BERMUDAGRASS YIELD RESPONSE TO IRRIGATION AND NITROGEN IN THE SOUTHEASTERN COASTAL PLAIN

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Abstract. *In the Southeastern region of the US, the cattle industry has a critical need for sustainable hay production. However, production is threatened by frequent short-term regional drought that can be mitigated by properly managed irrigation. In this study on Tifton 85 bermudagrass, irrigation management, nitrogen fertility levels, and harvest interval were evaluated for their impact on hay quality and yield. The optimal irrigation rate (100%) was set to maintain soil water potentials below -30 kPa. The reduced irrigation treatments received water in rates of 0, 33, and 66% of the 100% irrigation rate. In addition, each irrigation treatment had nitrogen rates of 168, 336, and 504 kg N/ha. The irrigation and nitrogen treatments were harvested at 4- or 8-week intervals. Over all harvests, nitrogen significantly increased bermudagrass hay yield. When irrigation was required, it significantly increased hay yields and hay yields increased linearly with increasing irrigation rate. The 4-week harvest interval was more responsive to irrigation. Additionally, we observed a linear relationship between non-irrigated bermudagrass hay yields and average soil water potential. As soil moisture was depleted, non-irrigated hay yields decreased 31 kg/ha per kPa. Thus, irrigation management should be critically assessed for its potential role in sustaining hay production in the southeastern Coastal Plain.*

Keywords. *Bermudagrass, Irrigation, irrigation management, Nitrogen, forage quality.*

INTRODUCTION

In most Southeastern US states, cattle production ranks in the top 10 leading commodities by cash receipts (USDA-ERS, 2011). This cattle production is vital to the regional economy. In this region, the cattle production industry has a critical need for sustainable hay production. Bermudagrass has become a major crop for forage and hay production crop in the Southeastern US (Muir et al., 2010; Alderman et al., 2011). However, hay production has been impacted by frequent short-term regional drought. This drought threat can potentially be mitigated by properly managed irrigation.

Most previous research on bermudagrass water use reported that periods of low rainfall or drought can impact production (Doss et al.,1962; Ashley et al.,1965; Marsalis et al., 2007; da Fonseca et al., 2007). Stone et al. (2010) reported that climate change and weather extremes were impacting water resources availability in the US and throughout the world. These weather extremes particularly short term droughts have the potential to impact bermudagrass hay production. The expectation of more frequent drought periods provides an incentive to investigate irrigation responses for stable bermudagrass hay production. Additionally, most of the previous research on bermudagrass irrigation was conducted with older cultivars that yielded about 75% of the current cultivars (Burton et al., 1993). Increased forage production with the newer cultivars suggests that reaching the genetic potential for yield may require more aggressive management. The objective of this research is to determine the impact of irrigation, nitrogen, and harvest interval on 'Tifton 85' bermudagrass hay yield and forage quality.

MATERIALS AND METHODS

In the spring of 2007, 'Tifton 85' bermudagrass was sprigged under a 6-ha site-specific center pivot irrigation system (Camp et al., 1998) on a relatively uniform Norfolk loamy sand (Typic Kandiudult) near Florence, South Carolina. In 2008 and 2009, an experiment was conducted to determine the impact of irrigation and nitrogen on bermudagrass hay yield and forage quality. Irrigation rate, nitrogen rate, and harvest intervals were evaluated. There were four irrigation treatments (0, 33, 66, and 100% irrigation). For each 100% irrigation application, the other irrigation treatments received a proportional application depth. In addition, each irrigation treatment had nitrogen treatments of 168, 336, and 504 kg N ha^{-1}. The irrigation and nitrogen treatments were harvested at 4- or 8-week intervals. The experimental design was a split-plot with harvest interval as main plots and the irrigation by N levels as subplots. The plot size was 20 m wide by 20 m long with four replicates (96 total plots). All treatments remained in the same plots for both years.

SOIL WATER POTENTIAL MEASUREMENT

Soil water potentials (SWP) were measured in all irrigation treatments and harvest intervals for the high N rate using tensiometers at two depths (0.30 and 0.60 m). Measurements were recorded at least three times each week. A 12.5 mm irrigation was initiated when SWP at the 0.30-m depth was below -30 kPa in the 100% irrigation plot with high N. The other irrigation treatments received a proportional application (0%, 33%, 66% of 12.5-mm). Additionally, if SWPs decreased below -50kPa, an additional 12.5 mm irrigation was applied if the rainfall forecast was less than 50%.

FERTILIZER APPLICATIONS

All nitrogen fertilizer was applied via fertigation through the center pivot in three annual split applications. In the spring, one-third of the total N per year for each treatment was applied at green-up, with the rest being applied in equal applications after the 8-week harvests. Low, medium, and high rates were 56, 112, and 168 kg N ha^{-1} per application. Total annual N application rates were 168, 336, and 504 kg N ha^{-1}. Phosphorus and K were uniformly applied in granular form across all plots each spring based on soil testing and recommendations of the Clemson University Extension Agricultural Service Laboratory. Fertilizer applied was 56 kg ha^{-1} P_2O_5 and 112 kg ha^{-1} K_2O in 2008, and 56 kg ha^{-1} P_2O_5 and 168 kg ha^{-1} K_2O in 2009. Nitrogen applications were applied with the minimal water application depths in order to minimize irrigation water applications to non irrigated plots.

HARVEST

The bermudagrass hay was harvested at 4- and 8-week intervals. In 2008, 4-week harvests occurred on 5/27, 6/24, 7/21, 8/18, and 9/18. The 8-week hay harvests were on 6/24, 8/18, and 10/14. There was not a 4-week harvest on 10/14 because of a lack of growth in those plots. In 2009, the 4-week hay harvests were on 6/22, 7/21, 8/17, 9/14, and 10/19. The 2009 8-week harvests were on 6/22, 8/17, and 10/19. In 2009, the 4-week bermudagrass treatments were delayed coming out of dormancy, so we postponed the initial harvest until June 2009 (8-weeks for this interval) to allow the crop to establish. Bermudagrass hay was harvested by cutting with a 3-m wide rotary mower/conditioner thorough the center of the plots. A 3-m windrow was then raked onto a small tarp and weighed for yield. A small sub-sample was collected for moisture calculations, C&N analysis, and forage quality testing. The rest of the plot was then mowed, dried, raked, baled, and removed from the field.

STATISTICAL ANALYSES

All data were statistically analyzed in SAS (Statistical Analysis System, SAS Institute, Cary, NC.) using a mixed model analysis. Each harvest in each year and total hay yield for the year were analyzed separately using the GLIMMIX procedure. Irrigation rate and N level were considered as fixed effects and replicates were considered random. Using the ESTIMATE command in GLIMMIX, linear, quadratic, and deviation from quadratic effects were tested for irrigation and linear and deviation from linear effects were tested for N.

RESULTS

HAY YIELDS

In 2008 and 2009, the mean bermudagrass hay yields for the rainfed treatments were 9.2 and 14.4 Mg ha^{-1}, respectively. Initial analysis indicated that the two years were significantly different, so we analyzed years separately. The differences between the years were mostly attributed to the differences in rainfall distribution. In 2008 and 2009, the total rainfalls for the growing season were 701 and 522 mm, respectively. However, the rainfall distribution and irrigation applications were different for each growing season (see Table 1). In 2008, the rainfall occurred during the latter part of the growing season. In 2009 the rainfall occurred during the first part of the growing season. In August and September 2009, the monthly rainfall was below normal and irrigation was required to meet crop demand. The total water applied was greater in 2008 than in 2009 due to the poor early season rainfall. In 2008, the 100% irrigation treatment received irrigation amounts of 152 mm and 191 mm for the 4- and 8-week harvest, respectively. The corresponding 2009 100% irrigation treatments received 89 and 102 mm of irrigation for the 4- and 8-week harvest, respectively.

Table 1. Number of irrigations (n) and rainfall for the 2008 and 2009 bermudagrass hay 4 and 8 week harvest intervals over the irrigation treatments.

		month													
		5		6		7		8		9		10		Total	
		n	Rain	n	Rain	n	Rain	n	Rain	n	Rain	n	Rain	n	Rain
		(mm)													
Harvest	year														
4	2008	2*	83	3	39	2	133	0	165	0	199	0		7	619
	2009			0	251	0	97	0	63	2	29	5	82	7	522
8	2008			11	122			4	299			0	281	15	701
	2009			0	251			1	161			7	111	8	522

* The 100% irrigation treatment received 12.5 mm per irrigation. The other irrigation treatments received a percentage of that amount per irrigation.

IRRIGATION TREATMENTS

Irrigation generally increased bermudagrass hay yields both annually and across cutting intervals. Irrigation linearly increased bermudagrass hay yields in five of ten 4-week harvests and in two of six 8-week harvests. In 2008, the overall yearly 4-week harvest hay yields were significantly linearly correlated with the irrigation treatments (Table 2). Likewise, the individual 4-week harvests were also positively linearly correlated with irrigation treatment for all harvest except the August 2008 harvest. The August harvest was negatively correlated to irrigation treatment. During the growth period for this harvest, no irrigation was applied because of

Table 2. Mean 2008 and 2009 bermudagrass hay yields for the 4 and 8 week harvest intervals over the irrigation treatments.

			month						
			5	6	7	8	9	10	Total
			Yield (kg ha^{-1}) [1]						
Harvest	year	Irrigation							
4	2008	0	1552	664	1455	1904	3063	.	8638
		33	1547	1151	1939	1570	3090	.	9297
		66	1666	1332	2303	1546	3350	.	9893
		100	1733	1450	2160	1352	2966	.	9504
		Linear	*	**	**	**	ns		**
		Quadratic	ns	*	ns	ns	ns		**
	2009	0	.	6986	3253	2441	733	1514	14927
		33	.	6684	3003	2402	886	1734	14708
		66	.	6328	2985	2605	812	2101	14831
		100	.	7172	3055	2654	947	2293	16121
		Linear		ns	ns	ns	ns	**	ns
		Quadratic		*	ns	ns	ns	ns	ns
8	2008	0	.	2889	.	2789	.	4171	9755
		33	.	3327	.	3036	.	4062	10426
		66	.	3349	.	2749	.	3535	9658
		100	.	3869	.	2819	.	3783	10446
		Linear		*		ns		ns	ns
		Quadratic		ns		ns		ns	ns
	2009	0	.	6000	.	5103	.	2710	13813
		33	.	5481	.	5380	.	3248	14109
		66	.	6188	.	4543	.	3624	14356
		100	.	5439	.	5173	.	4313	14925
		Linear		ns		ns		**	ns
		Quadratic		ns		ns		ns	Ns

[1] *, and ** indicate contrast was significant at the P<0.10, and 0.05, respectively. ns indicates no significant difference.

plentiful rainfall. Additionally, the plant nitrogen removed in the hay had a similar negative trend possibly indicating that 165 mm of rainfall during that harvest interval may have leached available N below the root zone.

During the first part of the 2008 growing season, rainfall totals were below normal and irrigation was required to keep soil water levels at an adequate level. This corresponded to the observed low soil water potential values from May to July (DOY 142 to 191, Figure 1). Both the 30-cm and 60-cm deep soil water potentials followed the same trend (60-cm soil water potential data not shown). During this time period, the 100% irrigations applications (12.5 mm per application) were generally not large enough to keep the 30-cm deep soil water potential <-30 kPa, but soil water potential were still greater than -50 kPa and did not trigger the additional 12.5 mm irrigation.

The overall 2008 8-week hay yields were not correlated to the irrigation treatments. Only in the first 8-week harvest in June 2008 did yield significantly increase with irrigation. Because of sufficient rainfall, the remaining two 8-week harvests were not correlated to irrigation treatments.

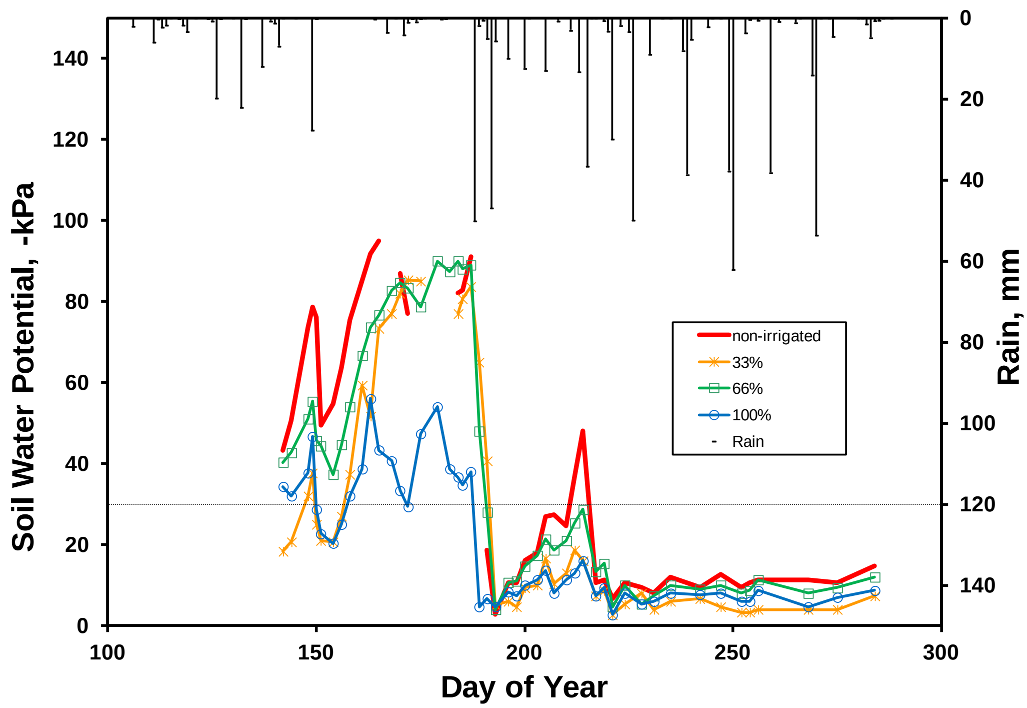

Figure 1. Soil water potentials for the 2008 4-week harvest interval, 30-cm irrigated bermudagrass.

In 2009, the overall 4- and 8-week hay yields were not correlated to the irrigation treatment. Only the, October 2009 4- and 8-week harvests were correlated to irrigation treatment. The 2009 rainfall distribution was at or above normal for most of the early growing season. However in late August and September (DOY 225-272), the rainfall was well below normal. This low rainfall contributed to both the low observed soil water potentials (Figure 2) and the yield response to increasing amounts of irrigation.

Additionally, we plotted yield versus average soil water potential for the harvest period for both harvest intervals and each irrigation treatment across both years (Figures 3 and 4). For the 4-week harvest interval, the non-irrigated soil water potentials were correlated to yield (r^2=0.68,

Figure 3), but the irrigated soil water potentials were not (r^2=0.33, 0.31, and 0.44 for the 33, 66, and 100% treatments, respectively). The 8-week harvest intervals generally had slopes similar to the 4-week harvest intervals (Figure 4). The 8-week non-irrigated SWPs were less correlated (r^2=0.49) than the 4-week results. Interestingly, the non-irrigated 4- and 8-week harvest intervals had similar slopes, -30.4 and -31.8 kg ha^{-1} kPa^{-1}, respectively. The 8-week irrigated SWPs had a very poor correlation to yield (r^2=0.29, 0.08, and 0.01 for the 33, 66, and 100% treatments, respectively), yet the 33% and 66% treatments had slopes similar to the 4-week harvest interval. The poor correlations were also expected because the range of SWP values was much smaller and corresponded to the increasing irrigation application depth treatments.

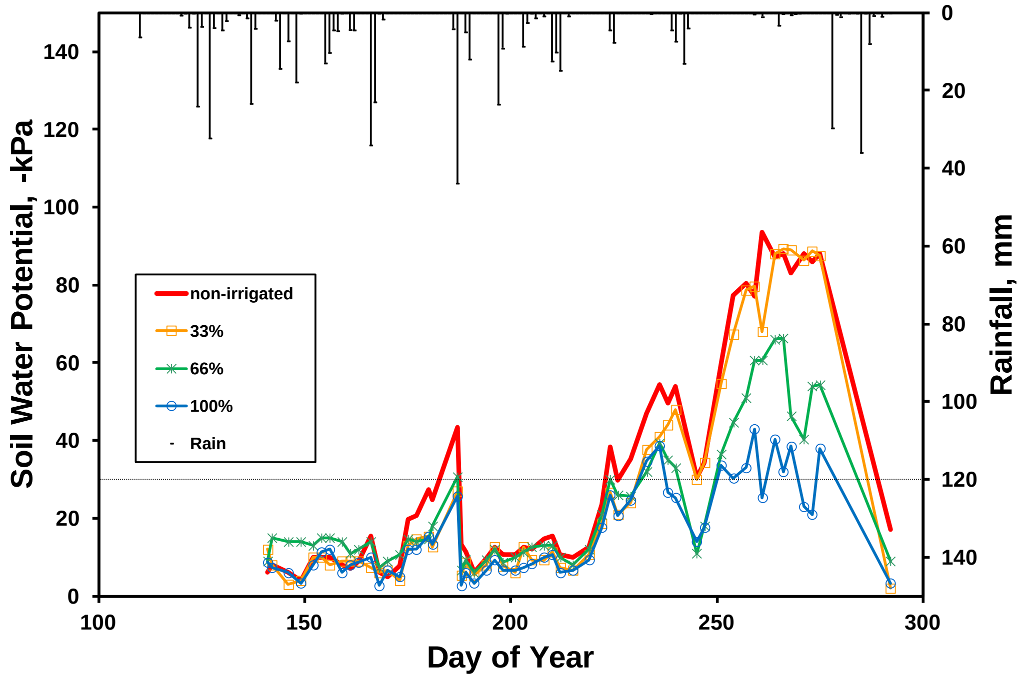

Figure 2. Soil water potentials for the 2009 4-week harvest interval, 30-cm irrigated bermudagrass.

NITROGEN RATES

For both years and over both harvest intervals, the annual hay yields had a significant linear correlation to increasing N rate (Table 4). Additionally, the 2008 4-week, and 2009 8-week harvest interval hay yields had significant deviation from linear trend to increasing N rate. The correlation between increased N rate and yields has been observed in other studies (Burns et al., 1985; Mandebvu et al., 1999; Adeli et al., 2005; da Fonseca et al., 2007; Garcia et al., 2008; Alderman et al., 2011).

For the individual 4- and 8-week harvest intervals, all had linearly correlated yield increases with increasing N rates. Only the 4-week harvest interval harvest in September 2008 and the 8-week harvest in June 2009 had a significant deviation from linear response.

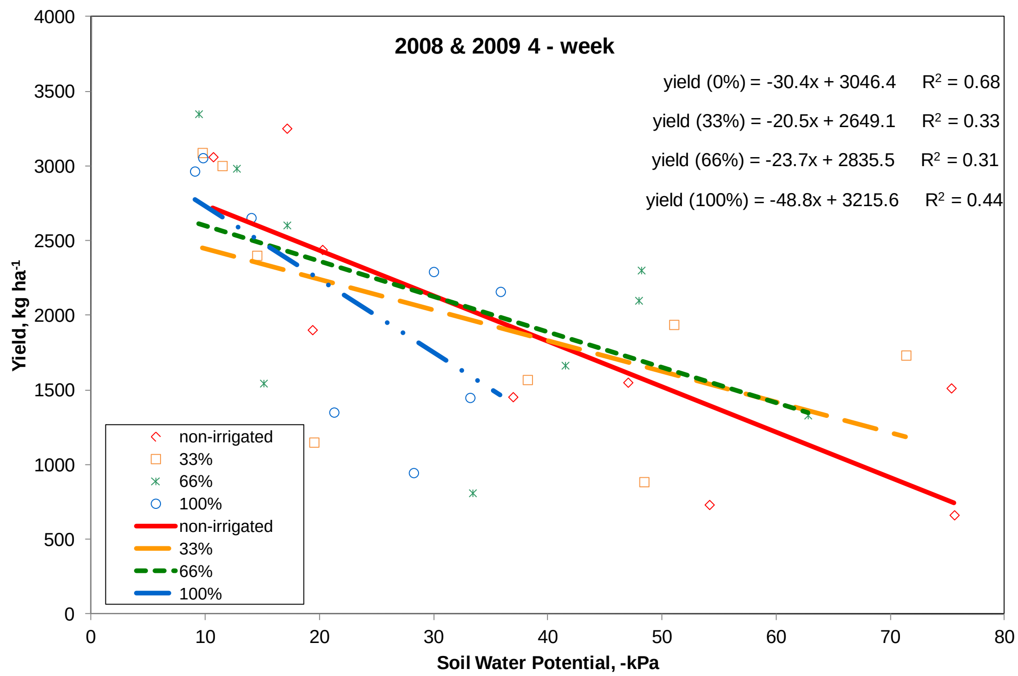

Figure 3. Bermudagrass hay yields as influenced by soil water potential for the 4-week harvest intervals.

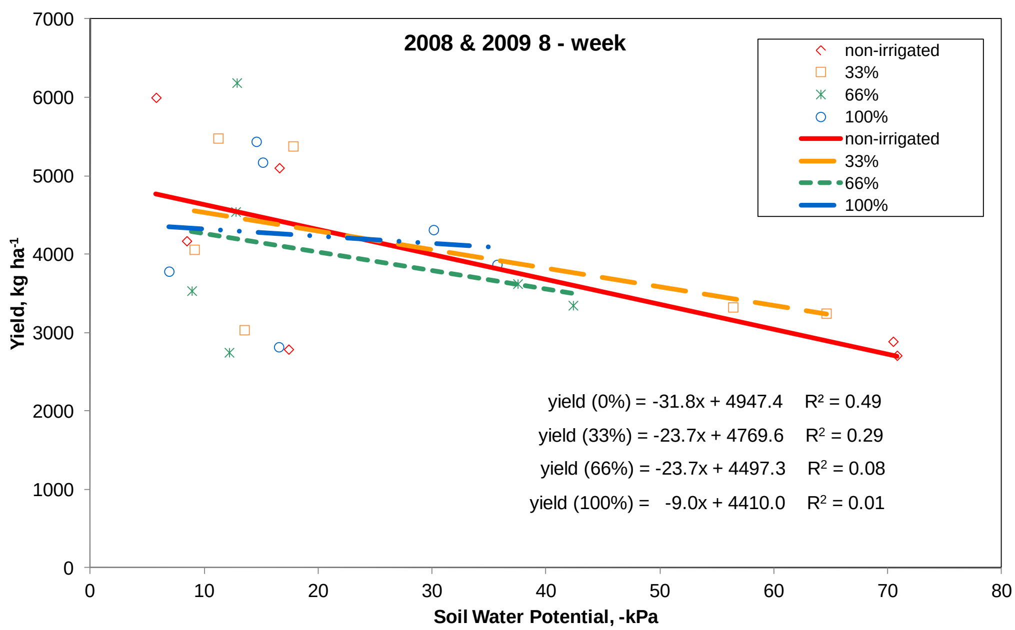

Figure 4. Bermudagrass hay yields as influenced by soil water potentials for the 8-week harvest intervals.

Table 4. Mean 2008 and 2009 bermudagrass hay yields for the 4 and 8 week harvest interval over the nitrogen treatments.

			month						
			5	6	7	8	9	10	12
			Yield (kg ha^{-1})[1]						
Harvest	Year	Nitrogen							
4	2008	1	1273	673	1245	1421	1989	.	6601
		2	1701	1038	2225	1527	3422	.	9913
		3	1899	1737	2422	1907	3941	.	11842
		Linear	**	**	**	**	**		**
		Deviation from Linear	ns	ns	ns	ns	**		*
	2009	1	.	5579	2330	2026	304	1307	11545
		2	.	7023	3200	2373	951	1964	15510
		3	.	7777	3692	3178	1278	2461	18386
		Linear		**	**	**	**	**	**
		Deviation from Linear		ns	NS	ns	ns	ns	ns
8	2008	1	.	2679	.	1969	.	2537	7185
		2	.	3300	.	3109	.	4045	10445
		3	.	4097	.	3617	.	5081	12975
		Linear		**		**		**	**
		Deviation from Linear		ns		ns		ns	ns
	2009	1	.	4817	.	3853	.	2172	10843
		2	.	6275	.	5275	.	3669	15219
		3	.	6239	.	6022	.	4580	16841
		Linear		**		**		**	**
		Deviation from Linear		*		ns		ns	**

[1] *, and ** indicate contrast was significant at the $P<0.10$, and 0.05, respectively.
ns indicates no significant difference.

HARVEST INTERVALS

Harvest intervals did not have a significant impact on the annual bermudagrass hay yields. In 2008, the 4- and 8-week hay yields were 9.3 and 10.1 Mg ha^{-1}, respectively. In 2009, the 4- and 8-week hay yields were 15.1 and 14.3 Mg ha^{-1}, respectively. The most noticeable difference between the harvest intervals was for the June, August, and October harvests. Since nitrogen fertilizer was applied at 8-week intervals, these harvests were typically lower in yield than the May, July, and September harvests possibly due to lower available N.

More 4-week harvests had significant yield increases with irrigation than 8-week harvests. This could be the result of short term droughts (7 to 20 days). Sheridan et al. (1979) documented that in the Southeastern Coastal Plain that there was a 50% chance of a 20 day drought annually. A drought of this length would more likely impact a 28 day harvest interval than a 56 day harvest interval. In North Carolina, Stone et al. (2008) reported on the impact of several short term drought periods on bermudagrass production and found similar trends in hay yields.

CONCLUSIONS

We conducted a two year study to investigate the response of bermudagrass hay production to irrigation and nitrogen application rates. In both years, when irrigation was required to maintain soil water potentials greater than -30 kPa, bermudagrass hay yields significantly increased with increasing water application rate treatment. During these cutting intervals, the 4-week 100% irrigation treatments increased mean yields 612 kg ha^{-1} per cutting over the non-irrigated treatment and the 8-week 100% irrigation treatment increased mean yields 1600 kg ha^{-1} per cutting. Additionally, for the non-irrigated bermudagrass hay yields, we observed a linear relationship between hay yield and soil water potential. Non-irrigated hay yields were shown to decrease (-31 kg ha^{-1} kPa^{-1}) as soil water was depleted. Both nitrogen and irrigation were found to positively impact bermudagrass hay production. Bermudagrass can benefit from timely supplemental irrigation applications to boost yields and maintain forage quality. Bermudagrass irrigation management to maintain soil water potentials above -30 kPa can increase yields and sustain production levels in the southeastern Coastal Plain.

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