THE EFFECT OF HARVEST CUTTING HEIGHT AND HYBRID MATURITY CLASS ON FORAGE NUTRITIVE VALUES AND RATOON REGROWTH POTENTIAL OF SORGHUM SUDANGRASS IN THE TEXAS HIGH PLAINS

By

Preston Sirmon

A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree

MASTERS OF SCIENCE

Major Subject: Plant, Soil, and Environmental Science

West Texas A&M University

Canyon, TX

December 2023

Abstract

Sorghum Sudangrass (*Sorghum x drummondi*), a crop that is drought tolerant and readily regrows, is an option that producers in the Texas High Plains are turning to as water limitations become more prevalent. The objective of this study was to i) investigate the effect of clipping height on yield and ratoon production, and ii) evaluate the forage nutritive values of a single harvest versus ratoon harvest system of sorghum sudangrass varieties under limited irrigation in the Texas High Plain. Seven different sorghum sudangrass hybrids were cut to leave 10 and 20 cm of stubble and allowed to regrow. Cutting height did not affect yields, with cumulative yields in 2019 ranging from 8.99 to 16.23 Mg ha^{-1} and 7.59 to 13.09 Mg ha^{-1} for the 10 and 20 cm cutting height, respectively; and cumulative yields in 2020, ranging from 4.61 to 7.84 Mg ha^{-1} and from 3.95 to 8.15 Mg ha^{-1} for the 10 and 20 cm cutting height, respectively. A ratoon crop was only achieved with the early maturing hybrids in this study. Forage Nutritive values were greatest with the early maturing hybrids and their ratoon crops; however, overall yield was greater for the longer maturing hybrids.

Acknowledgements

This thesis would not have been possible without the support of quite a few people. First, I would like to thank Dr. Jourdan Bell for allowing me to conduct the research under her program in Bushland and for her assistance in analyzing the data and guidance in writing this paper. I would also like to thank the other members of my committee, Dr. Brock Blaser and Dr. Tim Steffens, who helped guide me through the arduous process of writing this thesis.

I would also like to thank Carla Naylor, Dr. Kevin Heflin, and Nick Porter for their guidance, assistance, and their continuous urging me to finish this paper. I would also like to thank Layney Miller and Shelby Lain for their assistance with the field work required for this study.

My wife and family have supported, encouraged, and kept me accountable throughout my graduate degree and I would not have been able to complete this degree without them.

Approved:

Co-Chairman, Thesis Committee Date

Co-Chairman, Thesis Committee Date

Member, Thesis
Committee Date

Head, Department of Agricultural Sciences Date

Dean, Paul Engler College of Agriculture Date
and Natural Sciences

Dean, Graduate School Date

Table of Contents

Abstract……………………………………………………………………………………ii

Acknowledgement…………………………………………………………………………..iii

List of Tables……………………………………………………………………………..vi

List of Figures……………………………………………………………………………vii

Chapter 1: Literature Review……………………………………………………………...1

History……………………………………………………………………………..1

Ratoon Cropping…………………………………………………………………..2

Single vs. Ratoon Harvest System………………………………………………...4

Nutritive Value of a Single vs. Ratoon Harvest System………………………….6

Growth Stage……………………………………………………………………...8

Growth Stage and Nutritive Values……………………………………………...10

Cutting Height……………………………………………………………………12

Effect of Cutting Height on Nutritive Values……………………………………14

Summary…………………………………………………………………………15

Chapter 2: The Effect of Harvest Height and Hybrid Maturity on Forage Nutritive Values and Ratoon Regrowth Potential of Sorghum Sudangrass in the Texas High Plains …….16

Abstract……………………………………………………………………..16

Introduction…………………………………………………………………17

Materials and Methods………………………………………….............19

Statistical Analysis…………………………………………………….22

Results and Discussion……………………………………………………..22

Total Forage Yields……………………………………………………23

Cutting Height…………………………………………………………23

Node and Tiller………………………………………………………..25

Forage Nutritive Value………………………………………………..26

Ratoon Forage Nutritive Value………………………………………..29

Conclusion…………………………………………………………………….31

Tables and Figures……………………………………………………………….33

Literature Cited……………………………………………………………...…42

List of Tables

Table 1. Sorghum Sudangrass Hybrid Information…………………………………….…...34

Table 2. Jullian Harvest Dates for Sorghum Sudangrass Plots…………………………..35

Table 3. 2019 Cumulative Yield and Single Harvest Nutritive Values for Sorghum Sudangrass……………………………………………………………………………….36

Table 4. 2020 Cumulative Yield and Single Harvest Nutritive Values for Sorghum Sudangrass……………………………………………………………………………….37

Table 5. 2019 First and Ratoon Cutting Yields and Forage Nutritive Values for Early Maturing Hybrids…………………………………………………………………….....38

Table 6. 2020 First and Ratoon Cutting Yields and Forage Nutritive Values for Early Maturing Hybrids…………………………………………………………………….....39

List of Figures

Figure 1. 2019 Forage Sorghum and Sorghum Sudangrass Weather Data………………40

Figure 2. 2020 Forage Sorghum and Sorghum Sudangrass Weather Data………………41

Chapter I

LITERATURE REVIEW

History of Sorghum and Sudangrass

Originating in Africa, sorghum (*Sorghum bicolor*) was first spread through Asia and Australia before arriving in the USA sometime at the end of the 19th century (Smith and Frederikson, 2000). Originally from Sudan, sudangrass (*Sorghum x drummondi*) was introduced to America as the result of a search for a Andropogon species to be used as a forage crop that did not have rootstocks, such as Johnsongrass (*Sorghum halepense*) (Vinall, 1914). American researchers began testing at the Texas A&M University Forage Crop Field Station in Chillicothe, TX in 1909 (Vinall, 1914). Researchers began evaluating planting dates, seeding rates and harvest stages to optimize production for Texas producers (Karper et al., 1929). By 1918, the value of sudangrass was estimated to be $10.5 million (Vinhall and Getty, 1921) and by 1928, sudangrass was considered the most important pasture crop in Texas (Karper et al. 1928). Researchers noticed that sudangrass would cross easily with other sorghum species and a sorghum sudangrass hybrid was being evaluated as early as 1912 (Vinhall, 1914)

Because sorghum species are adapted to poor soils and limited water (Lang, 2001), many producers ignore recommended agronomic practices for producing sorghum sudangrass. As a result, sorghum sudangrass often has a reputation and negative perception of reduced yields and poor forage nutritive value (Miller and Stroup, 2004). However, with newer, genetically improved, hybrids and proper management, sorghum sudangrass can be high yielding and a high nutritive value forage (Marsalis, 2011; Miller and Stroup, 2004). Sorghum sudangrass is capable of rapid regrowth and is well suited for multiple harvests, or ratoon cropping (McCormick et al., 1995).

Ratoon Cropping

Ratoon cropping is the practice of harvesting a crop multiple times from a single planting (Duncan and Gardner, 1983). Regrowth is produced from tillers. Tillers are secondary stems that emerge from the crown of a plant (Sheaffer and Moncada, 2009). Depending on the intended use of a crop, tillers can be considered either good or bad. Prolific tillering is a desired trait in forage to increase overall leaf to stem ratios, however, limited tillering is desired for grain sorghum to help concentrate resource use on developing a grain yield (Lui and Finlayson, 2019). The literature is unclear about the origination of the ratoon within the plant. Ardiyanti et al. (2019) suggest that ratoon crops are developed through the nodal buds of the stubble left from the original crop. Ball et al. (2007), Escalada and Plucknett (1977), and Lui and Finlayson (2019) report that tillers are produced from the basal buds near the crown of the plant. Alston (1966) identified and differentiated growth originating from both basal and nodal buds but considered each to be a form of ratoon growth. Escalada and Plucknett (1977) suggested production and development of healthy tillers will determine the outcome of a ratoon crop. Tiller production is promoted by leaves that provide photosynthate for early bud growth

(Kebrom and Mullet, 2015), but Lui and Finlayson (2019) reported that tillering actually occurred in a “series of steps” starting with the development of an axillary meristem in the leaf axil if conditions were favorable. Ardiyanti et al. (2019) suggested clipping of the stubble stimulates the plant to increase the number of buds and leaves. Alston (1966) investigated the effects of clipping height and frequency on tiller and branch development and found that tiller production was increased at shorter clipping heights, 15-30 cm, while branch production was more prevalent with a longer clipping height of 46 cm. Escalada and Plucknett (1977) concluded that a lower cutting height of 8 cm produced a more vigorous and consistent tiller. As with all crop production, the success of a ratoon crop is often the result of management decisions such as hybrid selection (Ardiyanti et al., 2019), growth stage at harvest and cutting height (Alston, 1966) and the management of the original crop (Wakano et al., 2021), which plays an important role in determining the outcome of a ratoon crop (Livingston and Coffman, 2022, Duncan and Gardner, 1983). Crop growth stage at harvest and the amount of biomass remaining after harvest will affect sorghum sudangrass varieties significantly (Alston, 1966). Duncan and Moss (1987) suggest that hybrid selection will influence a ratoon crop similarly to environmental and climatic factors. Genotype (variety) has a significant effect on ratoon regrowth (Ardiyanti et al., 2019).

In a study conducted by Duncan and Gardner (1983), ratoon yields of14 different sweet sorghum varieties were evaluated for fresh yield, sugar production, and insect damage. Fresh weight ratoon yields differed significantly by hybrid, ranging from 45% (19 Mg ha^{-1}) of the original crop (42 Mg ha$^{-1)}$ for hybrid MN960), to 142% (35 Mg ha^{-1}, hybrid Ramada) of the original crop (24 Mg ha^{-1}) in hybrid Ramada, with the majority ranging between 50-80% of the original crop. Bean et al. (2007), who conducted a sorghum hay variety trial in Bushland, TX, also reported a wide range of ratoon yields for different hybrids. The trial evaluated 29 different sorghum sudangrass, sudangrass, forage sorghum and millet hybrids. Cumulative yields ranged from 11.1 to 24.5 Mg ha^{-1}, and ratoon yields ranged from 49% to 71% of the total yield. Average ratoon yield for this study was 58% if the total yield. This extreme difference in ratoon yield can be attributed to hybrid genotype. Similar differences in yield and forage nutritive values are reported in the yearly forage sorghum trial conducted in Bushland, TX by Texas A&M AgriLife (Bell et al., 2019, 2020, 2021, 2022) for forages that are marketed as the same maturity class.

One notable concern of ratoon cropping in a water limited cropping system is limited water availability, is there sufficient soil moisture, precipitation and/or irrigation for a ratoon crop, or is the ratoon crop using stored soil water for regrowth that otherwise would be used by the subsequent main crop (Whish and Bell, 2008). Livingston and Coffman (2022) suggest that a grain sorghum crop needs on average 53 cm of water to produce a successful grain crop, and the next years dryland crop was usually successful.

Single vs Ratoon Harvest System

In a study conducted from 2004 - 2006 at the USDA Grazinglands Research Lab in El Reno, OK (Venuto and Kindiger, 2008) evaluated 21 different forage sorghum hybrids, sorghum sudangrass hybrids, and sudangrasses for yield and nutritional values in a single harvest system and two-harvest system. The single harvest system averaged, across all years, 1.6 Mg ha^{-1} more than the two-harvest system; however, the single (29.7 Mg ha^{-1}) vs. two-harvest system (23.9 Mg ha^{-1}) was only significantly different in 2004.

Similar results were observed in 2016 and 2017 by Machicek et al. (2019). Their study evaluated sorghum sudangrass and pearl millet (*Pennisetum glaucum*) under three different harvest intervals: three 30 day, two 45 day, and one 90-day harvest. Maximum yields were achieved for both crops at the single 90-day harvest. The three 30-day harvest (5.38 and 6.53 Mg ha^{-1} in 2016 and 2017, respectively) and two 45-day harvest yields (4.99 and 7.05 Mg ha^{-1} in 2016 and 2017, respectively) only averaged 45% of the single 90-day yields (11.05 and 15.51 Mg ha^{-1} in 2016 and 2017, respectively) for the sorghum sudangrass in both years. For the pearl millet, the three 30-day harvest (3.96 and 6.00 Mg ha^{-1} in 2016 and 2017, respectively) and the two 45-day harvest systems (3.81 and 5.64 Mg ha^{-1} in 2016 and 2017, respectively), yielded 60% of the single 90-day yield (6.29 and 9.87 Mg ha^{-1} in 2016 and 2017, respectively). The multiple harvest systems were not significantly different for both crops.

Contrary to Machicek et al. (2019) and Venuto and Kindiger (2008), McCormick et al (1995) reported greater total yields with a two-harvest system at earlier growth stages compared to a single harvest at hard dough. When the initial harvest occurred at late vegetative, boot and bloom stages, total dry matter yields were 7.6, 7.8, and 7.9 Mg ha^{-1}, respectively, compared to a single harvest at hard dough, 7.2 Mg ha^{-1}. It is important to note the environmental differences between the study locations. McCormick et al (1995), who conducted his research in Louisiana, likely had a longer growing season for regrowth to occur and more precipitation. In contrast, Machicek et al. (2019) conducted their study in semi-arid and northern region of Texas, which likely had a shorter growing season and less precipitation.

Nutritive value of a Single vs Ratoon Harvest System

A single harvest can yield more than multiple harvests depending on harvest stage, as indicated above; however, forage nutritive values are affected by plant maturity. As a plant matures, forage dry matter production increases and nutritional values decrease (Atis et al., 2012; Ball et al.,2001, Mueller and Orloff, 1994), but nutritive values can be improved by more frequent harvesting (Machicek et al. 2019). A producer must determine whether they are going to produce for quantity or for quality.

In livestock production, the ultimate test of forage quality and productivity is animal performance. Forage quality and forage nutritive value are not the same. The nutritive value of a forage consumed directly affects animal production (weight gain or milk production) and encompasses the amount of energy, minerals, protein, and digestibility of the forage. Forage quality includes both the nutritive values of a forage but also an intake component. Newman et al. (2007) stated that forage quality "reflects the chemical, physical, and structural characteristics" of a forage, so it reflects the nutritive value and the intake potential of a forage that is to be grazed, while forage nutritive values refer to the concentration of nutrient. Because forage is necessary to support rumination and digestion (Owens et al., 1998), it is important to understand how agronomic management impacts the quality and nutritive value of harvested forages.

Forage testing laboratories evaluate forages nutritive value, which includes digestibility parameters, such as neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), acid detergent fiber (ADF), in vitro dry matter digestibility (IVDMD), and crude protein (CP). The NDF is a measure of the total fiber content of a forage representing cellulose, hemicellulose, and lignin (Sanz-Saez et al., 2012). The NDFD is the portion of NDF that is digestible and used for energy (Oba and Allen, 1999; Hoffman et al., 2001). Research has demonstrated that lactating dairy and beef cows will eat more dry matter (DM) and produce more milk or gain more weight when fed forages that have higher NDFD (Kendall et al., 2009; Hoffman et al., 2001). The ADF only represents cellulose and lignin not hemicellulose as in the NDF. Sheaffer et al. (1995) explained that as ADF values increase, forage digestibility decreases. Forage labs also use in vitro methods to measure digestibility; the IVDMD is the percent of intake that is digestible over a certain length of time. The IVDMD is a laboratory method first developed by Tilly and Terry (1963) to evaluate the digestibility of feed and forages.

Crude Protein (CP) is another important measure of feed and forage nutritive value because protein is important for livestock health, muscle gain and development (Hardy and Olson, 2020). CP is the total nitrogen content of a feed sample, multiplied by 6.25, based on the assumption that true protein contains 16% nitrogen (Stokes and Prostko, 1998).

In research previously discussed by Machicek et al. (2019), the authors reported that as harvest interval increased, forage nutritive values decreased. The authors reported that from 30 to 90 days, CP decreased for sorghum sudangrass from 10.2% to 4.4%.

Average CP levels in the 30-day interval were 10.2 % and 10% in 2016 and 2017, respectively. The CP decreased to 6.2% and 8.3% for the 45-day interval in 2016 and 2017, respectively and to 4.4% and 4.2% for the single 90-day harvest in 2016 and 2017, respectively.

McCormick et al. (1995) reported similar results for forage nutritive values with forage sorghum where the yield, and forage nutritive values of first harvest and ratoon harvest forage sorghum were compared and the effect of five different growth stages at harvest were examined. Growth stages investigated were mid-vegetative, late vegetative, boot, bloom/milk, and hard dough, with a first and second harvest occurring for all growth stage treatment except hard dough. Ratoon harvest occurred on the same day, so ratoon harvest from later growth stages had less growing time than those harvested at earlier growth stages. Crude protein levels in the single hard dough harvest (6.6% CP) were lower than any of the other two harvest interval growth stages (9.4 to 12.8% CP). The IVDMD decreased with maturity in the first harvest, 70.5% at mid vegetative to 54.2% at hard dough. There was no difference between harvest maturities in the ratoon crop, however, these values, which averaged 64.9%, were still greater than the hard dough harvest maturities.

Growth Stage

One of the most important considerations of harvesting a forage crop is the growth stage of the plant when harvested (Woodward et al., 1939). The growth stage that a forage is harvested can affect forage yields, nutritive values, and ratoon potential. Dahlberg et al. (2015) suggest that the appropriate harvest growth stage depends on the intended use of the forages, such as hay or silage. Hay is typically at boot to decrease the amount of time required to cure the hay and optimize forage nutritive values (Marsalis, 2011; Livingston et al., 1995). Karper et al. (1928) reported no difference in yield of sudangrass hay yields when harvesting from boot to full bloom; however, yields were reduced by 335 kg ha^{-1} when harvested at a milk stage. As a plant matures, digestibility decreases; however, most forage is harvested at later maturities due to plant moisture levels (McCormick et al., 1995). High moisture levels affect the ensiling process by reducing fermentation efficiency, and the resulting forage is poor quality or unpalatable.

McCormick et al. (1995) found that for the first harvest, dry matter yields increased from mid-vegetative (3 Mg ha^{-1}) to the hard dough stage (7.2 Mg ha^{-1}). The yield of the ratoon crop, however, was the opposite, with yields decreasing from mid vegetative (3.5 Mg ha $^{-1}$) to the bloom stage (1.6 Mg ha^{-1}). The results were due to the length of time available for regrowth, with regrowth ranging from 64 days after harvest (mid vegetative) to 36 days after harvest (bloom). Beck et al. (2013) found similar results when investigating the growth stage at the first harvest in sudangrass. When considering the cumulative yields of each growth stage, yields ranged from 6.5 Mg ha^{-1} to 7.9 Mg ha^{-1}. These results are similar to results reported by Alston (1966), where forage harvested at early bloom produced the greatest yields, regardless of the clipping height used.

Brown Midrib (BMR) sorghum sudangrass hybrids are lower in lignin and, therefore, more digestible than non-BMR sorghum sudangrass hybrids (Kilcer et al., 2007). Beck et al. (2013) investigated the effect of maturity at harvest and BMR trait on forage yield and nutritive values in sudangrass. Plots were established at the University of

Arkansas Southwest Research and Extension center near Hope, Arkansas in 2009. Forage was harvested at the boot and dough stages and nutritive values were assessed on fresh samples. Dry matter yield was significantly higher for both BMR and Non-BMR hybrids at the dough stage, 20,677 and 13,163 kg ha^{-1}, respectively, than for the boot stage, 10,581 and 10,726 kg ha^{-1}, respectively.

Miron et al. (2006) found different results in a study conducted in 2003 in Moshav Timorim, Israel. In this study, three hybrids were evaluated for yield, nutritive value, and ensiling properties for two growth stages in the summer and into the fall. The hybrids were harvested at early heading and soft dough in the summer and again at soft dough of a ratoon crop in the fall. Dry matter yields were greatest at the early heading stage in the summer and decreased with each subsequent harvest, with yields averaging 14.7 Mg ha^{-1} at early heading, 13.5 Mg ha^{-1} at soft dough in the summer, and 10.1 Mg ha^{-1} at soft dough in the fall.

Growth Stage and Nutritive Value

Prioritizing yield detracts from the forage nutritive value (Livingston et al., 1995). With increasing age, forage intake by animals is reduced (Ball et al., 2001). Black et al. (1980) investigated the optimum growth stage for forage nutritive value in sorghum silage. In this study, a forage sorghum hybrid was harvested at the following growth stages: early bloom, bloom, milk, late milk to early dough, dough, and hard dough. Advancing maturity showed decreased crude protein and NDF. Crude protein decreased from 8.4% at early bloom to 5.8% and 5.9% at the dough and hard dough stages, respectively. The NDF was 68.4% and 69.4% at early bloom and bloom stages, respectively, and decreased to 63.9% at hard dough.

Beck et al. (2013) reported that forage nutritive values decreased with maturity. Crude protein was significantly reduced from the boot stage (8.5%) to the dough stage (6.2%) with no effect from the BMR trait. Forage NDFD decreased from 62.1% and 61.6% at boot, BMR and Non-BMR, respectively, to 50% and 48.4%, at the dough stage, BMR and Non-BMR, respectively.

McCormick et al (1995) reported similar nutritive value observations. Crude protein decreased from 17% at the mid vegetative to 6.6% at the hard dough stage. Ratoon nutritive values were similar to the first harvest, with CP decreasing with age. The oldest regrowth occurred in the mid-vegetative treatment (8.6%) and the highest CP levels in the regrowth were observed in the bloom stage (10%). IVDMD decreased with age, with mid vegetative (70.5%) being the most digestible to hard dough being the least digestible (54.2%) in the first harvest. The ratoon harvest was not significantly different, with digestibility ranging from 63.9% to 65.5% across all growth stages.

A study by Miron et al. (2006) found similar results for CP values; however, found different results for forage digestibility. Average CP levels were 7.65, 6.91 and 6.65% for first cutting at early heading, soft dough and ratoon cutting at soft dough, respectively. The IVDMD did not differ between either growth stage in the first harvest (early heading, 73.4% and soft dough, 73.1%), however, the regrowth had significantly lower digestibility (70.9%).

Cutting Height

The success of a ratoon crop depends on healthy tillers developing from the stubble of the previous crop, so the amount of stubble left should influence the subsequent crop (Escalada and Plucknett, 1977). Cutting height can also affect the forage yield, Miller and Stroup (2003) suggest that with every inch of stubble left in the field, as much as 2.2 Mg ha^{-1} of forage can be lost. If multiple cuttings are desired, adequate stubble must be left to facilitate regrowth, Livingston et al. (1995) and Marsalis (2011) suggest that producers leave 20 cm and 15 cm of stubble.

Escalada and Plucknett (1977) investigated the effects of nitrogen fertilizer and cutting heights on grain sorghum ratoon crops in Kauai, Hawaii. Plots were established June of 1971, with harvest occurring September and December of 1971, and April, August, and October of 1972. Grain heads were harvested, and the stubble were removed to 3, 8, and 18 cm above the soil surface. Ratoon grain yields were greatest when stubble was clipped to 8 cm. Stover yields were reduced with the taller stubble heights; however, the addition of fertilizer increased the stover yields. It is also noteworthy to mention that the time of year that a growing season occurs, even in a tropical environment, can affect crop outcomes. Ratoon crops in the winter growing season had reduced grain and stubble yield when compared to the yields reported in the spring and summer growing season.

Burger and Hittle (1967) and Alston (1966) reported similar yield results. Burger and Hittle (1967) investigated the effect of harvest frequency and cutting height on yield and plant nutritive composition in sorghum sudangrass, sudangrass and pearl millet. Cutting height treatments consisted of harvesting at 8 cm, 15 cm, and 8 to 15 cm.

Average yields were 14.2, 13.4, and 13.8 Mg ha^{-1} for the 8, 15 and the 8 to 15 cm cutting height treatments, respectively, across both harvest frequencies. Alston (1966) reported that the cumulative yields were greatest at a shorter cutting height. Plots were harvested three times and cutting height treatments consisted of cutting at a 15 cm, 46 cm, and a treatment that increased from 15, 30.5, 46 cm with each consecutive cutting. Forage yields were 14.3, 12.2, and 11.4 Mg ha-1 for the 15 cm, 15-46 cm, and 46 cm cutting heights, respectively.

Beaty et al. (1965) reported similar results in their 1961-1963 study at the University of Georgia Agronomy farm near Athens, Georgia. They investigated the effect of varying clipping heights and the frequency of harvest on forage yields of Sudangrass, millet, and sorghum sudangrass hybrids. Plots were harvested at 2-, 3-, 4-, and 5- week intervals, with 1/3, ½, ¾, and 7/8 removal of above ground biomass. Dry matter yields increased with increasing biomass removal, except the 7/8 removal, which yielded lower than the ¾ removal. This decrease in yield is attributed to the amount of stubble left from the ¾ versus the 7/8 removal increment, 10-15 cm, and 2.5-7.5 cm, respectively. Overall, yields were greatest when ¾ of the above ground biomass was removed, which produced 17.5% more than removing only the top 1/3 of biomass.

Granados-Nino et al. (2021) found different results than Escalada and Plucknett (1977), when investigating fresh and dry matter yields of forage sorghum. They reported that forage yields were not affected by cutting height until cutting height reached 60 cm. Forage yield and nutritive values were evaluated when forage sorghum was harvested at 10, 20, 30, 40, 50, and 60 cm above the soil surface. Harvest occurred once the sorghum had reached a milky-dough growth stage. Dry matter yields ranged from 18.7 Mg ha^{-1} when clipped at 10 cm, to 16.1 Mg ha^{-1} when clipped at 60 cm. Fresh and dry matter yields were not affected until clipping reached 40 to 50 cm above the soil surface.

Iptas and Brohi (2003) investigated the effect of clipping height and nitrogen on forage yield and the nutritive values in sorghum sudangrass. Plots, established in 1995 and 1996 in Turkey, were harvested once they reached 110-120 cm in height and were clipped to 7, 14, and 21 cm. Dry matter yields were only significantly higher when clipped at 7 cm in 1995. The 7 cm clippings yielded 10.9, 9.1, 9.1 for the 1st, 2nd, 3rd clippings, respectively, in 1995. The DM yields of the other clipping heights were not significantly different. Two-year data averages were 26.5-, 25.7-, and 25.3-tons ha^{-1} for the 7, 14, 21 cm clipping heights, respectively. Although the 7 and 14 cm clipping heights averaged numerically greater dry matter yields, there was no difference in yields in either the second or third harvest.

Effect of Clipping Height on Nutritive Values

Granados-Ninos et al. (2021) suggests that when clipping height increases, the nutrient composition of a forage improves; however, dry matter yields suffer at the expense of the improved nutritive values. A small leaf to stem ratio in the harvested forage improves the nutritional composition of the forage since the leaves contain higher nutritive value than the stem (Ball et al., 2001). Increasing the clipping height is a practical way to reduce lignin and improve the digestibility of a forage (Granados-Ninos, 2021).

Nutritive values decreased as clipping height increased in a study by Granados-Ninos et al. (2021). Lignin content was significantly reduced when cutting height was increased from 7.7% at 20cm to 6.4% at 30 cm. The NDFD was greatest when the forage was clipped at 60 cm (38.6%), with the greatest nutrient yield achieved at the 40-60 cm clipping height. Differences in NDFD yields were not different across clipping heights. Clipping forage sorghum between 20 and 40 cm from the soil surface showed that dry matter yields were not affected and will produce a product that is low in lignin and higher in digestibility.

Burger and Hittle (1967) reported crude protein levels were increased with a shorter cutting height for the four cutting harvest frequency only, 17.9% at 8 cm and 17.38% at 15 cm. In the three-harvest frequency, crude protein levels were 15.1% for both the 8 and 15 cm cutting height. Iptas and Brohi (2003) reported that crude protein was only increased in the 7 cm cutting height for the third cutting. All other cuttings and cutting heights did not differ.

Summary

While forage crops are produced worldwide, the management decisions and strategies that producers employ vary from region to region, especially for forage species like sorghum sudangrass. The goal of the study conducted herein was to learn the effect of cutting height to optimize sorghum sudangrass production and its ratoon potential and the effect it had on the forage nutritive qualities for the Texas High Plains.

Chapter II

THE EFFECT OF HARVEST CUTTING HEIGHT AND HYBRID MATURITY CLASS ON FORAGE NUTRITIVE VALUES AND RATOON REGROWTH POTENTIAL OF SORGHUM SUDANGRASS IN THE TEXAS HIGH PLAINS

A paper to be submitted to Agronomy Journal

Preston S. Sirmon, Jourdan Bell, Brock Blaser, Tim Steffens

Abstract

Sorghum Sudangrass (*Sorghum x drummondi*), a crop that is drought tolerant and readily regrows, is an option that producers in the Texas High Plains are turning to as water limitations become more prevalent. The objective of this study was to i) investigate the effect of clipping height on yield and ratoon production, and ii) evaluate the forage nutritive values of a single harvest versus ratoon harvest system of sorghum sudangrass varieties under limited irrigation in the Texas High Plain. Seven different sorghum sudangrass hybrids were cut to leave 10 and 20 cm of stubble and allowed to regrow. Cumulative yields in 2019 ranging from 8.99 to 16.23 Mg ha^{-1} and 7.59 to 13.09 Mg ha^{-1} for the 10 and 20 cm cutting height, respectively; and cumulative yields in 2020, ranging from 4.61 to 7.84 Mg ha^{-1} and from 3.95 to 8.15 Mg ha^{-1} for the 10 and 20 cm cutting height, respectively. No difference was detected between cutting heights on cumulative

yields. A ratoon crop was only achieved with the early maturing hybrids in this study. Forage nutritive values were greatest with the early maturing hybrids and their ratoon crops; however, overall yield was greater for the longer maturing hybrids.

Introduction

In semi-arid regions, forage production is limited by water. Sorghum Sudangrasses (*Sorghum x drummondii*) are a drought and heat tolerant forage option to meet forage goals in both a limited irrigation and dryland setting (Dahlberg et al., 2015). While there is often a negative perception about reduced yield and the forage nutritive value of sorghum sudangrass, genetic improvements and proper management can result in increased yields, nutritive values and therefore feed values. Sorghum sudangrass is also capable of rapid regrowth and can be well suited for multiple harvest systems (Marsalis, 2011).

Hybrid selection can greatly affect the outcome of a forage crop. Variable hybrid yield and nutritive value response, even in the same marketed maturity class, is evident in long-term forage sorghum silage trials conducted by Texas A&M AgriLife at Bushland, Texas (Bell et al., 2019, 2020, 2021, 2022). This hybrid difference can be altered by management, environmental conditions, and the genetic traits of a given hybrid.

Because sorghum species are adapted to limited water, many producers often ignore recommended agronomic practices for optimal sorghum sudangrass production. But if properly managed, sorghum sudangrass can be a high yielding forage species, with high forage nutritive value that is capable of rapid regrowth. This makes sorghum sudangrass well suited for multiple harvest or ratoon cropping systems (Marsalis, 2011; Miller and Stroup, 2004, McCormick et al., 1995). Ratoon crops are harvested from new shoots or tillers that have emerged from the crown of a harvested crop, but producers must consider the impact to forage yield and nutritive value.

When planting forages for livestock, producers must consider the end user's goal to determine whether nutritive value or tonnage is desired. Plant maturity directly impacts forage nutritive values; as forages mature, quality and nutritive value decline, but yield increases (Atis et al., 2012; Beaty et al., 1965). Harvesting at boot is recommended for sorghum sudangrass hay crops to maximize yields and nutritive value (Worker and Marble, 1968), but forage production is a compromise between quality and quantity (Beck et al., 2013) for most producers.

The success of a ratoon crop is dependent on the development of tillers from the stubble of the original crop (Escalada and Plucknett, 1977). Regrowth originates at either the basal buds or nodes along the stem and is fueled by the carbohydrate reserve left in the stubble in the field (Alston, 1966). So, the number of nodes and the amount of carbohydrate reserve left in the field will directly affect the regrowth potential of a ratoon crop.

Escalada and Plucknett (1977) found that tillering capacity was affected by clipping height and the number of productive tillers was affected by the amount of nitrogen fertilizer added for sorghum grown on the Hawaiian island of Kuai. The best results were obtained by clipping at 8 cm, which supplied sufficient carbohydrates to nodal bud for tiller establishment and growth. However, during the winter growing season, the longer stubble height of 13 cm improved tiller bud survival.

Alston (1966) found regrowth was rapid when active meristems were left on the plant. Clipping heights that removed apical meristems stimulated new growth, while clipping heights that refrained from removing apical meristems retained all original meristems from the original harvest. The shorter clipping height of 15 cm left few nodes above ground, which promoted new growth to occur from the basal buds. Frequent harvesting reduced the number of leaves on the plant, which negatively impacted the recovery of carbohydrates for regrowth of biomass.

The objectives of this study were to i) investigate the effect of clipping height on yield and ratoon production, and ii) evaluate the forage nutritive values of a single harvest versus ratoon harvest system of sorghum sudangrass varieties under limited irrigation in the Texas High Plains.

Materials and Methods

Research was conducted near the Texas A&M AgriLife Research Center at Bushland, TX in a cooperators field (35°11’56”N, 102°02’14”W) in 2019 and 2020. Plots were established on a Pantex silty clay loam (Fine, mixed, superactive, thermic Torrertic Paluestolls) with a 0-1% slope, under a center pivot irrigation system in a wheat (*Triticum aestivum*) hay, forage sorghum (*Sorghum bicolor*) rotation. In 2019, the study was designed as a completely randomized design. In 2020, the study design was blocked by maturity to address concerns of shading effect between varieties with different maturity classes. Seven experimental hybrids (Table 1) from Gayland Ward Seed (Hereford, TX USA) consisting of three maturity classes (early, long, photoperiod sensitive (PS)), were evaluated for ratoon regrowth at two harvest clipping heights (10- and 20- cm) with 3 replications per treatment. Plots were strip-tilled prior to planting. Soil samples were taken (0-91.5 cm) in 15 cm increments (0-15, 15-30.5, 30.5-61, 61-91.5) prior to planting to determine the fertility needs. Granular urea (46-0-0) fertilizer was applied at a rate of 224 kg N ha^{-1} in 2019 and 240.5 kg N ha^{-1}, in 2020 to meet the nitrogen requirements. Fertilizer was applied using a Gandy 10-T (Gandy Company, Owatonna, MN) tractor mounted fertilizer spreader.

Plots were 23.6 m^2 (8, 38 cm wide rows by 7.6 m). Plots were established 18 June 2019 and 2020, using a 4-row cone planter on 76 cm row spacing and a seeding rate of 1,005,000 seeds ha^{-1}. Two planter passes per plot were used to achieve the 38 cm row spaces. Plots were divided into harvest height sub plots; rows 1-4 were designated as the 10 cm treatment and rows 5-8 were the 20 cm treatment. Pre-plant herbicide was Bicep® (Atrazine + S-metolachlor) and was applied in both 2019 and 2020, at a rate of 1.75 L ha^{-1}. All hybrid seeds were safened with Concept 3® (Fluxofenim). In 2020, a post emergence application of Facet L (quinclorac) was applied at a rate of 2.3 L ha^{-1}. Sugarcane aphids (*Melanaphis sacchari*) were discovered on 5 August 2019, and 7 August 2020. Sivanto™ (flupyradifurone) was used in both years to control sugarcane aphids, 0.7 L ha^{-1} was chemigated with 0.6 cm of irrigation in 2019 and 0.4 L ha^{-1} was aerially applied with a total application volume of 28 l ha^{-1} in 2020. No significant damage from sugarcane aphids occurred in either year due to timely insecticide applications. Plots received 16.8 cm of precipitation and 12.7 cm of irrigation in 2019 and 15.8 cm of precipitation and 15.8 cm of irrigation in 2020.

Harvest occurred when 50% of the plants within a plot had reached the boot maturity stage; plot harvest dates are available in Table 2. The center two rows of each sub plot were hand harvested using a hand sickle at either 10 or 20 cm clipping height. Cutting height was insured by using a board cut to the appropriate height. Prior to harvest, plant height measurements were recorded from each plot. At harvest, fresh samples were immediately weighed.

A uniform subsample was processed through a woodchipper (CS3310 chipper-shredder, Cub Cadet). Forage dry matter (DM) was determined by drying a subsample for each plot at 105°C for 24 hours (Undersander et al., 1993), and a 600 g sample was frozen and sent to Dairyland Laboratories, Arcadia, WI. for forage nutritive value analyses using near infrared reflectance spectroscopy. Forage nutritive values were reported on a DM basis. After a plot was sampled, node and tiller counts were randomly taken from 5 plants in the sampled areas of each plot. The remaining plot area was harvested with a Carter Forage Harvester to match the 10 and 20 cm harvest height of the subplots and excess biomass was removed from the field to encourage uniform regrowth.

Although a research goal was to determine regrowth for all evaluated hybrid maturity classes, due to seasonal limitations, regrowth was only evaluated for the early hybrids because there was insufficient time for regrowth of the long and photoperiod sensitive hybrids.

Statistical Analysis

Statistical analysis was performed on SAS 9.4 by year using the GLM procedure (SAS Institute, 2017). When a significant difference was detected, Tukey-Kramer mean separation was used to determine differences at α=0.05. Maturity class comparison was conducted by cumulative yield and only the first cutting for each hybrid within the maturity class for forage nutritive values. Since a ratoon crop was only successfully grown by hybrids within the early maturing class, statistical analysis on ratoon regrowth and nutritive value data were performed only on the early maturing. A correlation procedure, also using SAS 9.4, was used to evaluate correlation between tillers and nodes to dry matter yield.

Results and Discussion

Results were a function of variable weather conditions that differed from year to year and impacted forage production over the course of this two-year study. Late season weather in 2019 (Fig. 1) was more favorable for plant regrowth than in 2020 (Fig. 2). Timely in-season rainfall and moderate temperatures contributed to the positive regrowth response documented in 2019. In 2019, 16.5 cm of precipitation was received at the study site after the first cutting from 7 August, through 26 September 2019 which coincided with moderate daytime temperatures and warm nightly temperatures. In 2020, only 6.1cm of precipitation was received after the first cutting and daily temperatures were cooler after the first cutting and not ideal for regrowth. On 9 September 2020 temperatures were below 7.2˚C for 19 hours with the low reaching 1.6°C. Hannaway and McGuire (1982) reported that sorghum growth does not occur at temperatures below 15.5°C.

Total Forage Yield

Variable year to year environmental and weather conditions caused yields to be dramatically reduced in 2020 from 2019. Cumulative yields consisted of a single harvest of the long and PS maturing hybrids and both harvest of the early maturing hybrids. Overall trial yield averages were 12.27 Mg DM ha^{-1} in 2019 to 6.41 Mg DM ha^{-1} in 2020 (Tables 3 & 4). Cumulative yields for both cuttings were not affected by maturity classes in either 2019 or 2020 (*p* 0.3764 and 0.0798, respectively).

Cumulative yields were not affected by maturity class for either 2019 or 2020 (*p* 0.3764 and 0.0798, respectively). In 2019, cumulative yields for the early, long and PS maturity classes were 8.30, 14.66, and 13.86 Mg DM ha^{-1}. Cumulative yields were 4.28, 7.99, and 6.96 Mg DM ha-1 for the early, long and PS maturity classes, respectively.

Cutting Height

Cumulative yields and forage nutritive values for maturity classes are provided in Tables 3 & 4. Cutting height did not affect yearly cumulative yields in either 2019 or 2020 (*p* 0.1793 and 0.9617, respectively). Average yields in 2019 for 10 and 20 cm cutting heights were 15.29 and 13.52 Mg DM ha^{-1}, respectively. Average yields in 2020 for 10 and 20 cm cutting heights were 7.74 and 7.17 Mg DM ha^{-1}, respectively. Iptas and Brohi (2003) reported similar results, where yields did not differ between cutting heights of 7 cm (26.5 Mg DM ha^{-1}), 14 cm (25.7 Mg DM ha^{-1}) and 21 cm (25.3 Mg DM ha^{-1}). Granados-Ninos et al. (2021) reported that yields did not differ from a cutting height of

10 cm (18.7 Mg DM ha^{-1}) till cutting height reached 60 cm above the soil surface (16.1 Mg DM ha^{-1}).

Ratoon yields and forage nutritive values are presented in Tables 5 & 6. For the ratoon cutting harvest system, cumulative yield was not affected by cutting height in 2019 (*p* 0.3661); however, in 2020, yield was affected by cutting height (*p* 0.0001). In 2019, total cumulative yields for 10 cm and 20 cm were 14.92 and 14.29 Mg DM ha^{-1}, respectively. In 2020, total cumulative yields for 10 cm and 20 cm were 8.43 and 6.24 Mg DM ha^{-1}, respectively. Average ratoon yields in 2019 were 66% and 88% of the first cutting yields for 10 and 20 cm cutting heights, respectively, and 83% and 63% of the first cutting yields of the 10 and 20 cm cutting heights, respectively, in 2020. This indicated that the increased cutting height increased the ratoon yield by 22% yield in 2019; conversely, in 2020, there was a 20% decrease in the ratoon yield for the 20 cm cutting height.

Potential ratoon regrowth was only significant in 2019 (*p* 0.0048). Ratoon cutting yields were 5.91 and 6.69 Mg DM ha^{-1}, for the 10 and 20 cm cutting height, respectively. The increased yields observed for the second cutting in 2019 can be attributed to both the improved environmental conditions and the longer clipping height. Data suggests that while regrowth is possible, weather, and environmental conditions play a critical role in the year-to-year variability and overall success of a ratoon crop in the Texas High Plains region.

Nodes and Tillers

Since ratoon growth only occurred in the early maturing hybrids, node and tiller data was only analyzed for the early maturing hybrids. Node and tiller data differed from year to year and data is presented in Tables 5 & 6.

Nodes per plant were affected by year (p 0.0501), averaging 1.7 and 1.6 in 2019 and 2020, respectively (Tables 5 & 6). In 2019, the 20 cm stubble height had a greater number of nodes left ($p<0.0001$), averaging 1.91 nodes per plant and the 10 cm cutting height averaging 1.49 nodes per plant. In 2020, cutting height affected the number of nodes ($p<0.0001$), with the 20 cm cutting height averaging 1.89 nodes per plant and the 10 cm averaging 1.31 nodes.

Tillers per plant differed from 2019 to 2020 (p 0.0304), averaging 1.09 tillers in 2019 and 1.27 tillers in 2020 (Tables 5 & 6). In 2019, the ratoon cutting averaged 1.3 tillers, while the first cutting averaged 0.89 tillers (p 0.0002). In 2020, the first cutting average 0.74 tillers and the ratoon cutting averaged 1.79 tiller per plant ($p<0.0001$); however, the first cutting of hybrid 18179 averaged 1.3 tiller per plant, which was similar to the ratoon cutting tillers. Alston (1966) reported increased branching from nodal buds with increasing stubble height, which was also affected by the frequency of harvest. When harvest occurred at every 76 cm of regrowth, 15 cm of stubble averaged 2.4 branches and 46 cm of stubble resulted in an average of 7.1 branches.

It was hypothesized that increasing clipping height would increase nodes and tillers, thereby promoting greater regrowth (Alston, 1966). Although increasing the cutting height did produce a greater number of nodes, increased nodes did not correlate to increased regrowth (*p* 0.0907).

Forage Nutritive Values

Forage nutritive values were only compared between first cuttings of all maturity classes (Tables 3 & 4), due to no significant regrowth occurrence for the long or photoperiod sensitive hybrids.

Brown Midrib (BMR) hybrids are marketed to improve crude protein and reduce lignin content of a forage (Miller and Stroup, 2004; Kilcer et al., 2005). When evaluating the influence of maturity class and the BMR trait, the early maturity class had the lowest lignin values (*p* <0.0001). Hybrids with a BMR trait had decreased lignin levels (*p* 0.0003); however, crude protein levels were unaffected by BMR trait (*p* 0.6710).

Historically, CP has been an important consideration for forage nutritive values. Crude protein represents the nitrogen content of the forage sample and contains both soluble and insoluble proteins. Crude protein levels were greater in the early maturity hybrids in both years (*p*<0.0001) (Table 3 & 4). The early maturing hybrids were harvested, on average, 28 days earlier than the long maturing hybrids in 2019, and 39 days earlier in 2020. The earlier harvest may have contributed to the increased CP in the early maturity class (Stokes and Prostko,1998). There was no difference in CP for clipping height. Nitrates accumulate in the base of the stem and by harvesting more of the lower stem, inflated CP levels might have occurred (Stichler and Reagor, 2001; Provin and Pitt, 2012). The elevated capture of nitrates increases the risk of nitrate toxicity. The environmental conditions in 2019 were likely favorable for nitrate-nitrogen conversion to CP but under adverse conditions, nitrates would accumulate and not be converted to CP. Elevated CP levels in 2019 prompted the monitoring of nitrate levels in 2020.

While CP has been a historically important forage value, soluble protein can provide livestock producers with an indication of the quality of the protein. Soluble proteins are degraded within the first few minutes after intake, while the remaining proteins may take several hours to degrade (Rayburn, 2020). Soluble protein was affected by year (p<0.0001), where trial averages were 38.56% and 50.46% in 2019 and 2020, respectively. Maturity class also affected SP values for both 2019 and 2020 (p 0.0003 and <0.0001. respectively). In 2019 and 2020, the early maturing hybrids averaged 34.31% and 41.09%, respectively, the long maturing hybrids, 39.04% and 47.24%, respectively, and the PS hybrids, 42.35% and 63.06%, respectively.

A higher NDFD value indicates a more digestible, and therefore, high-quality forage (Schroeder, 2018). Maturity had a significant effect on NDFD values in both 2019 and 2020 (p<.0001. respectively). Early maturing varieties, in 2019, had greater NDFD values, 64.3%, when compared to both longer and photoperiod sensitive maturing hybrids, 58% and 54.9%, respectively (p<0.0001). In 2020, all three maturities were significantly different (p<0.0001) with the early, long and photoperiod sensitive hybrids ranging from 65.4% to 60.3% to 55.5%, respectively. The primary factor influencing NDFD is plant maturity; as a plant ages, it develops more lignin (Hoffman et al. 2001). Because there is greater lignin, digestion slows as a forage matures. NDF fraction of the forage are more difficult to digest than the non-fiber components of a forage and as a plant ages, NDF concentrations increase and intake potential decreases (Ball et al., 2001).

Lignin levels differed from year to year (*p* <0.0001). In 2019, lignin levels averaged greater in the photoperiod sensitive maturity class, 3.29%, than either the early or long maturity classes, 2.57 and 2.42%, respectively (*p* <0.0001). Maturity class did not affect lignin levels in 2020 (*p* 0.3200).

Invitro total dry matter digestibility (IVTDMD48), is the measure of total digestibility after 48 hours. IVTDM48 was different (*p*<0.0001) for each maturity class in 2019 (early 80.2%, long 77.1%, and photoperiod sensitive 73.1%). In 2020, the early maturing hybrids were also different (*p*<0.0001) from the photoperiod sensitive and long maturing hybrids, 81%, 78%, and 76.7%, respectively. The two-year dataset suggests that IVTDMD48 may be greater for early maturing hybrids because of reduced lignin, but the response is limited to the evaluated genetics.

Water-soluble carbohydrates (WSC), consist of sucrose, glucose, fructose and fructans. These sugars accumulate in the stem and act as a reserve until the plant transitions to anthesis, when the carbohydrates are distributed to the developing grains (Pietragalla and Pask, 2012). The WSC levels were greater (*p*<0.0001) for the long and photoperiod sensitive maturity than for the early maturing hybrids (18.1%, 17.1%, and 12.6%, respectively) in 2019 and in 2020 (20.1%, 13.9%, and 19.4%, respectively). Escalada and Plucknett (1977) stated that water soluble carbohydrate reserves promote greater regrowth; however, regrowth was not possible for the longer maturing hybrids in the Texas High Plains. Lower levels of water soluble carbohydrates in the early maturing hybrids were due to the shorter growing season of these hybrids (Table 2).

Ratoon Forage Nutritive Values

In the early maturity class, crude protein was affected by cutting in both years (*p*<0.0001). Crude protein levels were greater for the initial harvest of all hybrids compared to the ratoon harvest (Tables 5 & 6) in both 2019 and 2020 (*p*<0.0001, respectively). In 2019, CP levels for the first and ratoon cuttings averaged 12.40% and 9.58%, respectively; however, the ratoon harvest of hybrid 18182 was similar to the first cuttings of 18178 and 18182. In 2020, the first and ratoon cuttings averaged 11.34% and 8.85%, respectively.

NDFD differed in 2019 and 2020 (*p*<0.0001). In both years, the ratoon cutting of 18179 had the least digestibility (*p*<0.0001), 57.1% in 2019 and 62.3% in 2020. All other hybrids were similar, and digestibility ranged from 62.8% to 65.2% in 2019, and 65.1% to 67.6% in 2020. In both years, hybrid 18179 had significantly reduced digestibility (*p*<0.0001, respectively), which is likely a result of the genotype of this variety.

Lignin levels decreased from the first to the ratoon cutting. Lignin in the first cutting average greater than the ratoon cutting (2.57% and 2.34%, respectively) in 2019; however, the ratoon cutting of hybrid 18179 had the highest levels of lignin in (*p* 0.0022). The first cutting in 2020 averaged (2.15%) greater levels of lignin than the ratoon cutting (1.07%).

IVTDMD was affected by year (p<0.0001). In 2019, an interaction (p<0.0001) between hybrid and cutting was detected. There was a difference (p<0.0001) between the hybrids and cuttings. In 2019, the ratoon cutting of hybrids 18178 and 18182 had increased IVTDMD values (81.94% and 82.04%, respectively) when compared to the initial harvest of these varieties (80.88% and 80.39% respectively). Hybrid 18179 had the opposite results, where the ratoon harvest had lower IVTDMD values than the initial harvest, 79.30% and 74.92%, respectively. In 2020, there was also an interaction between hybrid and cutting (p0.0013). The IVTDMD of the ratoon cutting of hybrids 18178 and 18182 (84.64% and 83.44%, respectively) was increased compared to the initial harvest (81.81% and 81.87%, respectively). Hybrid 18179 did not differ between cuttings, 80.43% and 81.30%, respectively. These differences in hybrid 18179 in both 2019 and 2020 can be attributed to a genetic response to conditions experienced in each year.

Water-soluble carbohydrates values were different between 2019 and 2020 (p<0.0001), averaging 14.40% and 17.21% across all treatments, respectively. The ratoon harvest in 2019 and 2020 had higher WSC levels, 16.17% and 20.56%, respectively, than the first cutting, 12.64% and 13.85%, respectively.

It is of note that cumulative yields of early hybrids, compared to longer maturing hybrids, yields were not different, statistically. This suggests that, unless nutritive value is your main objective and you are only producing for quantity of forage, a single harvest of a longer maturing hybrid may be more beneficial. On the other hand, an early maturing hybrid would mature quicker and may not be affected by adverse environmental and agronomic conditions.

Conclusion

This study found no differences between harvesting sorghum sudangrass at 10 and 20 cm; however, numerical data suggest that leaving longer stubble height might increase regrowth potential if optimal growth conditions occurred in the Texas High Plains. This yearly environmental variability suggests that long term evaluation of cutting heights is needed to fully comprehend the effects of cutting heights on ratoon regrowth potential.

Forage yields were not affected by maturity class in this study, with the cumulative yield of the early maturity class, harvested twice, was similar to the single harvest yields of the long or photoperiod sensitive maturity class. Even though there were significant differences in yield for 2019 and 2020, forage nutritive values were not affected by reduced yields. Cutting height did not affect any of the forage nutritive values assessed in this study. Early maturing hybrids, and their ratoon cutting, produced a higher nutritive value forage compared to the longer and photoperiod sensitive maturing hybrids.

Previous study has shown that increasing cutting heights would produce greater nodes and likely greater potential for regrowth (Alston, 1966); however, in the Texas High Plains, the increased nodes did not correlate to greater regrowth. Future study is needed to determine the effect of clipping height on regrowth origins and its effect on basal and nodal buds.

Year to year environmental factors and management decisions play an important role in determining forage production and nutritive values. Data from this study suggest that total yields were similar for a ratoon harvest system compared with a single harvest system and regrowth was only obtainable with the short growth season of an early maturing hybrid. This suggests that if a producer's goal is to produce a high yielding forage crop, a single harvest of a later maturing hybrid produced greater yields without incurring the associated cost of producing and harvesting a secondary ratoon crop of an early maturing hybrid within the same year. If a producer is looking to produce a high nutritive value forage; however, an early maturing hybrid, cut multiple times, produced similar yields to a single harvest of a later maturing hybrid, with better forage nutritive values. McCormick et al. (1995) suggested that the cost associated with producing a ratoon crop may be influenced more by an improvement in ruminant performance than by yield increases.

Tables and Figures

Table 1. Sorghum Sudangrass Hybrid Information

Hybrid	Maturity	BMR Trait
18178	Early	Yes
18179	Early	No
18182	Early	Yes
18180	Long	No
19153	Long	No
18181	Photoperiod Sensitive	Yes
19102	Photoperiod Sensitive	No

Table 2. Jullian Harvest Dates for Sorghum Sudangrass Plots

		2019		2020	
Maturity	Hybrid	First Cutting	Ratoon Cutting	First Cutting	Ratoon Cutting
Early	18178	225	273	224	289
	18179	229	273	219	289
	18182	228	283	224	289
Long	18180	248		261	
	19153	254		261	
PS	18181	291		286	
	19102	283		286	

Table 3. 2019 Cumulative Yield and Single Harvest Nutritive Value by Maturity Class

Maturity	Yield	Crude Protein	Soluble Protein	NDFD 48	IVTDMD 48	Lignin	WSC
	Mg DM ha^{-1}				%		
Early	8.30*a*	12.4*a*	34.31*b*	64.27*a*	80.19*a*	2.57*b*	12.64*b*
Long	14.66*a*	8.27*b*	39.04*ab*	57.99*b*	77.06*b*	2.42*b*	18.05*a*
Photoperiod Sensitive	13.86*a*	6.29*c*	42.35*a*	54.89*c*	73.07*c*	3.29*a*	17.13*a*

Values are averages of all hybrids within the maturity class

Averages in the same column, with the same letter, are not significantly different (α=0.05)

Table 4. 2020 Cumulative Yield and Single Harvest Nutritive Values by Maturity Class

Maturity	Yield	Crude Protein	Soluble Protein	NDFD 48	IVTDMD 48	Lignin	WSC
	Mg DM ha^{-1}			%			
Early	4.28*a*	11.34*a*	41.09*c*	65.44*a*	81.04*a*	2.15*a*	13.85*b*
Long	7.99*a*	7.64*b*	47.24*b*	55.49*c*	76.75*b*	2.12*a*	19.38*a*
Photoperiod Sensitive	6.96*a*	6.63*c*	63.06*a*	60.14*b*	77.77*b*	1.92*a*	19.88*a*

Values are averages of all hybrids within the maturity class

Averages in the same column, with the same letter, are not significantly different (α=0.05)

Table 5. 2019 First and Ratoon Cutting Yields and Forage Nutritive Values for Early Matuing Hybrids

Hybrid	Cutting	Cutting Height	Yield	Crude Protein	Soluble Protein	NDFD 48	IVTDM D 48	Lignin	WSC	Nodes Per Plant	Tillers Per Plant
			Mg ha^{-1}					%			
18178	First	10 cm	8.89	12.09*ab*	33.43*abc*	64.88*a*	80.88*ab*	2.44*bc*	12.96*b*	1.33*b*	1.07*ab*
		20 cm	8.57							1.73*a*	
	Ratoon	10 cm	6.67	10.10*c*	42.05*a*	65.17*a*	81.94*a*	1.95*c*	17.14*a*	1.67*b*	1.80*a*
		20 cm	6.77							1.93*a*	
18179	First	10 cm	7.43	13.06*a*	32.59*bc*	62.83*a*	79.30*b*	2.84*ab*	12.30*b*	1.6*b*	1.07*ab*
		20 cm	5.24							2.00*a*	
	Ratoon	10 cm	5.97	7.86*d*	27.83*bc*	57.07*b*	74.92c	3.35*a*	15.29*a*	1.20*a*	1.27*a*
		20 cm	7.74							1.73*b*	
18182	First	10 cm	10.68	12.05*ab*	36.905*ab*	65.11*a*	80.39*ab*	2.43*bc*	12.66*b*	1.27*b*	0.54*b*
		20 cm	8.97							1.87*a*	
	Ratoon	10 cm	5.10	10.77*bc*	37.3*ab*	65.06*a*	82.04*a*	1.735*c*	16.10*a*	1.87*b*	1.30*a*
		20 cm	5.55							2.20*a*	

Values in the same column, with the same letter, are not significantly different (α=0.05)

Table 6. 2020 First and Ratoon Cutting Yields and Forage Nutritive Values for Early Maturing Hybrids

Hybrid	Cutting	Cutting Height	Yield	Crude Protein	Soluble Protein	NDFD 48	IVTDMD 48	Lignin	WSC	Nodes Per Plant	Tillers Per Plant
			Mg ha^{-1}				%				
18178	First	10 cm	4.19	10.98*a*	43.52*a*	65.55*ab*	81.82*c*	1.67*a*	14.95*b*	1.60*b*	0.47*b*
		20 cm	4.33							1.87*a*	
	Ratoon	10 cm	3.45	8.725*b*	55.27*b*	67.6*a*	84.64*a*	0.79*b*	21.68*a*	1.13*b*	1.74*a*
		20 cm	2.63							1.67*a*	
18179	First	10 cm	4.56	12.16*a*	38.05*a*	65.01*b*	80.43*d*	2.61*a*	12.95*b*	1.47*b*	1.3*a*
		20 cm	3.38							2.13*a*	
	Ratoon	10 cm	4.98	8.71*b*	56.99*b*	62.31*c*	81.3*cd*	1.44*b*	20.27*a*	1.27*b*	1.8*a*
		20 cm	2.61							1.87*a*	
18182	First	10 cm	5.08	10.88*a*	41.69*a*	65.73*ab*	80.87*cd*	2.17*a*	13.67*b*	1.40*b*	0.47*b*
		20 cm	4.12							2.13*a*	
	Ratoon	10 cm	3.02	9.13*b*	53.44*b*	66.31*ab*	83.45*b*	0.98*b*	19.75*a*	1.00*b*	1.84*a*
		20 cm	2.18							1.67*a*	

Values in the same column, with the same letter, are not significantly different (α=0.05)

Figure 1. 2019 Weather Data for Sorghum Sudangrass Ratoon Trial

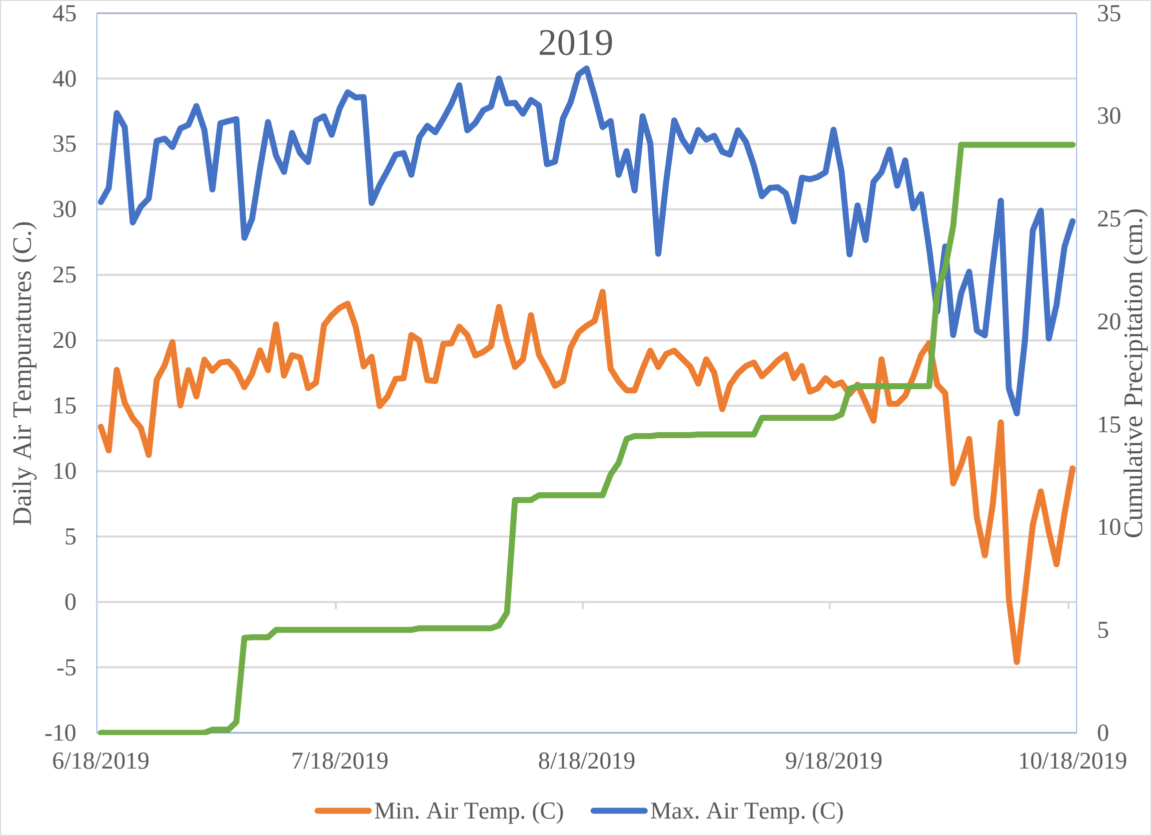
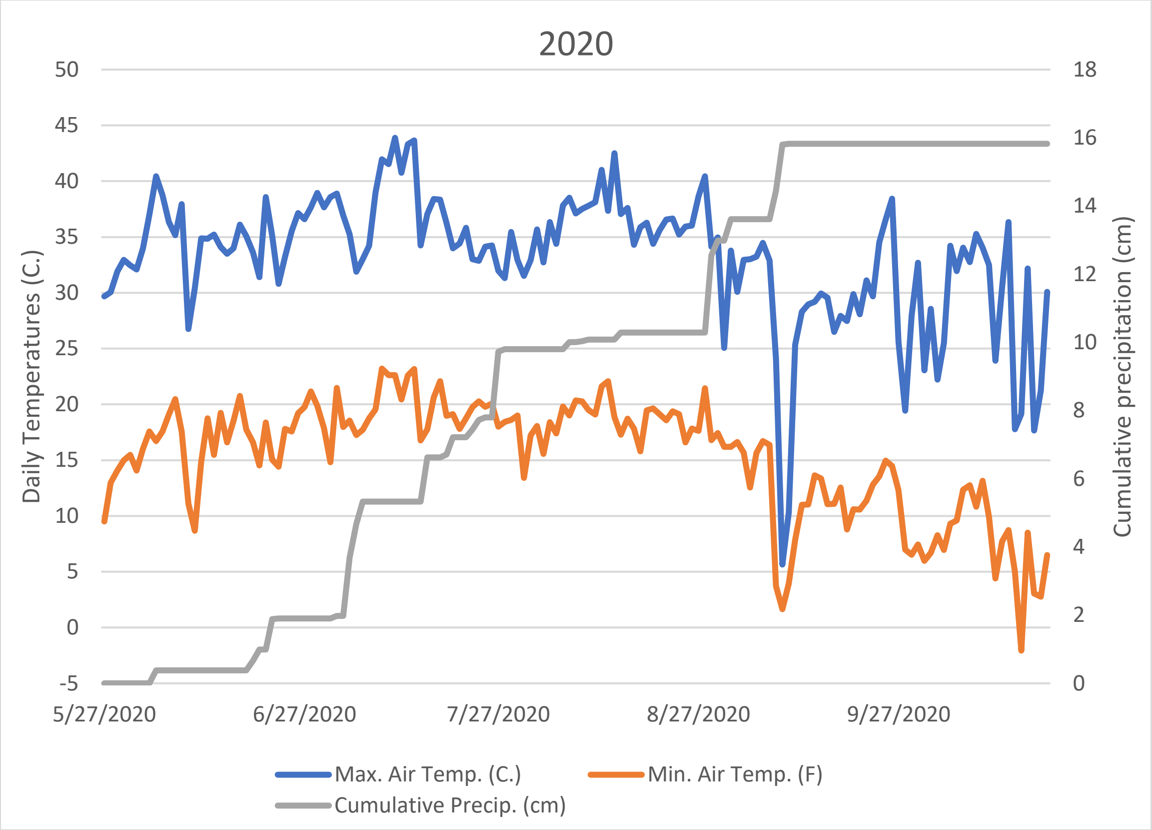


Figure 2. 2020 Weather Data for Sorghum Sudangrass Ratoon Trial



Literature Cited

Atis, I., O. Konuskan, M. Duru, H. Gozubenli and S. Yilmaz, 2012. Effect of harvesting time on yield, composition and forage quality of some forage sorghum cultivars. Int. J. Agric. Biol., 14: 879–886.

Alston, G. D. 1966. The Influence of Management on Growth Responses of Sudangrass-Sorghum Hybrids. Thesis. Texas A&M University, Graduate College. College Station, TX.

Ardiyanti, S. E., Sopandie, D., Wirnas, D., Trikoesoemaningtyas. 2019. Ratoon Productivity of Sorghum Breeding Lines (Sorghum bicolor (L.) Moench). IOP Conference Series. Earth and Environmental Science **399** 012030.

Ball, D. M., Collins, M., Lacefield, G. D., Martin, N. P., Mertens, D. A., Olson, K. E., Putnam, D., Undersander, D., & Wolf, M. W. (2001). Understanding forage quality. *American Farm Bureau Federation Publication*, *1*(01), 1-15.

Ball, D. M., Hoveland, C.S. Lacefield, G.D. 2007. Southern Forages, Modern Concepts for Forage Crop Management. 4th Edition. International Plant Nutrition Institute.

Bean, B., McCullum, T., Villarel, B., Robison, J., Vanmeter, R., Pietsch, D. 2007. Texas Panhandle Sorghum Hay Trial. Texas Cooperative Extension. Texas Agricultural Experiment Station. The Agriculture Program, Texas A&M University.

Beaty, E. R., Smith, Y.C., McCreery, R. A., Ethredge, W. J., Beasley, K. 1965. The Effect of Cutting Height and Frequency on Forage Production of Summer Annuals. Agronomy Journal, 1965, vol. 57, issue 3, pg. 277-279

Beck, P., Poe, K., Stewart, B., Capps, P., Gray, H. Effect of Brown Midrib Gene and Maturity at Harvest on Forage Yield and Nutritive Quality of Sudangrass. 2013. Japanese Society of Grassland Science. Grassland Science, 59, 52-58.

Bell, J., Naylor, C., Heflin, K., Sirmon, P., Schnell, R., Horn, K. 2019 Texas A&M AgriLife Bushland Forage Sorghum Silage Trial. 2019. Available at: https://amarillo.tamu.edu/files/2020/02/2019-Texas-AM-AgriLife-Forage-Sorghum-Silage-Trial.pdf.

Bell, J., Naylor, C., Heflin, K., Sirmon, P. Porter, N., Schnell, R., Horn, K. 2020 Texas A&M AgriLife Bushland Forage Sorghum Silage Trial. 2020. Available at: https://amarillo.tamu.edu/files/2021/01/2020-AgriLife-Forage-Sorghum-Silage-Trial.pdf

Bell, J., Naylor, C., Heflin, K., Sirmon, P. Porter, N., Schnell, R., Horn, K. 2021 Texas A&M AgriLife Bushland Forage Sorghum Silage Trial. 2021. Available at: https://amarillo.tamu.edu/files/2021/12/2021-AgriLife-Forage-Sorghum-Silage-Trial.pdf

Bell, J., Naylor, C., Heflin, K., Sirmon, P. Porter, N., Schnell, R., Horn, K. Peneiro, J., Banta, J., Smith, J. 2022 Texas A&M AgriLife Bushland Forage Sorghum Silage Trial. 2022. Available at: https://amarillo.tamu.edu/files/2023/01/2022-AgriLife-Forage-Sorghum-Silage-Trial-Report.pdf

Black, J. R., Ely, L. O., McCullough, M. E., Sudweeks, E. M. 1980. Effect of Stage of Maturity and Silage Additives Upon the Yield of Gross and Digestible Energy in Sorghum Silage. Journal of Animal Science, Vol 50, No 4. 1980

Burger, A. W., Hittle, C. N. 1967. Yield, Protein, Nitrate, and Prussic Acid Content of Sudangrass, Sudangrass Hybrids, and Pearl Millet Harvested at Two Cutting Frequencies and Two Stubble Heights. Agronomy Journal, Vol 59, May-June 1967.

Dahlberg, J. A., Hutmacher, R., & Wright, S. 2015, December 2 -4. *Sorghum: An Alternative Feed, Hay and Forage*. *Proceedings*. Reno, NV. Retrieved April 4, 2023, from https://alfalfa.ucdavis.edu/+symposium/2015/index.aspx.

Duncan, R. R., Gardner, W. A. 1984. The Influence of Ratoon Cropping on Sween Sorghum Yield, Sugar Production, and Insect Damage. Canadian Journal of Plant Science, Vol 64, pg. 261-273,

Duncan, R. R., Moss, R. B. 1987. Comparative Yields of Ratoon Cropped Temperately and Tropically Adapted Grain Sorghum Hybrids. Crop Science, Vol 27, pg. 569-571.

Escalada, R. G., Plucknett, D. L. 1977. Ratoon Cropping of Sorghum. III. Effect of Nitrogen and Cutting Height on Ratoon Performance. Agronomy Journal, Vol 69, May-June 1977.

Granados-Ninos, J. A., Reta-Sanchez, D. G., Santana, O. I., Reyes-Gonzalez, A., Ochoa-Martinez, E., Diaz, F., Sanchez-Duarte, J. I. 2021. Effect of the Cutting Height of Sorghum at Harvest on Forage Yield and Nutritional Value of Silage. Revista Mexicana de Ciencias Pecuarias, 2021; 12 (3): 958-968.

Hannaway, D. B., McGuire, W. S. Growing Sorghum and Sudangrass for Forage. 1982. Oregon State University. Oregon State University Extension Service. Publication FS 290. November 1982.

Hardy, A. and K. Olson. 2020. Chapter 14: Nutrient Requirements of Beef Cows. SDSU Extension. https://extension.sdstate.edu/sites/default/files/2021-05/S-0013-14.pdf

Hoffman, P. Shaver, R. Combs, D. Undersander, D. Bauman, L. Seeger, T. 2001. Understanding NDF Digestibility of Forages. Focus on Forage, Vol. 3, No. 10. University of Wisconsin- Madison, Extension Team Forage. Available at https://fyi.extension.wisc.edu/forage/files/2016/10/NDFDig-2.pdf.

Iptas, S., Brohi, A. R. 2003. Effect of Nitrogen Rate and Stubble Height on Dry Matter Yield, Crude Protein Content and Crude Protein Yield of a Sorghum-Sudangrass Hybrid [Sorghum bicolor (L.) Moench x Sorghum Sudanese (Piper) Stapf.] in the Three-Cutting System. Blackwell, Verlag, Berlin. Journal of Agronomy and Crop Science, Vol 189, pg. 227-232, 2003.

Karper, R. E., Quinby, J.R., Jones, D. L. 1928 Sudan Grass for Hay, Seed, and Pasture. Texas Agricultural Experiment Station. Bulletin 396. Texas A&M University.

Kebrom, T. H., Brutnell, T. P., & Finlayson, S. A. 2010. Suppression of sorghum axillary bud outgrowth by shade, phyB and defoliation signalling pathways. Plant, Cell & Environment, 33, 48–58.

Kilcer, T. F., Ketterings, Q. M., Cherney, J. H., Cerosaletti, P., Barney, P. 2005. Optimum Stand Height for Forage Brown Midrib Sorghum X Sudangrass in North-eastern USA. Blackwell Verlag, Berlin. J. Agronomy and Crop Science. Volume 191, pg. 35-40.

Kilcer, T., G. Albrecht, P. Cerosaletti, P. Barney, Q. Ketterings, and J. Cherney. 2007. Brown Midrib Sorghum Sudangrass, Part I: Successfully Growing a High Energy Grass for Dairy Cows Cornell University Cooperative Extension Service. Agronomy Factsheet Series: Fact Sheet 14. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet14.pdf

Kendall, C., Leonardi, C., Hoffman, P. C., Combs, D. K. 2009. Intake and Milk Production of Cows Fed Diets that Differed in Dietary Neutral Detergent Fiber and Neutral Detergent Fiber Digestibility. J. Dairy Science, 92, 313-323.

Lang, B. Sudan/Sorghum Forage Management. 2001. Iowa State University Extension. Fact Sheet BL-50.

Livingston, S. D., Bade, D. H., Dorsett, D. J. 1995. Haygrazers and Canes for South Texas. Texas A&M University. Texas Agricultural Extension Service. Publication L-5145.

Livingston, S. D., Coffman, C. G. Ratooning Grain Sorghum on the Texas Gulf Coast. Texas A&M Agrilife Extension. SCSC-PU-091. September 2022.

Lui, R., Finlayson, S. 2019. Sorghum Tiller Bud Growth Is Repressed by Contact with The Overlying Leaf. Wylie Publishing. Plant, Cell, and Environment. Volume 42. Issue 7. Page 2057-2323.

Machicek, J. A., Blaser, B. C., Darapuneni, M., Rhoads, M. B. 2019. Harvesting Regimes Affect Brown Midrib Soughum-Sudangrass and Brown Midrib Pearl Millet Forage Production and Quality. Agronomy, Vol 9, 2019

Marsalis, M. A. Sorghum Forage Production in New Mexico. 2011. New Mexico State Cooperative Extension Service. Guide A-332

McCormick, M. E., Morris, D. R., Ackerson, B. A., Blouin, D. C. 1995. Ratoon Cropping Forage Sorghum for Silage: Yield, Fermentation, and Nutrition. Agronomy Journal, Vol 87, September-October 1995.

Miller, F. R., Stroup, J. A. 2003. Brown Midrib Forage Sorghum, Sudangrass and Corn: What is the Potential. Proceedings of the California Alfalfa and Forage Symposium, December 17-19, 2003. Monterey, California.

Miller, F. R., Stroup, J. A. 2004. Growth and Management of Sorghums for Forage Production. Proceedings of the National Alfalfa Symposium, December 13-15, 2004. San Diego, CA. UC Cooperative Extension, University of California, Davis.

Miron, J., Solomon, R., Adin, G., Nir, U., Nikachat, M., Yosef, E., Carmi, A., Weinberg., Kipnis, T., Zuckerman, E., Ben-Ghedalia, D. 2006. Effects of Harvest Stage and Regrowth on Yield, Composition, Ensilage and In-vitro Digestibility of new Forage Sorghum Varieties. Journal of the Science of Food and Agriculture, 86: 140-147, 2006

Mueller, S. C., Orloff, S. B. 1994. Environmental Factors Affecting Forage Quality. University of California. University of California Alfalfa Symposium. December 8-9, 1994. Redding, California.

Newman, Y. C., Lambert, B., Muir, J. P. 2007. Defining Forage Quality. Texas A&M University. Texas A&M Agrilife Extension. Publication L-5481. January 2007

Oba, M. and M.S. Allen. 1999. Evaluation of the importance of digestibility of neutral detergent fiber from forage: Effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci., 82: 589-596

Owens F. N., Secrist D. S., Hill W. J., and Gill D. R.. . 1998. Acidosis in cattle: a review. J. Anim. Sci. 76:275–286. doi: 10.2527/1998.761275x

Pietragalla, J., Pask, A. (2012). Ch. 16: Water Soluble Carbohydrate Content. In Physiological Breeding II: A Field Guide to Wheat Phenotyping (pg. 83-86). Essay. CIMMYT.

Proven, T. L., Pitt, J.L. 2012. Nitrates and Prussic Acid in Forages- Sampling, Testing and Management Strategies. Texas A&M University. Texas A&M Agrilife Extension. Publication E-543. Available at: http://forages.tamu.edu/PDF/Nitrate.pdf

Rayburn, E. Understanding Forage Analysis Important to Livestock Producers. West Virginial University Extension. Last reviewed Nov. 2020. Available at: https://extension.wvu.edu/agriculture/pasture-hay-forage/quality/understanding-forage-analysis

Sanz-saez, A., Gorka, E., Aguirreolea, J., Munoz, F., Sanchez-Diaz, M., Irigoyen, J. 2012. Alfalfa Forage Digesitibility, Quality, and Yield Under Future Climate Chance Scenarios Vary with *Sinorhizobium meliloti* Strain. Journal of Plant Physiology, 169, 782-788.

SAS Institute. 2017. SAS/STAT® 17.1 user's guide. SAS Institute

Schroeder, J.W., 2018. Interpreting Composition and Determining Market Value. North Dakota State University, Publication AS1251. Available at file:///C:/Users/preston.sirmon/Downloads/as1251.pdf.

Sheaffer, C. C., Moncada, K. M. 2009. Introduction to Agronomy- Food, Crops, and Environment. Pg. 538. Delmar Cengage Learning.

Smith, C. W., Frederiksen, R. A. 2000. Sorghum: Origin, History, Technology, and Production. Vol. 2. John Wiley and Sons.

Stichler, C., Reagor, J. C. 2001. Nitrate and Prussic Acid Poisoning. Texas A&M University. Texas A&M Agrilife Extension. Publication L-5231.

Stokes, S., Prostko, E. 1998. Understanding Forage Quality Analysis. Texas A&M Agrilife Extension. Publication L-5198. Available at: https://erath.agrilife.org/files/2011/07/nitrate-and-prussic-acid-poisoning.pdf

Tilly, J. M., and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc.18:104–111.

Undersander, D., Mertens, D. R., & Thiex, N. (1993). Forage analyses procedures. National Forage Testing Association. https://fyi.extension.wisc.edu/forage/files/2014/01/NFTA-ForageAnalysis-Procedures.pdf

Venuto, B., Kindiger, B. 2008. Forage and Biomass Feedstock Production From Hybrid Forage Sorghum and Sorghum-sudangrass Hybrids. Japanese Society of Grassland Science. Grassland Science, 54, 189-196. Blackwell Publishing.

Vinhall, H. N. 1914. Sudan Grass as a Forage Crop. United States Department of Agriculture. Farmers Bulletin 605.

Vinhall, H. N., Getty, R. E. 1921. Sudan Grass and Related Plants. United States Department of Agriculture. Bulletin Number 981.

Wakano, F., Nohong, B., Nompo, S. 2021. Growth and Yield Responses of Forage Sorghum Ratoon to Different Inorganic Fertilizers. IOP Conf. Series. Earth and Environmental Science **788** 012170.

Whish, J., and L. Bell. 2008. Trade-offs for ratooning sorghum after harvest to provide forage for grazing. https://www.researchgate.net/publication/237396341_Trade-offs_for_ratooning_sorghum_after_harvest_to_provide_forage_for_grazing

Woodward, T. E., Hosterman, W. H., Cardon, P. V., McComas, E. W. 1939. The Nutritive Value of Harvested Forages. United States Department of Agriculture. Yearbook of Agriculture, 1939.

Worker, G. F., Marble, V. L. 1968. Comparison of Growth Stages of Sorghum Forage Types as to Yield and Chemical Composition. Agronomy Journal, Vol 60, November-December, 1968.