Yield and Quality of Teff Forage as a Function of Varying Rates of Applied Irrigation and Nitrogen

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Introduction

(Background information is adapted from Stallknecht [1997] and Ketema [1997])

Background

Teff (*Eragrostis tef* [Zucc.], *Poaceae)* is a C4 annual tropical grass. It has a large crown, many tillers, and a shallow diverse root system. Teff is traditionally harvested for grain in Ethiopia, where it was first domesticated between 4000–1000 BC. Teff flour is preferred in the production of enjera, a major food staple in Ethiopia. Teff flour is also eaten as porridge or used as an ingredient of home-brewed alcoholic drinks. Teff is grown on a limited basis for livestock forage in other parts of Africa, India, Australia and South America. In the United States, small acreages of teff are grown for grain production (Caldwell, ID) and sold to Ethiopian restaurants throughout the United States, or used as a late-planted livestock forage (Larson, MN). The nutritional value of teff grain is similar to traditional cereals. Teff is considered to have an excellent amino acid composition, lysine levels higher than wheat or barley, and slightly less than rice or oats. Teff is also higher in several minerals, particularly iron. Teff contains very little gluten and is being evaluated in gluten-free food systems. Approximately 1 million Americans suffer from Celiac disease (gluten sensitivity) and teff may provide a niche for meeting these dietary requirements.

Teff germplasm is characterized by a wide variation of morphological and agronomic traits. Typical maturity for grain varies from 93 to 130 days. Grain color ranges from pale white to ivory white, very light tan to deep brown to reddish-brown purple. Teff seed is very small with l000-seed weight averaging 0.3–0.4 g, similar to timothy. Teff is adapted to environments ranging from drought-stressed to water-logged soil conditions. In its native habitat, maximum production occurs at elevations of 5,900 – 6,900 ft, growing season rainfall of 17–22 inches, with a temperature range of 50–85°F. Teff is day length sensitive and flowers best at 12 hours of daylight. Tests at higher latitudes showed reduced flowering and seed formation for both short day (8

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Acknowledgements:

- This research was partially supported by Agricultural Research Foundation grant No. ARF8056.
- The authors also thank Hankins Seed Co., Bonanza, OR, and Van Leeuwen Seed Co., Halsey, OR for seed donated in 2005.

hours of light) and long day (16 hours of light) conditions. However, genetic diversity is wide for this species and grain production using selected landraces has been successful in some cases at temperate latitudes.

Several improved varieties have been selected for grain production and released in Ethiopia, South Africa, and the United States (Wayne Carlson, pers. comm., 2006). While the primary emphasis has been on grain qualities, some consideration of forage use has also occurred. Much of the teff seed available in commerce are common landraces, not released varieties, and thus have varying degrees of uniformity and unknown performance.

Past Work at Klamath Falls

In 2003 and 2004 teff was grown on a quasi-commercial scale at KES using the best available information and expertise of the station staff. We planted seed of an unnamed cultivar whose seed had been increased for grain production by James Van Leeuwen in the Willamette Valley. Its designation is VA-T1-Brown. This seed was not of a released variety, but had reportedly come directly from Ethiopia. We have continued to use it due to its favorable performance compared to limited plantings we made using seed samples from the USDA Germplasm Repository in Pullman, Washington. Future studies should include a more rigorous comparison of released varieties and unreleased landraces of common types to determine characteristics and performance of the various types.

Due to the reports of teff's frost intolerance, we delayed planting until early June each year. At KES the soils are sandy loams containing about 1.5 percent organic matter. The fields where teff was planted have a pH of 6.5-7.0. We applied 60 lb/acre nitrogen (N) at planting and another 60 lb/acre N after first cutting using 15-15-15 fertilizer. From these nonreplicated bulk plantings we made the following observations:

1. With a fine, firm seed bed, seedlings emerged in about 3 days both years.
2. Stands were poor when seed was planted deeper than 0.5 inch. Seed left on the surface did germinate given sufficient continuous surface moisture. A safe compromise seems to be planting seed around 0.125-0.25 inch deep.
3. Thick vigorous stands were achieved by seeding at 8-9 lb/acre. The plant tillered extensively. We suspected we could have reduced the seeding rate to 5-6 lb/acre without sacrificing yield.
4. Early growth was vigorous when daytime maximum air temperatures were consistently in the 80-90° F range after emergence in 2003, but the teff grew very slowly when daytime maximum air temperatures remained in the 60-75° F range after emergence in 2004.
5. Under good conditions, it was about 50-55 days from planting to first cutting, and another 40-45 days from first cutting to second cutting.
6. After cutting, regrowth was vigorous if cutting height was kept at 3-4 inches (leaving more leaf area for photosynthesis). If teff was cut at a 1- to 2-inch height it regrew much slower.
7. The root system was not strong and plants were easily pulled from the ground if the swather glide plate was dragging on the ground too much. We suspect this would also be true if

animals were allowed to graze the teff, especially before first cutting.
8. Crude protein ranged from 12 to 17 percent depending on the cutting time.
9. Teff seems to accumulate fairly high levels of potassium (K), which may be of concern in some feed rations. We commonly saw K concentrations around 3 percent by dry weight.
10. Teff was more prone to lodge if cutting was delayed until after seedhead emergence.
11. Teff took about a day longer than orchardgrass to cure sufficiently in the field for baling.
12. Informal taste tests suggested horses considered teff to be very palatable compared to orchardgrass. Informal testing with cattle has been less conclusive.
13. Mature teff was 100 percent killed when temperatures dipped slightly below 32^{o}F.

Objectives

1. We sought to evaluate teff's yield and forage quality response to varying levels of N fertilizer and irrigation at three locations representing different climate regimes and possible production areas in Oregon.
2. We also wanted to make additional observations on seeding rate and other agronomic factors where possible at least at one location.

Procedures

Klamath Falls

Approximately 2.6 acres of teff was planted on a Poe fine sandy loam soil containing about 1.5 percent organic matter on June 6 using a John Deere grain drill with a grass seed attachment. The previous crop was a uniform area of bulk teff for forage in 2004. A portion of the field was used for the irrigation rate by N rate study. Half of that area was seeded at a 3 lb/acre rate, and the other half was seeded at 6 lb/acre. These two areas were separated by an irrigation line that provided a "line source" for variable irrigation rates during the season. The response to available moisture was evaluated by harvesting small plots laid out at various distances from the line source. The plots closer to the line source received the higher irrigation rates (Table 1). Nitrogen rates were applied at planting and after first cutting (Table 2). Due to an error, the N rate by irrigation study at Klamath Falls did not include a true N_0 (no nitrogen) treatment. In another portion of the field, an area used for a separate N rate study did include a true N_0 treatment. This area was grown under uniform irrigation. In all cases, the N rates were applied in a randomized complete block design with four replications. An herbicide tank mix of 2,4-D amine at 0.54 lb a.i./acre plus dicamba at 0.19 lb a.i./acre was applied on July 7 to control broadleaf weeds.

The first teff cutting was made on August 8 and second cutting was made on September 13. The first cutting occurred perhaps a week later than ideal in order to demonstrate the teff trial at a public field day, resulting in seed heads that were almost completely emerged. At the time of second cutting, seedheads were just beginning to emerge. Forage fresh weights were measured immediately in the field and samples were collected from each plot for drying to correct yields to a dry weight basis as well as to perform forage quality analysis. After drying and weighing, samples were ground to 2-mm-sieve size in a Wiley Mill (Arthur H. Thomas Co.) and to 1-mm-sieve size in a Udy Mill

(Udy Corp.) before being analyzed in a near infrared spectrophotometer (NIRS) (NIRSystems) to determine forage quality. Quality testing at KES is accomplished using the NIRS and equations developed by the NIRS Consortium, Madison, Wisconsin. Calculated forage quality parameters included crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), relative feed value (RFV) and relative forage quality (RFQ). We used NIRS equations developed for other grasses due to the limited data available for teff.

Medford

Approximately 0.5 acre of teff was planted on May 13 on a Central Point sandy loam containing about 5 percent organic matter using a John Deere grain drill with a grass seed attachment. The previous crop had been sugar beets for seed. Due to the crude adjustment of seeding rate on that machine, the first pass seeded only about 1.2 lb/acre. After making a slight adjustment, the second run seeded about 9.2 lb/acre for a total seeding rate of 10.4 lb/acre. The irrigation line source was set up down the middle of the plot area to provide the various irrigation rates (Table 1). Nitrogen rates were laid out perpendicular to the irrigation line across the width of the field. N rate treatments were applied in a randomized complete block design with four replications (Table 2). The first cutting was made on July 22 and second cutting was made on September 3. In both cases the plots were cut when seedheads were just beginning to emerge. Samples were dried from each plot for moisture correction and quality analysis was done as at the other sites.

To control broadleaf weeds that emerged with the teff, a tank mix of 2,4-D at 0.7 lb a.i./acre plus dicamba at 0.25 lb a.i./acre was applied on June 23, resulting in no visible damage to the teff. Weed competition after the herbicide application was minimal due to the vigorous teff stand.

Ontario

Approximately 0.5 acre of teff was planted on June 23 on a Nyssa silt loam containing about 1.5 percent organic matter. The field was fallow the previous year. Seed was broadcast by hand using an Earthway Hand Spreader at a uniform rate of 3 lb/acre, and was incorporated only by irrigation droplet impact on the bare soil. As at the other locations, irrigation treatments were imposed by installing an irrigation line source and harvesting plots at different distances from the line source (Table 1). N rates were applied in a randomized complete block design with four replications (Table 2). Small broadleaf weeds were controlled with an application of bromoxynil at 0.25 lb a.i./acre shortly after crop and weed emergence, with no visible damage to the teff. Harvests occurred when seed heads were beginning to emerge. First cutting was on August 15 and the second cutting was on September 12. Further details on the Ontario trial can be found in the 2005 Malheur Experiment Station Annual Report.

Statistical Analysis

Statistics on yield and quality data were calculated using SAS® for Windows, Release 9.1 (SAS Institute, Inc.) software. Treatment significance was based on the F test at the $P = 0.05$ level. If this analysis indicated significant treatment effects, least significant difference (LSD) values were calculated based on the student's *t* test at the 5 percent level. For this report, the N rate x irrigation rate studies were analyzed as a split-block design, with irrigation rate as the main plot and N rate as subplot. Because of the inherent design limitations of line-source irrigation systems, irrigation rate treatments could not be randomized, so that a strictly valid error term could not be calculated for the main plot irrigation rate effect. Thus, while caution must be exercised in interpreting the irrigation rate results, the large responses observed in this study should be valid even with this less robust statistical method. Because the N rates were randomized, the N rate and irrigation by N rate interaction error terms are completely valid for interpretation in these studies.

Results and Discussion

Klamath Falls Nitrogen Rate under Uniform Irrigation

For the first cutting, there was a significant difference between N rate treatments only for yield and CP (Table 3). The biggest effect was the difference between the N_0 treatment and the two higher N rates. For the second cutting, however, there was a significant treatment effect for all yield and quality factors except RFQ (Table 3). Yield and quality were greatest at the highest N rate and lowest for the N_0 rate for all but RFQ, although the largest difference tended to be between the N_0 treatment and the two higher N rates, which were only significantly different from one another for CP, NDF, and RFV.

Klamath Falls Irrigation by N rate

Germination and emergence were good, except at the farthest reaches from the irrigation line, where very slight differences in moisture resulted in obvious stand differences.

3 lb/acre Seeding Rate

Irrigation treatments had a significant effect on all yield and quality parameters for the first cutting (Table 4). The most obvious effect was the lack of measurable yield at the low irrigation rate treatment (plants existed, but were too small and stunted to be harvested normally). Ignoring the low irrigation treatment, teff yield and quality tended to be better at the medium irrigation rate than at the high rate, although differences between the two were not always significant.

For first cutting, N rates had a significant effect on yield and all quality parameters except RFQ (Table 4). Looking at just the N rate effects within the high and medium irrigation rates, the N_2 treatment was significantly better than the N_1 treatment for CP, ADF, NDF, and RFV, but was significantly worse than the N_1 treatment for yield. This N rate response illustrates a classic tradeoff between yield and quality, but it is uncertain why the yield would be lower for the N_2 treatment.

The irrigation results were less obvious at the second cutting, as there was a significant irrigation treatment effect only for CP (Table 5). However, there was a significant N rate effect for CP, ADF, NDF, and RFV. Yield was not significantly affected by either irrigation or N rate. The higher N rate resulted in significantly greater CP and RFV within each irrigation treatment, as well as significantly lower ADF and NDF. Thus the trade-off between yield and quality that was observed for first cutting was also observed for second cutting at the 3 lb/acre seeding rate, although the obvious beneficial effects of irrigation observed at first cutting were not significant for the second cutting.

6 lb/acre Seeding Rate

There was a significant response to the irrigation treatments for all yield and quality parameters measured for first cutting (Table 6). The low irrigation treatments had significantly lower yields than the medium and high treatments. For all the quality parameters, quality tended to decrease as irrigation increased, although not all differences between irrigation rates were significant.

Nitrogen rates had a significant effect on CP, but not on yield or other quality parameters at first cutting. At all irrigation rates, the N_2 treatment had higher CP than the N_1 treatment.

By the second cutting, teff planted at the 6 lb/acre rate exhibited a significant response to irrigation only in terms of CP, ADF, and RFV (Table 7). The trends in quality were not as obvious as they had been for first cutting. Yields tended to increase with increasing irrigation, but the differences were not significant.

There were no significant differences between N rates for any of the yield or quality parameters, although the trend was for increased yield at the higher N rate. There was a significant interaction between irrigation rate and N rate in some cases, indicating that the response to N rate was not the same at different irrigation rates.

Comparison of 3 lb/acre vs 6 lb/acre Seeding Rates

Due to nonrandomization of the seeding rate, statistical comparisons between the 3 lb/acre and 6 lb/acre seeding rates cannot be made. In general, however, it appeared that yield and protein were more sensitive to differences in N rate at the 3 lb/acre seeding rate than at the 6 lb/acre seeding rate. Yield tended to be higher for the 6 lb/acre seeding rate at first cutting, but the reverse tended to be true at second cutting. In general, under good conditions of irrigation and N nutrition, there was little obvious difference in total yield, although quality seemed to be somewhat better at first cutting for teff seeded at the higher rate.

Medford

Teff emergence was good. Rainfall soon after planting initially resulted in a uniform stand across all treatments. There was a significant irrigation effect on all yield and quality parameters at first cutting (Table 8). The largest difference was between the low irrigation rate and the other two rates, but the differences between the medium and high irrigation rates were significant in some cases. As was seen in Klamath Falls, there was often a trade-off between yield and quality as a function of irrigation rate.

At first cutting there was not a significant yield response to N rate, but the quality parameters were significantly affected by N rate, especially within the medium and low irrigation rate zones. Interestingly, at the time of first cutting it was difficult to visually distinguish the various N rate treatments. The N_0 treatment area was only slightly shorter and a slightly lighter shade of green than the other two treatments for a comparable irrigation rate. Because the soil in Medford is a sandy loam containing about 5 percent organic matter, it is hypothesized that sufficient N mineralization occurred in the early summer to supply most of the plants' N requirements before first cutting. For first cutting, the visual nonresponse to added N confirmed the measured yield data, but not the quality data, illustrating the potential error that can occur when evaluating forage quality by visual information only (Table 8).

At second cutting there was a significant irrigation treatment effect on yield and all quality parameters, similar to results observed at first cutting (Table 9). Unlike first cutting, however, there were significant differences in yield between the high and medium irrigation rates for both the N_2 and N_1 treatments at second cutting. The quality parameters followed a pattern similar to that observed elsewhere, with increased irrigation rate producing greater yield, but lower quality.

By the second cutting, the different N rate treatments were visually very obvious by differences in color and plant height. Unlike first cutting, N rates at second cutting had a significant effect on yield and CP, but none of the other quality parameters. For yield, the largest difference was between the N_1 and N_0 treatments, whereas the largest difference for CP was between the N_2 and N_1 treatments. Like first cutting, the visual response to added N at second cutting confirmed the N rate effect on yield data, but did not predict the lack of response of forage quality other than CP, once again illustrating the potential error that can occur when evaluating forage quality by visual information only (Table 9).

Ontario

Teff emergence at Ontario was less uniform than at the other locations. Emergence was very poor where the soil remained driest due to the lack of moisture availability. However, where moisture was adequate the surface-seeded teff at Ontario germinated well and produced solid stands.

Irrigation treatments did not have a significant effect on first cutting yield or RFQ, although the yield did tend to decrease somewhat under the very low irrigation treatment (Table 10). The irrigation treatment effect was significant for the other quality parameters. Hay quality generally increased as irrigation rate decreased, although not all differences were significant.

There was a significant effect of N rate treatments only for yield, CP, and ADF for first cutting. Although the N_2 treatment had the highest yield in all but the high irrigation rate zone, the largest consistent difference in yield was between the N_0 rate and the other two rates. For CP, within each irrigation zone the highest CP was the N_1 treatment, whereas the lowest CP was the N_2 treatment, although the differences were only sometimes significant. This result does not seem to have a ready explanation. A similar pattern was observed for ADF.

For the second cutting, there was a significant irrigation treatment effect for all yield and quality parameters (Table 11). Although the yields were quite a bit lower than at first cutting due to the much shorter growth period, the yield clearly was reduced for the low and very low irrigation treatments. The pattern observed at the other sites where higher irrigation rates resulted in reduced quality, but higher yields, was also observed at Ontario.

Unlike first cutting, the N rate treatments did not have a significant effect on any of the quality parameters at second cutting, although the effect on yield was significant. There tended to be only small differences and no observable pattern between values of a given parameter for the three N rates under a particular irrigation regime. The effect on yield was unexpected, with the N_0 treatment producing the highest yield within a given irrigation zone.

Conclusion

Teff grew well and produced good yields and quality at all three locations that represent different climate types in Oregon. Although the responses to irrigation and N rates varied somewhat at the different locations and varied between first and second cuttings, in general there were consistent responses. The lowest rate of irrigation and lack of added fertilizer N clearly reduced yields. However, the highest rate of irrigation and N fertilizer often did not improve yield or quality compared to a moderate rate of both N and irrigation. Thus, under the range of conditions examined here, it appeared that teff responded to some added N, but that N fertilization greater than about 80-90 lb N/acre during the growing season was probably not justified. Teff also responded to a moderate level of irrigation. Using automated weather data collected at the three trial sites, it appears that yield and quality did not improve when irrigation exceeded about 0.5-0.6 of calculated Kimberly-Penman evapotranspiration rate (data not shown), but a more detailed examination of this conclusion is beyond the scope of this report. If teff is planted to a well-prepared seedbed, and adequate moisture is present after planting, it appears that a 3 lb/acre seeding rate may be sufficient to result in a good stand and optimal yield, although it also appears teff might be more sensitive to nonideal conditions at the lower seeding rate.

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Table 1. Planting date, harvest dates, and irrigation plus precipitation treatments for teff forage production at three Oregon sites, 2005.

Location	Planting date	1st Cutting date	2nd Cutting date	Irrigation treatment	Irrigation plus precipitation from planting to 1st cutting	Irrigation plus precipitation from 1st cutting to 2nd cutting
					—— inches	——
Klamath Falls	June 6	Aug 8	Sept 13	High	9.87	8.2
				Medium	4.41	3.58
				Low	0.19	0.00
Medford	May 13	July 22	Sept 3	High	14.88	15.4
				Medium	8.64	8.09
				Low	2.93	1.39
Ontario	June 23	Aug 15	Sept 12	High	13.25	3.75
				Medium	10.42	2.96
				Low	7.65	2.19
				Very Low	4.68	1.36

Table 2. Treatment labels assigned to rates of nitrogen (N) applied during entire season at three Oregon locations, 2005. N applications were split, with approximately half applied at planting, and half after first cutting.

Location	Treatment N_0	Treatment N_1	Treatment N_2
	——	lb N/acre	——
Klamath Falls	0	91	195
Medford	0	84	168
Ontario	0	80	160

Table 3. Teff forage yield and quality response to different rates of nitrogen grown under uniform irrigation at the Klamath Experiment Station, Klamath Falls, OR in 2005.

Cutting	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
First	N_2	1.74	16.6	35.2	59.5	96	99
	N_1	1.72	14	36.5	60.7	93	100
	N_0	1.02	11.9	34.9	59	97	113
P value		0.012	0.014	0.459	0.302	0.37	0.084
$LSD_{(0.05)}$		0.44	2.6	NS	NS	NS	NS
Second	N_2	2.68	16	35.4	57.4	100	101
	N_1	2.62	13.6	36.6	59.5	95	110
	N_0	2.26	9.1	38.8	60.8	90	108
P value		0.01	<0.001	0.005	0.015	0.004	0.271
$LSD_{(0.05)}$		0.24	1.3	1.6	2	4	NS

Table 4. Teff forage yield and quality response to different rates of irrigation and nitrogen at first cutting. Results are shown for teff planted at the 3 lb/acre seeding rate in 2005 at the Klamath Experiment Station, Klamath Falls, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	2.6	16.2	31.4	56.8	106	125
	N_1	2.9	13.5	34.7	60.9	94	119
Medium	N_2	2.64	17.2	30.1	56.3	108	128
	N_1	3.2	14.1	32.6	58.7	101	123
Low	N_2	0	0	0	0	0	0
	N_1	0	0	0	0	0	0
P value (irrig)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		0.37	1.6	0.8	0.8	2	8
P value (N rate)		0.028	<0.001	0.001	<0.001	<0.001	0.165
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		0.25	0.9	0.9	0.8	2	NS
P (irrig x N rate interaction)		0.162	0.017	0.024	0.003	0.006	0.584

Table 5. Teff forage yield and quality response to different rates of irrigation and nitrogen at second cutting. Results are shown for teff planted at the 3 lb/acre seeding rate in 2005 at the Klamath Experiment Station, Klamath Falls, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	1.22	19.2	30.6	54.3	111	108
	N_1	1.41	16.1	32.9	56.2	105	115
Medium	N_2	1.06	19.2	29.8	54	113	112
	N_1	1.14	16.4	31.2	55.6	108	120
Low	N_2	1.26	17.1	29.3	55.1	112	119
	N_1	1.48	13.8	32.1	57.2	104	122
P value (irrig)		0.43	0.037	0.498	0.403	0.643	0.083
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		NS	1.9	NS	NS	NS	NS
P value (N rate)		0.141	<0.001	0.002	0.023	0.007	0.066
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		NS	1.3	1.1	1.6	4	NS
P (irrig x N rate interaction)		0.864	0.935	0.55	0.962	0.845	0.751

Table 6. Teff forage yield and quality response to different rates of irrigation and nitrogen at first cutting. Results are shown for teff planted at the 6 lb/acre seeding rate in 2005 at the Klamath Experiment Station, Klamath Falls, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	3.08	15	32	58.1	102	125
	N_1	3.15	12.9	34.3	60.7	95	123
Medium	N_2	2.82	16.6	28.5	54.1	115	142
	N_1	3.1	15.1	29.8	55.1	111	139
Low	N_2	1.58	17.1	27.9	55	114	141
	N_1	1.06	15.4	28	54.8	114	145
P value (irrig)		0.007	0.029	<0.001	0.002	<0.001	0.038
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		0.97	1.6	1.3	2.1	5	15
P value (N rate)		0.733	0.048	0.116	0.266	0.220	0.934
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		NS	1.7	NS	NS	NS	NS
P (irrig x N rate interaction)		0.214	0.948	0.483	0.515	0.593	0.569

Table 7. Teff forage yield and quality response to different rates of irrigation and nitrogen at second cutting. Results are shown for teff planted at the 6 lb/acre seeding rate in 2005 at the Klamath Experiment Station, Klamath Falls, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	1.07	19.7	29.6	53.2	115	113
	N_1	0.97	16.1	32.5	56.1	106	117
Medium	N_2	0.82	17.5	28.9	53.7	115	136
	N_1	0.72	20.9	27.6	52.8	119	116
Low	N_2	0.6	14.4	32	55.4	108	124
	N_1	0.3	12.9	31.1	55.8	108	133
P value (irrig)		0.106	0.007	0.008	0.103	0.029	0.051
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		NS	2.8	1.7	NS	6	NS
P value (N rate)		0.306	0.485	0.57	0.212	0.354	0.429
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		NS	NS	NS	NS	NS	NS
P (irrig x N rate interaction)		0.838	0.014	0.008	0.095	0.046	0.007

Table 8. Teff forage yield and quality response to different rates of irrigation and nitrogen at first cutting, 2005, when grown at the Southern Oregon Research and Extension Center, Medford, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	2.39	8.2	41.2	71	74	86
	N_1	2.16	8.1	40.3	69.7	77	90
	N_0	1.89	7.4	42	72.2	72	86
Medium	N_2	2.03	10.5	36.4	66.2	86	111
	N_1	1.92	7.8	39.4	68.9	79	94
	N_0	1.96	7	40.4	70.5	76	89
Low	N_2	0.3	14.6	27.7	55	114	169
	N_1	0.22	12.3	29.4	56.6	109	156
	N_0	0.22	9.2	35.4	65.8	89	120
P value (irrig)		<0.001	0.004	0.002	0.002	0.001	<0.001
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		0.65	1.9	4.2	4.5	10	19
P value (N rate)		0.44	0.002	0.028	0.008	0.013	0.033
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		NS	1.6	3.1	3.4	8	18
P (irrig x N rate interaction)		0.821	0.196	0.334	0.15	0.164	0.193

Table 9. Teff forage yield and quality response to different rates of irrigation and nitrogen at second cutting, 2005, when grown at the Southern Oregon Research and Extension Center, Medford, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	2.04	10.5	39.6	67.4	80	98
	N_1	2.06	7	39.6	68	80	97
	N_0	0.8	5.9	39.3	64.9	84	96
Medium	N_2	1.58	13.6	32.9	61	97	126
	N_1	1.42	9	33	61.6	96	125
	N_0	0.84	7.2	35.2	62.2	92	112
Low	N_2	0.1	14.7	29.8	60.2	102	150
	N_1	0.06	13.5	30	60.5	101	144
	N_0	0.25	12.6	31.3	59.8	101	139
P value (irrig)		<0.001	0.006	0.003	0.019	0.012	<0.001
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		0.13	2.8	3.7	4.2	11	13
P value (N rate)		<0.001	0.001	0.369	0.497	0.92	0.151
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		0.25	2.1	NS	NS	NS	NS
P (irrig x N rate interaction)		<0.001	0.534	0.78	0.446	0.672	0.782

Table 10. Teff forage yield and quality response to different rates of irrigation and nitrogen at first cutting, 2005, when grown at the Malheur Experiment Station, Ontario, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	1.9	12.6	39	63.3	86	101
	N_1	2.02	15.5	36.8	61.8	91	103
	N_0	1.58	13	38	62.8	88	103
Medium	N_2	2.24	17	35.4	60.2	95	104
	N_1	2.12	18.1	33.2	58.4	101	108
	N_0	1.61	17.8	34	58.9	99	106
Low	N_2	2.32	17.7	33	58.6	100	110
	N_1	2.11	18.9	32	57	104	112
	N_0	1.97	18.8	32.4	57.4	104	110
Very Low	N_2	1.29	17.8	32.1	57.3	105	111
	N_1	1.23	21.6	28.5	53.3	117	110
	N_0	1.16	20.6	29.3	54.3	113	114
P value (irrig)		0.059	<0.001	<0.001	<0.001	<0.001	0.134
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		NS	2.1	2.3	2.4	6	NS
P value (N rate)		0.01	0.034	0.042	0.083	0.07	0.772
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		0.24	1.6	1.8	NS	NS	NS
P (irrig x N rate interaction)		0.66	0.795	0.958	0.956	0.956	0.98

Table 11. Teff forage yield and quality response to different rates of irrigation and nitrogen at second cutting, 2005, when grown at the Malheur Experiment Station, Ontario, OR.

Irrigation treatment	Nitrogen treatment	Yield (ton/acre)	Crude protein (%)	ADF	NDF	RFV	RFQ
High	N_2	1.09	14.2	34.5	56.9	101	121
	N_1	1.08	15.3	34	56.8	102	118
	N_0	1.24	14	35	57.5	100	120
Medium	N_2	1.1	18.4	30.8	55	110	116
	N_1	1.11	18.1	30.9	54.6	111	118
	N_0	1.46	17.6	31.2	55.4	109	119
Low	N_2	0.82	17.6	30.1	53.6	114	123
	N_1	0.58	18.4	28.7	52.9	117	126
	N_0	1.08	18	30.4	55.3	110	117
Very Low	N_2	0.38	16.9	28.1	53	118	140
	N_1	0.27	16.7	29	54.1	114	139
	N_0	0.52	16.7	28	52.7	118	142
P value (irrig)		<0.001	0.001	<0.001	0.04	0.008	<0.001
$LSD_{(0.05)}$ between irrig rates (for a given N treatment)		0.32	1.5	2.2	2.6	8	8
P value (N rate)		0.003	0.664	0.672	0.413	0.531	0.983
$LSD_{(0.05)}$ between N treatments (at a given irrig rate)		0.17	NS	NS	NS	NS	NS
P (irrig x N rate interaction)		0.771	0.956	0.688	0.393	0.43	0.488