Forage Quality and Nutrient Uptake Potential of Triticale

by

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Abstract

Two triticale cultivars, Trical® 342 and Trical® 2700, were amended with 3 fertilizer treatments: commercial nitrogen (N) fertilizer, broiler litter, or control (no treatment). Forage yield, forage quality, and concentration of copper (Cu), zinc (Zn) and phosphorus (P) were determined for 3 stages of forage maturity: early-tillering stage, stem extension, and boot-flowering stage. Commercial N consistently provided the greatest ($P < 0.10$) dry matter yields and crude protein (CP) concentrations. However, as forages matured, accumulation of cell wall constituents in commercial fertilizer-amended forages outweighed the benefit of greater CP concentration, thus contributing to the lowest total digestible nutrient (TDN) concentration values among treatments. No difference ($P > 0.10$) was found for nutrient mitigation potential between cultivars at boot-stage harvest. However, among fertilizer sources, commercial fertilizer-amended forages showed the greatest nutrient mitigation potential due to greatest effect on biomass yields.

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Literature Review

TRITICALE

Background

Triticale (*Triticosecale* Wittmack) is a small-grain crop species resulting from a polyploid cross between wheat (*Triticum*) and rye (*Secale*) (Oelke et al., 1989). Triticale was developed to combine the hardiness and stress tolerance of rye, and the yield and processing value of wheat (AAFRD, 2005). Hybrid crosses of wheat and rye date back to 1875. However, early crosses resulted in sterile offspring, which were late-maturing and yielded shriveled grains unsuitable for market. It wasn’t until the 1930s that breeding of modern triticale varieties became successful, and not until the 1960s that the scientific community became interested in quantifying and comparing the agronomic performance of triticale against more traditional small grains (Bishnoi and Hughes, 1978).

Triticale is now widely adopted by the agronomic community as a viable small grain. Annual U.S. triticale production for grain totals 2.5 million bushels produced in 30 states, a 50% increase in production over the previous decade (USDA, 2007). Global production of triticale is estimated at over 3 million hectares, leaving the U.S. ranking outside of the top 10 producing countries (AAFRD, 2005). The majority of triticale production for forage and grazing use in the US is centered in two regions: the West Coast and the Great Plains, totaling an estimated half million hectares (Resource Seeds, 2004)

Cultivars

Current commercially available triticale cultivars have alleviated the issues of past cultivars that were susceptible to lodging, frost damage, ergot, leaf rust and low agronomic yields (Oelke et al., 1989). Genetic development of high-yielding, disease-resistant triticale cultivars can be attributed to Dr. Charles Jenkins at The University of Manitoba dating back to 1954 (Resource Seeds, 2004). There are two main types of triticale according to their growth habits: winter varietals, which require vernalization to seed out, and spring varietals, which do not (Royo, Blanco, 1998). Depending on the production system practiced, small-grain forage production may or may not culminate with harvesting of the grain.

Cultivar response to soil nutrients and environmental conditions are likely a product of genetic inheritance (Mugwira et al., 1978), and extrapolating existing data from research on prior cultivars may not accurately estimate agronomic performance. Therefore, cultivar development and marketing tends to be region-specific. Cultivars developed specifically for the southeastern US include: Trical® 342, developed at the Universities of Florida and Georgia, and Trical® 2700, developed by Resource Seeds Inc. (Myer et al., 2009). Triticale production in the southeastern US tends to be focused on the production of forage as opposed to grain.

Nutritional Value

Feeding value and nutritional composition among triticale cultivars vary significantly. Additionally, limited scientific data exist on nutritional value of triticale forage grown in the southeastern US (Myer and Lozano del Rio, 2004; Myer et al., 2009). Most of the research on the nutritional value of triticale has been strictly focused on grain and its potential for supplementation in corn-based diets. Triticale grain has been shown to have superior lysine content to that of wheat, with lysine being the most limiting amino acid in high-concentrate ruminant diets (Ahmed and McDonald, 1974, Richardson and Hatfield, 1977).

Growth patterns and biomass partitioning at various stages of maturity can differ significantly not only among varieties, but also between cultivars. General agronomic practice when mechanically harvesting triticale forage for hay or silage is to harvest at the late milk to soft dough stages before grain production is realized (AAFRD, 2005). Preliminary forage data show nutritional composition of Trical® 342 and Trical® 2700 to have similar CP and NDF values to that of annual ryegrass, which is currently the most common winter annual in the southeastern US at an estimated acreage of nearly a half-million hectares (Myer et al., 2009). In a nutritive value comparison of small-grain forages, Coblentz and Walgenbach (2009) found DM yield of Trical® 2700 to be superior to that of 2 winter wheat varietals, but inferior to that of 5 oat varietals. Additionally, Trical® 2700 was found to be the earliest maturing forage among the small grains tested, and consequently ADF, NDF, and TDN values upon harvest were least desirable due to the fact all forages were harvested on a specific day rather than a uniform stage of growth.

Small Grain and Triticale Forages in Alabama

The climate of the southeastern US is particularly suited for triticale and other cool-season annual forages. Small-grain forage production in Alabama is primarily focused in two areas: overseeding of a winter annual on a dormant summer perennial pasture such as bermudagrass or bahiagrass, and planting of a winter-annual small grain to be harvested as hay or silage. Summer perennial pasture acreage in Alabama is estimated at over 800,000 hectares; however, only a relatively small portion of this area is overseeded with a winter-annual forage crop (Ball, 2007).

Total hay production in Alabama in 2007 reached nearly 2 million tons, providing an economic impact of $112 million (USDA, 2007). However, small-grain hay production constituted less than 6% of the total hay production in tons harvested, for a total area of 20,000 hectares statewide (USDA, 2007). Triticale forage production figures for Alabama aren't currently published; however, since the development and marketing of specific triticale cultivars for forage and grazing use, the estimated 5,000 hectares currently planted in the southeastern US is expected to significantly rise (Myer et al., 2009).

BROILER LITTER

Production in Alabama

Alabama ranks number three in the US for broiler production with over 1 billion broilers produced annually. Alabama's poultry industry generates cash receipts of more than 3 billion dollars, constituting greater than 70% of the state's agricultural products income (USDA, 2007). The Sand Mountain region and the Wiregrass region of Alabama make up the majority of the state's broiler production (Hall, 1993). With an estimate of 1.22 kg of poultry litter generated per broiler over its growing cycle (Mitchell, 1995), Alabama's broiler industry generates more than 1 million metric tons of litter annually.

Broiler litter is composed of excreta, feathers, wasted feed, and bedding materials, and may vary considerably in its nutrient concentration (Hall, 1993). Broiler litter characteristics make it ideal for use as a nutrient source for crops; it has a high percentage dry matter (75-80%), and contains N-P-K as well as secondary and micronutrients: Ca, Mg, S, Cu, Fe, Mn, Zn and B (Mitchell, 1995). In addition to generally having a greater nutrient concentration than other livestock manures, broiler litter is easily collectible, contributes to soil structure and increases water- and nutrient- holding capacities (Sims and Wolfe, 1994). While highly variable, the average N-P-K ratio of broiler litter in Alabama is 3-2-2 (Stephenson et. al, 1990). The use of broiler litter as a fertilizer source for crops and forages is increasing due to the rising cost of commercial inorganic fertilizers (Evers, 2002). One disadvantage of poultry litter is that the nutrient ratio of the litter may not match the nutrient requirement ratio of the crop to which it is applied, leading to accumulation of some nutrients and the potential deficiency of others (Sims, 1995).

Accumulation of nutrients on land in immediate proximity to poultry-producing regions is a product of nutrient value and bulk density of poultry litter. Commercial fertilizer market value and transportation cost analysis estimate that broiler litter can economically be transported approximately 260 km from the production facility to the land application site (Paudel et al., 2004). Consequently, many agricultural lands in the Sand Mountain and Wiregrass regions of Alabama have accumulated excessive nutrients due to long-term litter application, posing an environmental threat (Hall, 1993).

Application of Inorganic and Organic Fertilizers

Use of fertilizers in forage production is good agricultural practice and necessary to maximize yield and forage quality potential. Application of fertilizers to a forage system is typically based upon crop requirement as well as any limiting factors identified by a soil test. The cost of commercial fertilizers continues to increase as the cost of energy escalates. For those in close proximity of concentrated animal feeding operations, the use of animal manure as a source of plant nutrients can be an economically viable alternative to inorganic fertilizer use (Evers, 2002). In addition, most southeastern US soils are sandy, acidic, and have a low nutrient-holding capacity, making broiler litter a viable alternative to commercial fertilizer use (Evers, 2002).

When using organic or manure-based fertilizers, waste disposal is often the primary objective; long-term application could lead to soil concentrations of phosphorus (P) exceeding the crop requirement by more than 500% (Lui et al., 1997). Split-application techniques for fertilizer application can provide greater forage yields and allow higher application rates. In addition, split-application minimizes the potential for substantial surface runoff, nutrient leaching and volatilization of N should a significant rainfall event occur (Schroeder et al., 2004, McGrath et al., 2010). The University of Arkansas Cooperative Extension system recommends a poultry litter application rate of 11.2 Mg/ha, not to exceed 5.6 Mg/ha per application (Shreve et al., 1995). Long-term application of both inorganic and organic fertilizer can have significant environmental effects if little regard if given for the potential accumulation of nutrients. McGrath et al., (2010) found that litter amended soils had a tendency to increase pH over a period of only two years. Poultry litter pH can range as high as 8, combined with the fact that P binds more efficiently to aluminum and iron oxalates at low pH (Maguire et al., 2008; McGrath et al., 2010), long-term application of poultry litter could potentially alter the soil pH, only exacerbating P loss and the potential for eutrophication.

Phosphorus

Poultry litter has historically been land-applied to meet the N requirement of the crop, thus over-applying P (Sims, 1995). Loss of agricultural phosphorus via surface runoff is the primary contributor to eutrophication of lakes and streams (USEPA, 1998). Long-term application of poultry litter to agricultural soils has been shown to elevate extractable P to a level more than 6 times than that of non-litter amended soils to a depth of 60 cm (Kingery et. al, 1994). In a two-year study on soil chemistry effects of poultry litter application, McGrath et al., (2010) found P levels to increase from 8.6 mg/kg to 123 mg/kg, levels well above the recommended agronomic optimal value of 55 mg/kg (Maguire and Heckendorn, 2009).

Phosphorus is a relatively immobile element with a tendency to accumulate in surface soils, leaving it particularly susceptible to loss via surface runoff (Schroeder et al., 2004). However, in long-term application of poultry litter on sandy textured soils, applied P may exceed both plant requirements and soil adsorption capacity leaving excess P susceptible to leaching (Barrow, 1980, Kingery et. al, 1994). Accumulation of high concentrations of P in poultry litter-amended soils is due to the difference in N-P-K ratio of the litter and the N-P-K ratio requirement of the plant (Evers, 2001). Plants generally utilize between 7 to 15 % of applied P, leaving most P bound to soil particles and thus susceptible to pollution via sediment loss (ANR, 1993). Newton et al., (2001) found that P fertilizer source played a tremendous role in forage utilization of applied P. Forage crops grown on manure-based organic fertilizers resulted in a

42% removal of applied P, while forages grown on commercial fertilizer removed 204% of the applied P.

Agricultural Pollution in Alabama

The federally mandated discharge permit program implemented by the Clean Water Act of 1972 significantly reduced the degree of point source pollution; however, it did little to establish a federal regulatory outline for nonpoint source pollution. It's difficult, if not impossible to determine the exact source of most agricultural pollution, thus it is referred to as non-point source (NPS) pollution. Agricultural NPS pollution constitutes an estimated 50 to 70 % of all NPS pollution nationwide (EPA, 2010). The degree and extent for potential NPS pollution is variable and dependant upon several factors: rainfall, vegetation, soil type, erodibility, topography, and physical disturbance of the soil structure.

The frequency of heavy rainfall events in Alabama, combined with the nearly 2 million hectares of cropland and its subsequent tillage practices leaves over 500,000 hectares susceptible to high erosion rates (ANR, 1989). Identification of specific agronomic practices that minimize potential for NPS pollution have led to the development of Best Management Practices (BMPs). BMPs consist of two types: structural modifications and nonstructural measures.   Structural modifications refer to the use of physical barriers to minimize or prevent sediment loss, whereas nonstructural measures include specific techniques in fertilizer and nutrient management, as well as alteration of various agronomic practices (ANR, 1993). Current Alabama law requires compliance with NRCS guidelines when dealing with animal and livestock waste from animal feeding operations. Current regulations are outlined by Alabama Department of Environmental

Management Water Quality Program and defined by the Alabama Conservation Practice Standard: Nutrient Management code 590 (ADEM, 2010).

NUTRIENT MANAGEMENT

Practices and Nutrient Mitigation

The transition of livestock animal production to modern-day confinement production has caused environmental concerns when dealing with animal waste. Phosphorus-driven eutrophication has forced the agronomic community to develop P indices as a tool for managing the application of nutrients, thus minimizing their potential detrimental effects on the environment. In the recent past, threshold P values determined by a soil test report were all that was recommended as a way of limiting the potential for P-driven eutrophication (Sharpley et al., 1996). As the agricultural community developed a better understanding of the complex relationship between environmental and physiological factors and how they contribute to potential P pollution, it was realized that more than recommended threshold values were needed if agriculturally caused eutrophication was to be curbed. The development and adoption of P index assessment tools has been fundamental in assessing and minimizing the risk for P loss in agronomic practices.

The use of a P index takes into consideration specific site characteristics in which they are given a weighted value assuming that certain factors lead to a greater susceptibility for P loss. Eight site characteristics: soil erosion, irrigation erosion, runoff class, soil P test, P fertilizer application rate, P fertilizer application method, organic P source application rate and organic P source application method are assessed and given a categorical value: none (0), low (1), medium

(2), high (4), or very high (8). Each of the 8 characteristics is given a weighted value according to its risk potential for P loss, the categorical value is multiplied by the weighted value and the sum of the index identifies sites in which potential for P loss may be significant (NRCS, 1994).

The P index does not take into account the crop on which the fertilizer is to be applied. Identifying forages capable of maximum nutrient uptake could facilitate removal of nutrients on litter-applied soils when mechanical harvesting and removal of the forage is practiced (Pederson et al., 2002). Utilizing cropping systems as a tool to hasten the decline of soil-test P can yield up to a 50% decline in the P concentration of soils, significantly benefiting soil remediation (Brown, 2006). Forage uptake, in addition to soil adsorption, plays a critical role in reducing soil P concentration and bioavailable P (Lui et al., 1997). Maximizing nutrient uptake by forages can be limited by any nutrient deficiency that limits growth, most commonly nitrogen. The addition of a commercial N fertilizer on poultry litter-amended pastures can yield a 23% increase in P uptake by forages (Evers, 2002). Research has shown strong relationships between N concentration and P uptake in plants. However, P concentrations among genotypes can differ independently of N concentration (Belanger et al., 2002). Nutrient removal by forage or cropping systems is a function of both nutrient concentrations in the plant and biomass yield. Genotypic variations in biomass partitioning show that P uptake potential varies not only among cultivars, but also within plant parts (Belanger et al., 2002). Research has shown that the stem portion of forages may contain up to 60% of the total P within the plant (Pederson et al., 2002). In addition, the stem portion also contains an N:P ratio closest to that of poultry litter; therefore, maximizing the stem fraction of mechanically harvested forage should result in removal of the most ideal N:P ratio (Pederson et al., 2002). Most crops average an N:P ratio of 8:1 (Sims and Wolfe, 1994), typically poultry litter N:P ratios range from 2:1 to 2.9:1 (Pederson et al., 2002).

Ideally, identification of forage with an N: P accumulation closest to that of poultry litter would best suit nutrient management practices.

Utilizing Forage for Nutrient Mitigation

The relationship of environmental factors and soil characteristics, combined with variability among small-grain varieties and cultivars, makes extrapolation of the limited existing data on P uptake of forages beyond their growth requirement unreliable. Annual ryegrass and Coastal bermudagrass have been shown to accumulate P in excess of growth requirements when grown on high-P concentration soils (Evers and Doctorian, 1998). Highly variable P removal rates have been shown to range from 22 kg/ha for low-input forage systems (Mcgrath et al., 2010) to 73 kg/ha for high-yielding bermudagrass cultivars (Brink et al., 2004). Limited research exists on quantifying the P removal potential of triticale on manured or high-nutrient concentration soils. Triticale grown for forage has shown potential to capture and utilize relatively large amounts of nitrogen and phosphorus when nutrient requirements for growth are met (Mackowiak, et al., 2008). Triticale is currently the most common small grain used for boot stage forage in the intermountain western US, and is commonly grown on animal manure-amended soils (Brown, 2006). The National Research Council (NRC) default value for P concentration of boot-stage triticale forage is 0.34% (Brown et al., 2009)

In a triticale forage trial quantifying P removal on manured soils, Brown et al. (2009) found total forage P concentration ranged from 0.18% to 0.53%. Moreover, they also determined that only one-third of the samples were within 10% of the NRC default value. Therefore, when the default value is used to calculate total P removal, calculations could grossly over- or under- estimate actual P removal. Additionally, the NRC P removal value, as well as the range in P concentration determined by Brown et al. (2006) was not specific to any particular cultivar, but rather an average from which actual P removal could drastically differ when extrapolation is practiced. Ideally, P concentration values would be determined on a cultivar-specific basis if nutrient mitigation were the objective. In the present study, two triticale cultivars commonly recommended for forage use in Alabama were selected (Trical® 342 and Trical® 2700) to receive amendments of commercial fertilizer, broiler litter or a control (no fertilizer application). The cultivar response to fertilizer amendments was measured to identify if either the cultivar or the amendment had any significant effect on forage characteristics. In addition, concentration and uptake of specific nutrients of environmental concern were measured to determine if fertilizer amendment had an effect on forage concentration on nutrients, as well as identifying if either cultivar had potential for a nutrient mitigation tool.

Materials and Methods

Research site

The experiment was conducted in the fall, winter, and spring of 2007/2008 and 2008/2009 at the Chilton Area Horticulture Substation in Clanton, AL (32° 55’ 09.65” N latitude, 86° 40’ 14.12” W longitude, 208 m above MSL). Soil type was a Dothan sandy loam with a pH of 5.9. In each of the two years, 216 field plots (2.4 × 0.5 m ea.) were harrowed and cultipacked prior to seed drilling. Plots were organized into 36 blocks, each consisting of 6 plots that represented the 6 experimental treatments. The Auburn University Soil Testing Laboratory determined soil nutrient values and poultry litter nutrient values.

Forage establishment, fertilization, and harvesting

Plots were seeded on October 15, 2007 and October 20, 2008 at a recommended seeding rate of 112 kg/ha. The seed drill made 12 longitudinal passes alternating Trical® 342 and Trical® 2700. Fertilizer was applied by hand 14 days post-planting at an N application rate of 112 kg/ha, latitudinally crossing the field and alternating treatments of commercial fertilizer, broiler litter and control. Commercial fertilizer for both trial years was an ammonium sulfate-urea blend (33:0:0). Nutritive value analysis of the poultry litter averaged a 3.8:3.4:3.7 concentration over the two years. The control treatment did not receive any fertilizer application.

Three harvest dates were selected throughout the growing season to enable detection of differences in biomass partitioning between cultivars. Harvest dates were February 18, March 17, and April 14 for the 2007/2008 trials, and February 16, March 16, and April 13 for the 2008/2009 trials. February, March, and April harvest coincided with early-tillering stage, stem extension, and boot-flowering maturity stages respectively. Only primary-growth forage was harvested for each harvest date, at which time 12 blocks were selected and harvested at random. For each harvest, each of the six plots within the 12 selected blocks was sampled by randomly placing a 0.38-m^2 PVC quadrant within the plot and cutting to a uniform stubble height of 5 cm using a gas-powered sickle bar mower. Fresh-cut forage from each plot was then placed in a tared cloth bag and weighed to determine wet weight. Samples were then placed in a drying oven at 60° C until a constant weight was reached, and DM yield was calculated based on dry-weight data.

Laboratory analysis

Prior to analysis, forage samples were dried for 24 hours at 60° C and then air-equilibrated. Samples were then ground in a Wiley mill to pass a 1-mm screen, and final DM concentration was determined by oven-drying samples at 100° C following the procedures of AOAC (1995). Kjeldahl procedure (AOAC, 1995) was used to determine concentration of N, from which N x 6.25 was used to calculate CP. Concentration of ADF and NDF were determined by the procedures outlined by Van Soest et al. (1991). Values for TDN were calculated according to the prediction equations of Robinson et al. (2004). Copper, Zn, and P concentrations were determined by dry-ashing and wet-digestion of 0.5-g forage sample with 1 N HNO_3 followed by solubilization in 1 N HCL (Hue and Evans. 1986). Inductively coupled argon plasma (ICAP) spectroscopy (Spectro Ciros CCDF, Germany) was then used to determine mineral concentration. Nutrient uptake was calculated by using the DM yield and the determined concentration of nutrients and minerals.

Statistical analysis

Data were analyzed using the general linear models (GLM) procedure of SAS (SAS Inst. Inc., Cary, NC) for a replicated randomized block design, significance at: $\alpha = 0.10$. Independent variables included cultivar, fertilizer amendment and the cultivar × fertilizer amendment interaction. Dependent variables were; wet weight (wet wt), and forage concentrations of DM, CP, NDF, ADF, TDN, Cu, Zn and P. Variables of interest were reported and analyzed as both a percentage of the forage, as well as kilogram per hectare (kg/ha) on a DM yield basis. Samples were pooled by year, then grouped into their respective month and analyzed separately to account for biomass partitioning differences due to stage of forage maturity. The least square means procedure was used to generate means for comparative analysis.

Results

Early- tillering stage

Nutrient concentrations

No difference was observed in CP concentration between the two cultivar treatments (Table 1). However, among the fertilizer source treatments, forages amended with commercial fertilizer had greater CP concentration than either the broiler litter or control treatments (P = 0.0004 and 0.0009, respectively; Table 2). Neutral detergent fiber concentration was greater (P < 0.0001) for Trical® 342 than for Trical® 2700 (Table 1). Additionally, analysis of NDF concentrations among fertilizer source treatments revealed that commercial fertilizer and control were greater than broiler litter (P = 0.0154 and 0.0521, respectively; Table 2). There was no difference between cultivars in ADF concentration (Table 1). However, ADF concentrations of the commercial fertilizer and the control treatments were greater than that of the broiler litter treatment (P = 0.0369 and 0.0580, respectively). Concentration of TDN when calculated by reference to NDF was greater (P < 0.0001) for Trical® 2700 than for Trical® 342 (Table 1). Conversely, no difference was found for NDF-predicted TDN concentration among fertilizer source treatments (Table 2). Concentrations of TDN calculated using ADF was not different either between cultivars (Table 1), or among fertilizer source treatments (Table 2).

Forage Yield

Analysis of cultivar effect on wet weight yield revealed Trical® 342 to be greater (*P* = 0.0027) than Trical® 2700 (Table 3). Conversely, fertilizer source had no effect on wet weight yield (Table 4). No effect was observed for DM yields between cultivars (Table 3). However, DM yield of commercial fertilizer amended forage was greater than either broiler litter or control (*P* = 0.052 and 0.061, respectively; Table 4). No difference was seen in CP yield between cultivars (Table 3). However, CP yield for the commercial fertilizer treatment was greater than for either the broiler litter or control treatments (*P* = 0.0088 and 0.0120, respectively; Table 4). Neutral detergent fiber yield, both between cultivars (Table 3), and among fertilizer sources (Table 4) did not differ. Similarly, no effect was found in ADF yield between cultivars (Table 3) or among fertilizer sources (Table 4). No effect was seen in TDN NDF yield between cultivars (Table 3). However, commercial fertilizer amended forages were greater in TDN NDF yield than either the broiler litter or control treatments (*P* = 0.0488 and 0.0149, respectively; Table 4). Total digestible nutrient ADF yield values between cultivars did not differ (Table 3). Among fertilizer sources, TDN ADF values were greater for commercial fertilizer than for either broiler litter or control treatments (*P* = 0.0463 and 0.0185, respectively; Table 4).

Mineral analysis

Copper concentration was neither affected by cultivar (Table 5) nor by fertilizer source (Table 6). However, Cu yield was greater (*P* = 0.0328) for Trical® 342 than Trical® 2700 (Table 5). Fertilizer source showed no effect on Cu yield (Table 6). Zinc concentration was neither affected by cultivar (Table 5) nor by fertilizer source (Table 6). No difference was observed in Zn yield between cultivars (Table 5). However, Zn yield in the commercial fertilizer amended forages was greater than in the broiler litter amended and the control forages (*P* = 0.021 and 0.056, respectively; Table 6). Phosphorus concentration was greater (*P* = 0.0634) in Trical® 2700 than Trical® 342 (Table 5). However, phosphorus concentration among the fertilizer sources did not differ (Table 6). Phosphorus yield did not differ either between cultivars (Table 5) or among fertilizer sources (Table 6).

Stem extension stage

Nutrient Concentrations

No difference was found in CP concentration between cultivars (Table 7). Among fertilizer sources, commercial fertilizer-amended forages had a greater CP concentration than either broiler litter-amended or control treatments (*P* = 0.0037 and 0.0049, respectively; Table 8). A cultivar × fertilizer source interaction was observed for NDF concentration such that Trical® 342 forages amended with broiler litter, commercial fertilizer and control treatments had greater NDF concentrations than Trical® 2700 amended with commercial fertilizer (*P* = 0.0002, 0.0011 and 0.0058, respectively) which was greater in NDF concentration than Trical® 2700 broiler litter-amended and control treatment forages (*P* = 0.0058 and < 0.0001, respectively (Table 9). Additionally, a cultivar × fertilizer source interaction was observed for ADF concentration such that Trical® 342 amended with broiler litter, commercial fertilizer and the control treatment in addition to Trical® 2700 amended with commercial fertilizer had greater ADF concentrations than Trical® 2700 amended with either broiler litter (*P* = 0.0002, < 0.0001, < 0.0001 and < 0.0001, respectively) or control (*P* = 0.0009, < 0.0001, 0.0001 and 0.0004, respectively; Table 9). Consequently, the TDN values calculated with the NDF and ADF concentration values also revealed a cultivar × fertilizer source interaction. Trical® 2700 amended with broiler litter and Trical® 2700 control had greater TDN NDF values than Trical® 2700 amended with commercial fertilizer (*P* = 0.0007 and 0.0006, respectively), which had greater TDN NDF values than Trical® 342: broiler litter, commercial fertilizer and control (*P* = 0.0003, 0.0237 and 0.0018, respectively (Table 9). Additionally, Trical® 2700 control and Trical® 2700 amended with broiler litter had greater TDN ADF concentration values than Trical® 2700 amended with commercial fertilizer (*P* = 0.0077 and 0.0105, respectively) as well as Trical® 342 broiler litter (*P* = 0.0037 and 0.0051, respectively), commercial fertilizer (*P* = 0.0122 and 0.0162, respectively) and control amendment source (*P* = 0.0002 and 0.0003, respectively; Table 9).

Forage yield

Wet weight yield was greater (*P* = 0.0001) for Trical® 342 than for Trical® 2700 (Table 10). Additionally, commercial fertilizer-amended forages had greater wet weight yields than either broiler litter or control treatments (*P* = 0.0001 and 0.0001, respectively (Table 11). Dry matter yield was greater (*P* = 0.0553) for Trical® 342 than for Trical® 2700 (Table 10). Dry matter yield for commercial fertilizer-amended forages was greater than for either broiler litter or control (*P* = 0.0006 and 0.0001, respectively; Table 11). Crude protein yield was greater (*P* = 0.0049) for Trical® 342 than for Trical® 2700 (Table 10). Commercial fertilizer-amended forages were greater in CP yield than were forages amended with either broiler litter or control treatment (*P* = 0.0002 and <0.0001, respectively; Table 11). Neutral detergent fiber yield for Trical® 342 was greater (*P* = 0.0063) than for Trical® 2700 (Table 10). Forages amended with commercial fertilizer had greater NDF yields than those amended with either broiler litter or control treatments (*P* = 0.0031 and <0.0001, respectively; Table 11). Acid detergent fiber yield for Trical® 342 was greater (*P* = 0.037) than that of Trical® 2700 (Table 10). Commercial fertilizer-amended forages had greater ADF values than forages amended with either broiler litter or the control treatments (*P* = 0.0019 and 0.0001, respectively; Table 11). No effect on TDN NDF was identified between cultivars (Table 10). However, TDN NDF yield was greater for commercial fertilizer-amended forages than for either broiler litter or control treatments (*P* = 0.0043 and 0.0002, respectively; Table 11). Total digestible nutrient ADF yield for Trical® 342 was greater (*P* = 0.0748) than that of Trical® 2700 (Table 10). Commercial fertilizer-amended forages were greater in TDN ADF yield than either broiler litter or control treatments (*P* = 0.0049 and 0.0001, respectively; Table 11).

Mineral analysis

No difference in Cu concentration was identified either between cultivars (Table 12), or among fertilizer sources (Table 13). However, Trical® 342 Cu yield was greater (*P* = 0.0272) than Trical® 2700 (Table 12). Fertilizer source had no effect on Cu yield (Table 13). Zinc concentrations were greater (*P* < 0.0001) for Trical® 342 than for Trical® 2700 (Table 12). No effect on Zn concentration was observed among fertilizer sources (Table 13). Zinc yield was greater (*P* < 0.0001) for Trical® 342 than for Trical® 2700 (Table 12). No effect on Zn yield was observed among fertilizer sources (Table 13). No effect on P concentration was observed either between cultivars (Table 12) or among fertilizer sources (Table 13). Phosphorus yields for Trical® 342 were greater (*P* = 0.0274) than for Trical® 2700 (Table 12). Phosphorus yield for forages amended with commercial fertilizer were greater than either broiler litter-amended or control treatments (*P* = 0.0655 and 0.0167, respectively; Table 13).

Boot-flowering stage

Nutrient Concentrations

Concentration of CP in Trical® 2700 was greater (P = 0.0101) than in Trical® 342 (Table 14). Among fertilizer sources, no effect was observed on CP concentration (Table 15**).** A cultivar × fertilizer interaction was observed for NDF concentration such that Trical® 2700 amended with commercial fertilizer had a greater concentration of NDF than Trical® 2700 broiler litter-amended and control treatments (P = 0.0118 and 0.0051, respectively), which were both greater than Trical® 342 broiler litter (P = 0.0012 and 0.0005, respectively), commercial fertilizer (P = 0.0004 and 0.0002, respectively) and control amendments (P = 0.0002 and < 0.0001, respectively; Table 9). Acid detergent fiber concentration was greater (P = 0.0001) in Trical® 2700 than in Trical® 342 (Table 14). Among fertilizer sources, ADF concentrations for forages amended with commercial fertilizer were greater than for either broiler litter amended forages or control (P = 0.0020 and 0.0074, respectively; Table 15). A cultivar × fertilizer source interaction for TDN NDF concentration was observed such that Trical® 342 broiler litter, commercial fertilizer and control amendments were greater than Trical® 2700 control (P = 0.0097, < 0.0001 and 0.0027, respectively) and broiler litter amendments (P = 0.0260, 0.0056 and 0.0080, respectively), which were greater than Trical® 2700 amended with commercial fertilizer (P = 0.0326 and 0.0108, respectively; Table 9). Concentration of TDN ADF was greater (P < 0.0001) in Trical® 342 than in Trical® 2700 (Table 14). Among fertilizer sources, both the broiler litter-amended and the control forages were greater in TDN ADF concentration than the commercial fertilizer-amended forages (*P* = 0.0231 and 0.0754, respectively; Table 15).

Forage Yield

Wet weight yield was greater (*P* = 0.0064) for Trical® 2700 than Trical® 342 (Table 16). Commercial fertilizer-amended forages had the greatest (*P* = 0.0005) wet weight yield, followed by broiler litter-amended forages which were greater (*P* < 0.0001) than control treatments (Table 17). No difference was observed in DM yield between cultivars (Table 16). Among fertilizer sources, commercial fertilizer amendments yielded the greatest (*P* < 0.0001) DM, followed by broiler litter-amended forages, which were greater (*P* = 0.0157) than control treatments (Table 17). Crude protein yield did not differ between cultivars (Table 16). However, CP yield for commercial fertilizer-amended forages was greater than for either broiler litter-amended forages or control treatments (*P* = 0.0002 and < 0.0001, respectively; Table 17). Yield of NDF for Trical® 2700 was greater (*P* = 0.0121) than for Trical® 342 (Table 16). Commercial fertilizer-amended forages had the greatest (*P* < 0.0001) NDF yield followed by broiler litter-amended treatments, which were greater (*P* = 0.0192) than control treatments (Table 17). Trical® 2700 had greater ADF concentration values (*P* = 0.0023) than Trical® 342 (Table 16). Yield of ADF was greatest (*P* < 0.0001) for the commercial fertilizer-amended forages, followed by the broiler litter-amended treatment, which was greater (*P* = 0.0444) than the control treatment. No difference in TDN NDF yield was observed between cultivars (Table 16). However, forages amended with commercial fertilizer had the greatest (*P* < 0.0001) TND NDF yield, followed by broiler litter, which was observed to be greater (*P* = 0.0155) than the control treatment. No difference was observed in TDN ADF yield between cultivars (Table 16). Yield of TDN ADF among fertilizer sources identified commercial fertilizer-amended forages to be greatest (*P* <

0.0001), followed by broiler litter, which was greater (P = 0.0108) than the control treatments (Table 17)

Mineral analysis

No difference in Cu concentration was observed either between cultivars (Table 18) or among fertilizer sources (Table 19). Copper yield between cultivars did not differ (Table 18). However, forages amended with commercial fertilizer were greater (P = 0.0296) in Cu yield than broiler litter treatments, with the control being intermediate and not significantly different from either (Table 19). No effect on Zn concentration was observed either between cultivars (Table 18) or among fertilizer sources (Table 19). While cultivars did not differ in Zn yield (Table 18), forages amended with commercial fertilizer had greater Zn yields than either broiler litter or control treatments (P = 0.0435 and 0.0023, respectively; Table 19). Phosphorus concentration did not differ either between cultivars (Table 18) or among fertilizer sources (Table 19). Additionally, no effect on phosphorus yield was detected either between cultivars (Table 18) or among fertilizer sources (Table 19).

Tables

Table 1. Nutrient concentrations (% DM basis) of triticale cultivars harvested at early-tillering stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
CP	12.59	12.46	0.21
NDF	60[a]	58[b]	0.37
ADF	31.12	30.88	0.23
TDN NDF	54.26[b]	55.46[a]	0.2
TDN ADF	59.08	59.15	0.15

[a,b] Within a row, values without a common superscript differ (*P* < 0.01)

Table 2. Nutrient concentrations (% DM basis) for fertilizer amendment effect on triticale forage harvested at early-tillering stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
CP	12.06[b]	13.37[a]	12.16[b]	0.25
NDF	57.86[b]	59.32[a]	59.12[a]	0.45
ADF	30.46[b]	31.31[a]	31.23[a]	0.28
TDN NDF	55.16	54.89	54.54	0.25
TDN ADF	59.19	59.35	58.81	0.19

[a,b,c] Within a row, values without a common superscript differ (*P* < 0.10)

Table 3. Forage yields (kg/ha) for triticale cultivars harvested at early-tillering stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
WET WT	21,807[a]	18,830[b]	688
DM	3,155	2,990	95
CP	405	385	14
NDF	1,949	1,869	54
ADF	1,010	1,008	30
TDN NDF	1,686	1,637	47
TDN ADF	1,852	1,772	50

[a,b]Within a row, values without a common superscript differ (*P* < 0.01)

Table 4. Forage yields (kg/ha) for fertilizer amendment effect on triticale harvested at early-tillering stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
WET WT	20,137	21,382	19,435	843
DM	2,924[b]	3,305[a]	2,989[b]	117
CP	372[b]	437[a]	376[b]	17
NDF	1,838	2,020	1,867	66
ADF	967	1,069	990	36
TDN NDF	1,620[b]	1,783[a]	1,582[b]	58
TDN ADF	1,764[b]	1,940[a]	1,732[b]	62

[a,b,c] Within a row, values without a common superscript differ (*P* < 0.10)

Table 5. Concentration (DM Basis) and yield of minerals for triticale harvested at early-tillering stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
Cu (mg/kg)	6.32	5.37	0.44
Zn (mg/kg)	42.98	48.25	7.5
P (mg/kg)	3,447.76[b]	3,695.72[a]	93.5
Cu (kg/ha)	0.024[a]	0.018[b]	0.002
Zn (kg/ha)	0.165	0.16	0.024
P (kg/ha)	12.35	12.74	0.48

[a,b]Within a row, values without a common superscript differ (*P* < 0.10)

Table 6. Concentration (DM basis) and yield of minerals for amendment effect on triticale harvested at early-tillering stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
Cu (mg/kg)	6.21	5.87	5.46	0.53
Zn (mg/kg)	35.47	61.02	40.36	9.3
P (mg/kg)	3,601.45	3,559.4	3,554.36	114.25
Cu (kg/ha)	0.021	0.023	0.019	0.0022
Zn (kg/ha)	0.122[b]	0.223[a]	0.142[b]	0.03
P (kg/ha)	11.98	13.37	12.28	0.59

[a,b]Within a row, values without a common superscript differ (*P* < 0.05)

Table 7. Nutrient concentrations (% DM basis) for triticale cultivars harvested at stem-extension stage

	Cultivar		
Mar	Trical® 342	Trical® 2700	SE
CP	11.75	11.61	0.15
NDF	64.95[a]	60.99[b]	0.25
ADF	34.18[a]	32.55[b]	0.24
TDNNDF	51.27[b]	53.31[a]	0.15
TDNADF	56.95[b]	57.79[a]	0.16

[a,b]Within a row, values without a common superscript differ (*P* < 0.01)

Table 8. Nutrient concentrations (% DM basis) for fertilizer amendment effect on triticale forage harvested at stem-extension stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
CP	11.42[b]	12.17[a]	11.44[b]	0.18
NDF	62.57[b]	63.93[a]	62.41[b]	0.31
ADF	32.8[b]	34.22[a]	33.08[b]	0.29
TDN NDF	52.38	52	52.48	0.19
TDN ADF	57.65	57.14	57.42	0.19

[a,b]Within a row, values without a common superscript differ (*P* < 0.01)

Table 9. Interaction effects (cultivar × fertilizer amendment) for nutrient concentrations for triticale

Cultivar		Trical 342			Trical 2700			
Stage of Maturity		Broiler litter	Commercial fertilizer	Control	Broiler litter	Commercial fertilizer	Control	SE
Stem-extension stage	NDF	65.28[a]	64.95[a]	64.62[a]	59.87[c]	62.91[b]	60.2[c]	0.43
	ADF	33.92[a]	34.38[a]	34.23[a]	31.66[b]	34.05[a]	31.94[b]	0.41
	TDN-NDF	51.03[c]	51.57[c]	51.23[c]	53.75[a]	52.43[b]	53.74[a]	0.27
	TDN-ADF	57[b]	57.16[b]	56.67[b]	58.13[a]	57.1[b]	58.15[a]	0.28
Boot-flowering stage	NDF	71.07[c]	70.88[c]	70.73[c]	73.36[b]	75.33[a]	73.55[b]	0.49
	TDN-NDF	46.26[a]	46.5[a]	46.45[a]	45.4[b]	44.27[c]	45.17[b]	0.29

[a,b,c]Within a row, values without a common superscript differ ($P < 0.10$)

Table 10. Forage yields (kg/ha) for triticale cultivars harvested at stem-extension stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
WET WT	24,768[a]	21,083[b]	661
DM	3,640[a]	3,350[b]	106
CP	441[a]	389[b]	13
NDF	2,374[a]	2,098[b]	70
ADF	1,250[a]	1,131[b]	40
TDN NDF	1,868	1,773	54
TDN ADF	2,077[a]	1,927[b]	59

[a,b]Within a row, values without a common superscript differ ($P < 0.10$)

Table 11. Forage yields (kg/ha) for fertilizer amendment effect on triticale harvested at stem-extension stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
WET WT	21,794[b]	26,082[a]	20,900[b]	209
DM	3,358[b]	3,922[a]	3,206[b]	130
CP	392[b]	476[a]	376[b]	16
NDF	2,153[b]	2,520[a]	2,033[b]	86
ADF	1,133[b]	1,355[a]	1,083[b]	49
TDN NDF	1,759[b]	2,032[a]	1,670[b]	66
TDN ADF	1,941[b]	2,232[a]	1,833[b]	72

[a,b]Within a row, values without a common superscript differ ($P < 0.01$)

Table 12. Concentration (DM basis) and yield of minerals for triticale harvested at stem-extension stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
Cu (mg/kg)	4.82	3.84	0.46
Zn (mg/kg)	42.92[a]	29.39[b]	1.77
P (mg/kg)	3,461	3,378	86
Cu (kg/ha)	0.021[a]	0.013[b]	0.002
Zn (kg/ha)	0.186[a]	0.109[b]	0.008
P (kg/ha)	14.38[a]	12.68[b]	0.54

[a,b]Within a row, values without a common superscript differ ($P < 0.05$)

Table 13. Concentration (DM basis) and yield of minerals from fertilizer amendment effect on triticale harvested at stem-extension stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
Cu (mg/kg)	4.54	4.2	4.25	0.56
Zn (mg/kg)	36.64	35.62	36.21	2.17
P (mg/kg)	3,497	3,381	3,382	105
Cu (kg/ha)	0.017	0.016	0.015	0.003
Zn (kg/ha)	0.142	0.157	0.145	0.01
P (kg/ha)	13.13[b]	14.85[a]	12.62[b]	0.66

[a,b]Within a row, values without a common superscript differ (*P* < 0.05)

Table 14. Nutrient concentrations (% DM basis) for triticale cultivars harvested at boot-flowering stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
CP	7.75[b]	8.22[a]	0.12
NDF	70.89[b]	74.08[a]	0.28
ADF	38.89[b]	41.57[a]	0.2
TDN NDF	46.41[a]	44.93[b]	0.17
TDN ADF	52.34[a]	51.1[b]	0.13

[a,b]Within a row, values without a common superscript differ (*P* < 0.05)

Table 15. Nutrient concentrations (% DM basis) for fertilizer amendment effect on triticale forage harvested at boot-flowering stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
CP	7.97	8.08	7.89	0.16
NDF	72.22[b]	73.1[a]	72.14[b]	0.34
ADF	39.83[b]	40.89[a]	39.97[b]	0.24
TDN NDF	45.8	45.38	45.81	0.21
TDN ADF	51.92[a]	51.37[b]	51.8[a]	0.17

[a,b]Within a row, values without a common superscript differ (*P* < 0.10)

Table 16. Forage yields (kg/ha) for triticale cultivars harvested at boot-flowering stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
WET WT	25,116[b]	28,339[a]	822
DM	6,430	6,719	194
CP	532	556	21
NDF	4,583[b]	5,093[a]	142
ADF	2,533[b]	2,892[a]	81
TDN NDF	2,986	2,987	90
TDN ADF	3,364	3,401	100

[a,b]Within a row, values without a common superscript differ ($P < 0.05$)

Table 17. Forage yields (kg/ha) for fertilizer amendment effect on triticale forage harvested at boot-flowering stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
WET WT	26,153[b]	30,804[a]	23,225[c]	1,006
DM	6,346[b]	7,911[a]	5,466[c]	237
CP	519[b]	654[a]	459[b]	25
NDF	4,647[b]	5,803[a]	4,063[c]	173
ADF	2,582[b]	3,260[a]	2,295[c]	100
TDN NDF	2,879[b]	3,586[a]	2,494[c]	111
TDN ADF	3,271[b]	4,058[a]	2,819[c]	123

[a,b,c] Within a row, values without a common superscript differ ($P < 0.01$)

Table 18. Concentration (DM basis) and yield of minerals for triticale harvested at boot-flowering stage

	Cultivar		
Parameter	Trical® 342	Trical® 2700	SE
Cu (mg/kg)	4.14	4.46	0.46
Zn (mg/kg)	26.95	35.88	6.7
P (mg/kg)	3,281	2,695	512
Cu (kg/ha)	0.026	0.033	0.004
Zn (kg/ha)	0.185	0.205	0.016
P (kg/ha)	19.74	18.63	1.99

Table 19. Concentration (DM basis) and yield of minerals for fertilizer amendment effect on triticale harvested at boot-flowering stage

	Fertilizer Amendments			
Parameter	Broiler litter	Commercial fertilizer	Control	SE
Cu (mg/kg)	3.55	4.71	4.64	0.57
Zn (mg/kg)	38.3	28.41	27.54	8.2
P (mg/kg)	2,728	2,573	3,662	627
Cu (kg/ha)	0.021^{b}	0.039^{a}	0.029^{ab}	0.0049
Zn (kg/ha)	0.186^{b}	0.238^{a}	0.161^{b}	0.019
P (kg/ha)	17.57	21.39	18.59	2.43

^{a,b}Within a row, values without a common superscript differ ($P < 0.05$)

Discussion

Three separate harvest dates were selected for the present study in an effort to identify and compare transitions in forage quality throughout the maturation process of the 2 cultivars of triticale. Trical® 342 was consistent in its characterization as an early maturing cultivar, as DM yields in both the early-tillering stage and stem-extension stage harvests were superior to that of Trical® 2700. However, more importantly from a hay or silage producer's standpoint, Trical® 2700 surpassed Trical® 342 in DM yield by the boot-flowering stage (6,719 and 6,430 kg/ha, respectively). Similarly, Glass and Van Santen (2008) determined DM yield for Trical® 2700 and Trical® 342 to be 5,905 and 5,732 kg/ha, respectively. As an indication of potential N deficiencies in the broiler litter-amended and control forages, the DM yield for commercial fertilizer-amended forages exceeded 7,900 kg/ha, a DM yield very similar to the 7,972 kg/ha average for triticale determined by McCartney and Vaage (1994).

George and Bell (2001) observed the CP concentration of annual grasses and small grains to decline at an average rate of 1.44% as forage progressed through each stage of the twelve-stage Feekes scale. Additionally, Collar and Aksland (2001) observed that CP concentration of triticale declined from 25% in the leaf stages of maturity to 8% by the soft dough stage. In the present study, decline in CP concentration across treatments was lower than that reported by George and Bell (2001) and Collar and Aksland (2001) indicating the low CP concentration in the early-tillering stage was likely due to both low concentrations of N and low plant availability of N across all treatments. Commercial fertilizer-amended forages were initially higher in CP concentration during the early-tillering stage and stem-extension stages; however, by the boot-flowering stage, no difference was determined across fertilizer amendments. Findings indicate both a N deficiency in the broiler litter and control treatments across all stages of maturity, as well as potential benefit when either a split application or additional application of N is practiced in the commercial fertilizer treatment. Not surprisingly, the biomass accumulation of the earlier maturing Trical® 342 forages combined with the remaining bioavailable N during the stem-extension stage resulted in both greater concentrations and yields of CP compared with Trical® 2700. However, during boot-flowering stage, as either a result of nutrient deficiencies, genotypic effects or a combination of both, the later maturing Trical® 2700 surpassed Trical® 342 in CP concentration. No difference was observed in CP yield, as DM yield wasn't significantly higher for Trical® 2700.

While CP concentration plays an integral role in determination of forage quality (i.e., TDN), concentration of cell-well constituents is generally the more important factor in determining digestibility (Rohweder et al., 1978). Neutral detergent fiber comprises the total cell wall: cellulose, hemicellulose and lignin, consisting of partially and non-uniformly digestible fractions of the cell-wall constituents; it is used as a predictor of DMI in ruminants. Generally, as forage concentration of NDF increases, DM intake decreases (Schroeder, 1994). The ADF fraction includes the least digestible portion of the cell: cellulose and lignin. Acid detergent fibers values are used to predict digestibility values (i.e., DDM, TDN etc.). As forages mature, the less digestible stems make up a greater proportion of the plant; thus, NDF and ADF concentrations increase with maturity. However, with small grains, once grain development begins, highly digestible non-structural carbohydrate production dilutes existing fiber components (Collar and Aksland, 2001).

In the present study, interaction effects were observed in the stem-extension stage in that all fertilizer source combinations for Trical® 342 had greater NDF and ADF values than Trical® 2700 amended with commercial fertilizer, which was greater than Trical® 2700 amended with either broiler litter or control treatments. Predictably, the Trical® 342 was greater in concentrations of NDF and ADF due to earlier maturation; however, Trical® 2700 amended with commercial fertilizer was greater in NDF and ADF concentrations than either broiler litter or control, indicating that the broiler litter and control treatments failed to provide adequate nutrients, consequently affecting digestibility characteristics. Additionally, an interaction was observed for NDF concentration at the boot-flowering stage. Trical® 2700 amended with commercial fertilizer had the greatest NDF concentration, followed by the Trical® 2700 broiler litter and control treatments, which were greater than all fertilizer-source combinations for Trical® 342; the exact opposite of the interaction effect observed in the stem-extension stage. The fact that Trical® 2700 commercial fertilizer amended forages had an NDF value of 75.33%, while the same fertilizer-source treatment for Trical® 342 had an NDF value of 70.88%, would initially lead one to believe the differences were due to disparities in stage of growth. However, in concurrence with estimated heading dates for wheat varieties in Alabama (Mask et al.1994) both Trical cultivars appeared similar in stage of growth at the final harvest date in mid-April, each forage ranging from early boot to flowering stage with no harvested forages having yet achieved the milk stage. Despite relatively similar stages of maturity, Fohner (2002) determined that, within a triticale cultivar, DM yield from boot stage to dough stage ranged from 5,828 to 14,571 kg/ha, respectively, likely due to transition of nutrient composition in preparation of grain production. Conceivably, in analysis of the Fohner (2002) findings combined with the limited amount of triticale research regarding biomass partitioning relative to specific stages of growth, the inversion of interaction effects over the final 30-day period could be attributed to either genotypic differences between cultivars or relatively minor disparities in stage of maturity.

Prediction equations for TDN used in the present study were developed as a means of efficiently yet accurately estimating TDN values without experimentally determining the digestibility of the analyzable components. Two equations are utilized, one based on NDF and the other on ADF, both of which utilized CP concentration with r^2 values of 0.66 and 0.61, respectively (Robinson et al., 2004). Logically, TDN is often inversely related to maturity; as forages mature, digestibility and CP concentrations decrease. Predictably, the greatest TDN values were associated with the cultivar or the fertilizer source with the lowest NDF and ADF concentrations. Concentrations of TDN-NDF at boot-flowering stage for Trical® 342 was 46.41% and 44.93% for Trical® 2700. While forage-quality prediction equations for TDN are important, TDN expressed on a yield per unit basis is required to fully assess forage quality and productivity. Having provided more plant available N, commercial fertilizer amended forages achieved DM yields great enough to overcome their consistently low digestibility, indicated by their NDF and ADF concentrations as they routinely attained greatest TDN-NDF and TDN-ADF yields.

In addition to forage quality, mineral concentrations and yield of Cu and Zn were determined and calculated to identify any potential factors related to nutrient accumulation or mitigation. Applied broiler litter had a Cu concentration of 461 mg/kg and a Zn concentration of 633 mg/kg. In the present experiment, micronutrient concentrations in the soil were not determined. However, Tewolde et al. (2010) determined soil levels of Cu and Zn to be 1.09 and

1.82 mg/kg, respectively. Following applications of poultry litter that ranged from 321 to 495 mg/kg for Cu and 184 to 419 mg/kg for Zn. While the Cu and Zn concentrations in poultry litter determined by Tewolde et al. (2010) are well below the threshold limits (1500 and 2800 mg/kg, respectively) for land application of sewage sludge (Jackson et al., 2003) they are sufficiently high to suggest that long-term application may lead to accumulation in soils. In the present study, neither triticale cultivar nor fertilizer source had any consistent effect on forage concentrations of Cu or Zn. Vogel et al. (1989) reported that across 10 strains of wheatgrass, Cu and Zn concentrations did not differ. Additionally, the author determined the wheatgrass uptake for Cu:Zn to be approximately 1:5. In regards to the correlation of forage uptake for Cu and Zn, Pederson et al. (2002) found correlation coefficients of above ground plant parts for 16 forages to be 0.735 for leaves and 0.66 for stems. Brown et al. (2006) collected boot-stage triticale forage grown on 44 different manured fields and observed Cu and Zn concentrations to range from 1.3 to 38 mg/kg and from 12.7 to102 mg/kg, respectively; whereas, in the present study, boot-flowering stage triticale across all treatments averaged 4.3 and 31.5 mg/kg for Cu and Zn, respectively. While the Brown (2006) study determined triticale's Cu and Zn uptake to range much greater than that in the present study, the Cu and Zn soil concentrations of the present study, regardless of fertilizer source, were not great enough to reach the accumulation potential of triticale.

When nutrient mitigation is the objective, yield of Cu and Zn is of greater importance than forage concentration. Consequently, when a significant difference in mineral yield was identified for either Cu or Zn as affected by cultivar or fertilizer source, in every instance it coincided with greater DM yields for that particular treatment. Therefore, while this study did not identify either Trical® 342 or Trical® 2700 to vary in their concentration of Cu or Zn, to maximize nutrient removal selection for highest DM yield would be most beneficial.

As is commonly practiced in Alabama, N application rate recommendations were based upon crop requirements. Both the commercial fertilizer and broiler litter were applied at an N application rate of 112 kg/ha. Concentration of N:P:K in the broiler litter was 3.8:3.4:4.5 based upon the N application rate; approximately 2,947 kg/ha of broiler litter was applied, resulting in an application of 100 kg/ha of P_2O_5, twice that of soil test recommendation of 45 kg/ha of P_2O_5. Mitchell (2001) states that, for rye produced in central Alabama, expected N:P:K removal is 52:9:49 kg/ha. Additionally, Evers (2002) stated that maximum yield of annual ryegrass was achieved with N, P_2O_5, and K_2O rates of 340, 34 and 280 kg/ha, respectively, a ratio of 10:1:8. The discrepancy of ratios between broiler litter nutrient concentration and plant nutrient uptake leads to accumulation of P in the soil. Therefore, P concentration and yield were analyzed to determine if either cultivar or fertilizer source had an affect on characteristics contributing to P accumulation or P mitigation.

In accordance with the NRC default value for P concentration of triticale (0.34%), Brown et al. (2006) found a 0.33% value for boot stage triticale collected on manured fields; however, while the mean did not differ from the default value, the range of P concentration was 0.18 to 0.53%. In the present study, during early-tillering stage, the later maturing Trical® 2700 had the greater P concentration at 0.37%. While no cultivar effect was seen on P concentration for either the stem-extension or boot-flowering stages, P concentration declined with increasing maturity with the greatest boot-flowering stage P concentration observed in Trical® 2700 forages at 0.27%. Relative consistency of P concentrations, compared to the range found in the Brown study suggests the broiler litter applications in this two-year study did not significantly alter soil

P values so as to allow determination of P accumulation potential of triticale at high soil nutrient levels.

As with Cu and Zn, yield of P is of greater importance for the purpose of nutrient mitigation than is concentration. The only significant effect seen on P yield was during the stem-extension stage; Trical® 342 forages and commercial fertilizer amended forages provided the greatest P yields due to their high DM yields. In comparative analysis to existing data, the present study found P yield during the boot-flowering stage to be approximately 19 kg/ha, within the range of 8 to 40 kg/ha identified by Brown et al. (2006). The moderate P uptake of the present study in relation to the Brown et al. (2006) study, as well as the relative lack of significance seen in the Cu and Zn concentrations, indicates that two years of broiler litter application at a rate twice that of recommendations did not result in soil nutrient levels high enough to represent conditions found in soils subjected to long-term broiler litter application.

Implications

Results of this study indicate that the bioavailability of N in a commercial N fertilizer provided superior triticale forage productivity when compared against short-term application of broiler litter at the same N rate. Many of the beneficial soil characteristics commonly associated with broiler litter application were not realized due to the short duration of the study. While extrapolation of existing data may help identify potential nutrient mitigation qualities of triticale, amendment of soil with higher concentrations of nutrients more accurately representing characteristics associated with long-term application of broiler litter is required to determine both the nutrient accumulation potential, as well as tolerance of triticale to high nutrient soils.

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