GROWING AND HARVESTING TEFF GRASS FOR THE EQUINE MARKETPLACE: OPTIMIZING FOR CARBOHYDRATES, QUALITY AND YIELD.

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ABSTRACT

The demand for low non-structural carbohydrate (NSC) horse hay is growing due to increased prevalence of equine metabolic disease and the associated risk of laminitis. Teff (*Eragrostis teff* Zucc.) has been identified as an excellent forage for horses that require low NSC diets but growing and harvesting techniques that reduce NSC and increase quality must be refined in order to improve availability, consistency, and horse health outcomes. Eight teff production strategies and environmental factors were examined over three years in the Pacific Northwest as to their effects on the ethanol soluble carbohydrates (ESC), water-soluble carbohydrates (WSC), acid detergent fiber (ADF), neutral detergent fiber (NDF, lignin, crude protein, yield and digestible energy of teff hay. Statistical analysis revealed significant effects of nitrogen fertilization, stage of maturity, cutting number, variety, and time of day harvested. Cutting height, diurnal temperature fluctuations on harvest day, and growing degree days had less effect on the NSC of teff grass harvested for hay. Generally, as nitrogen fertilization increased, NSC decreased ($P<0.0001$) while advancing stages of maturity increased NSC ($P<0.0001$). Second cutting teff across multiple studies showed lower NSC values than first cutting ($P<0.0001$). In the teff variety trial, significant differences between NSC values across four varieties indicate selection potential for lower NSC teff. The Time of Day harvested showed PM cuttings with higher NSC values in all years ($P<0.0001$), but no variation in AM and NOON which increases the window of opportunity for growers. Digestible energy increased with higher levels of nitrogen application ($P<0.0001$), decreased with advancing stage of maturity ($P<0.0001$), and was highest for first compared to second cutting ($P<0.0001$). In summary, for teff to produce the highest possible quality and lowest NSC the crop should be fertilized at approximately 60 LB/A before each cutting, harvested before noon, and at early heading stage of maturity. Results from these studies illustrate teff's unique ability to meet the nutritional needs of horses while diversifying crop rotations for hay growers.

Key Words: teff grass, low carbohydrate hay, water soluble carbohydrates, ethanol soluble carbohydrates, equine metabolic syndrome, laminitis, nitrogen fertilization, maturity, yield, cutting number, time of day harvested, digestible energy, crude protein, warm-season

WHAT IS TEFF GRASS?

Teff grass is an annual, warm-season bunchgrass with shallow roots, fine stems, and an open panicle seed head. Teff is considered an ancient grain with historical mention dating back as early as 4,000 BC in Eastern Africa. Today, it maintains cultural and economic importance in Ethiopia where the seed is harvested to make a sourdough like flatbread called injera. Varieties

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have been developed for livestock forage around the globe including Africa, Australia and in the United States. In the United States, teff is considered palatable for all species with surprisingly high nutrient density compared to other summer annuals and even some perennial forage grasses.

Teff grass grows well in many irrigated regions of the western U.S. where summer temperatures increase rapidly in spring, growing seasons are long, and risk of fall frost is low. Planting occurs in late May or early June with first harvest just 40-45 days later. Most operations can expect a minimum of two cuttings (maximum of three cuttings) and up to 5-6 tons per acre under ideal conditions (Roseberg et al., 2005). As a summer annual, teff works well with rotations of early season, forage harvested winter annual cereals (i.e. triticale, barley, wheat, oats, garlic). Due to teff's rapid growth within the hottest months of the year, it may be planted after first cutting alfalfa or timothy if those stands were being taken out. Teff has also been successfully intercropped with alfalfa or timothy hay resulting in excellent forage quality and yield.

Warm season teff grass is unique, compared to common cool season grasses (i.e. timothy, orchardgrass, and fescues), due the way that the plant metabolizes and stores energy. Teff utilizes the C4-dicarboxylic acid cycle of carbon fixation which has helped the plant conserve water and recycle carbon in extremely hot climates of eastern Africa. C4 plants, like teff, tend to store energy in the form of sucrose and starch which are self-limiting. Cool season C3 grasses, using the Calvin cycle of carbon fixation, have the potential to store large amounts of energy in the form of fructans. These fructans, along with other simple carbohydrates, tend to accumulate in times of rapid growth and/or stress such as spring and fall. It is teff's inability to accumulate high levels of fructans that interests the equine community.

The unique carbohydrate metabolism of teff grass has the potential to help thousands of horses across the United States- preventing and treating many NSC sensitive diseases. For this purpose, NSC will be used to describe all reducing sugars (glucose and fructose), non-reducing sugars (sucrose), their oligosaccharides, fructans (aka fructosans), and starches as first described by Smith in 1969 (White, 1973). In forage analytical chemistry, these carbohydrate factions are measured as water soluble carbohydrates (WSC), ethanol soluble carbohydrates (ESC), and starch percentages. These carbohydrate fractions are used for energy metabolism, transport and storage in all plants to varying degrees, but each grass species is unique in its non-structural carbohydrate profile (Jensen et al., 2014). Teff is especially unique compared to other common grasses grown for horses including timothy, orchardgrass, fescues and bluegrass.

ADVANTAGES OF TEFF GRASS TO WESTERN HAY GROWERS

Increased teff hay production could positively impact western forage growers by providing a new, high margin niche market, offering an alternative mid-summer crop option, and addressing rising environmental concerns. The greatest potential market for increased teff production today is the equestrian market. Of the >115,300 horses in Oregon, Washington, and Idaho alone, up to 20% of the equine population could benefit from low NSC teff grass hay which would require over 462,930 U.S. tons per year with a return of $111.1 million to the PNW hay industry (Kilby, 2007; Geor & Harris, 2009). This value was estimated using $240 per U.S. ton which was based on median price of teff sold by PNW growers between 2015 and 2018.

Options for mid-summer crop rotations are few, but teff flourishes in the summer heat and the potential financial return for farmers is greater than other summer rotation crops. For example, in the timothy-rich Kittitas Valley of Central Washington, sudangrass is the most common summer annual used in rotations. Sudangrass haymaking is more difficult, and it is sold primarily to overseas markets where prices are unpredictable. In 2017, farmers were able to produce 3.5 TDM/A of sudangrass with a market high of $170 per ton. Teff grass in comparison will yield over 4 TDM/A with a domestic price of $250 per ton. In addition, nitrogen inputs are lower for teff. Compared to 70 LB/A for sudangrass, teff grass can save regional growers 20 LBS/A or an estimated $10 per acre in nitrogen. That is a net gain of $415 per acre. These regional PNW sudangrass calculations will fluctuate annually with overseas prices, but we hypothesize that local teff markets will consistently yield higher profits. Lifetime dietary changes for diseased horses will stabilize the teff market as it grows and reward growers for annual rotations of low NSC teff.

As a warm-season, drought resistant plant, teff addresses multiple problems of climate change while also addressing the challenging economic environment for farmers. First, inputs are relatively low- saving farmers the cost of fertilizer, water, pest control, fuel and labor. Roseberg 15 et al. (2018) determined that significantly less nutrient and water inputs are required to produce high quality teff grass hay compared to forages like timothy, orchardgrass and alfalfa. At the recommended 50 LBS/A, teff requires approximately half of the nitrogen required for these more traditional horse hays (Roseberg et al., 2018). Miller (2010) and Davison (2011) report teff rain plus irrigation requirements are 50-70% of alfalfa's water requirement at approximately 24 inches. More sophisticated water response parameters were produced by Roseberg et al. (2018). They standardized irrigation plus rainfall as a percentage of the area's evapotranspiration rate known as Relative Applied Irrigation Number (RAIN). They compared RAIN values to teff's modified yield (RFV*yield) and showed that RAIN above 0.5-0.6 was of no added benefit to the crop. These low RAIN values will be useful to producing consistently high quality teff forage across the country, but, to date, no research has examined water effects on teff NSC. Reports of insect damage in teff monocultures are rare, so currently, insecticide use is minimal. Teff's greatest pest is weeds. Some herbicide use is recommended before and after planting, but herbicides can be minimized with appropriate time of seeding and frequent irrigation within the first two weeks. Lastly, teff is very sensitive to freezing temperatures making it a true annual requiring no year-end chemical kills after temperatures drop to 32 degrees Fahrenheit. Mechanical inputs are also. Its shallow root system requires little to no primary tillage conserving soil moisture, fuel, and labor. Its versatility makes teff an excellent "emergency" forage option for farmers experiencing weather delays or after crop failures.

THE SIGNIFICANCE OF TEFF HAY IN EQUINE NUTRITION

Teff grass has been recognized as an excellent hay option for many types of horses by nutritionists, veterinarians, and owner/managers. Quality teff grass hay is palatable, safe, and meets most nutrient requirements for mature horses, but its greatest promise to the equine community is its carbohydrate metabolism discussed previously. The principal effects of equine diets low in simple carbohydrates is to both prevent and treat the occurrence of equine laminitis- a devastating condition of the equine hoof where the sensitive laminae responsible for

suspending the horses' coffin bone inside the hoof capsule becomes inflamed and compromised. In severe cases of laminitis, the coffin bone may drop and/or rotate resulting in founder which is extremely painful if not debilitating. Horses suffering from chronic laminitis and/or founder are often retired from work or euthanized. Today, laminitis is the second most common reason for equine euthanasia and may affect anywhere from 1.5-24% of the equine population (Wylie et al., 2011). If just 1.5% of the equine demographic develops laminitis with additional costs of $2,400 annually per animal, this one disease alone costs the equine industry over $324 million per year (Moyer, 2001). However, these estimates are outdated and extremely conservative. More than likely, the cost to the industry in veterinary bills, therapeutic products, feeds and supplements to treat horses with laminitis in the U.S. is in the billions of dollars. Horses suffering from metabolic ailments such as insulin resistance, Equine Metabolic Syndrome, Cushings, and obesity are at very high risk for laminitis. That is why these diseases are often mentioned when discussing low NSC diets.

Equine practitioners agree that 1 in 5 horses may be at risk for laminitis today, and this number is increasing. A multitude of factors have contributed to an increased number of horses at risk for laminitis; urbanization of the horse, lack of exercise, improved nutrition, better diagnosis from veterinarians, as well as increased understanding of metabolic diseases and their relationships to diet. A total equine diet (hay, pasture, and concentrates) containing less than 10% non-structural carbohydrates (NSC; % WSC + % Starch on dry matter basis) was first suggested by equine researchers who study Equine Metabolic Syndrome and laminitis in horses and this value has propagated throughout equestrian media over the last decade (Frank, 2011; Geor, 2013). The demand for low carbohydrate hays less than 10% NSC is increasing significantly, but, unfortunately, remain difficult for horse owners to source. It will be progressively more and more advantageous that the forage industry respond to the growing demand by researching, producing, and testing hays low in simple carbohydrates.

TEFF GRASS RESEARCH 2016-2018

Research was conducted in the Pacific Northwest (PNW) over three growing seasons in order to understand key factors affecting carbohydrate, digestible energy, quality and yield values of teff grass specifically for the purpose of feeding overweight, diseased horses. Multiple on-farm fields and on-station plots were planted, harvested and analyzed to quantify the effects of nitrogen fertilization, maturity at harvest, time-of-day harvested, cutting height, cutting number, temperature, and variety. Near infrared spectroscopy, standardized to grass hay, was used to determine protein, carbohydrates, and lignin of teff grass samples. Values tested focused on non-structural carbohydrates as measured by water soluble carbohydrates (%), ethanol soluble carbohydrates (%), fructans (%). Structural carbohydrates as measured by neutral detergent fiber (%) and acid detergent fiber (%) were also compared in order to calculate digestible energy. Table 1 shows a summary of all teff nutrient data collected over 4 years compared to national and regional mixed grass hay averages. The results support the hypothesis that teff grass, grown under a range of conditions, will average lower in NSCs and higher in quality compared to other grasses grown for horse hay.

Table 1. Pacific Northwest teff grass carbohydrate and quality means compared to national mixed grass and Pacific Northwest cool-season grass means and National Research Council: Nutrient Requirements of Horses 2007.

PNW Teff Grass	Nutrient	Unit	Horse Requirement	National Grass Hay	PNW Cool-Season Grass
4-year mean			500kg in Light Work	Equi-Analytical mean†	4-year mean unpublished data‡
n=1,136			*Intake=2% BW*	*n=66,633*	*n= 324*
11.53	Crude protein	%	9.3	10.89	...
2.09	DE (NRC, 1989)	Mcal kg^{-1}	2.00	2.00	...
0.39	Calcium	%	0.4	0.49	...
0.24	Phosphorus	%	0.24	0.24	...
36.48	ADF	%	36-40*	38.76	...
61.27	aNDF	%	58-62*	62.42	...
6.80	WSC	%	<8*	11.44	10.55
5.61	ESC	%	<6*	7.05	8.1
1.19	Fructan (WSC-ESC), %	%	2*	4.39	2.45

*Recommended values not found in literature review.
† Equi-Analytical Laboratories, 2018
‡Bohle, Unpublished data, 2012
DE, digestible energy; ADF, acid detergent fiber; aNDF, neutral detergent fiber; WSC, water soluble carbohydrates; ESC, ethanol soluble carbohydrates.

Nitrogen Fertilization

A primary factor found to affect carbohydrate and quality values of teff grass is the amount of available nitrogen for each cutting. Results from two on-station, Randomized Complete Block Design research plots across two years indicate a strong relationship between nitrogen fertilization levels at planting and the WSC, ESC, ADF, aNDF, crude protein, digestible energy and yield of the teff hay at harvest.

Both first and second cuttings were fertilized with either 0, 30, 60 or 90 LBS/A equivalent of nitrogen. Increasing levels of nitrogen fertilization had the effect of decreasing NSCs and structural carbohydrates while increasing protein, digestible energy and yield. These results suggest that the optimal treatment for teff grown for horse hay is to fertilize each cutting with approximately 60 LB/A of nitrogen and no more. At this level, profit margins are optimized by 1) moderating inputs, 2) balancing lower NSC with higher quality values (i.e. protein and

energy) thereby appealing to consumers, and 3) decreasing the risk of lodging. There is evidence to suggest that nitrogen fertilization levels trump other growing and harvesting factors affecting the NSC levels, so its importance cannot be understated.

Research results correspond neatly to generally accepted nitrogen recommendations set forth by earlier teff research. Fertilization below the recommended 50 LB/A (Norberg et al., 2009) resulted in significantly higher NSC values compared to nitrogen fertilization over 50 LB/A. These results support the hypothesis that nutrient stressed plants will produce less biomass and accumulate greater amounts of NSCs compared to un-stressed plants with plenty of available nutrients.

Maturity at Harvest

The stage of plant maturity at harvest is an important consideration in the production of high quality, low NSC teff hay. Teff plots harvested for research at boot stage, early heading, and late heading maturity stages (approximately 10 days between each harvest) showed a significant NSC increase with each advancing stage of maturity across both first and second cutting. The exact biological cause of this trend is unknown, but generally the younger the plant, the faster the rate of growth, and the lower the NSC value. If the lowest NSC value teff hay were the only goal, teff grass grown for horse hay would be cut at the boot stage. However, teff grass cut at late heading was significantly lower in digestible energy and higher in yield compared to boot and early heading stages. Therefore, when low NSC, lower calorie, higher yield teff is desired, the early heading (approximately 20% heading) stage of maturity is recommended for harvesting.

Time of Day Harvested

Research suggests that many factors influence NSC levels of teff grass at harvest. However, the time of day that the plant is cut may be one of the most important for a grower to consider. Research fields, grown and harvested over two years in a Randomized Complete Block Design, were cut at 6am, noon and 6pm to compare carbohydrate and quality values. Results show that afternoon harvests of teff had significantly higher NSC values compared to morning and noon harvest times. However, early morning and noon harvests were not significantly different from each other. These results suggest that cutting teff grass before noon will dramatically increase the potential for teff hay below 10% NSC. It is recommended that fields be cut as early in the day as possible and that harvesting ceases at noon to retain low NSC values.

Cutting Number

In the Pacific Northwest, most agricultural regions will support two cuttings of teff hay. In some regions with high Growing Degree Days and low frost risk, three cuttings are possible. Across all Oregon and Washington research plots between 2016 and 2018, teff was grown for two cuttings. Research results show that NSC values were significantly lower for second cutting likely due to consistently warmer temperatures and faster plant growth. There was only one location where second cutting did not contain lower NSC than first cutting, and that occurred where nitrogen fertilization across each cutting was inconsistent. This was yet another reminder that proper fertilization for both first and second cutting is necessary to produce consistently low NSC teff

hay. In addition, crude protein, digestible energy, and yield values were lower for second cutting. There are nutritional advantages to lower crude protein and digestible energy values of second cutting as the majority of the targeted equine demographic are overweight. Second cutting lower yields could be offset by higher retail prices when NSC and digestible energy values fall within preferred ranges for diseased horses.

Cutting Height

The cutting height at harvest was compared across teff plots showing no significant NSC differences between 1", 2", 3" and 4" cutting heights. At this time there is no evidence to support that lower cutting heights will increase NSC values. However, severely low cutting heights increases the chance of "burn" and plant death during hot temperatures resulting in lower yields. Our recommendations are not to cut less than 3" to promote rapid regrowth and boost higher successive cutting yields.

Teff Variety

Several forage specific teff grass seed varieties exist in both coated or uncoated seed forms but choosing a teff variety to plant will depend on local availability and cost. Four common brands of forage teff grass were planted in 2017 at a Grants Pass, Oregon research location. The results of the study showed significant differences between the NSC values of the four varieties, but no significant differences between crude protein or yield were found. These results suggest the potential for identification and proliferation of teff accessions with low NSC. Though encouraging, additional research is necessary to determine if the results are repeatable across a variety of climate regions. Therefore, a specific variety cannot be recommended at this time.

ADDITIONAL AGRONOMIC INFORMATION

Weed Control

Minimizing the presence of weeds in teff grass baled for horse hay is critical for consumer acceptance. Practices that limit time between planting and emergence, such as proper timing of planting and frequent, yet light watering, significantly decreases weed pressure. An herbicide mixture of dicamba (3,6-dichloromethoxybenzoic acid) and 2,4-D (2,4-Dichlorophenoxyacetic acid) known as Latigo® (Helena Agri-Enterprises, LLC, Collierville, TN, USA) is the only chemical labeled for teff grass. It should be applied within the first two weeks of growth or before the teff plant reaching six inches tall.

Irrigation

Research has not yet been conducted to determine how water quantity or frequency influences the carbohydrate values of teff grass. However, in 2017, teff grass research plots observed under severe water stress between planting and first cutting, resulted in abnormally low yields and high NSC values. More than likely, teff grown under water stress will average higher in NSC.

It is recommended at this time, that teff grass grown for low NSC horse hay only be grown under irrigation. Observations across multiple PNW stands showed poor yields, high weed pressure, and high NSC teff on non-irrigated systems.

Curing and Baling

In order to produce the highest quality, aesthetic teff hay, tedding/raking within three hours of harvest followed by 1-3 tedding operations per day for 3-4 days is recommended. Minimizing days between harvest and baling in addition to tarping or shed storing will help preserve color and improve quality which increases consumer satisfaction and may increase retail prices. Most equestrians prefer teff in small 2-3 string bales between 60-100 pounds. However, large bales or round bales are marketable in some areas.

Testing for Carbohydrates

Testing teff hay for water soluble carbohydrates (%), ethanol soluble carbohydrates (%) and starch (%) is required to determine NSC value and market your forage to horse owners. The proper procedure for sampling dry forage will not be discussed here, but is important for accurate, representative results. Resources for good coring and testing techniques can be found at https://extension.oregonstate.edu/crop-production/pastures-forages/testing-hay and http://www.extension.uidaho.edu/publishing/pdf/CIS/CIS1178.pdf. Most importantly, keep fields and cuttings separate from one another when sampling and submitting any forage for testing. Carbohydrate results of each field and cutting may vary due to the many factors verified in this research and discussed above.

There are multiple laboratories capable of testing forage carbohydrates, but make sure they can test for WSC, ESC as well as starch, either via wet chemistry or near-infrared spectroscopy (NIRS). Labs that offer horse digestible energy (DE; Mcal/lb) as well as a basic mineral package (i.e. calcium, phosphorus, iron, copper, zinc, and selenium) are useful to horse owners and nutritionists but are not mandatory. Labs vary greatly on their carbohydrate testing methods. Therefore, laboratory forage ratings can be found at https://www.foragetesting.org/certification to give growers and consumers' confidence in reports. Nitrate testing may also be appropriate as high nitrate teff has been found inconsistently in the PNW. Nitrate poisoning is not as common in horses as it is in cattle but may negatively affect equine reproduction and young horse growth at high levels.

Carbohydrate Results and Marketing

The exact definition of "low carb" horse hay has yet to be determined by state and federal regulating bodies. Whether hay has been analyzed using NIRS or wet chemistry, the NSC value is calculated from the dry matter column. Teff hay under an NSC value (WSC% + Starch%) of 10.0% are highly valued in the equine marketplace and demand the highest prices. However, most equine nutrition researchers agree that 13.0% NSC or less are effective for the treatment and prevention of metabolic disease in horses so test results between 10.0-13.0% NSC are considered appropriate for this demographic. NSC values above 13.0% and below 16.0% are higher than the national average for grass hays but may still be marketable to horse owners looking for good quality grass hay to feed healthy horses. Finally, NSC values above 16.0% NSC are considered "high carb" and should not be marketed or sold to horse owners with diseased horses. These four categories of teff, summarized in Table 2, offer growers a perspective on the equine marketplace and, thereby, goals for future teff production. Table 2 should be used to

compare the effects of production techniques from cutting to cutting, field to field, and year to year. To do so, dedication to carbohydrate forage testing is mandatory.

Table 2. Teff non-structural carbohydrates as indicators of consumer approval

Best	Acceptable	Appropriate for Healthy Horses Only	Unacceptable
<10.0%	10.1-13.0%	13.1-16.0%	>16.1%

CONCLUSION

Producing teff grass for the horse hay market will require a new way of thinking about hay quality as horse owners prioritize NSC values over other traits. However, adaptation of these low NSC techniques offer great profit opportunity for growers especially when compared to other common summer annuals. The goal of this research was to provide guidelines to produce high quality teff hay with NSC values consistently below 10.0%. Out of the many growing and harvesting factors studied over three years in the PNW, the most effective and practical techniques for low NSC teff are 1) fertilize each cutting appropriately, 2) harvest before noon, and 3) harvest at early heading (approximately 20-30% of the field is heading out). Table 3 will help growers understand the relative importance of each production factor according to recommendations informed by this research. Teff producers should consider primary factors carefully for optimal carbohydrate and quality results leaving tertiary factors for refinement over time. Opportunity for success is possible by following these three simple guidelines. Hopefully,

Table 3. Hierarchy of factors for producing teff hay with lowest possible NSC.

Primary factors	Secondary factors	Tertiary factors
Nitrogen Fertilization	Cutting Number	Cutting Height
Time of Day Harvested	Teff Variety	Growing Degree Days
Stage of Maturity	Location	Diurnal Fluctuation in Temperature on Harvest Day

in the future, new teff research will identify varieties with predictably lower NSC tendencies that grow well in a range of agricultural climates and conditions. Until then, optimal teff growing locations will include reliable irrigation, temperatures over 90 degrees Fahrenheit (37.8 degrees Celsius), high levels of solar radiation and nutrient rich soils. Horse owners will respond to improved quality and availability by paying premium prices, benefiting both the equine and forage industries. However, it is very important that any and all teff harvests be analyzed for

NSC values by an approved forage testing laboratory. Communication of these values is integral to its marketability. Finally, and most importantly, teff will increase the diversity of crop rotations available to western hay growers as climate and economic conditions change.

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