JOURNAL OF THE NACAA

ISSN 2158-9459

VOLUME 15, ISSUE 1 – JUNE, 2022

Editor: Donald A. Llewellyn

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Teff Grass Production and Tolerance to Post-emergence Herbicides

Abstract

There is limited information on the impact of labeled post-emergence herbicides on teff grass (*Eragrostis tef* [Zuccagni] Trotter) production. The purpose of this study was to evaluate the tolerance of 'Tiffany' teff grass to labeled forage post-emergence herbicides. The study was conducted in the fall of 2021 at the Henry H. Leveck Animal Research Farm at Mississippi State University. The experimental design was a randomized complete block with a split-plot arrangement with three replications. The main plots were two growth stages (leaf stages 4 and 6), and the subplots were 15 herbicide treatments (Check, Chapparal, Permit, Milestone, Crossbow, Redeem R+P, Duracor, Pasturegard, Weedmaster, Remedy, Grazon P+D, Grazon Next, Velpar). Teff grass was planted at a rate of 10 lb PLS ac-1 in 6' x 10' plots. Nitrogen was applied at 50 lb N ac-1 using urea ammonium sulfate (33-0-0-18S). Herbicide treatments were applied with a CO2 backpack sprayer calibrated to deliver 20-gal ac-1 output at 60 psi. Plots were rated for chemical injury, lodging, GCC, NDVI, and LAI at 7 and 14 DAT. Plots were harvested at 14-d post-application and samples were analyzed for CP, ADF, NDF, IVTDMD, WSC, and starch using a Foss DS2500 NIR instrument and the 2021 grass hay equation from the NIRS Forage and Feed Testing Consortium. There was a significant difference in yield between growth stages (*P*<0.0001), with leaf stage 6 yielding 56% more than leaf stage 4. Herbicide application impacted seasonal biomass (P = 0.0003) and Velpar had a 67% yield decline compared to check. Leaf stage 6 had a 33% increase in LAI and a higher GCC of 7% than leaf stage 4. Nutritional values were influenced by the growth stage with leaf stage 6 producing greater ADF and NDF and leaf stage 4 having greater CP, starch, and IVTDMD.

Abbreviations: PLS, pure live seed; PSI, pounds per square inch; N, nitrogen; DAT, days after treatment; LAI, leaf area index; GCC, green canopy cover; NDVI, normalized difference vegetative index; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTDMD, in vitro dry matter digestibility; WSC, water-soluble carbohydrates; LSD, least significant difference.

Keywords: teff grass, biomass yield, nutritive value, post-emergence herbicides.

Introduction

Teff grass (*Eragrostis tef* [Zuccagni] Trotter) also known as “teff” is an annual bunchgrass native to the Horn of Africa and cultivated for its edible seeds. In the USA, this grass has been used as a forage crop (hay) due to its high nutritional value. This grass is characterized by great palatability provided by its fine-stemmed and fine-leaved canopy with a relatively shallow root system. It can tolerate a wide range of soil types and conditions, from poorly drained soils to severe drought. The establishment of teff is recommended in a tilled, well-prepared bed and it should be kept clean until it is fully established. Teff is very competitive once it reaches a height of six to eight inches and can be harvested at the boot stage within 35 to 45 days after seeding. Miller (2011) has indicated that a single cut of teff grass can produce from 1.5 to 2.0 tons of dry matter and its high nutritive value can be compared to timothy (*Phleum pratense*). Such optimal yields are achieved in locations with soil temperatures about 65 °F at the time of establishment.

Weed control has been identified as the most limiting factor in attaining a good forage stand (Norberg and Felix, 2014). Ketema (1997) reported a 52% yield loss of teff grass without weed control. Tickes (2019) indicated that when using teff grass as a summer annual crop grown between vegetables indicated that Sharpen (Kixor, Treevix) produced as much as 70% stunting while Prowl/Dicamba (Clarity) tank mix, Pastora, and Tenacity caused 20 to 25% stunting. On the other hand, Goal, Prowl alone, 2,4-D, and dicamba (clarity) alone caused a slight injury. Mersie and Parker (2008) indicated that a seed dressing of the herbicide safener naphthalene- i.e., dicarboxylic anhydride [1,8-naphthalic anhydride (NA)] increased the tolerance of teff to chlorsulfuron by a factor of at least 3. In a two-year study, Hinds-Cook et al (2015) indicated that none of the post-emergence herbicides used in the study caused injury to teff grass when applied between the two and five tiller stages except the plots treated with flufenacet-metribuzin, which did not survive. Feldt et al. (2006) reported that at 8 weeks post-application, 2,4-D, bromoxynil, carfentrazone, dicamba, halosulfuron, and prosulfuron resulted in less than 5% injury on teff grass. Debelo (1992) indicated that the application of 2,4-D amine at the tillering stage increased teff yield by 64% (from 1065 to 1748 lb DM ac^{-1}).

Few herbicides are registered for “warm-season” grasses. However, no herbicides are currently labeled or registered for the control of broadleaf or grassy weeds in teff grass production in the southern USA. Producers are limited to the use of Glyphosate or Paraquat before planting to reduce weed competition during germination and establishment (Hinds-Cook et al., 2015). The objective of the study was to conduct a preliminary field study to evaluate the tolerance of teff to a variety of commercially available herbicides at two growth stages.

Materials and Methods

An exploratory study was conducted at the Henry H. Leveck Animal Research Farm at Mississippi State University in a Marietta fine sandy loam (Fine-loamy, siliceous, active, thermic Fluvaquenti Eutrudepts) during the fall of 2021. The experimental design was a randomized complete block in a split-plot arrangement with three replications. The main plots were two growth stages (GS) for herbicide application (4 and 6-leaf stages). Subplots were 15 post-emergence herbicide treatments (Table 1) applied to rates following the Weed Control Guidelines for Mississippi (2021). Herbicide treatments were applied with a CO_2 backpack sprayer fitted with four Teejet 8002 EVS nozzles and calibrated to deliver 20-gal ac^{-1} at 60 PSI. ‘Tiffany’ teff was planted at a rate of 10 lb

PLS ac^{-1} in 6 ft x 10 ft plots. Nitrogen was applied at a rate of 50 lb N ac^{-1} using urea ammonium sulfate (33-0-0-18S) when plants reached a height of two inches after emergence. Each plot was rated for herbicide injury at 0, 7, and 14 d after treatment application (DAT).

Each plot was harvested to a 3-inch stubble with a self-propel Cub Cadet mower equipped with a bagging system on October 22 and October 27 when 50% of the plots reached 12 to 15 inches tall for the 4 and 6-leaf stages, respectively. Forage subsamples were ground to pass through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and analyzed for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* dry matter digestibility at 48 h (IVTDMD), water-soluble carbohydrates (WSC) and starch using a Foss DS2500 Near Infra-red Reflectance Spectroscopy (NIRS) instrument (Foss North America, Eden Prairie, MN) and applying the 2021 grass hay equation developed by the NIRS Forage and Feed Testing Consortium (Berea, KY).

Physiological responses for percent injury, green canopy cover (GCC), leaf area index (LAI), and normalized difference vegetation index (NDVI) were taken at 0, 7, and 14 d after herbicide application. Visual evaluation of teff injury and lodging was done by rating the entire plot by two evaluators and then assessing a mean percentage between the scale of no injury/lodging (0%) and complete forage crop damage/lodging (100%). Percentage of GCC was obtained by taking two images at 3-ft above the canopy in the center of each plot and analyzed using the Canopeo® app (Oklahoma State University, OK) installed in MatLab (The MathWorks, Inc., MA). Leaf Area Index was measured using a line quantum sensor (LI-2000; Li-Cor, Lincoln, NE). Normalized Difference Vegetation Index was taken using a hand-held GreenSeeker® crop sensing system (Trimble, Sunnyvale, CA).

Table 1. Herbicide treatments applied to “Tiffany’ teff grass at Starkville, MS.

Herbicide Trade Name	Herbicide Chemical Name	Application Rate/ac
Control	--	--
Amine	2,4-D	2.0 pt
Chaparral	Aminopyralid + Metsulfuron	1.0 oz
Crossbow	Triclopyr + 2,4-D	1.0 qt + NIS*
Duracor	Aminopyralid + Floxyrauxifen	12.0 oz
GrazonNext	2,4-D + Aminopyralid	1.5 pt + NIS
Grazon P +D	2,4-D + Picloram	2.0 pt
Metsulfuron	Metsulfuron Methyl	0.25 oz + NIS
Milestone	Aminopyralid	4.0 oz + NIS
Pasturegard	Triclopyr + Fluroxypyr	2.0 pt + NIS
Permit	Halosulfuron	1.5 oz
Redeem R&P	Triclopyr + Clopyralid	1.5 pt
Remedy	Tricloplyr	1.0 pt + NIS
Velpar	Hexazinone	3.0 pt + NIS
Weedmaster	2,4-D + Dicamba	2.0 pt

*NIS = Non-ionic surfactant at 0.25% v/v.

Data were analyzed using harvest frequency as a repeated measure for each of the dependent variables. Data were tested and normality and homogeneity of variance were subjected to ANOVA using SAS PROC GLIMMIX procedure OF SAS and the least significant difference was used to determine treatment differences at α = 0.05.

Results

Weather

Precipitation levels were comparable to the long-term normal, but there were deficits during the active growth period of teff in this preliminary study. The mean temperature was warmer in October during the herbicide application which also provided a greater number of growing degree days.

Table 2. Weather conditions during the preliminary evaluation of teff grass tolerance to post-emergence herbicides in 2021 at Starkville, MS along with the 30-yr normal for each parameter.

	Month				
Weather Variable	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Precipitation (in)	11.6	4.4	2.7	1.2	3.8
30-yr Normal (in)	4.5	4.0	3.9	4.4	5.3
Deviation (in)	7.1	0.4	-1.2	-3.2	-1.5
Max Temp (°F)	90.6	85.2	78.5	65.8	67.7
Min Temp (°F)	71.6	64.4	56.6	38.2	45.5
Mean Temp (°F)	81.1	74.8	67.6	52.0	56.6
30-yr Normal (°F)	80.9	75.1	64.1	52.6	46.6
Deviation (°F)	0.2	-0.3	3.5	-0.6	10.0
GDD_{50}*	973	751	553	110	270
30-yr Normal	961	765	455	154	82
Deviation	12	-14	98	-44	188

*Growing degree days (GDD) base 50.

Physiological Measures

Visual Ratings: Crop Injury and Lodging

The visual ratings of teff injury resulting from the herbicide applications indicated significant differences between growth stages (P = 0.0003). Applications at the sixth leaf stage had a 15% greater injury than at the fourth leaf stage. There was a significant difference among herbicide treatments (P < 0.0001; Table 3). Metsulfuron was not significantly different from the untreated control. Herbicide injuries ranged from 3.5% (Metsulfuron) to 9.1% (Weedmaster) except the plots treated with Velpar did not survive.

Lodging was significantly affected by the growth stage ($P < 0.0001$). There was a 102% lodging increase between the fourth and sixth-leaf stage (23.6 vs. 47.5%). Herbicide treatments significantly impacted lodging ($P < 0.0001$; Table 3). Lodging was sectioned into clusters with 2,4-D and Remedy having lower lodging percentages than the control but with no significant differences among them. On the other hand, Chaparral, Duracor, and GrazonNext had higher percentages but no significant difference among them. The lodging percentage ranged from 13.7 to 43.5% except for the plots treated with Velpar (100%). There was a significant growth stage by harvest interaction ($P < 0.0001$). Most of the herbicides had a significant increase in lodging at the sixth-leaf stage except for control, metsulfuron, and Redeem R&P that experienced decreased lodging of 66, 86, and 36%, respectively.

Physiological Changes

Leaf area index (LAI) was significantly affected by the growth stage at the time of application ($P < 0.0001$). There was a 33% increase in leaf area between the fourth and sixth-leaf stages (2.9 vs. 2.2). There was a significant linear increase in LAI values at 7 and 14-d after treatment applications ($Y = 0.0439X + 2.268$, $R^2 = 0.9968$). There was a significant DAT x GS ($P<0.0001$) indicating that LAI at the 4th-leaf increased to the 7 DAT and leveled (Figure 1). On the other hand, LAI declined 7 DAT and increased by 14 DAT. This is an indication that herbicides might have minimum effect on teff growth. Leaf area index was affected by herbicide treatments ($P < 0.0001$) with values ranging from 1.4 (Velpar) to 3.1 (Chaparral; Table 3). Ten of the herbicide treatments indicated no significant difference from the control.

Table 3. Effect of herbicides on chemical injury, lodging, leaf area index (LAI), normalized difference vegetation index (NDVI), green canopy cover (GCC), seasonal biomass production of ‘Tiffany’ teff (Yield).

Herbicide	Injury (%)	Lodging (%)	LAI	NDVI	GCC (%)	Yield (lb DM ac^{-1})
Check	1.5	19.5	2.9	0.63	83.3	894
2,4-D	4.4	13.7	2.2	0.62	80.3	871
Chaparral	6.2	42.7	3.1	0.65	81.4	1160
Crossbow	5.9	29.7	2.8	0.62	79.5	1076
Duracor	7.1	42.9	2.5	0.63	75.8	932
GrazonNext	8.5	43.5	2.1	0.54	55.0	599
Grazon P+D	8.5	35.6	2.4	0.61	71.0	742
Metsulfuron	3.5	21.2	2.7	0.62	82.7	995
Milestone	8.1	38.2	2.9	0.64	80.5	1134
PastureGard	6.2	24.8	2.5	0.61	75.3	798
Permit	4.8	39.8	3.0	0.64	84.3	917
Redeem R&P	5.0	22.2	2.7	0.61	78.2	775
Remedy	4.9	19.3	2.7	0.59	71.1	959
Velpar	99.0	100.0	1.4	0.34	32.5	296
Weedmaster	9.1	40.4	2.8	0.63	71.6	952
CV, %	25.4	30.4	26.2	10.71	17.2	26
$LSD_{0.005}$	2.5	17.1	0.4	0.04	5.0	269

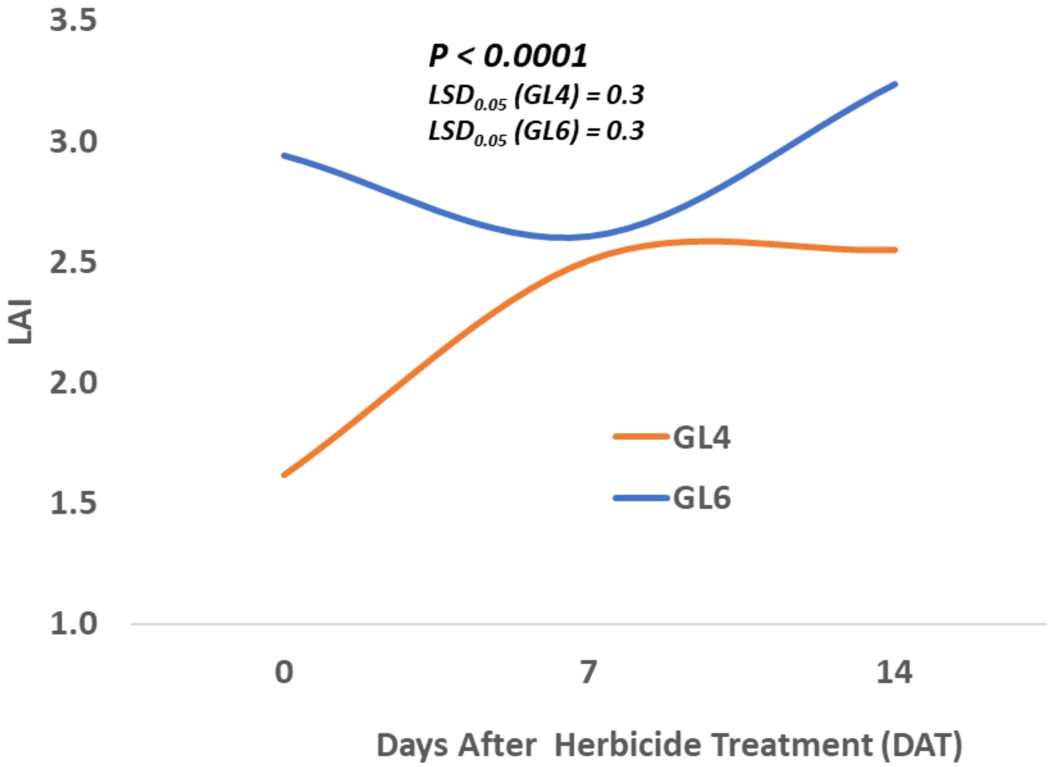

Figure 1. Influence of days after herbicide treatment at two growth stages (GL4 and GL6) on leaf area index (LAI) of ‘Tiffany’ teff at Starkville, MS in the fall of 2021.

Normalized difference vegetation index had a significant linear decline with DAT ($P < 0.0001$, $Y = -0.0084X + 0.6557$, $R^2 = 0.9919$). Herbicide application impacted NDVI values ($P < 0.0001$) ranging from 0.34 (Velpar) to 0.65 (Chaparral; Table 3). A significant GS x DAT ($P = 0.0067$) indicated a decrease in NDVI at 7 and 14 DAT for both growth stages (Figure. 2). A significant herbicide x DAT ($P < 0.0001$) indicated that NDVI values decline from 0 to 14 DAT for all herbicide treatments.

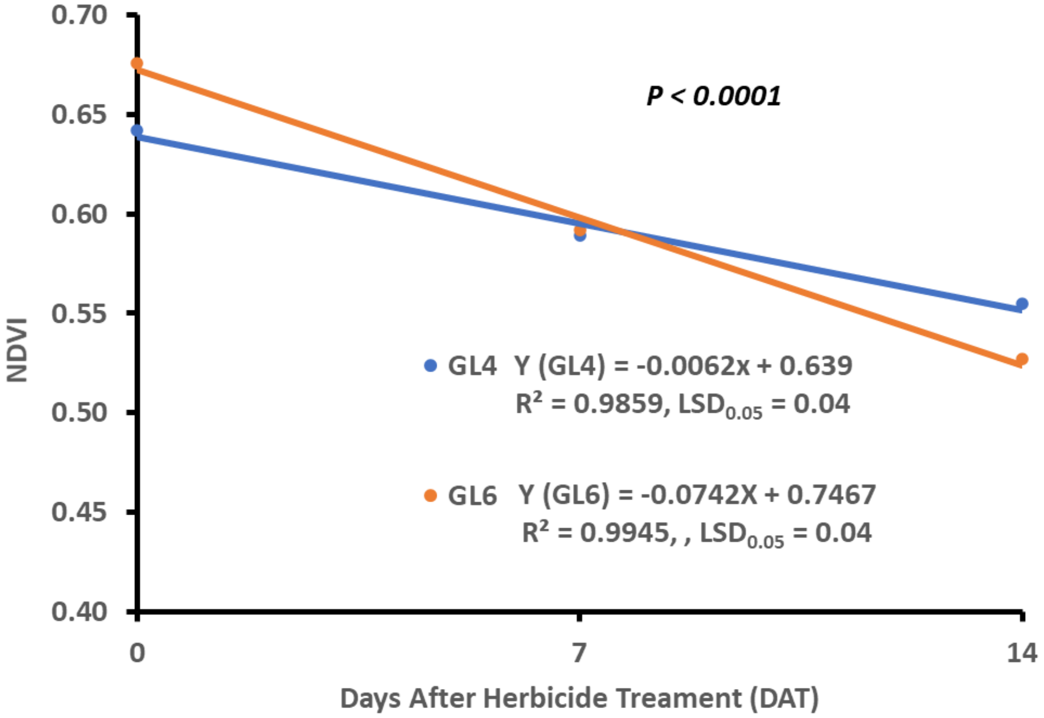

Figure 2. Influence of days after herbicide treatment at two growth stages (GL4 and GL6) on normalized difference vegetation index (NDVI) of ‘Tiffany’ teff at Starkville, MS in the fall of 2021.

Despite NDVI values declining, there was a significant GS effect in GCC ($P < 0.0001$). There was a 7% increase in GCC from GS4 to GS6. Green canopy cover significantly declined with DAT ($P < 0.0001$, $Y = -1.218X + 82.03$, $R^2 = 0.9209$). Herbicide treatment significantly impacted GCC ($P < 0.0001$) with seven herbicides not being significantly different from the control (Table 3). GrazonNext and Velpar had a 51 and 156% lower GCC compared to the control. There was a decline in GCC across DAT for herbicide treatments ($P < 0.0001$). While GCC declined from 0 to 14 DAT, 2,4-D showed an increase in GCC. A significant herbicide x GS interaction ($P < 0.0001$) showed an increase in GCC for most herbicide treatments at GS 6-leaf except for Chaparral and Milestone (Figure 3). A decrease in GCC for all herbicides was observed at (7 or 14?) DAT ($P < 0.0001$) except for 2,4-D that showed increases of 13 and 10% at 7 and 14 DAT, respectively. Overall herbicide application declined linearly for both growth stages from 0 to 14 DAT ($P < 0.0001$) with the greatest decline at GS 6-leaf.

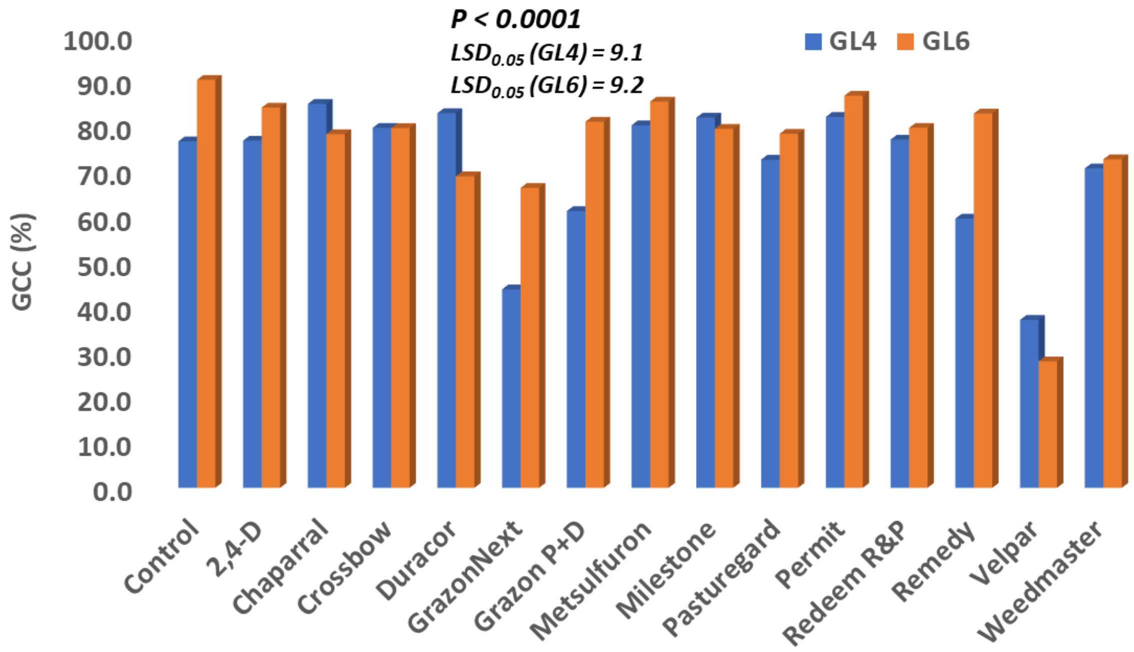

Figure 3. Influence of post-emergence herbicide application at two growth stages (GL4 and GL6) on the percentage green canopy cover (GCC) of 'Tiffany' teff at Starkville, MS in the fall of 2021.

Biomass Production

The teff grass biomass data collected during the study does not contain biomass data for the weed population since the study focused on teff tolerance to different post-emergence herbicides and not on herbicide efficacy on weed control. Across all herbicide treatments, GS6 had a 56% greater biomass production compared to GS4 ($P < 0.0001$). There were significant differences in teff biomass production between the post-emergence herbicides ($P = 0.0003$) mainly due to Velpar that produced the lowest measurable biomass (Table 3). Of the 14 herbicides used in this study, 12 of them were not significantly different from the control despite yield ranging from 741 (Grazon P+D) to 1159 lb DM ac^{-1} (Chaparral) and eight post-emergence herbicides had greater biomass production than the control. Herbicides containing 2,4-D (2,4-D amine, GrazonNext, Grazon P+D, and Pasturegard) along Velpar had lower biomass production compared to the control. These results indicate teff showed tolerance to these post-emergence herbicides and could be used to control different broadleaf weed species in teff production in the Southern USA. Further evaluation will be needed with this suite of herbicides to optimize application timings and rates in teff production.

Correlations were observed between seasonal biomass production and the physiological parameters (lodging, LAI, GCC). There was an increase in biomass when the lodging percentage was less than 40% (Figure 4). An increase in GCC and LAI are indicators of above-ground biomass. There were exponential and logarithmic increases in biomass production with increases in GCC (Figure 4) and LAI (Figure 5), respectively. These tools could be used to determine the possible impact of herbicide applications on estimated biomass production.

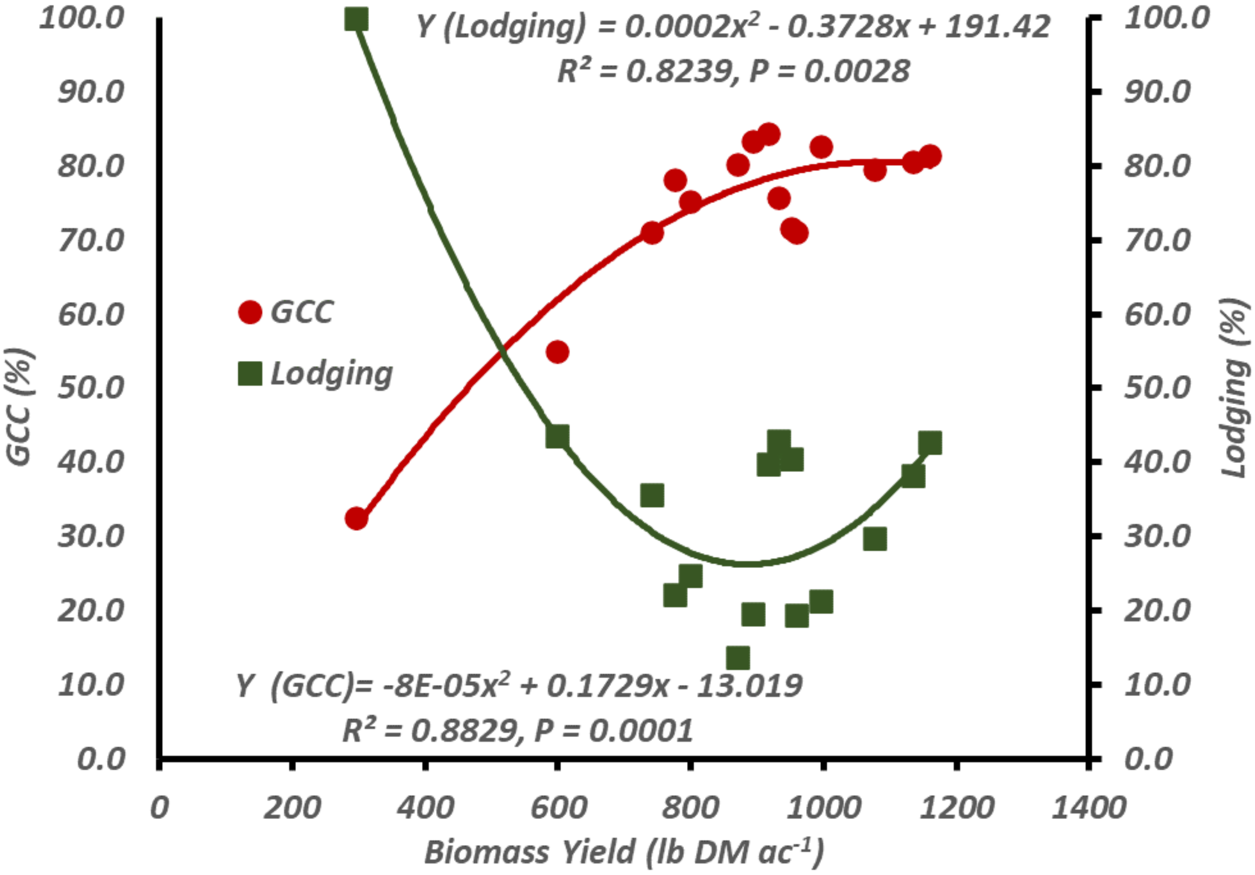

Figure 4. Relational influence of green canopy cover (GCC) and lodging percentage on biomass production of ‘Tiffany’ teff at Starkville, MS in the fall of 2021.

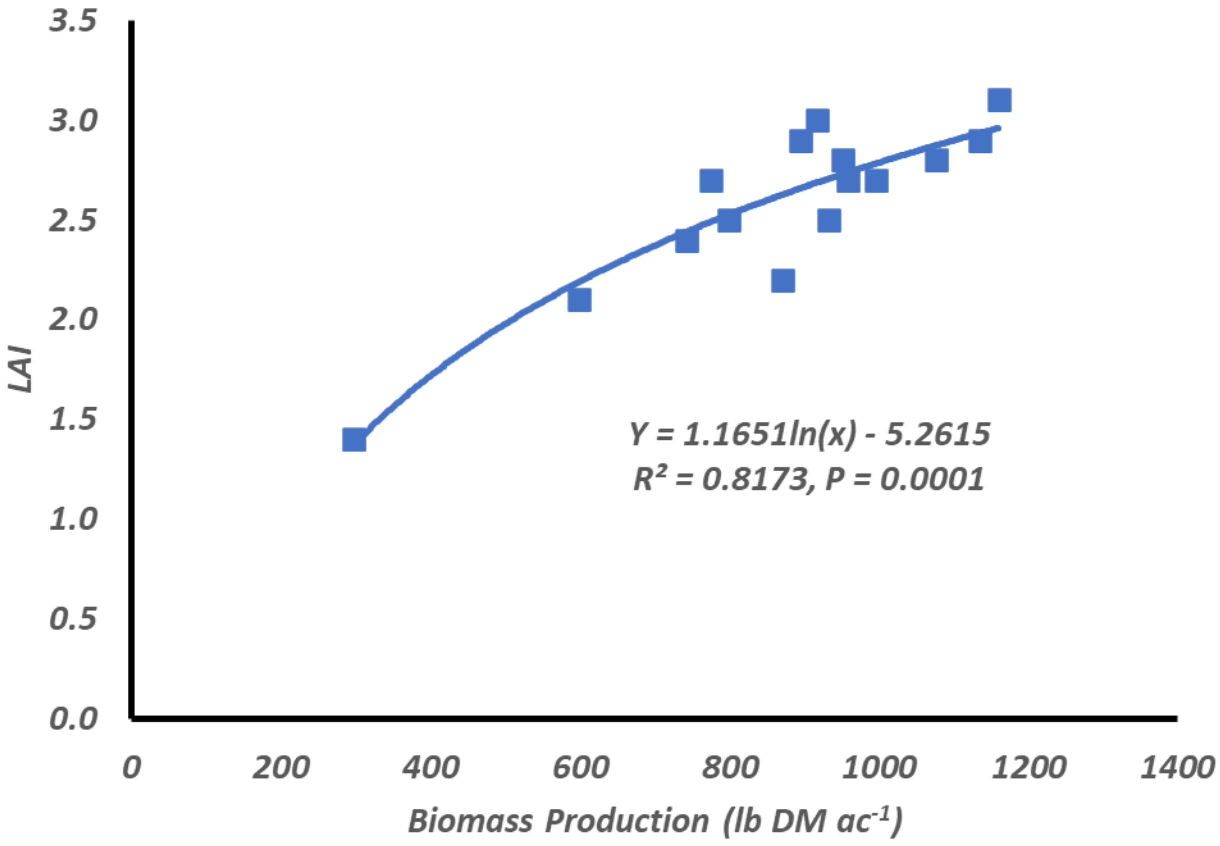

Figure 5. Relational influence of leaf area index (LAI) on biomass production of ‘Tiffany’ teff at Starkville, MS in the fall of 2021.

Nutritive Value

Nutritive values were mainly affected by the growth stage rather than herbicide treatments (Table 4). Crude protein and IVTDMD values declined at LS6 while ADF and NDF increased, respectively. There was a decrease in CP and IVTDMD values with an increase in maturity and an increase in fiber (ADF and NDF), respectively. Water-soluble carbohydrates and starch concentrations were very similar at both growth stages.

Table 4. Influence of growth stage on the nutritive value of 'Tiffany' teff at Starkville, MS in the fall of 2021.

	Nutritive Value					
Growth Stage	**CP**	**ADF**	**NDF**	**IVTDMD**	**WSC**	**Starch**
	% DM					
GL4	20.8	30.1	60.5	78.8	6.4	1.0
GL6	18.7	32.8	63.8	75.5	6.2	0.9
Diff, %	10.4	8.8	5.5	4.2	3.1	14.1
CV, %	3.2	7.2	5.0	3.8	10.9	5.8
$LSD_{0.05}$	1.0	1.0	1.3	1.2	NS	NS

CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; IVTDMD, in vitro dry matter digestibility; WSC, water-soluble carbohydrates.

Conclusions

Herbicide treatments showed adequate crop safety for teff and most of them have a pasture or hay label that would permit their use in teff except for Velpar. These preliminary results indicated that when applied at the recommended rates and these two growth stages, these could be useful practices to possibly reduce broadleaf competition on teff production in the southern USA. The growth stage did not impact herbicide injury, but it is important to indicate that the first harvest of teff generally occurs at the early boot stage (28 to 35 days after planting). There is a need to determine early growth stage applications and the impact in production to make sure that grazing or haying restrictions are met. Since there are no herbicides registered for teff production in the area, this information might be useful for future submission of the IR-4 labeling program.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgement

This publication is a contribution of the Mississippi Agricultural and Forestry Experiment Station (MAFES) and the Mississippi State University Extension Service (MSU-ES). This project was supported by the Undergraduate Research Scholars Program in the College of Agriculture and Life Sciences and funded by the Mississippi Agricultural and Forestry Experiment Station. This material is based upon work that is also supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch project under accession number 1016223, Project Number MIS-164010. Thank you to the student workers (Jon Albritton and Colton Pope) for assisting with data collection, sample processing, and analysis.

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