A PACIFIC NORTHWEST EXTENSION PUBLICATION

Photo: Richard Roseberg, © Oregon State University

Teff at heading stage. Cutting at this stage is slightly later than ideal for the optimum compromise between yield and quality.

Teff Grass for Forage:

Nitrogen and irrigation requirements

Richard Roseberg, Steven Norberg, and Brian Charlton

Teff (*Eragrostis tef*) is a warm-season annual grass with a long history in Africa and a relatively short period of experimentation by growers in the Pacific Northwest. Teff is a gluten-free grain known for its use in injera, a type of flatbread that has been a primary Ethiopian food staple for 3,000 years. In the United States, it was grown on fewer than 5,000 acres annually prior to 2004.

Acreage has exploded since then, as more growers turned to teff for its high yields of high-quality hay. Between 2005 and 2010, teff acreage in the US increased to more than 100,000 acres, based on encouraging research results in Oregon, New York, and elsewhere (Roseberg et al., 2006; Hunter et al., 2007; Roseberg et al., 2008). Teff is typically higher in protein and forage quality than other common forage grasses (Hunter et al., 2007; Twidwell et al., 2002; Nsahlai et al., 1998).

Teff is killed by freezing temperatures at all growth stages. In most places teff is managed as an annual crop with two, or possibly three, cuttings. In some cases only a single cutting is possible, such as when

Richard Roseberg, director, Southern Oregon Research & Extension Center, Oregon State University; Steven Norberg, regional Extension forage specialist for the Columbia Basin, Washington State University; and Brian Charlton, Klamath Basin potato faculty scholar, Klamath Basin Research and Extension Center, Oregon State University.

Oregon State University • University of Idaho • Washington State University
PNW 709 • June 2018

Photo: Richard Roseberg, © Oregon State University

Collection of teff cultivars evaluated for forage crop potential near Klamath Falls, Oregon.

there is a short growing season, planting is delayed, or there is a lack of irrigation water or rain later in the summer. In these cases the cutting date can be delayed to increase yield, although forage quality decreases as the plant matures. To meet the need for general recommendations for planting, managing, and harvesting teff hay, several states have developed Extension publications (Hunter et al., 2007; Norberg et al., 2009; Creech et al., 2012).

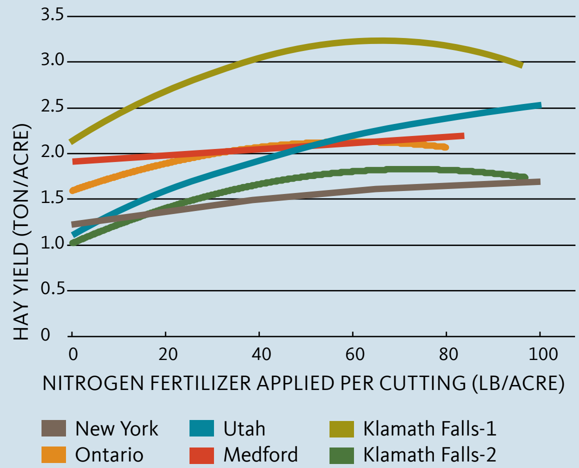
However, little research-based information was previously available on nitrogen (N) requirements or optimum water management, especially under irrigated conditions in the Pacific Northwest. Many growers initially assumed teff required large inputs of N fertilizer and irrigation, because it grows quickly into a lush-looking forage crop, typically has higher protein levels than other common forage grasses, and has a relatively small and shallow root system. To test these assumptions and address information needs, several research studies were initiated in Oregon and elsewhere.

The results show that teff compares favorably to other forage crops in its efficient use of water and fertilizer. Protein levels in teff hay are typically higher than common grass hay species, but are lower than alfalfa. However, teff requires less N fertilizer and irrigation water than comparable grass hay, and requires only about half the irrigation of alfalfa for optimum yields.

Nitrogen management

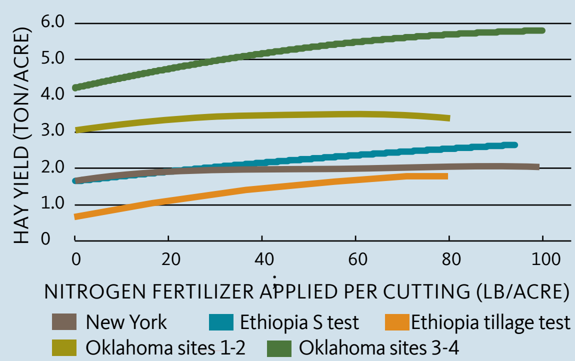
While soil types, climate, use of irrigation, and background nutrient levels vary across the country, teff's response to N fertilizer follows a surprisingly similar yield and quality pattern across most testing locations. This is likely related to teff's small rooting

Figure 1. Teff first cut yield



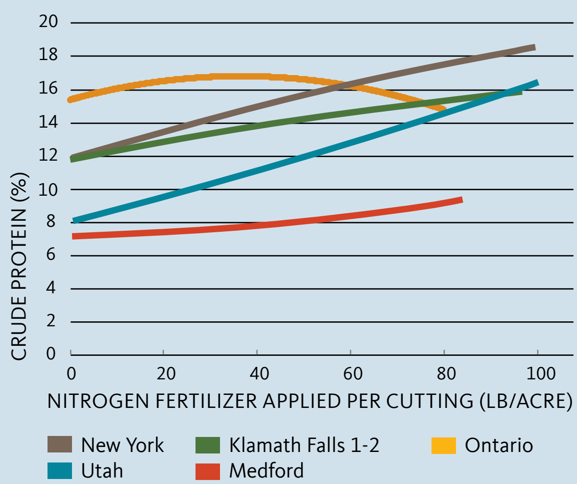
Data from Hunter et al., 2009; Creech et al., 2012; Roseberg et al., 2006

Figure 2. Teff single cut yield



Data from Hunter et al., 2009; Girma et al., 2012; Habtegebrial and Singh, 2006; Habtegebrial et al., 2007

Figure 3. Teff first cut crude protein



Data from Hunter et al., 2009; Creech et al., 2012; Roseberg et al., 2006

Photo: Richard Roseberg, © Oregon State University

Just prior to first cutting, teff grown near Medford, Oregon, that received no fertilizer N (left), and 84 lb N/ac of N fertilizer at seeding (right).

Photo: Brian Charlton, © Oregon State University

Swathing first cutting of teff in the Klamath Basin, Oregon.

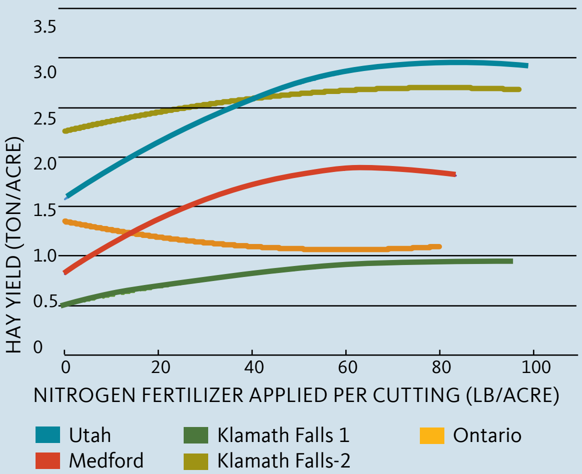
pattern, short but rapid growth periods, and lack of root nutrient reserves compared to many perennial forage grasses. Typically, teff yield and quality increase with moderate applications (approximately 50 lb N/acre/cutting). Sometimes teff yield increases only slightly with added N, but other factors limiting yield could be identified in such cases (Lauriault et al., 2013; Hancock and Durham, 2009).

First cutting yield and quality

First-cutting yield typically increases when 40–60 lb/acre of N fertilizer is applied near planting time (Figures 1 and 2, page 2). Typically, additional N does not increase yield, but in some cases additional N above 60 lb/acre can produce a small increment of additional yield (Utah site in Figure 1, one Oklahoma site in Figure 2). The yield response to added N for first cutting is also influenced by residual soil N values. The first cutting yields shown in Figures 1 and 2 with no fertilizer N applied are variable, ranging from about 0.5 to 2.0 ton/acre, with two locations in Oklahoma producing higher yields with no added N. Preseason residual soil N values have only rarely been reported in the literature, but as a general rule first cutting yield should be increased the most by added N fertilizer in situations where preseason soil N values are lower. For first cutting, crude protein may be increased by adding N fertilizer at rates higher than what is needed for optimum yield (adding more than 60 lb N/acre), but this response is not universal (Figure 3). Sites that have a good yield response to added N between zero and about 60 lb N/acre also tend to produce higher crude protein when more fertilizer N is applied (in the 60–100 lb N/acre range; compare Figures 1 and 3). The relationship between fertilizer N rate, yield, and crude protein is expected to vary, depending on other soil and crop growth conditions.

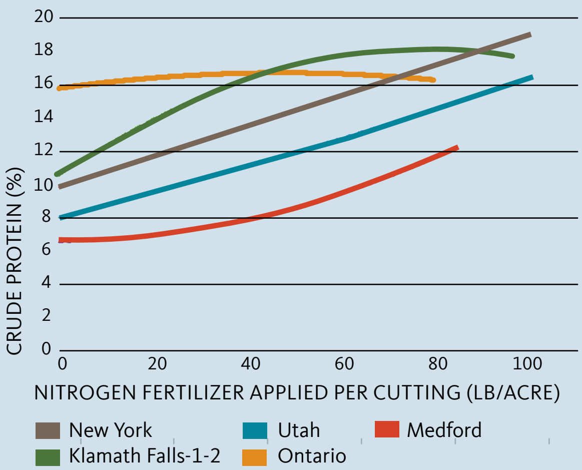
Excess nitrate accumulation can be a concern in some forage crops when high rates of N are applied, but no reports linking teff to excess nitrate accumulation have been published. Anecdotal reports and our unreplicated

Figure 4. Teff second cut yield



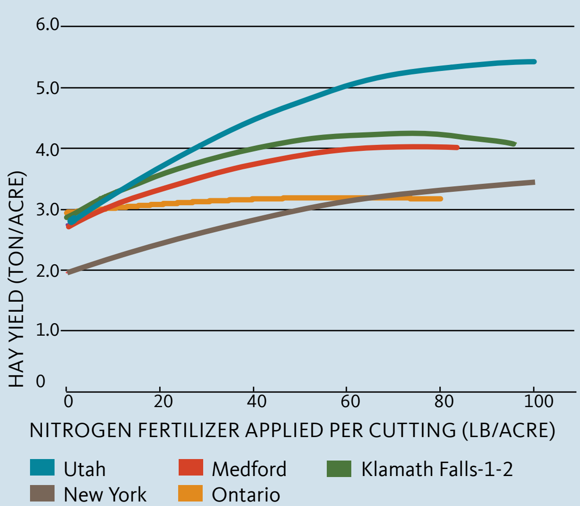
Data from Creech et al., 2012; Roseberg et al., 2006

Figure 5. Teff second cut crude protein



Data from Hunter et al., 2009; Creech et al., 2012; Roseberg et al., 2006

Figure 6. Teff total yield, two cuts



Data from Hunter et al., 2009; Creech et al., 2012; Roseberg et al., 2006

data suggest teff does not readily accumulate excess nitrate, but producers may want to test their hay to confirm low nitrate concentrations, especially if they suspect high levels of plant-available N in their fields.

Second cutting yield and quality

Regrowth rate and vigor after first cutting can vary widely for grass hay crops due to factors such as improper cutting height (removing meristematic growing points and/or leaving little photosynthetic leaf surface) and weather-related heat and moisture stress during initial regrowth.

Despite these factors, second cutting teff often responds to fertilizer N in a similar pattern to first cutting; yield generally increases when 40–60 lb N/acre is applied soon after the first cutting, and N in excess of 60 lb/acre does not increase yield (Figure 4). Application of more than 60 lb/ac of N fertilizer after first cutting, however, may increase crude protein in second cutting hay, but this response is not universal (Figure 5).

Sites that have a good yield response to added N between zero and about 60 lb N/acre also tend to produce higher crude protein when more N is applied (in the 60–100 lb N/acre range, compare Figure 4 and Figure 5). The same factors that affect teff regrowth between first and second cutting also affect teff regrowth after the last seasonal cutting until it is killed by the first hard frost. If weather conditions permit sufficient fall regrowth after the final hay cutting, teff can be grazed by livestock, allowing growers to preserve other forage sources such as perennial cool-season grasses during their critical fall regrowth period.

Total seasonal yield

A look at both the first and second cutting yields gives us a bigger picture of the entire growing season. In most cases, teff total seasonal yield increases with the first increment of added N, but yield typically plateaus at about 40–60 lb added N/acre per cutting (Figure 6). However, for locations with high yield potential (and those with low pre-season residual soil N), 60 lb N/acre per cutting may not be enough to maximize yield, as teff yield can continue to increase when more than 60 lb N/acre per cutting is applied in some situations. However, unless the goal is to increase crude protein to higher than typical levels, adding 50–60 lb N/acre per cutting produces optimum teff yield under many growing conditions.

One factor not reported in these N response tests is crop lodging and its harmful effects on yield, quality, and ease of harvest. In teff, lodging occurs when plant stems are not strong enough to hold the plant upright. Lodging problems typically arise near harvest time. Excess N fertilizer, excess irrigation, excess wind, and delayed harvest (alone or in combination) can increase the chances of crop lodging. Decisions on fertilization, irrigation,

Photo: Richard Roseberg, © Oregon State University

Teff grown near Medford, Oregon, shown prior to first cutting. The teff on the left received a total of about 15 inches of moisture from rain and irrigation between seeding and first cutting. The teff on the right received a total of about 3 inches of water from rain and irrigation between seeding and first cutting.

Photo: Richard Roseberg, © Oregon State University

First cutting of teff in windrows near Klamath Falls, Oregon (with irrigation wheel line). Teff requires only about half of the moisture that is typically applied to alfalfa and about one-third less than amounts typically applied to cool-season forage grasses.

and harvest timing should take into consideration their interaction with lodging and crop harvest management as well as biomass yield and crude protein.

Irrigation response

Teff grows well in a range of soil types, from clay soils to sandy. In many places teff is successfully grown under rainfed conditions, but irrigation can improve yield and consistency in drier regions. Appropriate crop management depends on anticipating the crop's response to moisture, whether from rain or irrigation.

Few water management studies have been conducted for teff. In New Mexico (Lauriault et al., 2013), irrigation in every furrow was compared with alternate furrow irrigation; teff yield was not increased by irrigating every furrow. However, rainfall varied greatly in the two years of this study (6.88 inches in year 1 and 17.28 inches in year 2). Irrigation treatment yield data was not shown for individual years, but overall yield was significantly lower at first and second cutting in year 2 (the wetter year) than in year 1.

One of the few data sets describing teff yield and quality response to irrigation is from three locations that are representative of much of the irrigated hay-growing climates in the Pacific Northwest (Ontario, Medford, and Klamath Falls, Oregon; Roseberg et al., 2006 and 2008). At all three locations, less than 20 percent of the annual total precipitation occurs during the main summer teff growing season (June–September).

The Ontario location represents a typical hot, dry summer, inland valley in the Pacific Northwest. It has a long, frost-free growing season (with a median of 144 days between killing frosts), and very warm summers, with July and August mean daily high temperatures of 93° F and 92° F. Mean annual precipitation is 9.45 inches.

The Medford location represents inland valleys west of the Cascade mountain range, with mean annual precipitation of 21.14 inches. Medford has a long, frost-free growing season (with a median of 144 days), and is typically warmer than other valleys in western Oregon and Washington, with July and August mean daily high temperatures of 88° F and 87° F. Thus, irrigation is required for commercial production of nearly all crops.

The Klamath Falls location represents the cool, dry inland regions found at higher elevations east of the Cascades. It receives a mean annual precipitation of 11.96 inches. It has a shorter frost-free growing season (a median of 102 days) than both of the lower elevation valleys in Medford and Ontario, and is also cooler during midsummer. Klamath Falls' mean daily high temperatures for July and August are both 83° F.

In locations such as these where rainfall during the growing season is insufficient, teff yield, crude protein (CP), and relative feed value (RFV) all respond (positively or negatively) to increased irrigation. These responses can be normalized and interpolated to other locations by expressing irrigation amounts as a Relative Applied Irrigation Number (RAIN), which expresses applied moisture as a fraction of a location's potential evapotranspiration (E_T) (Roseberg et al., 2008). In the studies cited here, E_T values were calculated by the US Bureau of Reclamation's AgriMet weather station network with the 1982

Figure 7. Forage yield as a function of RAIN, first cutting

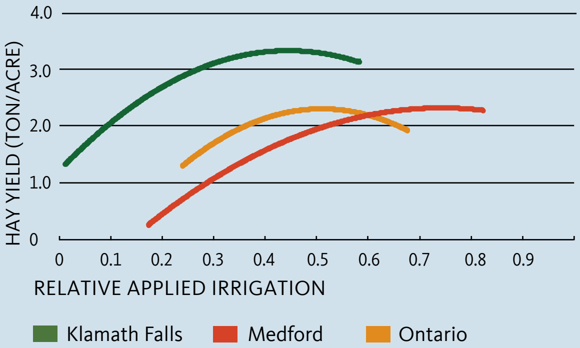


Figure 8. Forage yield as a function of RAIN, second cutting

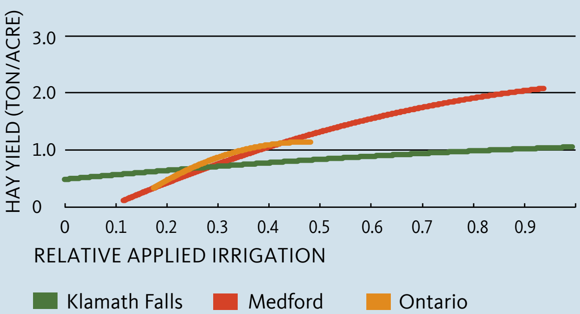
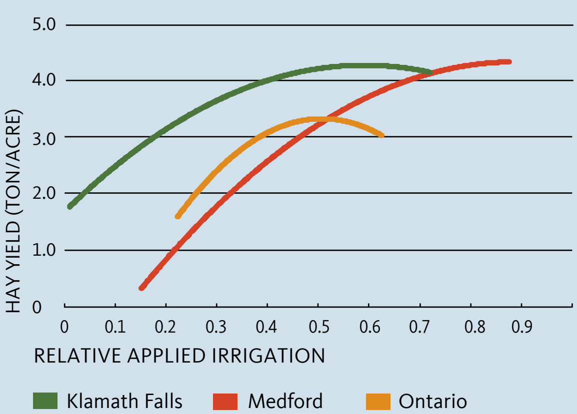


Figure 9. Forage yield as a function of RAIN, seasonal total



Data from Roseberg et al., 2006 and 2008

Kimberly-Penman model, which uses well-watered alfalfa as the reference crop (Dockter, 1994). This estimation of crop E_T is widely calculated for weather stations around the world, and is similar to evaporation from a free water surface (pan evaporation values), given the assumption of a well-watered, actively growing crop. However, because alfalfa is a full-season, perennial crop and teff is a late-planted annual crop, the RAIN values in these studies were calculated using E_T data only during the time period after teff had emerged and was actively growing. Applying these results to other locations and climates should follow the same assumptions for accuracy.

Forage yield

For first cutting, teff yields increase with irrigation until RAIN reaches a value of 0.4– 0.6 (Figure 7). Second cutting yields for teff are lower than first cutting yields, and this regrowth is less responsive to added irrigation than the initial crop growth (from seeding to first cutting, Figure 8). Thus, the shape of the total yield response to irrigation is mainly a function of the first cutting response (Figure 9). Total seasonal teff yield increases with added irrigation up to RAIN values of 0.5–0.6, except where a longer regrowth period prior to second cutting allows increased biomass production, thereby resulting in a longer time period of increased water use (Figure 9, Medford site).

Forage quality

Moderate irrigation rates do not greatly affect teff forage quality, but higher irrigation rates are often detrimental. CP at first cutting decreases with each increment of added irrigation (Figure 10, page 7). CP at second cutting may increase to a plateau at a RAIN value between 0.3 and 0.6 before declining at higher irrigation amounts (Figure 11, page 7). Similarly, RFV at first and second cutting decreases as irrigation increases, but results can be more variable for the second cutting (Figures 12 and 13, page 7).

Note that the apparent decrease in teff forage quality at higher irrigation rates is not related to advanced maturity stage of the crop. In general, teff maturity is delayed somewhat at higher irrigation rates. (Heading occurs a bit later.) Thus, the decrease in forage quality of teff at higher irrigation rates is due at least in part to some factor other than the stage of crop maturity.

Integrating yield and quality

To better integrate the influence of irrigation on crop yield and quality, we calculated a “modified yield” by multiplying forage yield by a quality factor such as RFV. The new modified yield calculations, illustrated in Figures 14–16, show a more pronounced optimum teff response range.

Figure 10. Crude protein as a function of RAIN, first cutting

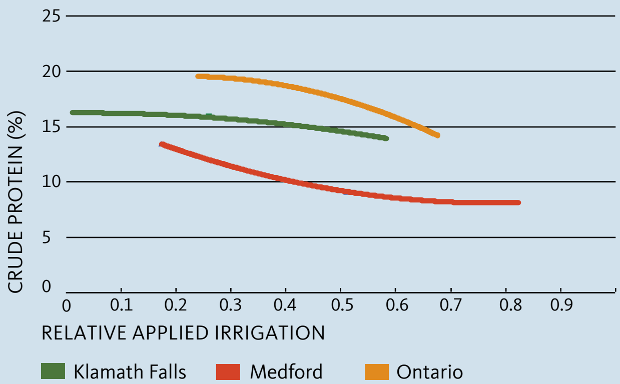


Figure 12. Teff relative feed value as a function of RAIN, first cutting

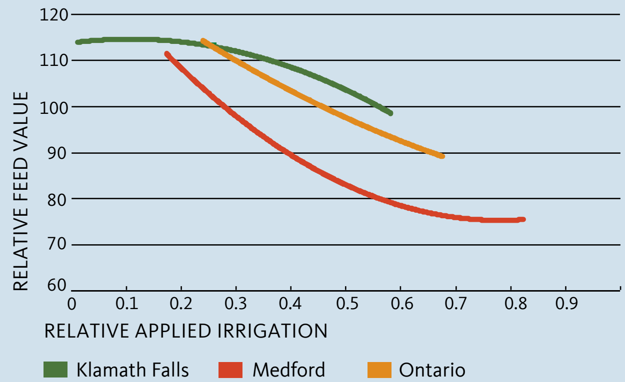


Figure 11. Crude protein as a function of RAIN, second cutting

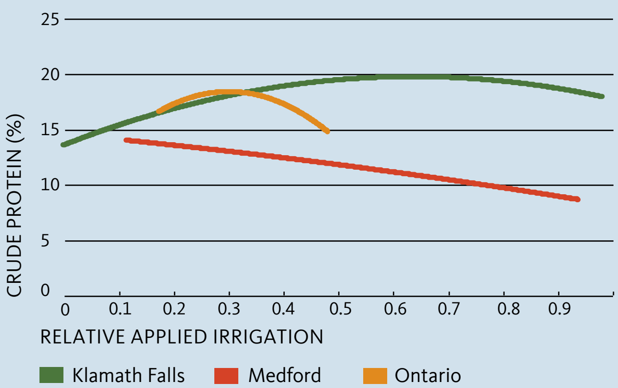
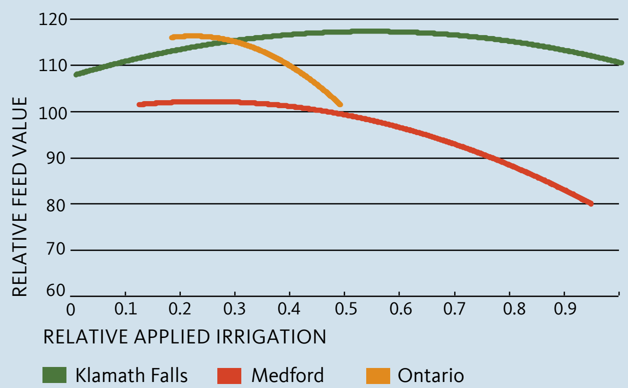


Figure 13. Teff relative feed value as a function of RAIN, second cutting



Data from Roseberg et al., 2006 and 2008

What is RAIN?

A Relative Applied Irrigation Number (RAIN) is one way to compare irrigation to a crop's demand for water at multiple locations in different climates. Instead of just looking at the amount of irrigation or rainfall, we can use the RAIN value to interpolate results from one location to another, since plants grown in different locations will have different demands for water based on different air temperatures, humidity, wind, etc. We start by looking at a location's potential evapotranspiration (E_T) rate, the amount of water that a standard reference crop (usually alfalfa) would use, or transpire, if available moisture were sufficient. RAIN value is calculated as the sum of precipitation (P) and irrigation (I), divided by the potential evapotranspiration rate over a given time period:

RAIN = [P+I] / E_T

For first cutting, the optimum modified yield values occur when RAIN values are in the range of 0.4–0.6 (Figure 14, page 8). Second cutting modified yield values are generally lower than first cutting values, and are less responsive to added irrigation (Figure 15, page 8). The general shape and magnitude of the total seasonal modified yield response (Figure 16, page 8) is mainly a function of the first cutting response (as was true for the simple yield response, Figure 9, page 6). However, with the quality factored in, the optimum range for RAIN values is more clearly 0.5–0.6, with little to no benefit at higher irrigation rates for any of the three sites.

Summary and recommendations

NITROGEN RESPONSE

Teff can produce a competitive yield of high-protein forage as compared to other common forage grasses, and may be a valuable option in various cropping systems. Research from several locations in diverse climates indicates teff yield and crude protein increase when N fertilizer is added, but

Figure 14. Teff modified yield as a function of RAIN, first cutting

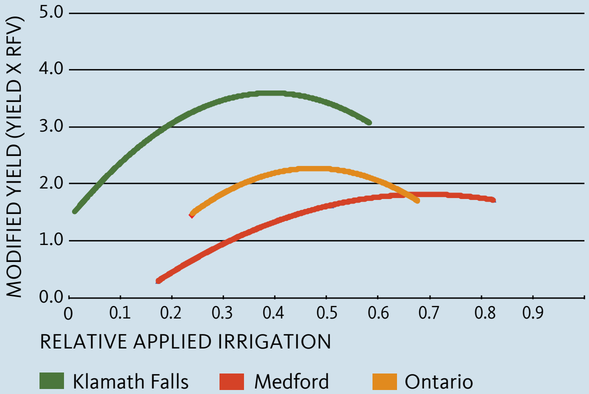


Figure 15. Teff modified yield as a function of RAIN, second cutting

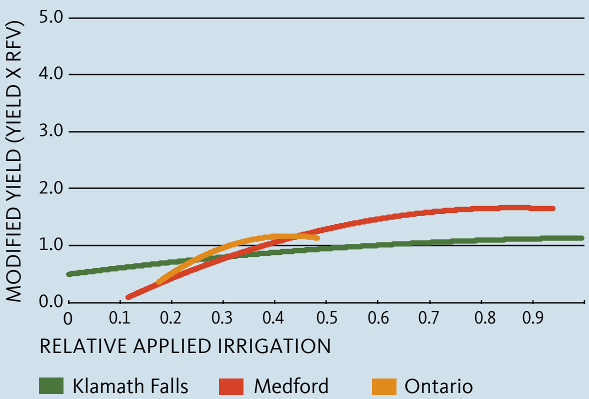
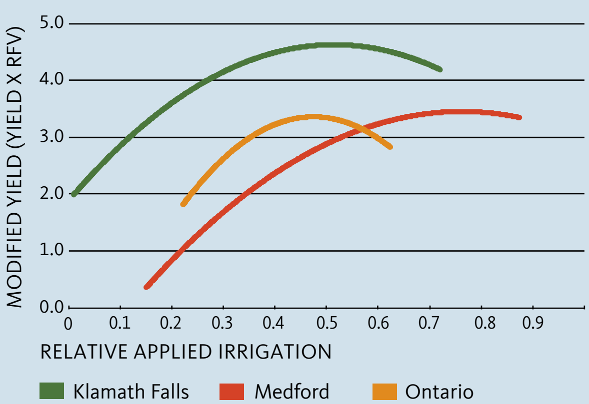


Figure 16. Teff modified yield as a function of RAIN, seasonal total (two cuttings)



Data from Roseberg et al., 2006 and 2008

response is limited to about 50–60 lb N/acre per cutting. Additional N applications do not typically increase yield, but the added N may increase protein by several percentage points. Limited data and anecdotal observations suggest teff does not readily accumulate excess nitrates, nor is it prone to prussic acid poisoning conditions during the growing season or after frost.

IRRIGATION RESPONSE

Teff requires about 2 inches of water (from either precipitation or irrigation) to germinate and survive until first cutting in the warmer regions of the Pacific Northwest (represented by Ontario and Medford), and about 1 inch in higher-elevation, cooler regions (represented by Klamath Falls). In addition to the water needed for establishment, first cutting teff requires 3.5 inches of water per ton of forage yield at the two warmest locations, and 2.7 inches per ton of yield at the cooler Klamath Falls location. Between first and second cutting, teff requires 1.0 inch of water to survive at the three locations. Second cutting teff requires an additional 5.5 inches of water per ton of forage yield at these three locations.

When expressed as the relative applied irrigation number (RAIN), teff yield increases as applied water increases, but only up to 0.4–0.6 of potential evapotranspiration in these sites. This amount of applied moisture is about half of what is typically applied to alfalfa and about one-third less than amounts typically applied to cool-season forage grasses grown under irrigation, indicating teff is a water-efficient crop with potential for competitive yields of high quality hay.

Additional irrigation or rainfall beyond that amount does not increase yield, and may decrease CP and RFV for reasons that are not well understood.

Using known or likely rainfall amounts, these responses to moisture can also be used to predict teff yield and quality in rain-fed regions with similar growing seasons.

KEY TEFF CROP PRODUCTION RECOMMENDATIONS

Based on earlier published recommendations (Hunter et al., 2007; Norberg et al., 2009; Creech et al., 2012) and these results, Table 1 (page 9) shows general principles for teff crop management through a typical growing season. In regions where three cuttings are possible (regions with a longer frost-free growing season than most of the Pacific Northwest), principles for the first and second hay cuttings (regrowth period, cutting management, fertilization, and irrigation) can be extended to the third cutting.

Table 1. Key teff management considerations and recommendations for a typical growing season in the Pacific Northwest

Action	Condition/timing	Recommendation
Seedbed preparation	Spring	Teff germinates best in a fine firm seedbed similar to alfalfa.
Fertilization	Before planting and before second cutting	Apply approximately 50 lb N/acre each time. With high soil residual N, reduce or eliminate the pre-plant fertilization.
Seeding date	After last killing frost	Teff does not tolerate freezing temperatures at any growth stage. It germinates best when 4-inch soil temperature is greater than 60° F and then grows quickly when daytime maximum air temperatures are consistently 70–85° F.
Seeding method	Grass seed attachment on grain drill or Brillion seeder or broadcast and cover with harrow or cultipacker	Place seed ¼-inch deep or less. Teff does not emerge well from greater depths.
Seeding rate	Raw seed or coated	Raw seed at 4–8 lb seed/acre. Increase rate if coated.
Irrigation	Keep soil moist until emergence.	After emergence apply irrigation + rain at rate approximately equal to 0.5 multiplied by the potential evapotranspiration rate for the location.
First cutting timing	About 6–8 weeks after seeding. Teff grows more quickly with consistently warm weather after emergence.	Harvest when seed heads are just starting to emerge to provide optimal yield and quality stage.
First cutting method	Cut higher than alfalfa: Leave 3–4 inches of stem and leaf uncut.	Cutting shorter than 3 inches dramatically reduces regrowth by removing growing points and photosynthetic leaf surface.
Curing and baling	Dry and turn as needed like other grass hays before baling.	Teff typically takes slightly longer than orchardgrass to dry sufficiently. Note: Teff "feels" drier than it really is compared to other grass hays.
Irrigation	Resume as soon as first cutting hay is removed from field.	Between first and second cutting, apply irrigation + rain at a rate approximately equal to 0.6 multiplied by the potential evapotranspiration rate for the location.
Second cutting timing	If crops have sufficient moisture and leaf area after the first cut, second cutting should be ready in 4–6 weeks.	In short growing season areas, anticipate first killing frost timing. If frost occurs, cut immediately to preserve hay quality.
Second cutting method	Okay to cut near ground level if you do not expect any fall regrowth.	If you expect a long frost-free period after second cutting and want to graze the regrowth, cut at 3–4-inch height like first cutting.

References

Creech, E., M. Laca, J. Barnhill, and S. Olsen. 2012. *Teff Hay Production Guidelines for Utah.* Utah State University Extension, AG/Forages/2012-01pr.

Dockter, D. 1994. Computation of the 1982 Kimberly-Penman and the Jensen-Haise evapotranspiration equations as applied in the US Bureau of Reclamation's Pacific Northwest AgriMet Program. U.S. Bureau of Reclamation Pacific Northwest Region Water Conservation Center. Revised January 2008, Peter L. Palmer. http://www.usbr.gov/pn/agrimet/h2ouse.html, pdf file: EFO792CCd01.

Girma, K., M. Reinert, M.S. Ali, A. Sutradhar, and J. Mosali. 2012. "Nitrogen and Phosphorus Requirements of Teff Grown Under Dryland Production System." *Crop Management.* https://doi.org/10.1094/CM-2012-0319-02-RS

Habtegebrial, K., and B.R. Singh. 2006. "Effects of timing of nitrogen and sulphur fertilizers on yield, nitrogen, and sulphur contents of tef (*Eragrostis tef (Zucc.) Trotter*)." *Nutrient Cycling in Agroecosystems* 75:213-222.

Habtegebrial, K., B.R. Singh, and M. Haile. 2007. Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of tef (*Eragrostis tef (Zucc.) Trotter*) and soil properties. *Soil and Tillage Research* 94:55-63.

Hancock, D. and R.G. Durham. 2009. "Forage Yield of Teff is Low in the Southeast and is Only Marginally Responsive to Nitrogen." *Forage and Grazinglands.* https://doi.org/10.1094/FG-2009-0819-01-RS

Hunter, M., P. Barney, T. Kilcer, J. Cherney, J. Lawrence, and Q. Ketterings. 2007. *Teff as Emergency Forage.* Cornell University Cooperative Extension, Agronomy Fact Sheet Series, Fact Sheet 24.

Lauriault, L., D. VanLeeuwen, and J. Turner. 2013. Irrigation and Nitrogen Treatments Slightly Affected Teff Yield and Quality in the Southwestern USA. https://doi.org/10.1094/FG-2013-0326-01-RS

Norberg, S., R. Roseberg, B. Charlton, and C. Shock. 2009. *Teff: A New Warm-Season Annual Grass for Oregon* (EC 8970-E). Oregon State University Extension Service. https://catalog.extension.oregonstate.edu/em8970

Nsahlai, I., N. Umunna, and M. Bonsi. 1998. The utilization of teff (*Eragrostis tef*) straw by sheep fed supplementary forage legumes with or without either crushed maize grain or wheat bran. *Small Ruminant Research* 29:303-315.

Roseberg, R., S. Norberg , J. Smith, B. Charlton, K. Rykbost, and C. Shock. 2006. "Yield and Quality of Teff Forage as a Function of Varying Rates of Applied Irrigation and Nitrogen." Research in the Klamath Basin 2005 Annual Report. OSU-AES Special Report 1069:119-136.

Roseberg, R., J. Smith, B. Charlton, and S. Norberg. 2008. Yield and Quality of Teff Forage as a Function of Irrigation Rate at Three Oregon Locations. www.researchgate.net/publication/266467883_Yield_and_Quality_of_Teff_Forage_as_a_Function_of_Varying_Rates_of_Applied_Irrigation_and_Nitrogen

Stallknecht, G.F., K.M. Gilberston, and J.L. Eckhoff. 1993. "Teff: Food Crop for Humans and Animals." J. Janick and J.E. Simon, eds. *New Crops.* Wiley, New York.

Twidwell, E., A. Boe, and D. Casper. 2002. *Teff: A New Annual Forage Grass for South Dakota?* Extension Extra, ExEx8071, South Dakota State University Extension, Brookings, South Dakota.

Published June 2018