tall fescue across both years of the study (Table 6). While there were some instances of difference between irrigated and non-irrigated growth rates of tall fescue at the Fletcher farm they were not significant (Figures 22 23). The effect of irrigation on tall fescue growth rates was not significant at the Bernie farm over both years (Table 7). The lack of significant effect on tall fescue growth rates is most likely due to the highly significant differences in individual paddock growth rates (Figures 24 - 25). Field uniformity was very high between tall fescue paddocks at the Fletcher site, so effect of paddock would not be expected. However, the Bernie paddocks were located in a floodplain which saw flooding throughout portions of both experiment years. Effects of the flooding caused plant densities and weed densities to vary even across paddocks.

The limitations of this study were predominately due to utilizing privately owned dairies. None of the farms in this study irrigated paddocks on the same day or for the same duration. While the sensor allowed for vast amounts of data to be collected, making comparisons across paddocks, farms and species as though they were equal would be an inaccurate assumption. The ultra-sonic sensor would be an ideal tool to optimize the timely use of forages in a grazing rotation.

REFERENCES

Auckly, K.L., and J.C. Guitjens. 1995. Alfalfa yield response to Ground Water after Termination of Irrigation. Journal of Irrigation and Drainage Engineering. 121:364-366. 10.1061/(ASCE)0733-9437(1995)121:5(364)

Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 2015. Southern Forages. Fifth Edition.International Plant Nutrition Institute, Peachtree Corners, GA.

Bransby, D.I., A.G. Matches, and G.F. Krause. 1977. Disk meter for rapid estimation of herbage yield in grazing trials. Agron. J. 69:393–396. doi:10.2134/agronj1977.00021962006900030016x

Brummer, E.C., and K.J. Moore. 2000. Persistence of Perennial Cool-Season Grass and Legume Cultivars under Continuous Grazing by Beef Cattle Project No. 2569, supported by Hatch Act and State of Iowa Funds. Agron. J. 92:466-471. doi:10.2134/agronj2000.923466x

Burow, E., P.T. Thomsen, J.T. Sørensen, and T. Rousing. 2011. The effect of grazing on cow mortality in Danish dairy herds. Preventive Veterinary Medicine 100, no. 3. 4:237-241. doi:10.1016/j.prevetmed.2011.04.0

Eckblad, J.W. 1991. How many samples should be taken? Bioscience 41:346–348. doi:10.2307/1311590

Fricke, T., and M. Wachenforf. 2013. Combining ultrasonic sward height and spectral signatures to assess the biomass of legume-grass swards. Comp. and Electr. in Agr. 99. 236-247.

Hanson, G.D. 1998. Increasing intensity of pasture use with dairy cattle: An economic analysis. J. Prod. Agric. 11:175–179.

Hanson, J.C., D.M. Johnson, E. Lichtenberg, and K. Minegishi. 2011. Competitiveness of management-intensive grazing dairies in the mid-atlantic region from 1995 to 2009 Journal of Dairy Science 96, 3:1894-1904. http://dx.doi.org/10.3168/jds.2011-5234

International Water Management Institute. 2007. Water for Food, Water for life. A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, UK.

Jefferson, P.G., and Cutforth, H.W.. 2005. Comparative forage yield, water use and water use efficiency of alfalfa, crested wheat grass and spring wheat in a semi-arid climate in southern Saskatchewan. Canadian Journal of Plant Science. 85, 4:877-888. https://doi.org/10.4141/P04-115

Joost, R.E.. 2001. Warm-season annual forage crops Agricultural MU Guide. G4661.

Kallenbach, R.L., R.J. Crawford, M.D. Massie, M.S. Kerley, and N.J. Bailey. 2012. Integrating bermudagrass into tall fescue-based pasture systems for stocker cattle. J. Anim. Sci. 90:387–394. doi:10.2527/jas.2011-4070

Kallenbach, R.L. 2015. Describing the Dynamic: Measuring and Assessing the Value of Plants in the Pasture. Crop Sci. 55:2531-2539. doi:10.2135/cropsci2015.01.0065

MacDonald, J.M., W.D. McBride, and E.J. O'Donoghue. 2007a. Low costs drive production to large dairy farms. Amber Waves. Vol. 5(4). US Department of Agriculture Economic Research Service, Washington, DC.

MacDonald, J.M., E.J. O'Donoghue, W.D. McBride, R.F. Nehring, C.L. Sandretto, and R. Mosheim. 2007b. Profits, costs, and the changing structure of dairy farming. Economic Research Report Number 47. United States Department of Agriculture Economic Research Service, Washington, DC

Neal, J., W. Fulkerson, and B. Sutton. 2011. Differences in water-use efficiency among perennial forages used by the dairy industry under optimum and deficit irrigation. Irrigation Sci. 29, 213-232.

Parker, W.J. 1992.Management and economic implications of intensive grazing on dairy farms in the northeastern states. J. Dairy Sci. 75:2587–2597.

Parker, W.J., L.D. Muler, S.L. Fales, and W.T. McSweeny. 1993. A survey of dairy farms in Pennsylvania using minimal or intensive pasture grazing systems. Prof. Anim. Sci. 9:159163.

Pierce, V.L., J.L. Horner, J.C. Coomer, D.K. Hardin, J.A. Hoehne, A.M. Millmier, R. Randle, B.J. Steevens, and J.M. Zulovich. 2002. Competitive audit of the Missouri dairy industry 67

Pittman, J.J., D.B. Arnall., S.M. Interrante, C.A. Moffet, , and T.J. Butler. 2015. Estimation of Biomass and Canopy Height in Bermudagrass, Alfalfa, and Wheat Using Ultrasonic, Laser, and Spectral Sensors. *Sensors (Basel, Switzerland)*, *15*(2), 2920–2943. http://doi.org/10.3390/s150202920

Schellberg, J., and E. Verbruggen. 2014. Fronteirs and perspectives on research strategies in grassland technology. Crop Pasture Sci. 65:508-523. doi:10.1071/CP13429

USDA NASS Table 9. Land in Farms, Harvested Cropland, and Irrigated Land, by Size of Farm: 2012 and 2007

USDA ERS. U.S. Consumption of All Dairy Products, Milk-Fat Milk Equivalent Basis, Per Capita. Pounds per Person. 1975 to 2014

Wani, S.P., Sreedevi, T.K., Rockström, J. and Ramakrishna, Y.S. (2009) Rain-fed agriculture past trend and future prospects. In Rain-fed agriculture: Unlocking the Potential. Comprehensive Assessment of Water Management in Agriculture Series. CAB International, Wallingford, UK. pp. 1-35.

World Water Assessment Programme. 2009. The United Nations World Water Development Report 3: Water in a Changing World. UNESCO, Paris, France; Earthscan, London, UK.

Table 1. ANOVA for Pasture Growth Rates of All Species on All Farms for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	6967.973	6967.973	1.97	0.1605
Paddock	53	3903795.806	73656.525	20.83	<0.0001
Farm	4	2989233.146	597846.629	169.09	<0.0001
Year	1	4411.381	4411.381	1.25	0.2641
Species	2	248827.111	248827.111	70.38	<0.0001

Table 2. ANOVA for Pasture Growth Rates of Ryegrass on the White Oak Farm for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	15077.940	15077.940	17.26	<0.0001
Paddock	2	2553.561	73656.525	1.46	0.2340
Year	1	461.224	461.224	0.53	0.4682

Table 3. ANOVA for Pasture Growth Rates of Ryegrass on the Thomlinson Farm for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	3229.722	3229.722	3.94	0.0478
Paddock	6	50411.217	73656.525	10.24	<0.0001
Year	1	387.266	387.266	0.47	0.4924

Table 4. ANOVA for Pasture Growth Rates of Ryegrass on the Mariposa Farm for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	4693.981	4693.981	3.14	0.0769
Paddock	6	106539.147	73656.525	14.89	<0.0001
Year	1	323.859	323.859	0.22	0.6417

Table 5. ANOVA for Pasture Growth Rates of Alfalfa on the Fletcher Farm for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	13773.224	13773.224	1.09	0.2979
Paddock	4	39676.951	9919.237	0.78	0.5369
Year	1	26172.685	26172.685	2.07	0.1516

Table 6. ANOVA for Pasture Growth Rates of Tall Fescue on the Fletcher Farm for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	1930.508	1930.508	1.16	0.2819
Paddock	2	589.347	73656.525	0.18	0.8374
Year	1	856.294	856.294	0.52	0.4732

Table 7. ANOVA for Pasture Growth Rates of Tall Fescue on the Bernie Farm for 2016-17

Source	df	Sum of Squares	Mean Square	F	P
Treatment	1	2009.105	2009.105	1.21	0.2714
Paddock	3	55916.824	18638.941	11.26	<0.0001
Year	1	3329.962	3329.962	2.01	0.1570

Figure 1. Location map of five pasture-based dairies in southwest Missouri for both study years 2016 and 2017.

Figure 2. Pivot irrigation system located on Bernie farm over a paddock of tall fescue in October of 2016.

Figure 3. Low pressure traveling gun irrigation system located at Fletcher farm deployed on alfalfa paddock shortly after grazing event in September of 2016.

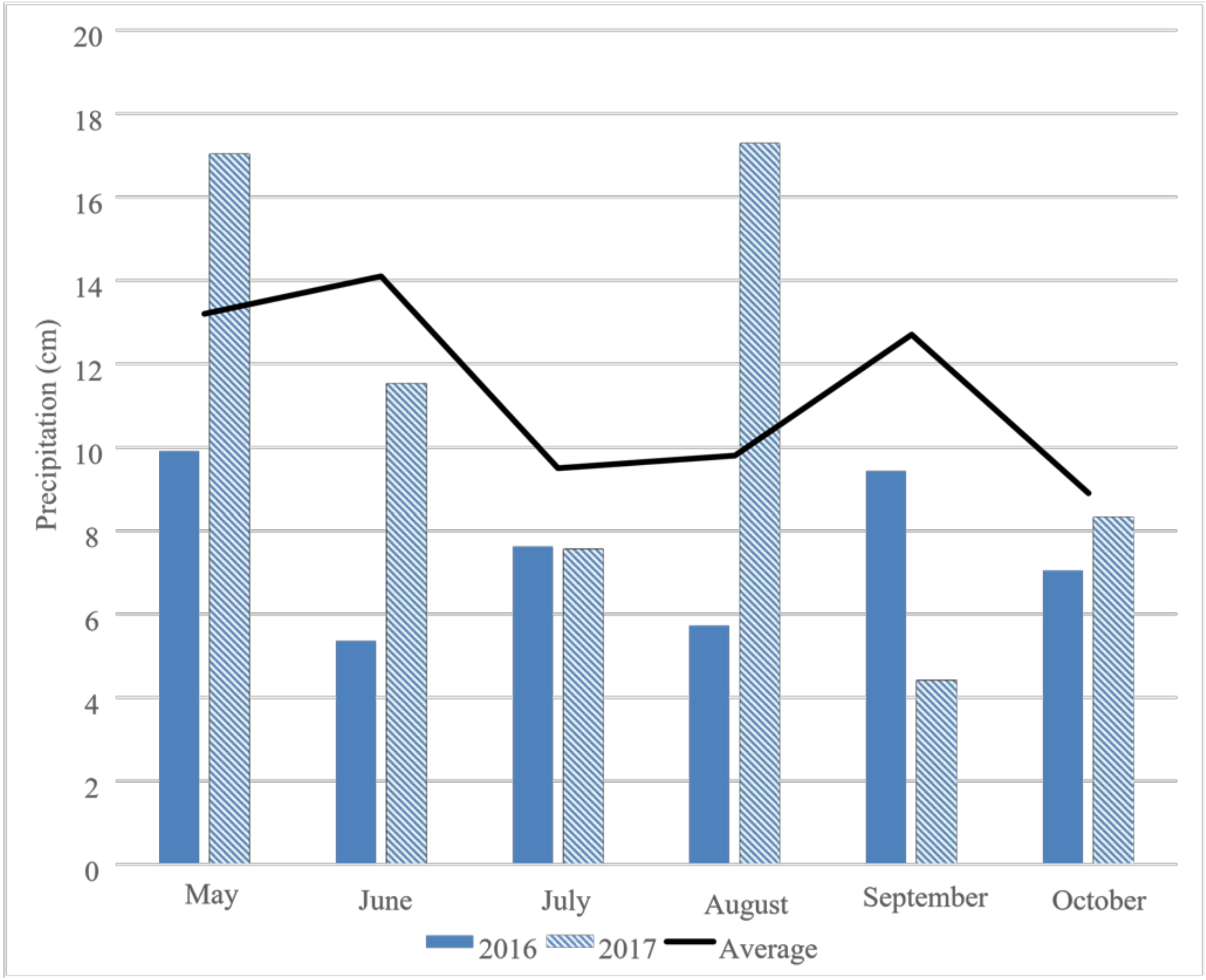


Figure 4. Rainfall amounts for the year of 2016 and 2017 and the 30-year average. Recorded by the weather station at the University of Missouri Southwest Research Center in Mount Vernon, Missouri.

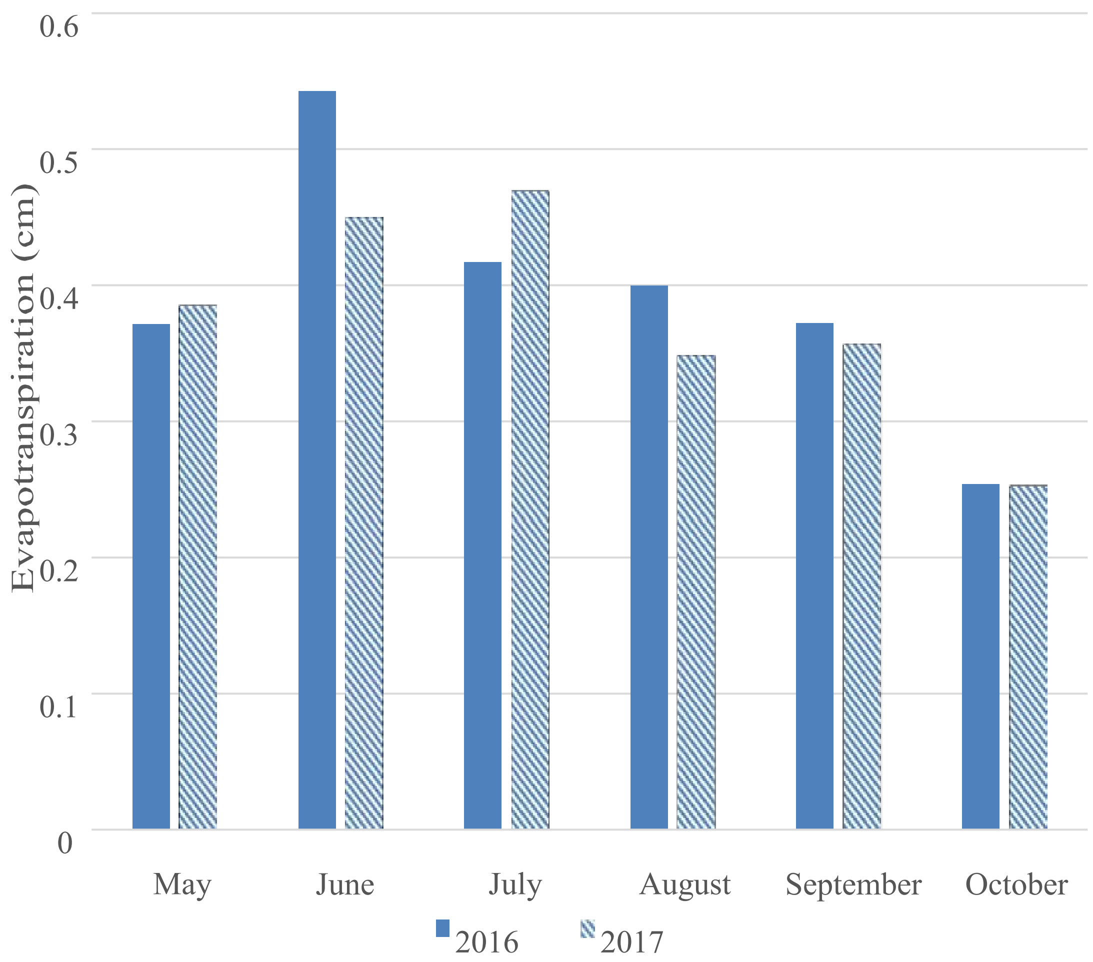


Figure 5. Evapotranspiration rates for the year of 2016 and 2017. Recorded by the weather station at the University of Missouri Southwest Research Center in Mount Vernon, Missouri.

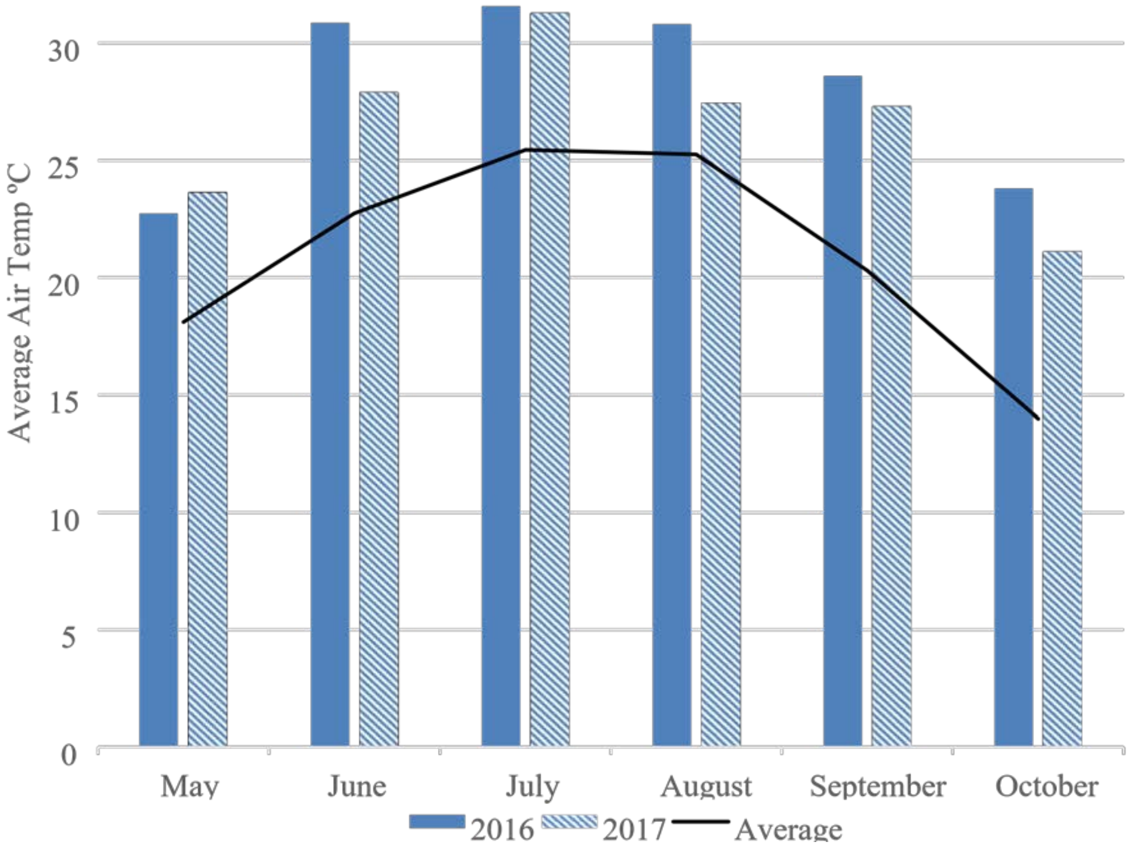


Figure 6. Average daily air temperatures (˚C) for the year of 2016 and 2017 and the 30 year average. Recorded by the weather station at the University of Missouri Southwest Research Center in Mount Vernon, Missouri.

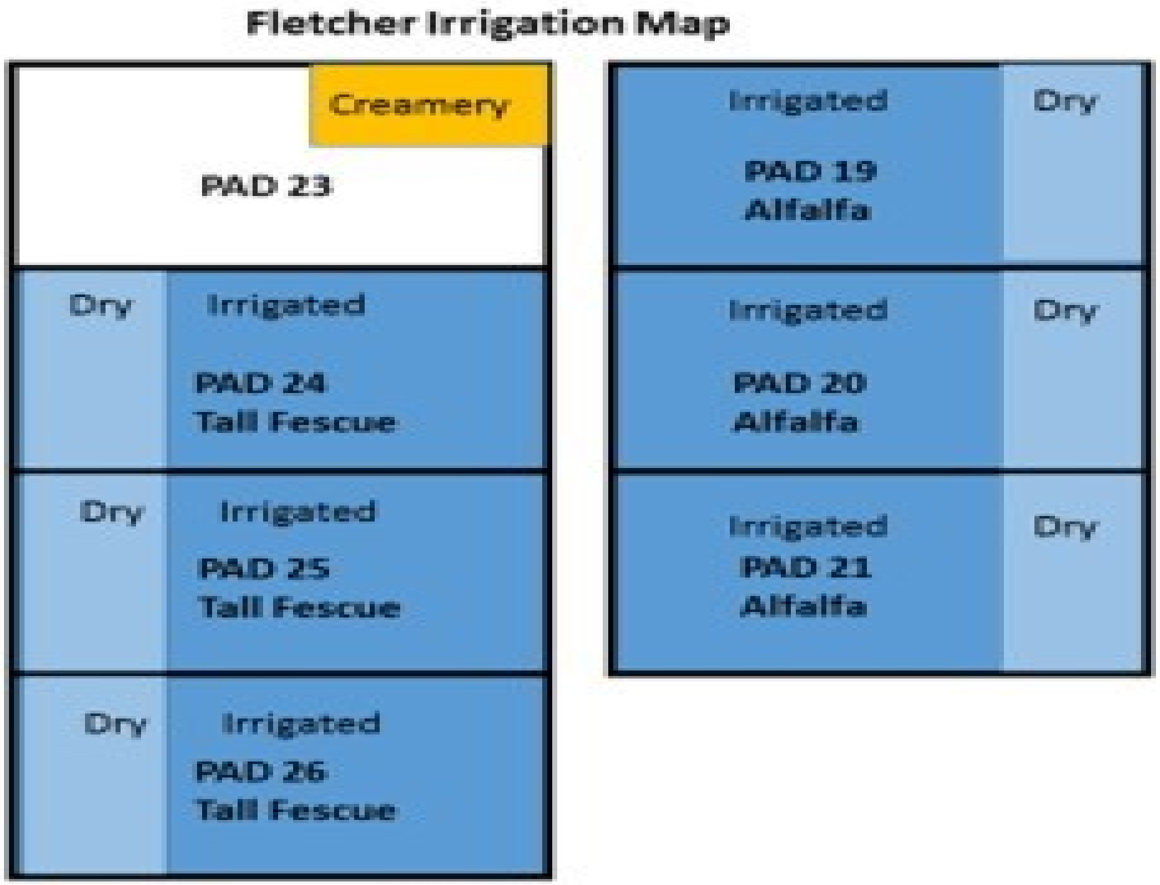


Figure 7. Plot map of the Fletcher farm for the first year of the study. Paddocks of alfalfa and tall fescue were flagged to allow for treatment area designation without disrupting grazing behavior or other paddock management.

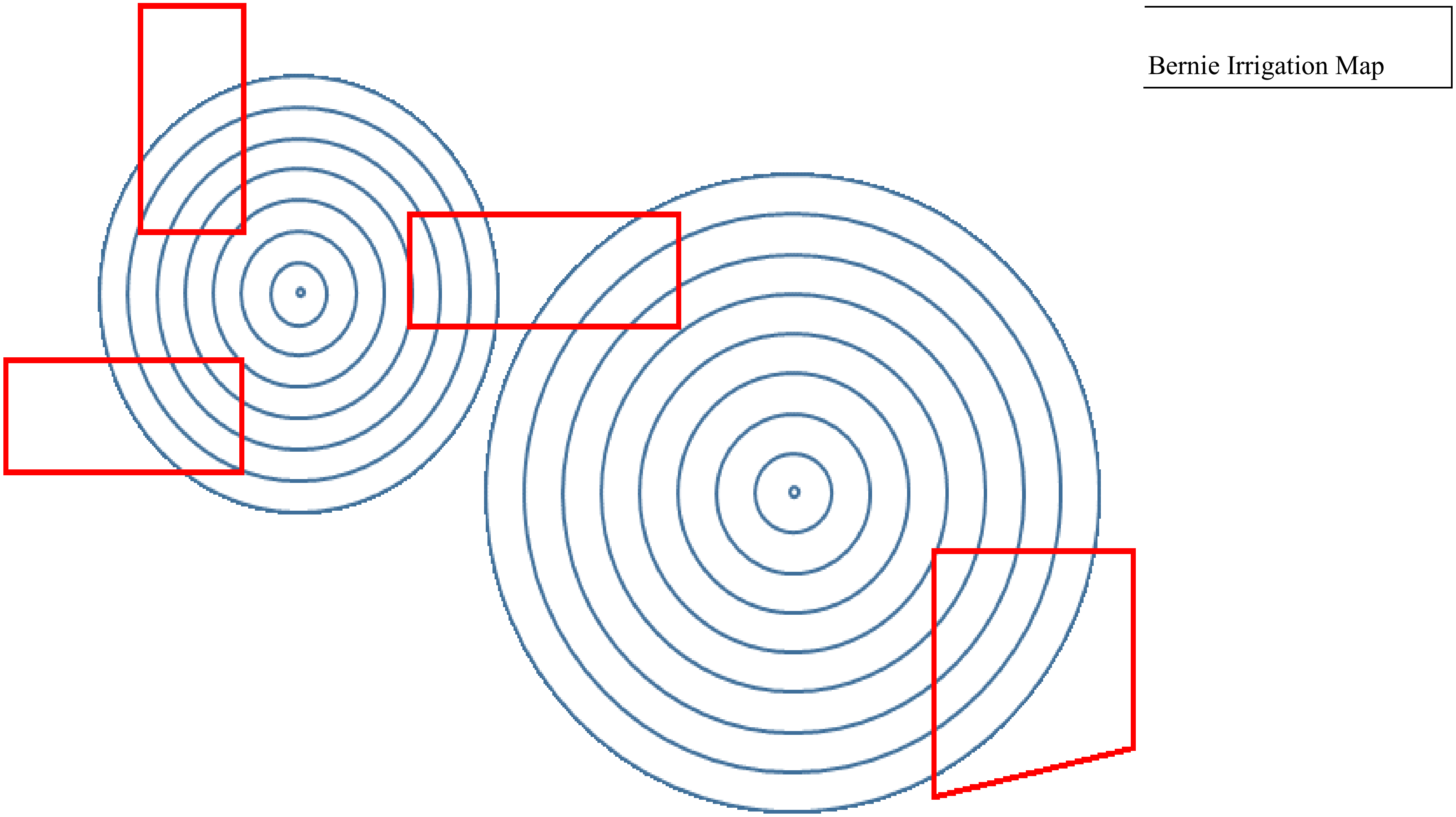


Figure 8. Plot map of the Bernie farm for 2017. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation system coverage of paddocks of tall fescue and a perennial ryegrass.

Figure 9. Plot map of the White Oak farm. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation coverage over perennial ryegrass paddocks.

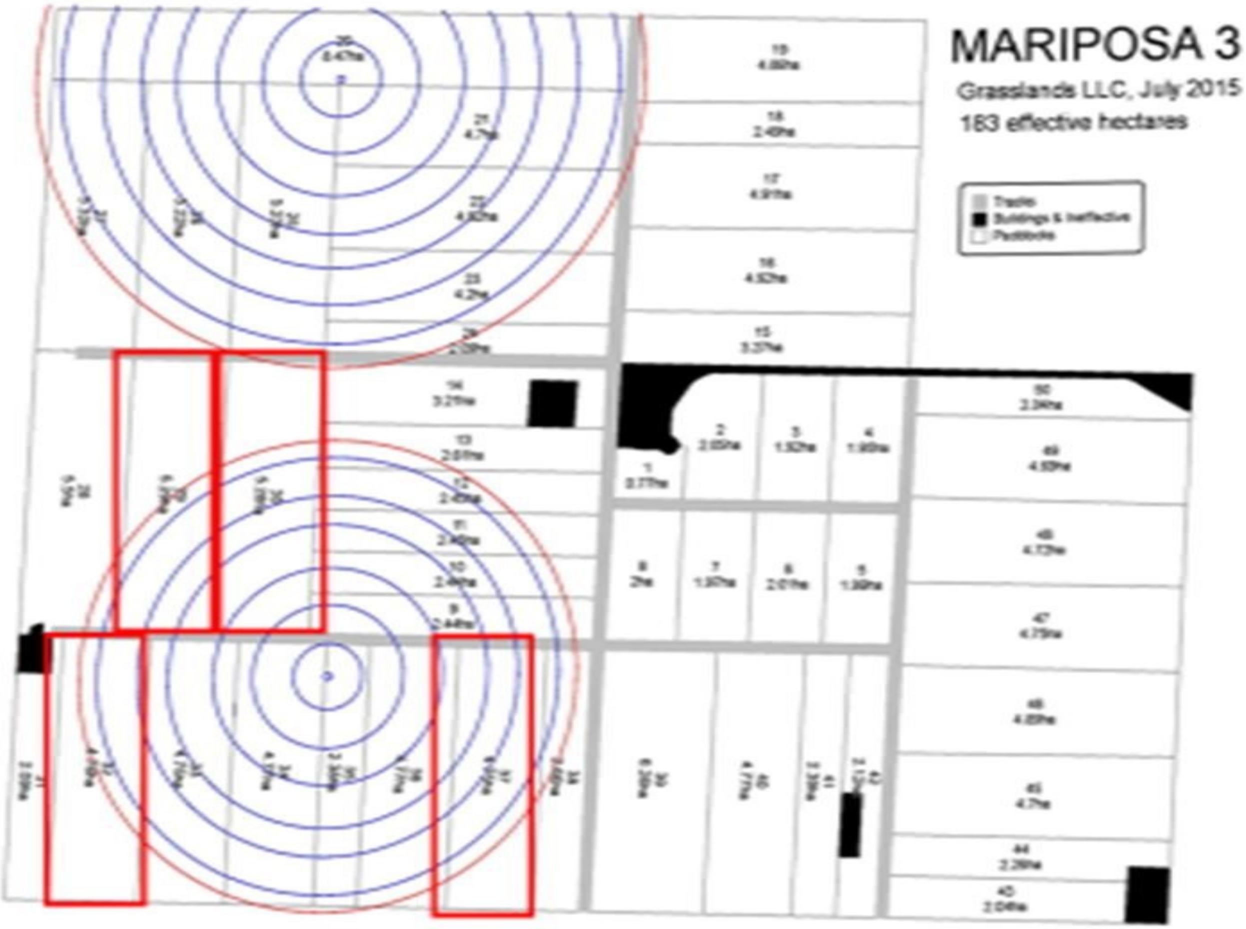
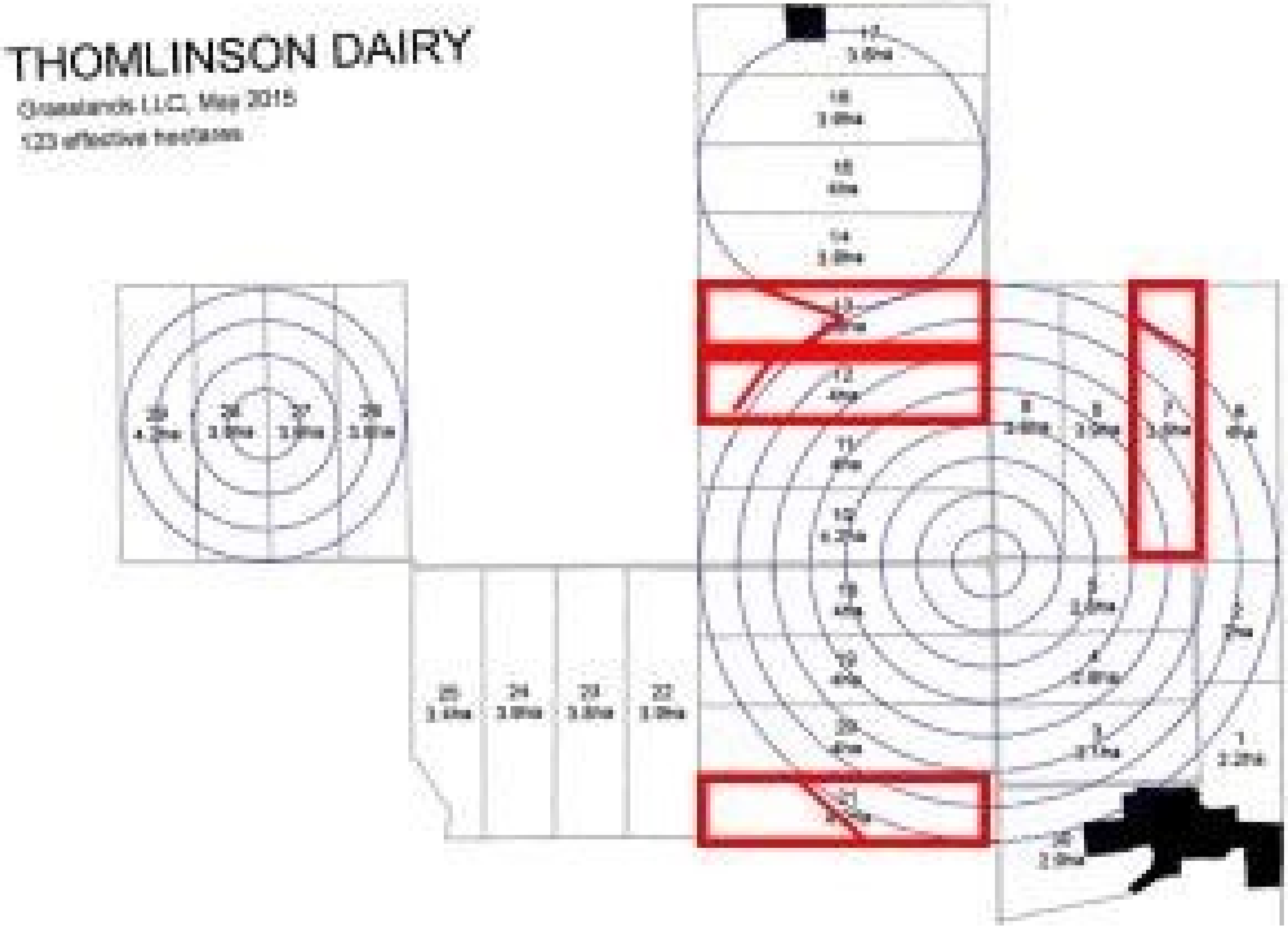


Figure 10. Plot map of the Mariposa farm for 2016. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation coverage over paddocks of perennial ryegrass.



.

Figure 11. Plot map of the Thomlinson farm for 2016. Paddocks outlined in bold were included in the study. Circles depict pivot irrigation coverage over perennial ryegrass paddocks.

Figure 12. Calibration harvester mounted behind a tractor and all-terrain vehicle equipped with ultrasonic sensor.

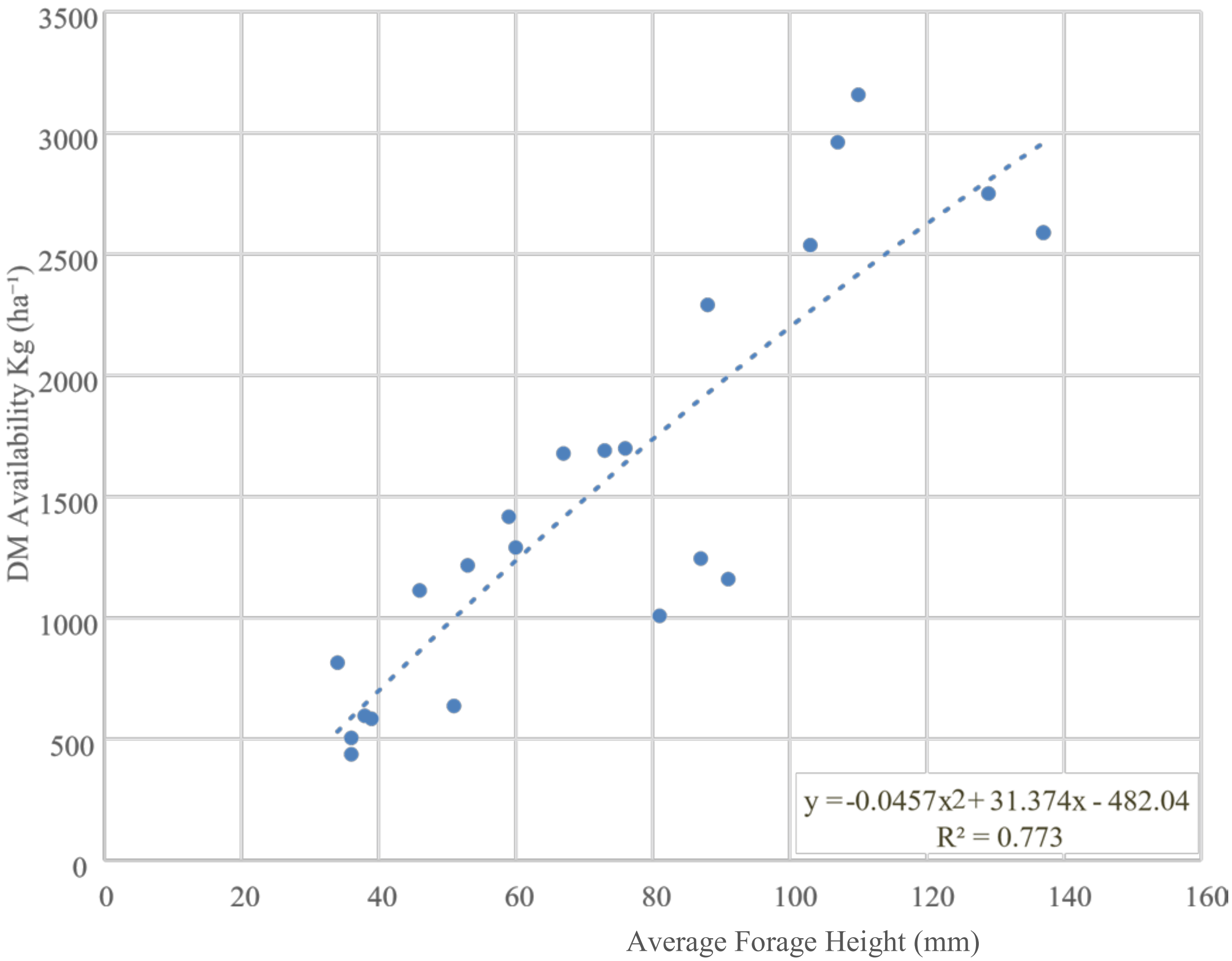


Figure 13. Linear regression of calibration harvest dry matter yields of perennial ryegrass to height measurements obtained using the ultrasonic sensor.

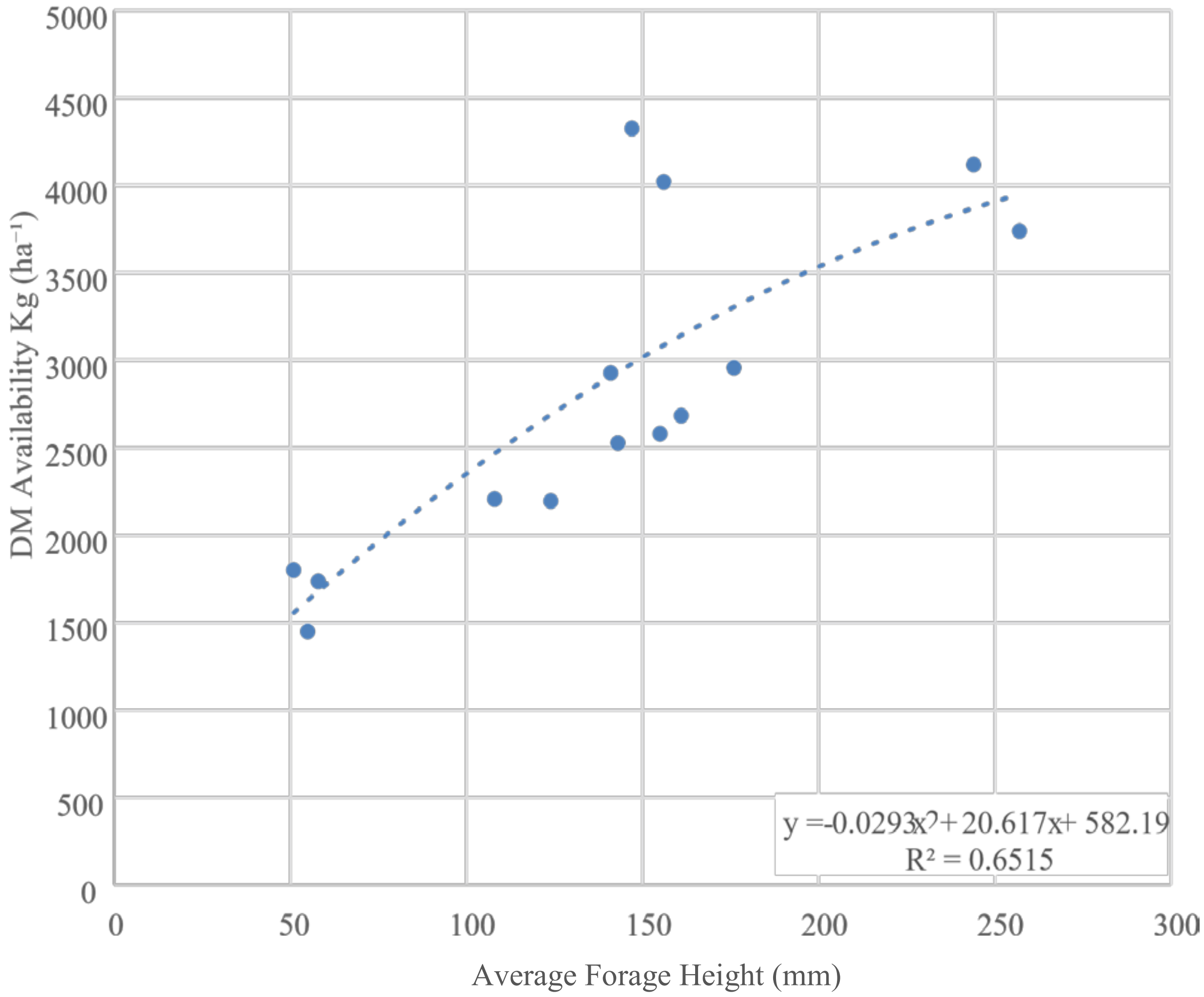


Figure 14. Linear regression of calibration harvest dry matter yields of alfalfa to height measurements obtained using the ultrasonic sensor.

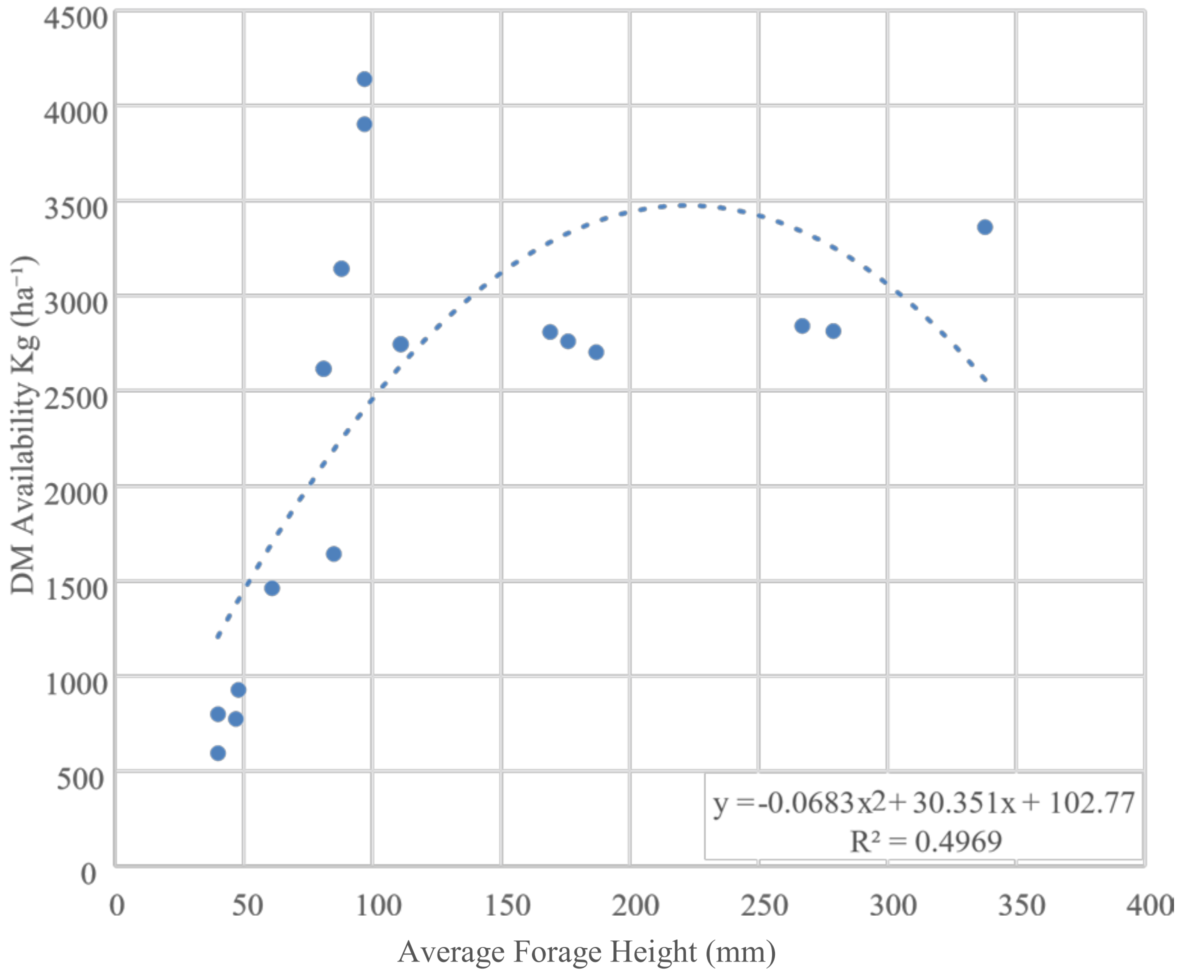


Figure 15. Linear regression of calibration harvest dry matter yields of tall fescue to height measurements obtained using the ultrasonic sensor.

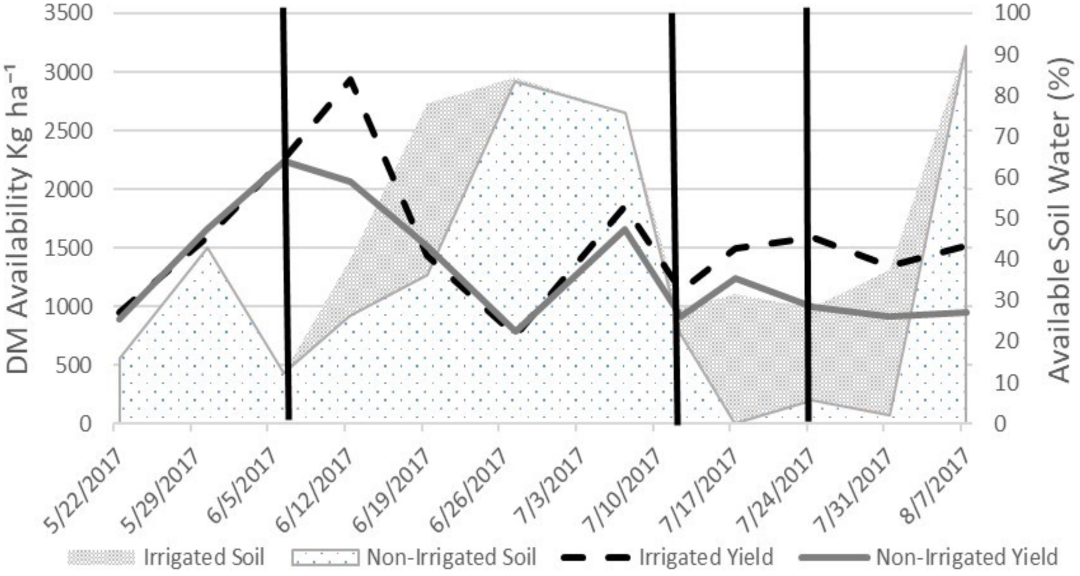


Figure 16. Irrigation of perennial ryegrass in paddock on the White Oak farm during 2017. Vertical lines represent irrigation events of 2.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

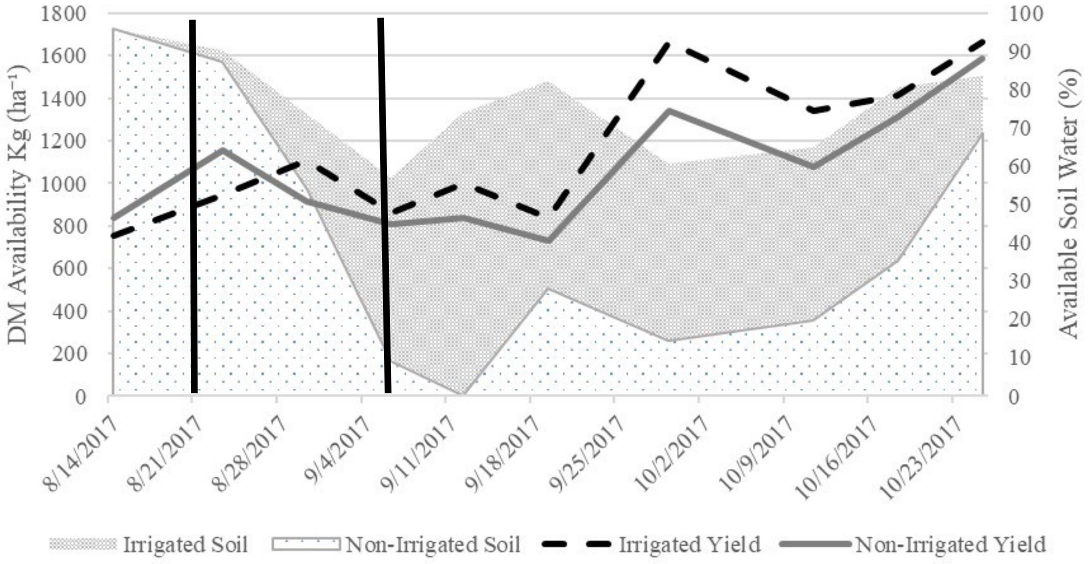


Figure 17. Irrigation of perennial ryegrass on the Thomlinson farm in 2017. Vertical lines represent irrigation events of 2.5 cm of applied water Height measurements at each date are an average of 500 to 2,000 readings.

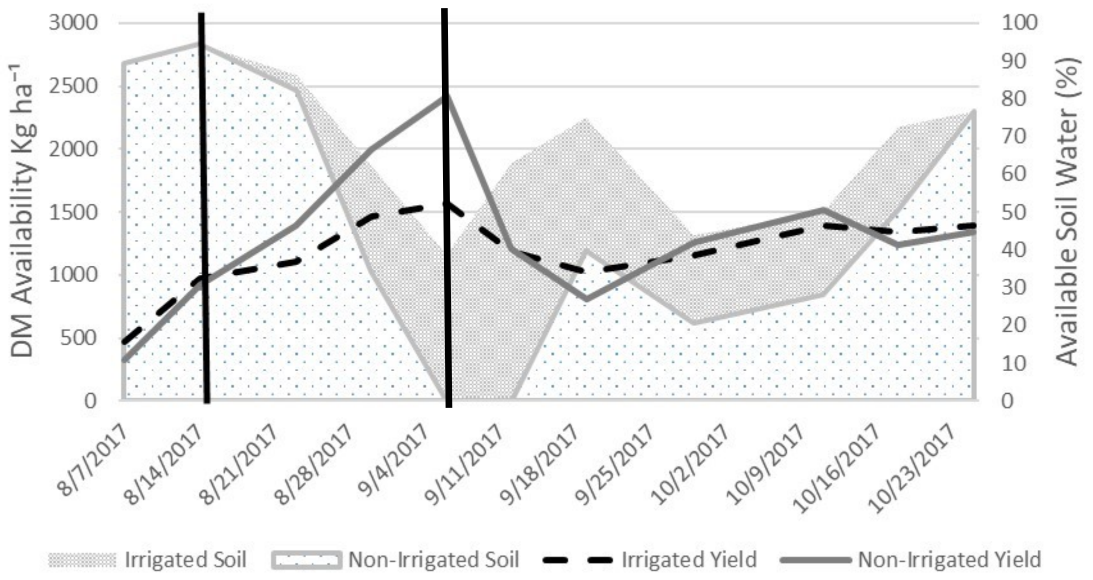


Figure 18. Irrigation of perennial ryegrass on the Mariposa farm during the summer of 2017. Vertical lines represent irrigation events of 2.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

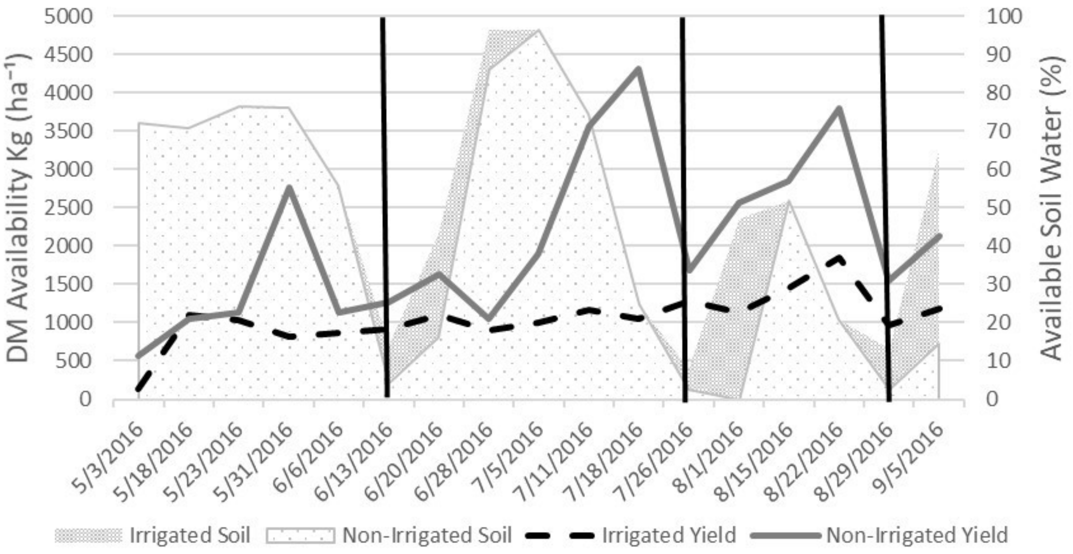


Figure 19. Irrigation of perennial ryegrass paddock on the Thomlinson farm during 2016. Vertical lines represent irrigation events of 2.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

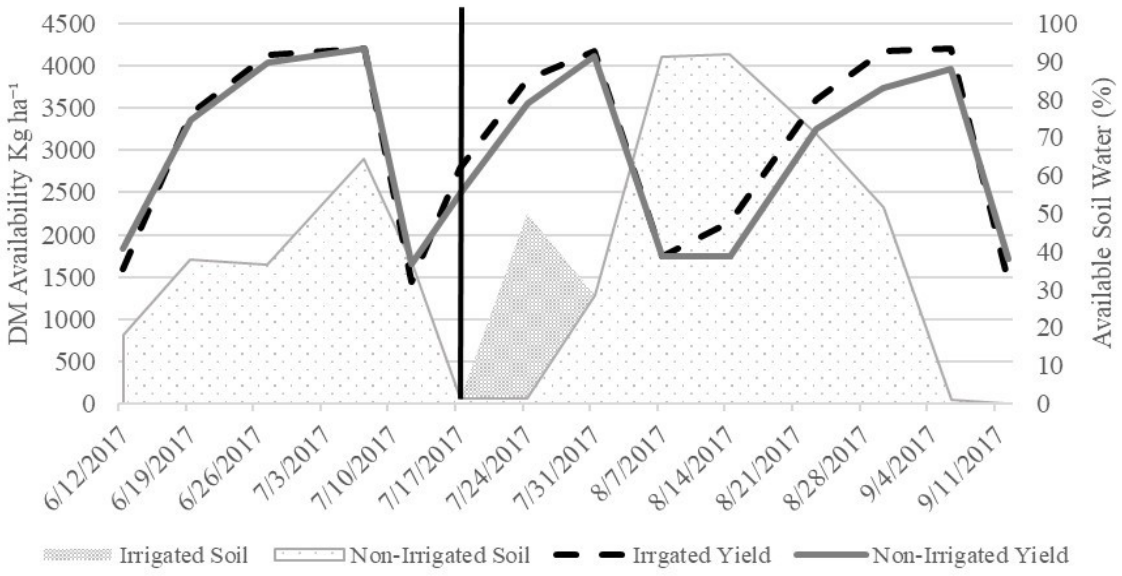


Figure 20. Irrigation of alfalfa paddock on the Fletcher farm during 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

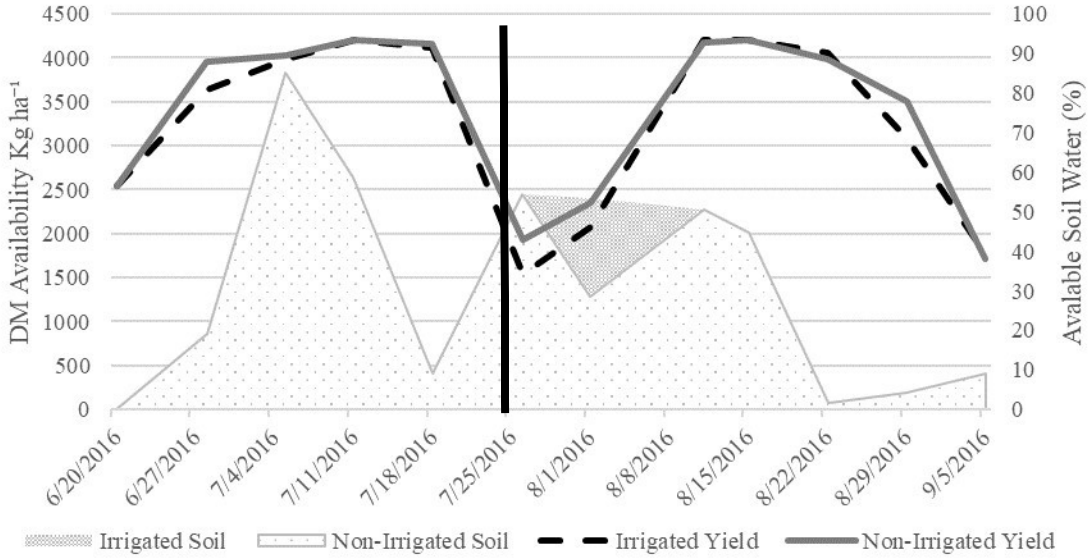


Figure 21. Irrigation of alfalfa paddock on the Fletcher farm in 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

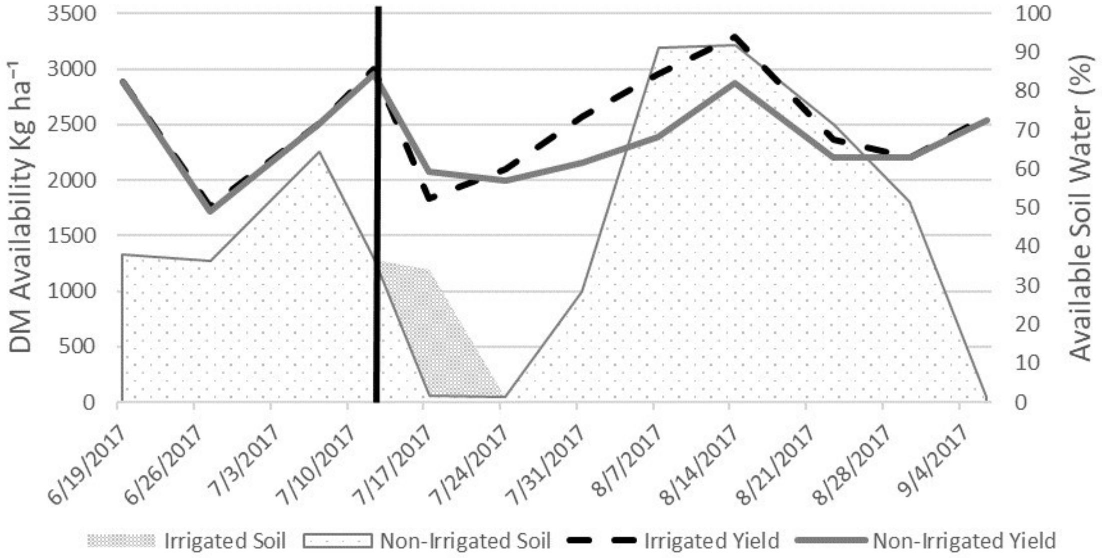


Figure 22. Irrigation of tall fescue paddock on the Fletcher farm during 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

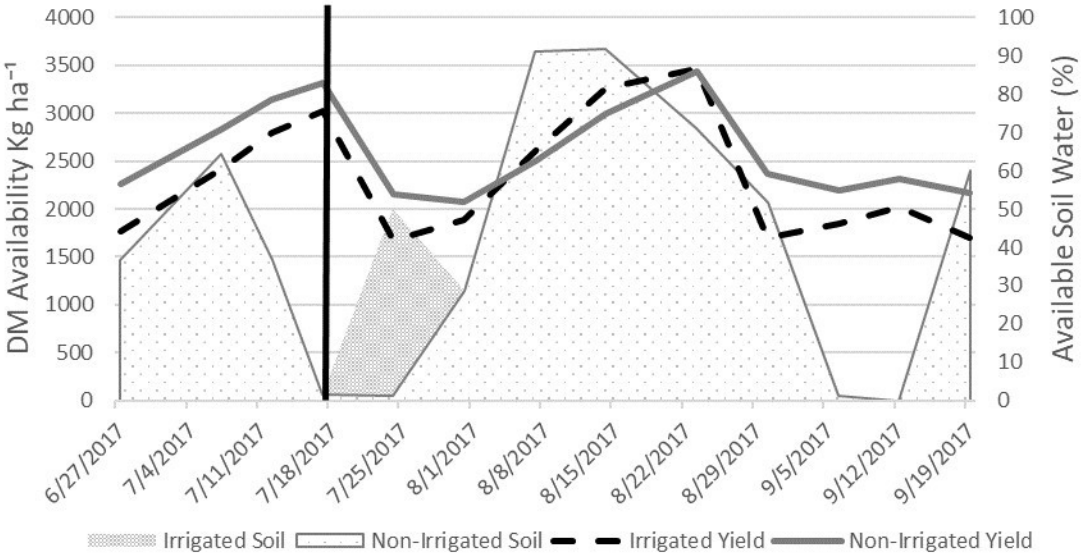


Figure 23. Irrigation of tall fescue paddock on the Fletcher farm during 2017. Vertical lines represent irrigation events of 3.5cm applied water. Height measurements at each date are an average of 500 to 2,000 readings.

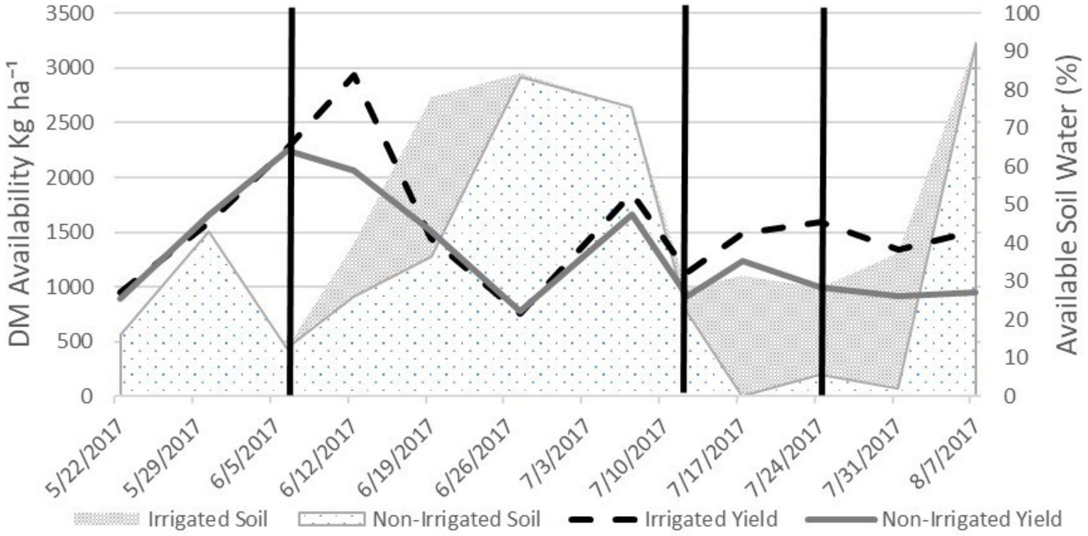


Figure 24. Irrigation of tall fescue paddock on the Bernie farm in 2017. Vertical lines represent irrigation events of varied amounts of applied water. Height measurements at each date are an average of 500 to 2,000 readings.

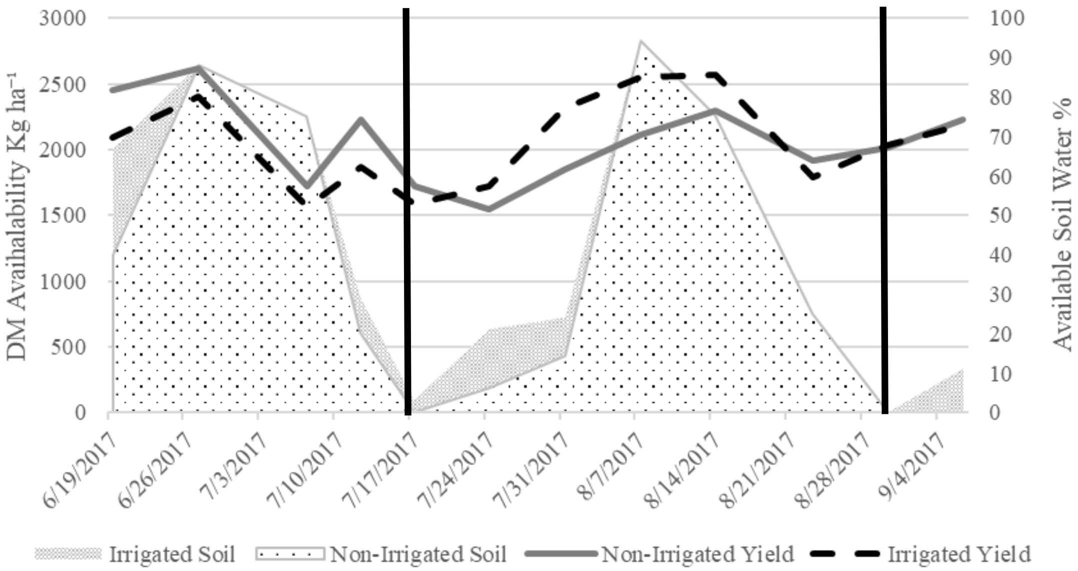


Figure 25. Irrigation of tall fescue on the Bernie farm in 2017. Vertical lines represent irrigation events of varied amounts of applied water. Height measurements at each date are an average of 500 to 2,000 readings.