Nutritional Considerations of Grass Seed Straw for Beef Cattle

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Introduction

The vast majority of U.S. grass seed production occurs in the states of Oregon, Washington, and Idaho. These states produce approximately 95% of all Kentucky bluegrass (*Poa pratensis* L.) grown in the United States. In addition, Oregon produces approximately 96% of all ryegrass and orchardgrass (*Dactylis glomerata* L.) seed and 87% of all fescue seed harvested in the United States (2007 Census of Agriculture; USDA, National Agricultural Statistics Service). A byproduct of grass seed production is straw. Using 2007 Census of Agriculture data for acres harvested and grass straw production data (Oregon State University, unpublished data), we approximate that almost 1,900,000 tons of grass seed straw is potentially available annually in Oregon (85%), Idaho (7%), and Washington (8%).

While grass seed straw is generally a low-quality forage source, the ruminant animal and its microbial population can utilize it with proper nutritional management. Also, straw is a major feed source for ruminants in Third World countries (Van Soest, 1994), yet in the United States, it is estimated that less than 1% of the total straw supply is used as a forage resource (Han, 1978).

Nutritional Quality of Grass Straw for Ruminants

Comparison to Other Low-Quality Forages. In general, grass seed straw is comparable in nutritional quality, on a crude protein (**CP**) basis, to most meadow hays and superior to most cereal grain straws (Table 1). However, there are usually CP differences between species of grass seed straw. Based on the average CP concentration of grass seed straw data presented in Table 1, a nutritional ranking of grass seed straw species is provided in Table 2. Briefly, bluegrass is the highest CP followed by perennial ryegrass, tall fescue, bentgrass, orchardgrass, other fescues (not including tall fescue), and annual ryegrass (Lolium multiforum).

As with CP, total digestible nutrients (**TDN**) can vary with species of grass seed straw. Table 1 lists two values for TDN. The first, TDNa, is based on a formula routinely used to estimate TDN for all classes of forages based on the acid detergent fiber (**ADF**) concentration. This equation, 88.9 – (0.79*ADF%), was developed primarily for legumes and grasses (Holland and Kezar, 1995) and often gives TDN values that over predict performance compared with that actually observed by cattle consuming low-quality forages like grass seed straw. The second equation, 71.7 – (0.49*ADF%), was developed specifically for low-quality straws (Davis et al., 2002). This equation provides TDN values that are roughly 7 to 8% less than those calculated using TDNa and, consequently, more accurately predicts performance of cattle consuming low-quality forages. Therefore, we suggest using TDNb, rather than TDNa, to evaluate cattle diets based on grass seed straw.

Variety differences and harvest conditions can affect grass seed straw quality and, thereby, alter the values reported in Table 1. In addition, age-of-stand of the grass seed crop (greater than five years) has been anecdotally observed to greatly reduce quality of the resulting seed crop residue. Consequently, grass seed straw should be tested for forage quality by a certified lab prior to purchase and/or use as a forage source.

Comparison to Animal Requirements. In most instances, feeding grass seed straw as a major component of the diet should only be practiced with rations designed for maintenance of mature bulls and non-lactating, mature cows. The nutritional requirements of various classes and stages of production of cattle are listed in Table 3. Crude protein and TDN requirements are highest for growing animals and lactating cows. When used as the major component of the diet, grass seed straw does not have the digestible CP and/or TDN to support optimal performance in these classes of livestock. Simply stated, beef cattle in high nutrient requirement production stages cannot consume enough grass seed straw to meet nutrient demands (Table 1; NRC, 1984). Also, grass seed straw will normally require some form of supplementation, usually CP and energy, to be used efficiently by mature bulls and non-lactating, mature cows.

Alkaloid Concerns. Some species of grass seed straw contain alkaloids produced by endophyte fungus, which can cause animal health and/or neurological concerns if the alkaloids are present in high concentrations. Consequently, concern over alkaloid concentration in grass seed straw has hampered its use as a forage source for ruminants. The two most common species of grass seed straw that can contain high levels of alkaloids are tall fescue and perennial ryegrass. The alkaloid most often associated with tall fescue straw is ergovaline while perennial ryegrass straw can have ergovaline and lolitrem B (Stamm, 1992).

Alkaloids in tall fescue have caused fescue foot, summer syndrome or fescue toxicosis, fat necrosis, agalactia (decreased milk production), and reproductive problems in ruminants consuming tall fescue (Hemken and Bush, 1989; Hemken et al., 1984; Stuedemann and Hoveland, 1988). The aforementioned research was conducted with tall fescue hay or pasture – not tall fescue straw. There has been limited data evaluating the affect of increasing alkaloid (ergovaline) concentration in tall fescue straw on physiological response variables and animal performance in ruminants (Stamm et al., 1994). Stamm et al. (1994) offered tall fescue straw containing increasing levels of ergovaline (up to 475 ppb) to beef cattle and reported no health problems, no negative affects on dry matter intake or nutrient digestibility, and no reduction in animal performance. However, spring-calving beef cows consuming approximately 400 ppb tall fescue straw during the winter of 2001-2002 in Eastern Oregon demonstrated clinical symptoms of fescue toxicosis (D. Bohnert, Eastern Oregon Agricultural Research Center files). Producers on three ranches used tall fescue straw as a forage source during a period of extended cold weather (two weeks of constant temperatures below 32ºF). It is believed that decreased peripheral blood flow to the extremities caused many of the cows to suffer severe frostbite to their feet, resulting in the sloughing of their hooves. Approximately 600 cows had to be destroyed due to this incident. Total long-term losses from the three ranches approached an estimated 1.25 million dollars.

Perennial ryegrass can contain ergovaline (an alkaloid present in tall fescue) in addition to lolitrem B. Stamm (1992) reported the ergovaline concentration of 136 samples of perennial ryegrass and 122 samples of tall fescue straw. She noted that the mean concentration was 86 ppb for tall fescue samples and 214 ppb for perennial ryegrass samples. Also, she stated that of the tall fescue fields sampled, 14% had ergovaline levels greater than 200 ppb while 42% of perennial ryegrass fields contained ergovaline levels greater than 200 ppb. Therefore, perennial ryegrass can cause health disorders normally associated with tall fescue, as well as a neurological disorder associated with consumption of lolitrem B called “Perennial Ryegrass Staggers”. This disorder normally manifests itself in ruminants after consuming lolitrem B infected perennial ryegrass for 7 to 14 days. Clinical symptoms include incoordination, staggering, tremors, head shaking, and collapse (Aldrich-Markham and Pirelli, 1995; Cheeke, 1995). Animals demonstrating clinical symptoms should be removed from the causative feed source, whereby symptoms normally subside in 2 to 14 days.

As noted with tall fescue straw, there is limited information available concerning the feeding of perennial ryegrass straw with increasing levels of lolitrem B to ruminants (Fisher, 2004). Fisher (2004) noted no adverse effects on nutrient intake and digestibility, physiological response variables, animal performance, or milk production in ruminants consuming perennial ryegrass straw with increasing lolitrem B concentration (< 100 to 2017 ppb). However, Fisher (2004) did report that 13 of 24 (54%) cows consuming perennial ryegrass straw containing 2017 ppb lolitrem B exhibited clinical symptoms of perennial ryegrass staggers.

Management Recommendations Concerning Alkaloids. Grass seed straws, primarily tall fescue and perennial ryegrass, are often purchased and fed to livestock without knowledge of the concentration of ergovaline or lolitrem B present in them. This increases the potential for incidences of fescue toxicity and/or perennial ryegrass staggers. Consequently, the first step in feeding potentially alkaloid infected grass seed straw is to have it tested for alkaloids. It should be noted that perennial ryegrass straw should be tested for lolitrem B and ergovaline. If you would like assistance deciding on what alkaloid test(s) are appropriate, and/or would like to send samples in for analysis, you can call Oregon State University's Endophyte Testing Laboratory at 541-737-2872.

Once the concentration of alkaloids in a grass seed straw is known, proper nutritional management can be carried out. Table 4 lists the estimated threshold levels of ergovaline and lolitrem B in the diet of cattle and sheep. These values can be used to minimize the chance of causing clinical symptoms of fescue toxicosis and perennial ryegrass staggers when feeding alkaloid infected grass seed straw. The threshold levels for ergovaline may vary because environmental factors and stress also play a role in the development of clinical disease. Specifically, the threshold levels for ergovaline decrease in colder weather. This is especially important to remember when feeding grass seed straw during periods of severe weather (freezing temperatures and snow).

Grass seed straws that contain alkaloid (ergovaline and/or lolitrem B) concentrations above the recommended threshold levels can be effectively used as forage resources. However, this will require increased nutritional management and diligent observation of livestock consuming the residue. The most common and effective means of feeding alkaloid infected grass seed straw is to blend it with non-or low-alkaloid infected forage. The "rule of thumb" is to use a 50:50 mix of infected and non- or low-alkaloid infected forage. This will normally be sufficient to eliminate, or greatly decrease, the chance of developing symptoms of alkaloid toxicity. A modified type of mixing or blending practice is to provide the high-alkaloid straw on a separate day from the low-alkaloid or alkaloid-free forage. The simplest example would be to provide high-alkaloid straw every-other-day with hay or low-alkaloid straw provided on the alternate days. This serves the same purpose as diluting the high-alkaloid straw by 50%. In addition to reducing the overall alkaloid intake, feeding straw on alternate days has the following additional benefits compared with a “hay mix” every day: 1) less work, and potential human error, feeding one forage source per day compared with two; 2) more consistent intake of both forage sources due to minimization of sorting and the “boss” effect caused by dominant animals in the herd or flock; and 3) better control over alkaloid intake, especially if alkaloid concentration and intake thresholds are known. For instance, it may be possible to provide the high-alkaloid straw two out of three days and still maintain alkaloid intake below threshold levels.

There has been some success with feed additives that minimize the effects of grass seed straw with high concentrations of ergovaline. The primary supplements proposed to ameliorate the effects of high concentrations of ergovaline (resulting in fescue toxicosis) include Integral (Alltech Animal Nutrition; Nicholasville, KY), Endo-Fighter (ADM Alliance Nutrition; Quincy, IL), and Tasco® (Acadian Seaplants Ltd.).

Integral supplementation has been shown to increase milk production and serum prolactin in beef cattle consuming high alkaloid tall fescue straw (Merrill et al., 2007) and improve weight gain of cows and calves grazing endophyte-infected tall fescue (Ely et al., 2006).

Endo-Fighter is “specifically formulated for cattle grazing fescue pasture or consuming fescue hay that is infected with the fescue toxin. The claims of the product include increased cow and calf gains, increased grazing time, and improved hair coat by cattle grazing endophyte-infected fescue pastures.

Tasco is a water-soluble extract of the brown seaweed *Ascophyllum nodosum* harvested off the coast of Nova Scotia and prepared by a proprietary process. Benefits of using the product have included improved hair coat and immune function in cattle consuming infected tall fescue, increased antioxidant activity in sheep and cattle, increased marbling and USDA quality grade, and increased shelf-life of meat from cattle grazing fescue pastures (Allen et al., 2001).

The data available for each of the aforementioned products suggests they are effective in reducing some of the symptoms of fescue toxicosis. However, they should not be considered a “magic bullet” to solve all of the problems associated with fescue toxicosis. Instead, they should be considered as tools that can be used in developing nutritional management plans to help producers use a forage resource in a safe and effective manner. Knowledge of alkaloid concentration, and associated threshold level(s), allows livestock producers, extension agents, and/or nutritionists to make safe decisions concerning the feeding of alkaloid-infected grass-seed residues.

Methods to Improve Nutritional Quality

The major advantage of ruminants over other livestock species is their ability to effectively use low-quality roughages such as grass seed straw. Beef cattle producers have a number of management alternatives that can be used to enhance the ability of ruminants to use grass seed straw. These include supplementation with CP, physical and chemical modification of grass seed straw, and use of fibrolytic enzymes.

Crude Protein Supplementation. Protein is normally the first limiting nutrient in grass seed straw diets and, therefore, is usually the most beneficial nutrient to supplement when an adequate quantity of grass seed straw is available. Because protein is required by the animal (for normal growth and production) and ruminal microorganisms (for microbial growth and ruminal digestion), a protein deficiency can severely depress animal performance and productivity. Most responses to protein supplementation are observed when the CP content of the grass seed straw is less than 6 to 7% (dry matter basis). This was illustrated in studies by Horney et al. (1996), Currier et al. (2002), and Bohnert et al. (2003). In each of these studies, CP supplementation of ruminants consuming grass seed straw containing less than 5% CP resulted in increased total dry matter intake and nutrient digestibility compared with no CP supplementation. Therefore, CP supplementation not only adds CP to the basal diet, but can also improve the total intake and TDN available to ruminants consuming grass seed straw.

Physical Modification of Grass Seed Straw. Physical modification (grinding and pelleting) has been shown to increase intake of forage while decreasing digestibility because of a faster passage rate through the gastrointestinal tract (King et al., 1963; Barton et al., 1992; Merchen and Bourquin, 1994). Barton et al. (1992) noted that steers consuming pelleted tall fescue straw consumed approximately 21% greater straw compared with steers consuming long stem tall fescue straw. However, dry matter digestibility was decreased approximately 10% for pelleted straw compared with long stem straw (45% vs 50%); nevertheless, the increased intake of pelleted tall fescue straw resulted in approximately 9% greater total digestion of nutrients compared with long stem straw. Based on these results, physical modification of grass seed straw improves the availability of nutrients for use by the ruminant animal.

Chemical Modification of Grass Seed Straw. Application of caustic chemicals has been observed to enhance ruminal degradability of low quality forages

(Berger et al., 1994). Of the compounds investigated, hydroxides (Na and Ca) and anhydrous ammonia have been found to be most effective. Particularly in North America, anhydrous ammonia is the chemical of choice as it is effective and available in almost any rural community from fertilizer suppliers. In addition, application of anhydrous ammonia to low-quality forage provides a supplemental source of non-protein nitrogen that increases the CP content of the straw. Application of 2.5 to 3.5% anhydrous ammonia is the economic optimum level of ammoniation (Sundstol and Coxworth, 1984); however, our research group found that 3% ammoniation of bluegrass was not as effective as 5% (Szasz et al. 2001). Van Soest et al. (1984) suggested that variability in effectiveness is a problem with ammonia treatment. Differences in bale density, moisture content, and ammonia level could account for much of the variation in ammoniation response. Grass seed straw is typically harvested during an extremely arid time of the summer and usually contains less than 8 percentage units of moisture. This low level of moisture will likely negatively affect ammoniation response as ammonia requires moisture to swell and effectively alter the plant cell wall. Grove et al. (2002) reported that 3% ammoniation of dry (92% dry matter), high density bluegrass straw bales was largely ineffective, however 3% ammoniation of moist (83% dry matter) bales resulted in a substantial improvement in ruminal in situ degradability. These data suggest that grass seed straw harvested with the intention of ammoniation should be harvested with at least 17% moisture such as that often provided from an over-night dew.

Some studies have also reported improved intake and digestibility of low-quality forage by the addition of exogenous fibrolytic enzymes (Beauchemin et al., 1995). Szasz et al. (2002) observed no benefit from the addition of fibrolytic enzymes when bluegrass straw was fed to growing beef heifers. In theory, exogenous fibrolytic enzymes will have the greatest benefit when the ruminal environment is in someway compromised resulting in less-than-optimal production of ruminal microbial fibrolytic enzymes. Especially when protein supplementation is provided, the ruminal environment within grass straw-fed ruminants is likely to be quite healthy. Current literature does not support the addition of these enzymes to grass straw diets.

Economics of Straw Feeding. The first step in determining if grass seed straw is an economical option for use as a forage source is to calculate the cost of the straw and compare it to other available forage sources on a dry matter basis. Once this is determined, the cost of CP supplementation must be estimated to determine the total cost comparison between the grass seed straw and the alternative forage source. For example, a cattle producer has a cowherd that averages 1,200 pounds and is in the last third of gestation (nutrient requirements listed in Table 3). The forages resources available for purchase include a grass seed straw and a meadow grass hay. In addition, the producer uses alfalfa hay (18% CP; $150/ton; $0.075/pound) as a CP supplement. The grass seed straw has a CP and neutral detergent fiber (**NDF**) concentration of 4.5 and 74%, respectively, and is available for $35/ton ($0.0175/pound). The meadow hay containing 6% CP and 60% NDF is available for $80/ton ($0.04/pound). If we assume the cows will consume 1.6% (19.2 pounds) or 2.0% (24.0 pounds) of body weight per day, respectively, of the grass seed straw or meadow hay (intake estimated as 120/NDF%), feeding grass seed straw will result in a shortage of 0.84 pounds of CP with grass seed straw and 0.26 pounds CP with meadow hay. Therefore, the grass seed straw will require supplementation with 4.7 (0.84/0.18) pounds of alfalfa hay while the meadow hay will require 1.4 (0.26/0.18) pounds of alfalfa hay to eliminate the shortage in CP. The cost of grass seed straw and meadow hay will be $0.336 and $0.960 per day, respectively. Also, alfalfa supplementation will cost $0.352 per day with grass seed straw and $0.105 per day with meadow hay. As a result, the total daily cost of feeding grass seed straw and meadow hay will be $0.688 (0.336 + 0.352) and $1.065 (0.960 + 0.105) per cow, respectively. This equates to approximately $20.64 compared with $31.95 for one month of feeding. Therefore, in this situation, feeding grass seed straw will reduce the monthly feed cost by 35% compared with feeding meadow hay.

The above calculations are pertinent to the consideration of ammoniating grass seed straw. The cost of ammoniation must be compared against the value of the increased energy and protein achieved by ammoniation. Importantly, the cost-benefit of ammoniation should be weighed against the cost of nutrients (energy and protein) provided by supplements (as described above). The cost of ammoniation includes the expense of the anhydrous ammonia, plastic to cover the stack of straw, and a modest expense for labor. The cost of the anhydrous ammonia usually parallels natural gas prices and is typically the most prohibitive of the costs associated with ammoniation. Currently the cost of ammoniation would be $36 to $40 per treated ton and the “rule of thumb” would be that ammoniation increases digestibility (energy content) by 12 percentage units. From a practical standpoint, ammoniation often improves the energy content of grass seed straw to an equivalent of feeder quality alfalfa – assuming good treatment (Carl Hunt, personal communication). Also, a 3% level of ammonia treatment would increase the crude protein content by 5 to 6 percentage units. Again, it is important to weigh this cost and the expected improvement in energy and protein content of the grass straw with the cost of energy and protein supplements available in a given region.

Conclusions

Given the availability of grass seed straw, and its ability to lower the cost of a ration, grass seed straw has the potential to be an economical management tool for most winter-feeding programs. However, it is recommended that when purchasing grass seed straw, a producer obtain a nutrient analysis and determine if the straw can contain toxic levels of alkaloids. If this is determined, it is strongly recommended that the producer have the appropriate test(s) conducted to determine the alkaloid concentration(s) of the grass seed straw. Listed below are a series of questions and recommendations that a ruminant livestock producer should use before feeding grass seed straw.

1) Determine nutritive value (CP, NDF, acid detergent fiber, and TDN) using a certified lab.
2) How does the price of grass seed straw compare with other forage sources? Evaluate cost per ton of dry matter and cost of supplementation, physical modification, and or chemical treatment.
3) What is the species of grass seed straw (tall fescue, perennial ryegrass, bluegrass, etc.) and does it have the potential to contain toxic levels of alkaloids?
4) If the grass seed straw has potential to contain elevated levels of alkaloids, have it tested for ergovaline (tall fescue and perennial ryegrass varieties) and/or lolitrem B (perennial ryegrass varieties).
5) Be aware of the recommended threshold levels for ergovaline and/or lolitrem B.
6) If the grass seed straw is considered acceptable for use, develop a nutritional management plan for its safe and effective use (contact your county agent, extension specialist, or nutritionist for assistance).

References

Aldrich-Markham, S., and G. Pirelli. 1995. Endophyte toxins in grass seed fields and straw: Effects on animals. EM 8598. Oregon State University Extension Service, Corvallis.

Allen, V. G., K. R. Pond, K. E. Sakers, J. P. Fontenot, C. P. Bagley, R. L. Ivy, R. R. Evans, R. E. Schmidt, J. H. Fike, X. Zhang, J. Y. Ayad, C. P. Brown, M. F. Miller, J. L. Montgomery, J. Mahan, D. B. Wester, and C. Melton. 2001. Tasco: Influence of a brown seaweed on antioxidants in forages and livestock – A Review. J. Anim. Sci. 79(E. Suppl.):E21-E31.

Barton, R. K., T. DelCurto, S. D. Brandyberry, M. M. Stamm, and M. R. Horney. 1992. Physical modification and(or) supplementation strategies to improve the nutritive value of tall fescue straw for beef cattle. Proc. West. Sec. Am. Soc. Anim. Sci. 43:544-547.

Beauchemin, K. A., L. M. Rode, and V. J. H. 1995. Fibrolytic enzymes increase fiber digestibility and growth rate of steers fed dry forages. Can. J. Anim. Sci. 75:641-644.

Berger, L. L., G. C. Fahey, Jr., L. D. Bourquin, and E. C. Titgemeyer. 1994. Modification of forage quality after harvest. In Forage quality, evaluation, and utilization. G. C. Fahey, Jr. (Ed.). p 922. American Society of Agronomy, Madison, WI.

Bohnert, D. W., T. DelCurto, A. A. Clark, M. L. Merrill, S. J. Falck, and D. L. Harmon. 2007. Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: Differences in intake and digestibility. Proc. West. Sec. Am. Soc. Anim. Sci. 58:217-220.

Bohnert, D. W., C. S. Schauer, and T. DelCurto. 2002. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: Cow performance and efficiency of nitrogen use in wethers. J. Anim. Sci. 80:1629-1637.

Bohnert, D. W., S. J. Falck, and C. S. Schauer. 2003. Comparison of urea and soybean meal as nitrogen supplements to cool-season, low-quality forage: II. Daily and alternate day supplementation effects on efficiency of nitrogen use in lambs. J. Anim. Sci. 81(Suppl. 1):92.

Bohnert, D. W., R. L. Sheley, S. J. Falck, and A. A. Nyman. 2006. Use of Russian knapweed as a protein supplement for beef cows consuming low-quality forage. Proc. West. Sect. Amer. Soc. Anim. Sci. 57:235-237.

Cheeke, P. R. 1995. Endogenous Toxins and mycotoxins in forage grasses and their effects on livestock. J. Anim. Sci. 73:909-918.

Church, D. C., and K. A. Champe. 1980. Digestibility of untreated and hydroxide-treated annual ryegrass straw. J. Anim. Sci. 51:20-24.

Church, D. C., and A. Santos. 1981. Effect of graded levels of soybean meal and of a nonprotein nitrogen-molasses supplement on consumption and digestibility of wheat straw. J. Anim. Sci. 53:1609-1615.

Currier, T. A., D. W. Bohnert, S. J. Falck, C. S. Schauer, and S. J. Bartle. 2002. Comparison of urea and biuret as nitrogen supplements to low-quality forage: Daily and alternate day supplementation effects on efficiency of nitrogen use in lambs. Proc. West. Sec. Am. Soc. Anim. Sci. 53:30-305.

Davis, G. V., M. S. Gadberry, and T. R. Troxel. 2002. Composition and nutrient deficiencies of Arkansas forages for beef cattle. Prof. Anim. Sci. 18:127-134.

Edgar, T. G. 1996. Composting grass seed straw. Oregon State University Extension Service. Extension Miscellaneous 8639, Corvallis. August 1996.

Ely, D. G., D. K. Aaron, J. Wyles, R. A. Zinner, A. K. Lunsford, and M. L. Mallory. 2006. A nutritional supplement for beef cattle grazing endophyte-infected tall fescue. I. Response of herd-managed cows and calves. J. Anim. Sci. 84 (Suppl. 1):396.

Fisher, M. J., D. W. Bohnert, C. J. Ackerman, C. S. Schauer, T. DelCurto, A. M. Craig, E. S. Vanzant, D. L. Harmon, and F. N. Schrick. 2004. Evaluation of perennial ryegrass straw as a forage source for ruminants. J. Anim. Sci. 82:2175-2184.

Grove, A. V., C. W. Hunt, and R. Lewis. 2002. Effect of bale density, moisture content, and ammoniation level on in situ degradability of bluegrass straw. Proc. West. Sec. Am. Soc. Anim. Sci. 53:320-323.

Guggolz, J., G. O. Kohler, and T. J. Klopfenstein. 1971. Composition and improvement of grass straw for ruminant nutrition. J. Anim. Sci. 33:151-156.

Han, Y. W. 1978. Microbial utilization of straw (A review). Appl. Environ. Microbiol. 23:119-153.

Hemken, R. W., J. A. Jackson, Jr., and J. A. Boling. 1984. Toxic factors in tall fescue. J. Anim. Sci. 58:1011-1016.

Hemken, R. W., and L. P. Bush. 1989. Toxic alkaloids associated with tall fescue toxicosis. In: P. R. Cheeke (Ed.) Toxicants of Plant Origin. Vol. 1: Alkaloids. Boca Raton, FL., CRC Press.

Herrera-Saldana, R., D. C. Church, and R. O. Kellems. 1982. The effect of ammoniation treatment on intake and nutritive value of wheat straw. J. Anim. Sci. 54:603-608.

Horney, M. R., T. DelCurto, M. M. Stamm, R. K. Bailey, and S. D. Brandyberry. 1996. Early-vegetative tall fescue hay vs alfalfa hay as a supplement for cattle consuming low-quality roughages. J. Anim. Sci. 74:1959-1966.

Horton, G. M. J. 1978. The intake and digestibility of ammoniated cereal straws by cattle. Can. J. Anim. Sci. 58:471-478.

Horton, G. M. J., and G. M. Steacy. 1979. Effect of anhydrous ammonia treatment on the intake and digestibility of cereal straws by steers. J. Anim. Sci. 48:1239-1249.

Hunt, C. W., J. F. Parkinson, R. A. Roeder, and D. G. Falk. 1989. The delivery of cottonseed meal at three different time intervals to steers fed low-quality grass hay: Effects on digestion and performance. J. Anim. Sci. 67:1360-1366.

Kellems, R. O. 1985. Beef cattle ryegrass straw feeding trials 1983-84. Report to the DEQ Technical Advisory Committee. O.S.U. Dept. Anim. Sci. Vol. 27-C, Jan. 1985.

Kellems, R. O., R. Miller, and D. W. Weber. 1984. Comparative supplementation methods (liquid supplement, injected liquid supplement, anhydrous ammonia) of ryegrass straw for wintering beef brood cows and feeder steers. Proc. West. Sec. Am. Soc. Anim. Sci. 35:184-189.

Kernan, J. A., W. L. Crowle, D. T. Spurr, and E. C. Coxworth. 1979. Straw quality of cereal cultivars before and after treatment with anhydrous ammonia. Can J. Anim. Sci. 59:511-517.

King, W. A., G. D. O'Dell, C. C. Brannon, and H. J. Webb. 1963. Effect of grinding and pelleting on the utilization of coastal Bermuda grass hay by dairy heifers. J. Dairy Sci. 46:34-37.

Males, J. R., W. E. McReynolds, C. T. Gaskins, and R. L. Preston. 1982. Supplementation of wheat straw diets to optimize performance of wintering beef cows. J. Anim. Sci. 54:384-390.

Merchen, N. R., and L. D. Bourquin. 1994. Processes of digestion and factors influencing digestion of forage-based diets by ruminants. Page 580 in Forage Quality, Evaluation, and Utilization. G. C. Fahey, Jr., ed. American Society of Agronomy, Inc. Madison, WI.

NRC. 1984. Nutrient Requirements of Beef Cattle. Sixth Ed. National Academy Press, Washington, DC.

Merrill, M. L., D. W. Bohnert, D. L. Harmon, A. M. Craig, and F. N. Schrick. 2007. The ability of a yeast-derived cell wall preparation to minimize toxic effects of high ergot-alkaloid tall fescue straw in beef cattle. J. Anim. Sci. 85:2596-2605.

Phillips, R. L., and M. Vavra. 1979. The influence of urea-molasses supplements on animal performance and fiber digestibility. Proc. West. Sec. Am. Soc. Anim. Sci. 30:291-293.

Phillips, R. L., M. Vavra, and R. J. Raleigh. 1975. Wintering cattle on grass straw. In: Official Proceedings: Tenth Pacific Northwest Animal Nutrition Conference. November 12-13, 1975, Portland, OR. p. 121.

Holland, C., and W. Kezar. 1995. Pioneer Forage Manual – A Nutritional Guide. Pioneer Hi-Bred International, Inc. pages 1-55.

Pritchard, R. H., and J. R. Males. 1982. Effect of supplementation of wheat straw diets twice a day on rumen ammonia, volatile fatty acids and cow performance. J. Anim. Sci. 54:1243-1250.

Ralston, A. T., and D. C. Andersen. 1970. Utilization of grass straw. In: Official Proceedings: Fifth Pacific Northwest Animal Nutrition Conference. Hanford, WA. p. 19.

Sanson, D. W., and D. C. Clanton. 1989. Intake and digestibility of low-quality meadow hay by cattle receiving various levels of whole shelled corn. J. Anim. Sci. 67:2854-2862.

Sanson, D. W., D. C. Clanton, and I. G. Rush. 1990. Intake and digestion of low-quality meadow hay by steers and performance of cows on native range when fed protein supplements containing various levels of corn. J. Anim. Sci. 68:595-603.

Stamm, M. M. 1992.Grass straw residues as a feed source for wintering beef cattle. M. S. Thesis. Oregon State University, Corvallis.

Stamm, M. M., T. DelCurto, M. R. Horney, S. D. Brandeberry, and R. K. Barton. 1994. Influence of alkaloid concentration of tall fescue straw on the nutrition, physiology, and subsequent performance of beef steers. J. Anim. Sci. 72:1068-1075.

Stuedemann, J. A., and C. S. Hoveland. 1988. Fescue endophyte: history and impact on animal agriculture. J. Prod. Agric. 1:39-44.

Sundstol, F., and E. M. Coxworth. 1984. Ammonia treatment of straw for feed. Develop. Anim. Vet. Sci. 14:196-247.

Szasz, J. I., C. W. Hunt, L. R. Kennington, G. T. Pritchard, A. V. Grove, K. A. Johnson, and S. M. Parish. 2001. Effect of ammoniation on digestibility of bluegrass seed straw in beef cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 52:25.

Szasz, J.I., T.M. McCalmant, C.W. Hunt, A.V. Grove, and L.R. Kennington. 2002. Effect of a fibrolytic enzyme preparation on intake and digestibility of bluegrass seed straw fed to beef cattle. Proc. Western Sect. Amer. Soc. Anim. Sci. 53:313-316.

Tor-Agbidye, J., L. L. Blythe, and A. M. Craig. 2001. Correlation of endophyte toxins (ergovaline and lolitrem B) with clinical disease: Fescue foot and perennial ryegrass. Vet. Hum. Toxicol. 43:140-146.

Van Soest, P. J. 1994 Nutritional Ecology of the Ruminant. 2nd ed. Cornell Univ. Press, Ithaca, NY.

Van Soest, P. J., A. M. Ferreira, and R. D. Hartley. 1984. Chemical properties of fibre in relation to nutritive quality of ammonia-treated forages. Anim. Feed. Sci. Technol. 10:155-164.

Waggoner, J. W., H. D. Radloff, and W. L. Eberhart. 1979. Nutrient content of forages harvested in Wyoming. In: R. H. Delaney, and J. Borrelli (Eds.) Proc. Symp. on Mangagement of Intermountain Meadows. June 7-9, 1979. Jackson, WY. p. 121.

Worrell, M. A., D. C. Clanton, W. W. Stroup, and J. T. Nichols. 1986. Effect of harvest date on meadow hay quality. I. Nutritional attributes, voluntary intake and rate of passage in growing cattle. J. Anim. Sci. 63:1527-1537.

Youngberg, H., and L. Vough. 1977. A study of the nutritive value of Oregon grass straws. O.S.U. Extension Service Special Report 473, Corvallis. Jan. 1977.

Table 1. Nutritional comparisons of some low-quality meadow hays, grass seed straws, and cereal grain straws[a]

Reference by Forage Type	Description	Nutritional Quality, Percentage Dry Matter Basis				
		CP	NDF	ADF	TDNa	TDNb
A. Low-Quality Meadow Hay						
Hunt et al., 1989	Meadow Fescue	6.6	65.4	39.0	58.1	52.6
Sanson and Clanton, 1989	Warm- and Cool-Season Grasses	5.2	70.8	46.1	52.5	49.1
		7.0	74.4	45.6	52.9	49.4
Sanson et al., 1990	Warm- and Cool-Season Grasses	4.3	72.9	46.2	52.4	49.1
Waggoner et al., 1979	Native Meadow (Brome, Fescue, and Crested Wheatgrass)	8.2	66.3	42.1	55.6	51.1
Worrell et al., 1986	Warm- and Cool-Season Grasses	8.5	68.1	34.3	61.8	54.9
Bohnert et al., 2002	Cool-Season grasses	5.2	60.1	32.0	63.6	56.0
		5.0	57.7	32.1	63.5	56.0
B. Grass Seed Straws						
Church and Champe, 1980	Annual Ryegrass	3.4	---	44.9	53.4	49.7
Guggolz et al., 1971	Fescue	5.1	---	53.0	47.0	45.7
Ralston and Anderson, 1970	Perennial Ryegrass	5.5	---	50.6	48.9	46.9
	Bluegrass	8.9	---	43.7	54.4	50.3
	Bentgrass	4.6	---	45.6	52.9	49.4
	Annual Ryegrass	4.8	---	49.7	49.6	47.3
Kellems et al., 1984	Perennial Ryegrass	6.9	71.7	42.5	55.3	50.9
Fisher, 2004	Perennial Ryegrass	4.6	63.0	33.0	62.8	55.5
		5.5	64.0	34.0	62.0	55.0
Kellems, 1985	Perennial Ryegrass	4.2	68.8	44.0	54.1	50.1
Phillips et al., 1975	Bluegrass	5.5	---	---	---	---
	Red fescue	3.7	---	---	---	---
Phillips and Vavra, 1979	Perennial Ryegrass	8.9	---	43.2	54.8	50.5
Grove et al., 2002	Bluegrass	5.9	---	---	---	---
Currier et al., 2002	Hard Fescue	4.3	73.8	32.0	63.6	56.0
Youngberg and Vough, 1977	Bluegrass	7.7	73.2	43.6	54.5	50.3
	Perennial Ryegrass – Turf type	6.7	68.1	42.4	55.4	50.9
	Tall Fescue	5.7	69.3	42.5	55.3	50.9
	Bentgrass	5.2	67.7	41.1	56.4	51.6
	Perennial Ryegrass – Forage type	4.9	72.1	45.5	53.0	49.4
	Orchardgrass	4.8	79.0	49.6	49.7	47.4
	Annual Ryegrass	3.7	75.6	50.5	49.0	47.0
	Chewings and Red fescue	3.1	81.1	51.5	48.2	46.5
Bohnert et al., 2006	Hard Fescue	3.8	---	---	---	---
Bohnert et al., 2007	Bluegrass	6.3	66.4	36.2	60.3	54.0
Stamm et al., 1994	Tall Fescue	6.3	67.4	44.6	53.7	49.8

		5.3	71.1	49.2	50.0	47.6
Merrill et al., 2007	Tall Fescue – High Alkaloid	5.6	72	43	54.9	50.6
	Tall Fescue – Low Alkaloid	6.5	71	43	54.9	50.6
C. Cereal Grain Straws						
Church and Santos, 1981	Wheat	3.8	---	49.0	50.2	47.7
		2.6	---	53.1	47.0	45.7
Herrera-Saldana et al., 1982	Wheat	2.9	---	50.1	49.3	47.2
Horton, 1978	Wheat	2.3	---	---	---	---
	Barley	3.8	---	---	---	---
	Oat	2.2	---	---	---	---
Horton and Steacy, 1979	Barley	3.9	---	---	---	---
	Wheat	2.5	---	---	---	---
	Oat	2.6	---	---	---	---
Kernan et al., 1979	Wheat	3.6	---	---	---	---
	Oat	3.8	---	---	---	---
	Barley	4.9	---	---	---	---
Males et al., 1982	Wheat	3.4	82.6	56.7	44.1	43.9
Pritchard and Males, 1982	Wheat	2.5	78.5	55.1	45.4	44.7

[a] Adapted from Stamm (1992); CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDNa = total digestible nutrients calculated as described by Holland and Kazar (1995; 88.9 – (0.79*ADF%)); TDNb = total digestible nutrients calculated as described by Davis et al. (2002; 71.7 - (0.49*ADF%)).

Table 2. Nutritional ranking, CP basis, of select grass seed straws by species[a]

Grass Seed Straw Species	Average CP (%)	Ranking
Bluegrass	6.9	**1**
Perennial ryegrass	6.0	**2**
Tall fescue	5.9	**3**
Bentgrass	4.9	**4**
Orchardgrass	4.8	**5**
Other fescues (not including tall fescue)	4.0	**6**
Annual ryegrass	4.0	**7**

[a] From data presented in Table 1.

Table 3. Nutrient requirements[a] of beef cattle (NRC, 1984; Dry matter basis)

Production Stage	Intake, lb	CP, %	CP, lb	TDN, %	TDN, lb
700 lb Steer, Gaining 1.0 lb/day	15.8	8.6	1.4	58.5	9.2
700 lb Heifer, Gaining 1.0 lb/day	15.1	8.4	1.3	62.0	9.4
1200 lb Mature Cow					
Mid-Gestation	20.8	6.9	1.4	48.8	10.1
Late-Gestation	22.3	7.8	1.7	52.9	11.8
Early Lactation	23.0	9.3	2.1	55.5	12.8
2000 lb Mature Bull					
Maintenance	31.3	6.8	2.1	48.4	15.2

[a] lb = pounds; CP = crude protein; TDN = total digestible nutrients

Table 4. Estimated alkaloid threshold levels (parts per billion; ppb) for fescue toxicosis and perennial ryegrass staggers in cattle and sheep (adapted from Tor-Agbidye et al., 2001)

Species	*Ergovaline (ppb)	Lolitrem B (ppb)
Cattle	400-750	1800-2000
Sheep	500-800	1800-2000

*****Threshold level is environmentally dependent and decreases in colder weather.