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Seeding Rate, Nitrogen Fertilzer, and Cutting Timing Effects on Teff Forage Yield and Nutritive Value

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SEEDING RATE, NITROGEN FERTILZER, AND CUTTING TIMING EFFECTS ON

TEFF FORAGE YIELD AND NUTRITIVE VALUE

by

Michael C. Laca

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Approved:

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ABSTRACT

SEEDING RATE, NITROGEN FERTILIZER, AND CUTING TIMING EFFECTS ON TEFF FORAGE YIELD AND NUTRITIVE VALUE

by

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Utah State University, 2021

Major Professor: Dr. J. Earl Creech
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Teff [*Eragostis tef* (Zucc.) Trotter] is a relatively new forage gaining popularity in the United States; however, information regarding agronomic production practices is lacking. This study was conducted to determine the combination of seeding rate, fertilization, and harvest timing to optimize teff dry-matter yield (DMY) and nutritive value. Four seeding rates (2, 5, 8, and 11 lb/acre), four nitrogen (N) fertilizer rates (0, 25, 50, and 100 lb/acre), and two harvest strategies [boot stage (2-cut) and full seed-head stage (1-cut; stockpiled)] were evaluated in 2010 and 2011 in Kaysville, UT and Yerington, NV. The effects of harvest (1- vs 2-cuts), seeding rate, N level, location, and year had a significant ($P < 0.05$) effect on teff dry-matter yield (DMY). Two-cut management produced 22% more DMY compared to stockpiled teff. Only at a seeding rate of 2 lb/acre was a significant ($P < 0.05$) decrease in teff DMY observed. Teff DMY responded significantly ($P < 0.05$) to each N treatment ranging from 4,457 lb/acre with no N applied to 8,394 lb/acre at 100 lb N applied. On average, the Kaysville, UT site produced 10% more DMY than Yerington, NV at 6,008 lb/acre. A 33% reduction ($P < 0.05$) in DMY was observed from 2010 to 2011. Responses to increased N fertilizer and DMY under stockpiled forage were not consistent across locations. Only at the UT site was there an associated increase in DMY ($P < 0.05$) with increased N. Under a 2-cut management, there were observed increases in DMY with increased N levels at both locations. Levels of crude protein (CP) and *in-vitro* true digestibility (IVTD48) were not affected by seeding rate, while acid detergent fiber (ADF) values remained constant regardless of location. Variation in locations and years had no effect on digestible neutral detergent fiber (dNDF48) values. Regardless of management or location, CP concentrations were greater when 100 lb N/acre was applied, while CP concentrations were similar among lower N levels. The results of this experiment suggest that under a 2-cut management system, teff economics will be optimized with a fertilizer application of 100 lb N/acre at a seeding rate of 5 lb/acre.

(30 Pages)

PUBLIC ABSTRACT

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Teff [*Eragostis tef* (Zucc.) Trotter] is a relatively new forage gaining popularity in the United States; however, information regarding agronomic production practices is lacking. This study was conducted to determine the combination of seeding rate, fertilization, and harvest timing to optimize teff dry-matter yield (DMY) and nutritive value. Four seeding rates (2, 5, 8, and 11 lb/acre), four nitrogen (N) fertilizer rates (0, 25, 50, and 100 lb/acre), and two harvest strategies [boot stage (2-cut) and full seed-head stage (1-cut; stockpiled)] were evaluated in 2010 and 2011 in Kaysville, UT and Yerington, NV. The effects of harvest (1- vs 2-cuts), seeding rate, N level, location, and year had a significant ($P < 0.05$) effect on teff dry-matter yield (DMY). Two-cut management produced 22% more DMY compared to stockpiled teff. Only at a seeding rate of 2 lb/acre was a significant ($P < 0.05$) decrease in teff DMY observed. Teff DMY responded significantly ($P < 0.05$) to each N treatment ranging from 4,457 lb/acre with no N applied to 8,394 lb/acre at 100 lb N applied. On average, the Kaysville, UT site produced 10% more DMY than Yerington, NV at 6,008 lb/acre. A 33% reduction ($P < 0.05$) in DMY was observed from 2010 to 2011. Responses to increased N fertilizer and DMY under stockpiled forage were not consistent across locations. Only at the UT site was there an associated increase in DMY ($P < 0.05$) with increased N. Under a 2-cut management, there were observed increases in DMY with increased N levels at both locations. Levels of crude protein (CP) and *in-vitro* true digestibility (IVTD48) were not affected by seeding rate, while acid detergent fiber (ADF) values remained constant regardless of location. Variation in locations and years had no effect on digestible neutral detergent fiber (dNDF48) values. Regardless of management or location, CP concentrations were greater when 100 lb N/acre was applied, while CP concentrations were similar among lower N levels. The results of this experiment suggest that under a 2-cut management system, teff economics will be optimized with a fertilizer application of 100 lb N/acre at a seeding rate of 5 lb/acre.

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CHAPTER I

SEEDING RATE, NITROGEN FERTILIZER, AND CUTING TIMING EFFECTS ON TEFF FORAGE YIELD AND NUTRITIVE VALUE

1 | INTRODUCTION

Teff [*Eragrostis tef* (Zucc.) Trotter] is an annual, warm-season grass that is new to the United States. In its native Ethiopia, teff is a major grain crop used for human consumption, but recently has drawn interest as a forage crop for cattle, horses, and other ruminants. It has forage traits similar to those of Timothy grass (Miller, 2009). Rodiek and Jones (2012) reported that alfalfa hay was preferred to wheat and teff hay by lactating dairy cows, but teff was preferred over oat hay. Conversely, Saylor et al. (2018) suggested that as a forage teff may replace alfalfa and corn silage in lactating dairy cattle rations without a loss in milk productivity. Norberg et al. (2009) reported relative feed quality (RFQ) of teff (78-108) as similar to that of full-bloom alfalfa hay.

Alfalfa is the most dominant forage crop in Utah and Nevada (USDA-NASS, 2017); however, due to the dry climate and increased summer temperatures, species available for alfalfa crop rotation are limited. Hoyt (2017) concluded that given the volatility and inconsistent demands for dairy alfalfa hay, there is need for Utah and Nevada farmers to have crop options to sustain economic viability of their operations. Teff as a forage crop offers the following positive attributes: ideal for forage rotations, excellent second crop for rotations, green manure crop, cover crop for erosion control and interseeding into a thin alfalfa stand to extend production for one season (Miller, 2009).

Girma et al. (2012) reported that reduced concentrations of N and P limited teff, DMY. Abay et al. (2009) concluded that relative to other crops, teff has a low N requirement (80 to 90 lb N/acre/year) to maintain acceptable DMY. Marsalis and Lauriault (2015) suggested a seasonal range of 50 to 120 lb N/ acre for teff. They further suggested that N applications be split with 30 to 50 lb N/acre at plantings and repeated after the first cutting.

Data describing the effects of varying seeding rates on teff DMY and nutritional quality are limited, particularly in the western U.S. Hall and Cherney (2010) reported that teff seeding rates of 9 lb/ac increased DMY by 600 lb/ac over 3 lb/ac, and concluded that for every 2 lb/ac increase in seeding rate an associated increase of 200 lb/ac DMY could be expected. Reda et al. (2014) reported that increased seeding rates led to increased lodging along with lower harvest grain index in teff (Reda et al., 2014). In winter wheat, ShouChen et al. (2018) reported that plant height, tiller number, and root biomass increased while leaf area decreased as seeding rates increased. Yield response of teff is also influenced by soil type and residual soil N values (Roseberg et al. 2018).

To date, a limited number of studies have focused on the effects of N fertilizer (Roseberg et al., 2005; Hancock and Durham, 2009; Hunter et al., 2009; Girma et al., 2012; Lauriault et al., 2013) or seeding rate (Hall and Cherney, 2010), individually, on teff DMY; however, data is lacking that describes the interactions between N fertilizer, seeding rate, and 1- vs 2-cut harvest system (boot-stage vs. full seed-head stage) and their effects on teff stand, DMY, and nutritive value. The objectives of this study were to determine the influence of seeding rate, N fertilizer rate, and harvest strategy, on teff DMY and nutritive value.

2 | EXPERIMENTAL DETAILS

Experiments were conducted in adjacent fields in 2010 and 2011 near Kaysville, UT and Yerington, NV. The Utah location was at the Utah Agricultural Experiment Station Kaysville Research Farm (41˚2.118'N 111˚56.316'E; elevation 4357 ft), with an average annual rainfall and temperature of 20 in and 51.9˚F, respectively. The Nevada location was on a private farm (38˚59.5726'N 119˚9.7887'E; elevation 4390 ft), with an average annual rainfall and temperature of 5 in and 53˚F, respectively. Information related to soils, fertility, previous crop, and dates of planting and harvest for each location and year are presented in Tables 1 and 2. Climate data for Kaysville was collected from a weather station within 7 miles of the study location and within 2 miles of the Yerington location (Western Regional Climate Center CLIMOD database, 2010 and 2011) (Table 3).

All sites were cultivated to a 6 in depth prior to planting. Plots were seeded using a cone seeder drill (HEGE Maschinen GmbH, Lichtenstein, Germany) with seven double disk openers spaced 6 in apart. Plots were arranged in a randomized complete block split-split plot design with four replications (blocks). The main plots were harvest strategies [boot stage (2-cut) and full seed-head stage (1-cut; stockpiled)] applied as strips randomized across each block. The subplots were randomized within harvest strategy and consisted of four N fertilizer rates (0, 25, 50, and 100 lb/acre). Urea (46-0-0) fertilizer was applied to each plot at rates to achieve the different N treatments after seeding using a Gandy fertilizer drop spreader and immediately incorporated into the soil with 0.8 in of sprinkler irrigation. Thereafter, teff was irrigated at a rate of approximately 2 in per week throughout the growing season to ensure that soil moisture was not limiting to plant growth. The sub-sub plots were randomized within fertilizer rates and consisted of four seeding rates (2, 5, 8, and 11 lb PLS/ac). Individual subplots measured 3.5 ft wide by 25 ft long.

Whole plots were harvested using a self -propelled forage harvester (HEGE 212, Wintersteiger AG, Ried im Innkreis, Austria) to a stubble height of 4 in. Under 2-cut management, forage harvest was initiated when less than 1% of panicles had emerged from the flag leaf with the 2nd harvest occurring at the same growth stage. The 1-cut management was harvested when developing teff caryopsis were in the soft dough stage, which corresponds to greater than 90% fully emerged inflorescences. Harvest dates are reported in Table 1.

At each harvest, a 1 lb subsample was obtained, weighed, and dried at a temperature of 140^{o}F in a forced-air oven to a constant weight and used to estimate DMY. Dried samples were ground in a Wiley mill and subsequently in a Cyclone mill to pass through a 0.04 in screen and scanned for forage nutritive value analysis with a Near-Infrared Reflectance Spectrophotometer (NIRS; Model 6500 FOSS NIRSystems, Silver Springs, MD), using equations developed by the NIRS Consortium for other grasses (Lauriault et al., 2013).

The effects of harvest timing, N fertilizer, and seeding rate on teff DMY and nutritive value was assessed using the General Linear Model of SAS (SAS Enterprise 9.4, 2016) and mean separation was done using Duncan's Multiple Range Test at the P = 0.05

level of significance. Statistical package PROC GLM with a random statement was used with harvest timing, N fertilizer rate, and seeding rate analyzed as fixed effects with replications as random.

3 | RESULTS AND DISCUSSION

3.1 | Dry-matter yield (DMY)

Regardless of the previous crop, at 0 lb N/ac, teff DMY were similar regardless of harvests and locations. Under the 1-cut harvest in Nevada, as N fertilizer rates increased, there were no significant associated increases in teff DMY observed (Table 4). However, under the same harvest at Utah, there was a 58% increase ($P < 0.05$) in teff DMY as fertilizer levels went from 0 to 100 lb N/ac (Table 4). The lack of any association between increased N levels and teff DMY at Nevada is of interest. A possible explanation might be that the Nevada location had been in alfalfa both years prior to seeding teff, resulting in residual soil nitrate (N) being 70% greater at Nevada than the Utah location (Table 2). This would suggest that having enough residual N in the soil to support growth was adequate for a 1-cut harvest at nitrate levels of 13 to 14 mg N/kg dry weight compared to 4 mg N/kg at Utah. These differences in background nitrate levels (Table 2) likely contributed to the significant ($P < 0.01$) interaction observed between harvest and location. Under a 2-cut harvest, there was a 26% and 70% increase in teff DMY when fertilizer rates increased from 0 to 100 lb N/ac, at Nevada and Utah, respectively (Table 4).

Hunter et al. (2009) found similar results in New York when teff forage yield increased with added N except where land had been fertilized with manure or rotated with legumes on preceding years. Roseberg et al. (2005) found that fertilization above 50 to 60 lb N/ac did not often improve teff DMY. This is similar to what we see in the Nevada 1-cut harvest.

The effect of seeding rate on teff DMY was less pronounced. Only at a seeding rate of 2 lb/ac was teff DMY reduced ($P < 0.05$) compared to seeding rates of 5, 8, and 11 lb/ac (Figure 1). As seeding rates increased from 5, 8, and 11 lb/ac, there was no associated increase in teff DMY, suggesting that planting at 5 lb/ac will, economically, achieve optimal DMY. Hall and Cherney (2010) reported a 600 lb increase in teff DMY when seeding rates increased from 3 lb/ac to 9 lb/ac. Roseberg et al (2005) concluded that reducing teff seeding rate of 8-9 lb/ac to 5 to 6 lb/ac would not likely reduce teff DMY.

3.2 | Teff nutritional quality

Crude protein, represented by total nitrogen x 6.25, are major building blocks that are required by livestock on a daily basis for maintenance, lactation, growth, and reproduction. There was positive significant ($P < 0.0001$) correlation between fertilizer rate and CP at Utah ($r=0.44$) and Nevada ($r=0.18$) observed, suggesting that as fertilizer rates increased so did CP percentages (Table 7). However, in general, increased ($P < 0.05$) CP percentages were only observed at the 100 lb/Ac fertilizer rate (Tables 5 and 6). Regardless of harvest, similar trends were observed at Utah and Nevada locations for CP percentages (Table 5). Crude protein percentages were 13.7 and 13.8 at Utah and Nevada, respectively, under the 2-cut (harvest 1) management. At Utah, 2-cut (harvest 2) CP percentage was greater ($P < 0.05$) at 10.5 compared to 8.1 observed in stockpiled forage. Conversely, at Nevada, the stockpiled forage was greater ($P < 0.05$) than the 2-cut (harvest 2) management. At both locations, the largest increase in CP percentages were observed between the 50 lb/ac and the 100lb/ac fertilizer rates. Regardless of harvest management, at Utah that increase ranged from 36 to 38% compared to Nevada that ranged from 12 to 22% (Tables 5 and 6). From this study, economically there is little if any advantage when you increase the fertilizer rate from 0 to 50 lb/ac.

Acid detergent fiber (ADF), defined as the least digestible plant components, including cellulose and lignin is often used as a predictor of voluntary intake by livestock. Values of ADF are inversely related to digestibility, so teff with low ADF percentages are usually higher in energy. Increased fertilizer rate had a small negative ($r=^{-}0.15$; $P < 0.005$) association with ADF. Jensen et al. (2014) reported negative correlations between ADF and CP and digestibility components. With the exception of ADF concentrations at Utah under the 2-cut management, all ADF concentrations remained similar regardless of the fertilizer rate (Tables 5 and 6). However, differences in ADF percentages were affected at the different harvest managements (Tables 5 and 6). In general, as teff matured, ADF percentages were greater ($P < 0.05$) in the stockpiled and 2-cut (harvest 2) management than 2-cut (harvest 1). From this study, any increases in fertilizer rates did not decrease ADF percentages thereby increasing teff forage quality.

A plant's structural components are a source of neutral detergent fiber (aNDF), specifically cell walls. Digestible neutral detergent fiber (dNDF48) is defined as that portion of NDF that is digestible. Typically, forage with low aNDF and high dNDF48 increases animal intake. At both locations, dNDF48 percentages did not increase with increased fertilizer rate, as supported by a non-significant correlation ($P < 0.30$; $P < 0.16$) between dNDF48 and fertilizer rate at Utah and Nevada, respectively. Percentages of dNDF48 were affected by different harvest managements (Tables 5 and 6). At Utah under a 2-cut (harvest 2) management, dNDF48 percentages decreased relative to those observed under the stockpiled and 2-cut (harvest 1) management.

Digestibility is defined as the extent to which a feedstuff is absorbed in the animal body as it passes through the digestive track. Greater digestibility results in better quality forage. Increasing fertilizer rates had no effect on teff IVTD48 at Nevada and at Utah, increases ($P < 0.05$) in teff IVTD48 were only observed at the 100 lb/ac fertilizer rate under the 2-cut management where the forage would have been less mature at harvest (Tables 5 and 6). However, differences ($P < 0.05$) in teff IVTD between harvest management were observed (Table 5). As expected, in nearly all cases the 2-cut (harvest 1) had greater ($P < 0.05$) teff IVTD48 percentages than did the other harvests, resulting from teff forage being harvested prior to the boot stage (Tables 5 and 6). This likely contributed to the significant positive correlation ($r=0.23$; $P < 0.0001$) between IVTD48 and fertilizer rate. Other interesting correlations ($P < 0.0001$) between IVTD48 and CP ($r = 0.65$), ADF ($r=^{-}0.79$), and dNDF48 ($r=0.77$) were observed. Based on a 2 to 4 % increase in teff IVTD48 by increasing the fertilizer rate from 50lb/ac to 100lb/ac economically my not be a sustainable means to increase teff digestibility. Similar results were seen in Hunter et al. (2009) research where N inputs did not affect forage digestibility.

Seeding rate had no effect on CP percentages at either location. Trends in ADF were inconsistent as seeding rate increased. At Utah ADF percentages were greater ($P <0.05$) at a seeding of 11 lb/ac. Conversely, at Nevada the 2 lb/ac seeding rate exhibited the greatest ADF percentages. Except for Utah seeded at 2 lb/ac where dNDF48 percentages were less ($P < 0.05$) all other seeding rates had no effect on dNDF48. At a seeding rate of 11 lb/ac at Utah, IVTD48 was less ($P < 0.05$); however, seeding rate had little to no effect on IVTD48 at both locations. The lack of observed trends between seeding rate and nutritional characteristics is supported by significant, but weak correlations between seeding rate and dNDF48 ($r=0.11$; $P <0.04$) and IVTD48 ($r=-0.11$; $P < 0.03$).

4 | CONCLUSIONS

The results of this study suggest that two-cut teff management can produce higher DMY (22%) than stockpiled teff. Only at a seeding rate of 2 lb/acre was a significant ($P < 0.05$) decrease in teff DMY observed. Teff DMY responded significantly ($P <0.05$) to each N treatment ranging from 4,457 lb/acre with no N applied to 8,394 lb/acre at 100 lb applied. On average, the Kaysville, UT site produced 10% more DMY than Yerington, NV at 6,008 lb/acre. A 33% reduction ($P < 0.05$) in DMY was observed from 2010 to 2011. Responses to increased N fertilizer and DMY under stockpiled forage were not consistent across locations. Only at the UT site was there an associated increase in DMY ($P < 0.05$) with increased N. Under a 2-cut management, there were observed increases in DMY with increased N levels at both locations. Levels of crude protein (CP) and *in-vitro* true digestibility (IVTD48) were not affected by seeding rate, while acid detergent fiber (ADF) values remained constant regardless of location. Variation in locations and years had no effect on digestible neutral detergent fiber (dNDF48) values. Regardless of management or location, CP concentrations were greater when 100 lb N/acre was applied, while CP concentrations were similar among lower N levels. The results of this experiment suggest that under a 2-cut management system, teff economics will be optimized with a fertilizer application of 100 lb N/acre at a seeding rate of 5 lb/acre.

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TABLE 1 Soil series, cropping history and planting and harvest dates of trials conducted in 2010 and 2011 in Utah and Nevada**.**

Location	**Year**	**Soil Series**	**Prior Crop**	**Planting Date**	**Harvest Dates**		
					2-Cut (Harvest 1)	2-Cut (Harvest 2)	1-Cut (Stockpiled)
Utah	2010	Kidman fine sandy loam	Triticale	Jun 11	7/30	9/16	8/14
Nevada	2010	Tocan sandy loam	Alfalfa	Jun 9	8/11	9/27	8/24
Utah	2011	Kidman fine sandy loam	Triticale	Jun 14	8/9	9/29	8/29
Nevada	2011	Tocan sandy loam	Alfalfa	Jun 9	Aug 8	Sep 26	Aug 30

TABLE 2 Initial soil fertility status at planting for trials conducted in 2010 and 2011 in Utah and Nevada.

Location	Year	pH	Phosphorus-P	Potassium-K	Nitrate-Nitrogen	OM
			-------------------------------Mg/kg---------------------------			%
Utah	2010	7.4	24.0	158	4.3	1.9
Utah	2011	7.8	15.0	170	3.5	2.1
Nevada	2010	6.9	11.5	432	14.1	1.5
Nevada	2011	7.1	11.1	474	13.4	1.7

TABLE 3 Monthly precipitation and temperature for study sites in Yerington, NV and Kaysville, UT where trials were conducted in 2010 and 2011.

		Total monthly precip.					Avg. monthly temp.				
Site	**Year**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**
		----------------in----------------					-------------------˚F------------------				
Utah	2010	1.91	.27	.81	.35	3.2	63	75	70	63	53
Nevada	2010	0	0	0	0	1.61	69	77	72	67	54
Utah	2011	1.7	.62	2.51	1.47	2.51	61	72	74	65	50
Nevada	2011	-†	-†	-†	.10	-†	67	75	75	70	56

†Data missing for these months

TABLE 4 Effect of N application rate on total dry-matter (DM) yield of teff grown in 1-cut (stockpiled) and 2-cut harvest systems in Utah and Nevada.

		N application rate				
Site	**Management**	**0**	**25**	**50**	**100**	***p* value**
		--------------(lb acre^{-1} harv^{-1})-----------				
Nevada	1-cut (stockpiled)	5153 a†	5759 a	5540 a	5562 a	0.3929
Utah	1-cut (stockpiled)	3583 a	4884 b	5614 b	8637 c	<0.0001
Nevada	2-cut	5591 a	6321 b	6721 b	7597 c	<0.0006
Utah	2-cut	3571 a	6566 b	8846 c	11707 d	<0.0001

† Yield values within a row followed by the same letter are not significantly different at $P = 0.05$.

TABLE 5 Effect of N application on crude protein (CP), acide detergent fiber (ADF), digestible neutral detergent fiber (dNDF-48), and in vitro true digestibility (IVTD) at the Utah site, 2010-2011.

Quality	Management	N application rate (lb/acre/harvest)												
		0			25			50			100			*p* value
		---------------------- % ----------------------												
CP	1-stockpiled	5.7	A*	b**	5.5	B	b	5.2	B	b	8.1	C	a	0.0012
	2-cut (Harvest-1)	7.7	B	c	8.0	A	bc	8.6	A	b	13.7	A	a	<0.0001
	2-cut (Harvest-2)	5.4	B	b	5.5	A	b	6.5	B	b	10.5	B	a	<0.0001
ADF	1-stockpiled	38.0	B	a	37.3	A	a	37.3	A	a	37.6	A	a	0.1812
	2-cut (Harvest-1)	35.0	A	a	35.2	B	a	35.5	B	a	34.0	B	b	0.0032
	2-cut (Harvest-2)	38.2	A	a	38.0	A	a	38.0	A	a	36.9	A	b	0.1149
dNDF48	1-stockpiled	35.2	A	a	36.1	A	a	35.6	A	a	36.0	A	a	0.6369
	2-cut (Harvest-1)	36.2	A	a	36.9	A	a	36.6	A	a	38.0	A	a	0.2882
	2-cut (Harvest-2)	33.9	A	a	34.0	B	a	32.9	B	a	33.5	B	a	0.6765
IVTD48	1-stockpiled	71.6	A	a	72.0	AB	a	71.6	AB	a	72.3	B	a	0.408
	2-cut (Harvest-1)	73.4	A	b	73.5	A	b	73.5	A	b	76.7	A	a	<0.0001
	2-cut (Harvest-2)	71.1	A	b	71.0	B	b	70.7	B	b	72.5	B	a	0.0342

* Quality values within a column followed by the same upper case letter are not significantly different at $P = 0.05$.

** Quality values within a row followed by the same lower case letter are not significantly different at $P = 0.05$.

TABLE 6 Effect of N application on crude protein (CP), acide detergent fiber (ADF), digestible neutral detergent fiber (dNDF-48), and in vitro true digestibility (IVTD) at the Nevada site, 2010-2011.

Quality	Management	N application rate (lb/acre/harvest)												
		0			25			50			100			*p* value
		-- % --												
CP	1-stockpiled	9.6	B*	b**	9.1	B	b	9.4	B	b	12.0	B	a	0.0065
	2-cut (Harvest-1)	12.1	A	a	12.7	A	a	12.2	A	a	13.8	A	a	0.0725
	2-cut (Harvest-2)	5.9	C	b	6.1	C	b	6.5	C	ab	7.5	C	a	0.1435
ADF	1-stockpiled	37.0	A	a	37.3	AB	a	38.0	A	a	36.7	AB	a	0.5716
	2-cut (Harvest-1)	35.3	B	a	34.29	B	a	36.0	A	a	35.3	B	a	0.2342
	2-cut (Harvest-2)	38.2	A	a	38.4	A	a	38.2	A	a	39.0	A	a	0.5197
dNDF48	1-stockpiled	34.8	B	a	35.1	AB	a	33.3	B	a	34.6	AB	a	0.1636
	2-cut (Harvest-1)	37.7	A	a	37.1	A	a	36.6	A	a	36.4	A	a	0.3628
	2-cut (Harvest-2)	33.8	B	a	33.1	B	a	32.8	B	a	33.1	B	a	0.7989
IVTD48	1-stockpiled	72.3	B	a	71.0	B	a	70.0	B	a	72.5	B	a	0.1169
	2-cut (Harvest-1)	6.6	A	a	76.2	A	a	75.3	A	a	76.0	A	a	0.3462
	2-cut (Harvest-2)	72.1	B	a	71.3	B	a	72.1	B	a	71.0	B	a	0.4882

* Quality values within a column followed by the same upper case letter are not significantly different at $P = 0.05$.
** Quality values within a row followed by the same lower case letter are not significantly different at $P = 0.05$.

TABLE 7 The significance of *F* values for fixed sources of variation at the Utah and Nevada study sites in 2010 and 2011.

Source	df	DMY	CP	ADF	dNDF48	IVTD48
		----------------------- Pr > F ---------------------				
HARV	1	<.0001	<0.001	<.0001	<.0001	<.0001
RATE	3	0.001	0.8602	0.0401	0.0219	0.7405
HARV*RATE	3	0.665	0.6511	0.4995	0.7158	0.4861
FERT	3	<.0001	<0.0001	0.026	0.3902	0.0004
HARV*FERT	3	0.0028	0.0276	0.7861	0.7647	0.7719
RATE*FERT	9	0.9836	0.4894	0.2923	0.3756	0.0774
HARV*RATE*FERT	9	0.9110	0.8484	0.2962	0.4362	0.3631
LOC	1	<.0001	<0.0001	0.7337	0.0291	0.0274
HARV*LOC	1	<.0001	0.0613	0.0581	0.033	0.0004
RATE*LOC	3	0.9470	0.6286	0.0527	0.4563	0.4018
HARV*RATE*LOC	3	0.7583	0.448	0.5083	0.5659	0.8373
FERT*LOC	3	<.0001	<0.0001	0.3452	0.0737	0.0474
HARV*FERT*LOC	3	<.0001	<0.0001	0.0683	0.2483	0.0154
RATE*FERT*LOC	9	0.9362	0.9249	0.7319	0.6559	0.6253
HARV*RATE*FERT*LOC	9	0.9952	0.4555	0.2537	0.8664	0.3423
YR	1	<.0001	<.0001	<.0001	0.1496	<.001
HARV*YR	1	0.06	0.5108	<.0001	0.0394	0.0027
RATE*YR	3	0.2672	0.0909	0.9256	0.2474	0.9912
HARV*RATE*YR	3	0.8162	0.5013	0.9767	0.9497	0.9357
FERT*YR	3	<.0001	<.0001	0.0003	0.0551	0.0162
HARV*FERT*YR	3	0.5219	0.9086	0.5101	0.6928	0.4447
RATE*FERT*YR	9	0.4423	0.7639	0.8654	0.289	0.7846
HARV*RATE*FERT*YR	9	0.9926	0.4805	0.7592	0.0278	0.6605
LOC*YR	1	0.0742	<.0001	<.0001	<.0001	0.5621
HARV*LOC*YR	1	<.0001	<.0001	<.0001	0.892	<.0001
RATE*LOC*YR	3	0.3490	0.7544	0.263	0.1351	0.2613
HARV*RATE*LOC*YR	3	0.8175	0.9609	0.9899	0.3372	0.5638
FERT*LOC*YR	3	<.0001	0.1525	0.0656	0.4593	0.7373
HARV*FERT*LOC*YR	3	0.3376	0.1904	0.5518	0.378	0.4027
RATE*FERT*LOC*YR	9	0.8791	0.2925	0.9464	0.985	0.9273
HAR*RATE*FERT*LOC*YR	9	0.9768	0.1312	0.9721	0.3028	0.8137

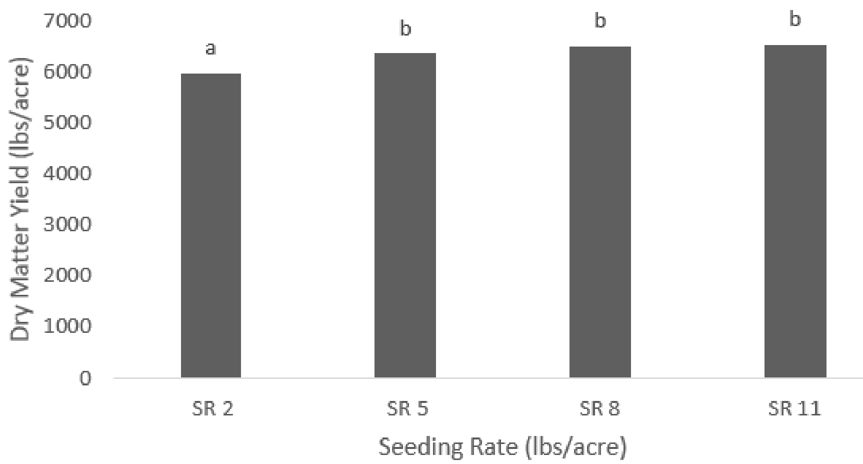

FIGURE 1 Teff forage DMY as influenced by seeding rate across all locations and years. Means followed by the same letters are not significantly different at P = 0.05.