J. Dairy Sci. 96:7195–7209
http://dx.doi.org/10.3168/jds.2013-6889

Unique interrelationships between fiber composition, water-soluble carbohydrates, and in vitro gas production for fall-grown oat forages[1]

W. K. Coblentz,*[2] S. E. Nellis,† P. C. Hoffman,† M. B. Hall,‡ P. J. Weimer,‡ N. M. Esser,§ and M. G. Bertram#
*US Department of Agriculture-Agricultural Research Service, US Dairy Forage Research Center, Marshfield, WI 54449
†Department of Dairy Science, University of Wisconsin, Madison 53706
‡US Department of Agriculture-Agricultural Research Service, US Dairy Forage Research Center, Madison WI 53706
§University of Wisconsin Marshfield Agricultural Research Station, Marshfield 54449
#University of Wisconsin Arlington Agricultural Research Station, Arlington 53911

ABSTRACT

Sixty samples of 'ForagePlus' oat were selected from a previous plot study for analysis of in vitro gas production (IVGP) on the basis of 2 factors: (1) high (n = 29) or low (n = 31) neutral detergent fiber (NDF; 62.7 ± 2.61 and 45.1 ± 3.91%, respectively); and (2) the range of water-soluble carbohydrates (WSC) within the high- and low-NDF groups. For the WSC selection factor, concentrations ranged from 4.7 to 13.4% (mean = 7.9 ± 2.06%) and from 3.5 to 19.4% (mean = 9.7 ± 4.57%) within high- and low-NDF forages, respectively. Our objectives were to assess the relationships between IVGP and various agronomic or nutritional characteristics for high- and low-NDF fall-oat forages. Cumulative IVGP was fitted to a single-pool nonlinear regression model: $Y = MAX \times (1 - e^{[-K \times (t - lag)]})$, where Y = cumulative gas produced (mL), MAX = maximum cumulative gas produced with infinite incubation time (mL), K = rate constant, t = incubation time (h), and lag = discrete lag time (h). Generally, cumulative IVGP after 12, 24, 36, or 48 h within high-NDF fall-oat forages was negatively correlated with NDF, hemicellulose, lignin, and ash, but positively correlated with WSC, nonfiber carbohydrate (NFC), and total digestible nutrients (TDN). For low-NDF fall-grown oat forages, IVGP was positively correlated with growth stage, canopy height, WSC, NFC, and TDN; negative correlations were observed with ash and crude protein (CP) but not generally with fiber components. These responses were also reflected in multiple regression analysis for high- and low-NDF forages. After 12, 24, or 36 h of incubation, cumulative IVGP within high-NDF fall-oat forages was explained by complex regression equations utilizing $(\text{lignin:NDF})^2$, lignin:NDF, hemicellulose, lignin, and TDN^2 as independent variables ($R^2 \geq 0.43$). Within low-NDF fall-grown oat forages, cumulative IVGP at these incubation intervals was explained by positive linear relationships with NFC that also exhibited high coefficients of determination ($R^2 \geq 0.75$). Gas production was accelerated at early incubation times within low-NDF forages, specifically in response to large pools of WSC that were most likely to be present as forages approached boot stage by late-fall.
Key words: fiber composition, in vitro gas production, oat, water-soluble carbohydrate

INTRODUCTION

Recently, several research projects have evaluated the potential of fall-grown oat (*Avena sativa* L.) for use as an emergency fall forage, to extend the grazing season, or for routine use as an additional unique forage option for dairy and other livestock producers located in the north-central United States (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010; Coblentz et al., 2011). Although the fall yield potential has proven to be encouraging, reaching maxima >8,000 kg of DM/ha under favorable weather conditions (Coblentz et al., 2011), several unique quality traits have also been identified consistently and warrant additional in-depth evaluation. Among these are reduced concentrations of structural fiber components, less extensive lignification, and a propensity to accumulate water-soluble carbohydrates (**WSC**) during late fall (Contreras-Govea and Albrecht, 2006; Coblentz and Walgenbach, 2010; Coblentz et al., 2012).

Several interrelated management, weather, and plant-physiology factors contribute to the expression of these unique forage-quality traits. When oat is grown during fall, the long-day photoperiod requirement for flowering (Dennis, 1984) is disrupted, thereby altering normal plant maturation and development. These natural developmental processes are further affected by

Received April 2, 2013.
Accepted July 13, 2013.
[1]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information, and does not imply either recommendation or endorsement by the US Department of Agriculture.
[2]Corresponding author: wayne.coblentz@ars.usda.gov

the onset of cold temperatures and frost events. Collectively, these factors act to slow maturation relative to normal responses following traditional spring planting dates. Contreras-Govea and Albrecht (2006) reported that 3 oat cultivars evaluated after a traditional spring planting date reached the mid-milk stage of grain fill 77 d after planting, whereas the same cultivars evaluated following an August planting date were far less mature after an identical time interval, reaching only the mid-boot stage of growth. In addition, the process of winter-hardening occurs within oat plants in response to cold temperatures. As a result, various solutes accumulate within plant tissues that include sugars (Eastin and Sullivan, 1984), some of which exist in the form of fructans for oat (Smith, 1981). Depending on planting date and cultivar selection, concentrations of WSC can exceed 15% of total plant DM by November (Coblentz et al., 2012). Furthermore, a positive relationship between temperature and lignification exists for many forages (Ford et al., 1979; Van Soest, 1982); therefore, it is reasonable to suspect that oat plants grown during fall should be lignified less extensively than comparable plants maturing during late spring or early summer. Cherney et al. (1983) reported lignin:NDF ratios of 0.074 to 0.106 for spring-established oat harvest 7 to 28 d postheading, and NRC (2001) reports similar ratios of 0.112 and 0.091 for headed oat hays and silages, respectively. In contrast, lignin:NDF ratios are often reduced by 50% or more within fall-grown oat forages, and particularly when seeding dates are delayed in Wisconsin until August (Coblentz and Walgenbach, 2010; Coblentz et al., 2012). In one study, ForagePlus oat (Wisconsin Foundation Seeds, Madison, WI) established in early August and harvested on several dates throughout the fall exhibited mean lignin:NDF ratios of 0.010 and 0.020 during 2006 and 2007, respectively (Coblentz and Walgenbach, 2010). Reductions of the lignin:NDF ratio also have a positive effect on estimates of in vitro NDF digestibility, which has been closely associated with lignin concentrations for fall-grown oat forages ($Y = 0.64x^2 - 11.9x + 89.1$; $R^2 = 0.95$; Coblentz et al., 2012).

These physiological responses for fall-grown oat can be manipulated further by various production management options, such as cultivar selection and planting date. Generally, maturity ratings such as early, mid, or late are based on growth and maturation responses following traditional spring establishment (Mochon and Conley, 2012). These relative maturity rankings also are maintained during fall growth, but differences in maturation rate between rating categories are often exacerbated (Coblentz et al., 2011). Establishment dates also can interact with relative maturity rankings, thereby complicating management strategies. For instance, late-maturing forage cultivars, such as ForagePlus, are the best management choice for planting dates ranging from mid-July to early August throughout central Wisconsin, but faster maturing grain cultivars may exhibit yield advantages with later establishment dates (Coblentz and Walgenbach, 2010). Furthermore, concentrations of WSC are dependent on both of these management factors; oat plants exposed to cold temperatures at the late-elongation or boot stages of growth frequently exhibit the greatest concentrations of WSC (Coblentz et al., 2012).

Despite undergoing winter-hardening, oat plants are unlikely to survive northern United States winters; however, their fall growth can still be utilized to meet various production goals. Furthermore, the substantial accumulations of WSC within these forage plants raise interesting questions about how ruminal fermentation may be affected. Potentially, accumulations of large quantities of WSC within elongated or boot-stage plants may shift the normal production paradigm in which DM yield and forage nutritive value are inversely related. Typically, management strategies require compromises between yield and nutritive value, but this may not be true for fall-grown oat. Our objectives were to assess the relationships between various agronomic or nutritional characteristics and in vitro gas production (**IVGP**) for high- and low-NDF fall-grown oat forages selected from a previous 3-yr project (Coblentz et al., 2011, 2012) conducted in Marshfield, Wisconsin. In vitro gas production was selected as a means of comparing rumen fermentation because it permitted rapid analysis of many samples, and is known to correlate strongly with VFA production (O'Hara and Ohki, 1973; Blümmel et al., 1994), and thus delivery of primary nutrients (VFA) to the animal during ruminal fermentation.

MATERIALS AND METHODS

Selection of Forages

The oat forages evaluated for this project were all grown in fall, and were a subset selected from a larger 3-yr plot study evaluating establishment dates, cultivar selection, and harvest dates conducted at the University of Wisconsin Marshfield Agricultural Research Station (44°39′N; 90°08′W) between 2007 and 2009. Full details describing experimental design, plot and harvest management, and assessment of nutritive value for these forages have been reported previously (Coblentz et al., 2011, 2012). A linear model (Stauss, 1994) was used to describe the growth stage of each forage at the time it was harvested. In this model, growth stages were defined as follows: (1) leaf development, 10–19;