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Growth Stage Influences Forage Yield and Quality of Winter Rye

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Abstract
Winter rye (*Secale cereale* L.) is a common cover crop in the Upper Midwest United States with potential as a forage crop; but little is known about the effect of maturity on its spring forage yield and quality. Our objective was to determine the forage yield and quality of three winter rye cultivars at six different maturities in four environments. The yield response to increased maturity was quadratic and variable over environment with ranges at boot (Zadok 41) of 1.2 to 2.7 tons/acre, at heading (Zadok 51) 1.4 to 4.2 tons/acre, and at dough (Zadok 81) of 4.4 to 9.5 tons/acre. Forage crude protein (CP), neutral detergent fiber digestibility (NDFD), and digestible dry matter (DDM) decreased with maturity while neutral detergent fiber (NDF) increased. Average NDF digestibility decreased linearly from 82.5% at tillering to 44.1% at soft dough. Rye cultivars had similar forage yield and quality except for CP. Vitallo had lower CP levels than Rymin or Spooner. Producers can maximize yield by harvesting at dough (Zadok 81) or forage quality by harvesting at tillering (Zadok 21). Rye provides good yield and high quality forage at many environments and maturities.

Introduction
Cereal rye is used in the Midwest United States as a winter cover crop following corn (*Zea mays* L.) or soybean (*Glycine max* L.) to scavenge excess soil N and to decrease water and soil runoff (9,17). Rye has superior winter-hardiness to other small grains and will reliably overwinter (10). Killed winter rye can also be used as mulch for weed control during production of soybean (20). Rye could be a valuable forage source in the Midwest because it has forage yields similar and sometimes greater than other small grains (5). Thelen and Leep (18) evaluated winter rye in Michigan as a double-crop forage in corn and soybean cropping systems when planted after corn. In that system, rye harvested at early boot (Zadok 41) yielded 1.7 tons/acre and had CP and NDF concentrations of 19.4% and 48.6%, respectively. In Canada, Tollenarr et al. (19) reported winter rye planted after corn yielded 3.2 and 5.7 tons/acre when harvested on 27 May and 8 June of the following spring. While this research demonstrates the potential of winter rye as a forage crop, it did not show the relationship of forage yield and quality over a range of maturities for multiple cultivars.

Previous research has shown differences in forage yield and quality in oat (*Avena sativa* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), winter rye as well as in cultivars within species (1,7,8). Typically, forage yield increases and forage quality decreases as small grains mature from vegetative to reproductive stages (1,5). Producers often harvest small grains at boot (Zadok

41) to obtain yields of high quality forage or at soft dough stage (Zadok 81) to obtain higher yield (1).

Environmental benefits of rye cover cropping are well documented, but widespread adoption would be enhanced by potential economic return. The harvest of rye as a hay or silage has potential to provide an additional income to producers. Therefore, our objective was to determine the effect of maturity at harvest on the forage yield and forage quality of cultivars of cereal rye grown as a winter annual in several environments.

Measuring Forage Yield and Quality

Research was conducted at four Minnesota environments: Roseau (49°00'N 95°76'W), Morris (45°59'N 95°91'W), St. Paul (45°00'N 93°05'W), and Lamberton (44°20'N 95°26'W). The soil series were: Zippel very fine sandy loam (coarse-silty, mixed, frigid Typic Endoaquolls) at Roseau; Hamerly clay loam (fine, loamy, frigid Aeric Calciaquoll) at Morris; well-drained Waukegan silt-loam (fine-silty over sandy or sandy-skeletal, mixed, mesic Typic Hapludolls) at St. Paul; and moderately well drained Normania clay loam (fine-loamy, mixed, mesic, Aquic Haplustoll) at Lamberton.

Rye was seeded on 5 September 2007 in Roseau, St. Paul, and Lamberton, and on 14 September 2007 at Morris. Rye followed silage corn at Morris and St. Paul, and wheat at Roseau and Lamberton. Crop residue was incorporated by chisel plowing or cultivation and rye was drilled at 90 lb/acre with a row spacing of 8 inches. Plots at St. Paul, Lamberton, and Roseau were not fertilized. Plots at Morris were fertilized with dairy manure providing 437 lb N/acre, 117 lb phosphate/acre (51 lb P/acre), and 308 lb potash/acre (255 lb K/acre). The available nitrate-N in the spring was 182 lb/acre at St. Paul, 110 lb/acre at Lamberton, 99 lb/acre at Roseau, and 180 lb/acre at Morris. Plot size was 6 ft × 15 ft.

The experimental design was a randomized complete block with a split plot arrangement of treatments with four replicates per environment. Whole plots were winter rye cultivars and sub plots were stage of maturity. Whole plot treatments were cultivars: Vitallo, 'Spooner, and Rymin, at Roseau, Lamberton, and St. Paul; and Vitallo and Rymin at Morris. These cultivars are grown in Minnesota for grain and cover cropping. Sub-plot treatments were target maturities corresponding to 21 (tillering), 31 (stem elongation), 41 (boot development), 51 (head emergence), 61 (anthesis begins), and 81 (dough development) on the Zadok maturity scale (21). With the addition of environment as a factor, the design was a split-split plot with environment as the whole plot, cultivar as the first split, and maturity as the split-split.

Data Collection and Analysis

A plot was considered to have reached a target growth stage if 50% of the plants in the plot were at a particular growth stage. We sampled weekly as proposed by Juskiw et al. (8). Roseau was only sampled six times due to early season snow cover. Aboveground biomass yield was determined by harvesting a 40-inch × 8-inch area of each plot to a 1-inch height. Samples were dried at 140° F for 72 h. Crude protein (CP), neutral detergent fiber (NDF), and in vitro true digestibility (IVTD) were determined via near infrared reflectance spectroscopy (NIRS) analysis (model 6500, NIRSystems, Silver Springs, MD) using NIRS equations developed for small grains (13). Equations for NIRS were developed using the software program Calibrate (NIRS 3 version 4.0, Infrasoft International, Port Matilda, PA) with modified partial least squares regression option (15,16). Random samples of rye were subjected to conventional chemical analysis for CP (Kjeldahl N × 6.25), NDF (3), and digestible dry matter (DDM) (3), and used as monitoring sets. Predicted values for CP, NDF, and DDM were adjusted for bias based on conventional analysis results from the monitoring sets. Neutral detergent fiber digestibility (NDFD) for each sample was calculated from NDF and IVTD (6).

Statistical analysis was conducted using R Statistical software package (14). Regression analysis was used to examine the relationship between forage yield, NDF, CP, DDM, NDFD based on the Zadok maturity scale. A significance level of *P* = 0.05 was used. Models were compared to determine the contribution of linear and quadratic effects. Models were fit to show the effect of maturity as a predictor of forage quality and yield. Environment was considered a fixed effect. Environments and cultivars were tested for differences in slope and intercept over the range of maturities.

Forage Yield

An environment by maturity interaction occurred ($P < 0.05$) for forage yield indicating differences in yield response to maturity between environments (Table 1). There was no cultivar by environment by maturity interaction (Table 1). Average yield was greatest at St. Paul, similar at Morris and Lamberton, and least at Roseau (Table 2, Fig. 1). The environmental effect incorporates soil fertility, climatic conditions, and other components. Prior to planting the rye, only Morris had manure fertilizer applied at the other three environments there was no fertilizer application. There were differences observed in spring measured soil nitrate-N between the four environments. St. Paul and Morris had the highest soil nitrate-N and the highest final yield (Zadok 81). Those locations also had the greatest cumulative spring growing degree days (*data not shown*). Roseau had the least yield and the least cumulative growing degree days. However, yield rankings did not follow soil nitrate-N at growth stages and the small soil nitrate-N differences between Morris and St Paul (2 lb/acre) or between Lamberton and Rosaeu (11 lb/acre) likely did not influence yield differences at these location pairs (Table 2). Previous work has shown that forage rye yield responds well to N soil fertility (10). Precipitation was unlikely to have been strongly related to yield differences as it was similar to the long-term average at all environments.

Table 1. *P*-values from ANOVA for the effect for cultivar, environment, and maturity and their interaction on forage yield, crude protein (CP), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), and digestible dry matter (DDM).

Effects	**Biomass**	**CP**	**NDF**	**NDFD**	**DDM**
Environment	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Rep	0.031	0.003	0.640	0.790	0.667
Cultivar	0.084	< 0.001	0.070	0.062	0.123
Env × Cul	0.135	0.183	0.250	0.010	0.147
Maturity	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Cul × Mat[x]	0.860	0.121	0.017	0.057	0.012
Env × Mat[y]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Env × Cul × Mat	0.083	0.160	0.760	0.300	0.646

[x] Cultivar × maturity interaction.
[y] Environment × maturity interaction.

Table 2. Winter rye forage yield at different growth stages at four Minnesota environments.

Zadok growth stage	**Location**[x]			
	SP	**L**	**R**	**M**
	Yield (tons/acre)			
21-25	0.98	0.09	0.49	0.49
31-35	1.34	0.49	0.71	1.43
39-41	2.14	1.20	1.25	2.68
45-51	4.19	2.19	1.43	3.92
61-65	5.22	3.43	2.63	4.59
81-85	9.54	6.42	4.37	7.54
LSD	1.20	1.04	0.87	0.79

[x] SP = St. Paul, L = Lamberton, R = Roseau, and M = Morris.

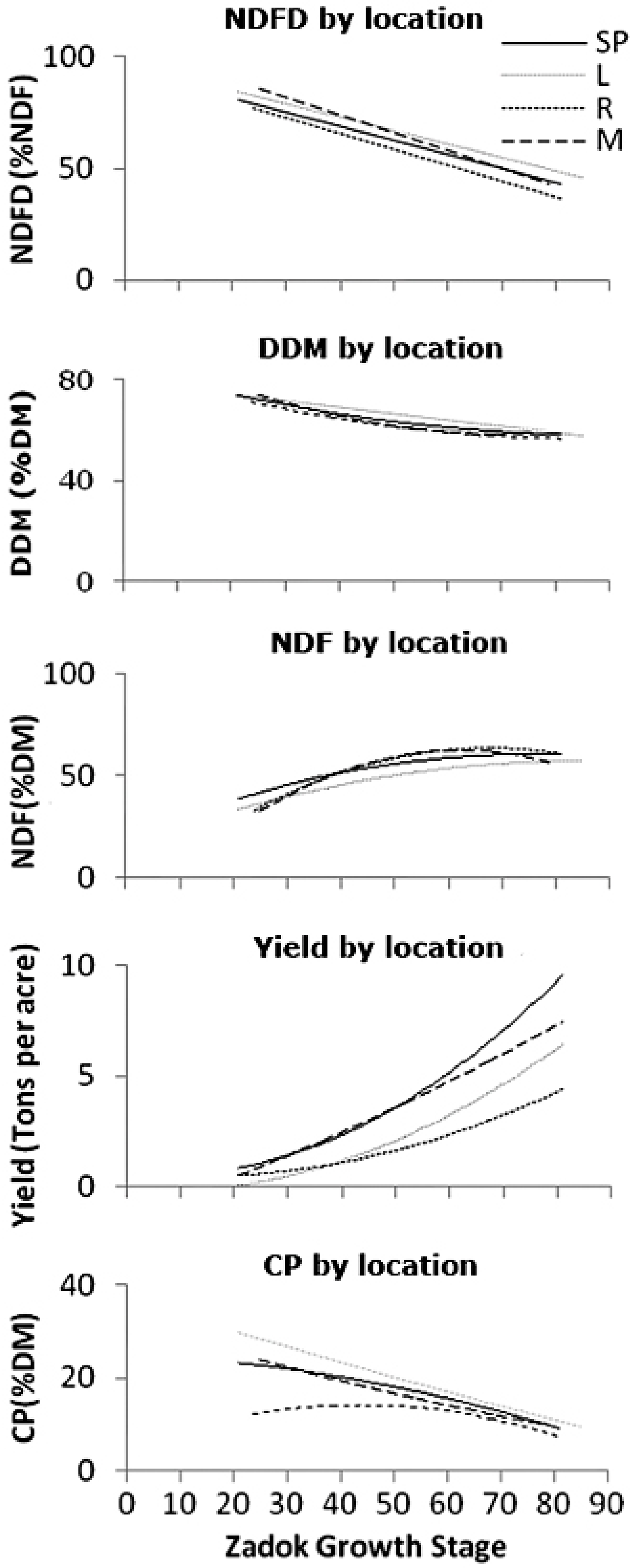

Fig. 1. Response curves for the effect of maturity on winter rye forage NDFD, DDM, NDF, yield, and CP in four Minnesota environments. The responses were based on regression equations shown in Table 3.

There was no difference ($P > 0.05$) among cultivars in yield or yield response to maturity; therefore, regression equations were created for each environment, but averaged over cultivars (Table 3, Fig. 1). Yield increased quadratically in response to maturity (Table 2, Fig. 1) but slopes and yields differed ($P < 0.05$) among environments (Table 3). Yield increased with maturity and was maximized at the soft dough stage (Zadok 81). Differences among environments increased with maturity. Yields were similar to those previously reported for winter rye (1.8 to 5.5 tons/acre), when harvested at similar growth stages Zadok 41 to Zadok 61 (2,4,18). Yield data were slightly non-normal; however, this data fit the biological activity better a transformed model so the non-transformed data were used.

Table 3. Regression equations for predicting rye forage yield and quality from spring tillering through dough development at four Minnesota environments.

Location	Location	Regression equation	Mean	R^2
Forage yield (tons/acre)	St. Paul	$2.47 - 0.12(gs^{†}) + 0.0026(gs)^2$	3.71a	0.90
	Lamberton	$-0.14 - 0.02(gs) + 0.0011(gs)^2$	2.28b	0.78
	Roseau	$0.41 - 0.016(gs) + 0.0008(gs)^2$	1.36c	0.82
	Morris	$-0.73 + 0.027(gs) + 0.00084(gs)^2$	2.81b	0.93
	LSD		0.61	
CP (%DM)	St. Paul	$25.06 - 0.045(gs) - 0.0019(gs)^2$	17.43b	0.79
	Lamberton	$36.29 - 0.32(gs)$	20.24a	0.86
	Roseau	$4.02 + 0.47(gs) - 0.005(gs)^2$	12.13c	0.53
	Morris	$30.27 - 0.26(gs)$	18.31b	0.79
	LSD		1.13	
NDF (%DM)	St. Paul	$18.9 + 1.11(gs) - 0.007(gs)^2$	53.61a	0.72
	Lamberton	$15.93 + 0.97(gs) - 0.005(gs)^2$	48.24d	0.82
	Roseau	$-8.64 + 2.14(gs) - 0.01(gs)^2$	52.07b	0.90
	Morris	$-20.4 + 2.66(gs) - 0.02(gs)^2$	49.25c	0.95
	LSD		0.69	
DDM (%DM)	St. Paul	$85.23 - 0.61(gs) - 0.003(gs)^2$	64.41b	0.76
	Lamberton	$79.36 - 0.25(gs)$	66.59a	0.83
	Roseau	$84.69 - 0.66(gs) - 0.004(gs)^2$	63.26c	0.86
	Morris	$95.35 - 1.02(gs) - 0.007(gs)^2$	65.77a	0.94
	LSD		0.95	
NDFD (%NDF)	St. Paul	$94.25 - 0.63(gs)$	62.62c	0.81
	Lamberton	$97.41 - 0.6(gs)$	66.93b	0.81
	Roseau	$94.18 - 0.71(gs)$	59.73d	0.90
	Morris	$105.44 - 0.79(gs)$	69.79a	0.85
	LSD		2.31	

[x] gs = growth stage

Forage quality

Effects of maturity were consistent with previous research (1,5) on other small grains showing decreasing nutritive value (CP, DDM, and NDFD) with maturity and an increase in NDF (Table 2). Slopes differed ($P < 0.05$) among environments (Table 1). In contrast, slopes for cultivars did not differ ($P > 0.05$). The only exception to this was CP. Crude protein data were slightly non-normal; however, the non-normal data fit the biological activity of plants better than the transformed model, so this model was used.

Neutral detergent fiber digestibility responses were linear decreasing until dough stage (Zadok 81) (Fig. 1). Responses in NDF were quadratic increasing until anthesis (Zadok 61) in every environment. Digestible dry matter decreased until anthesis after which it slightly increased. Crude protein decreased with increased maturity until dough development (Zadok 81).

Forage CP, DDM, and NDFD were lowest at Roseau, while NDF concentration at Roseau and St. Paul was highest. Lamberton or Morris was highest for CP, DDM, and NDFD and lowest for NDF. Cultivars had the same NDF, NDFD, and DDM concentration but differed ($P < 0.05$) in CP concentration (Table 1). Rymin and Spooner (18.3% and 17.8%) had a higher CP than Vitallo (16.3%).

Winter rye in this experiment had a higher CP level than those previously reported for triticale, wheat, or rye (4). Neutral detergent fiber was higher than other small grains (11), but similar to winter rye (4,18). Digestible dry matter was similar to reports for other small grains (1), but higher than previous reports in winter rye (12). Crude protein was within the range previously reported for winter rye (4,11,12). Our results of a large environmental effect are supported by Harmoney and Thompson (4), who also reported variation among cultivars to be secondary to environmental variation. This makes performance prediction more difficult as it is hard to account for the random environmental variability.

Summary and Conclusion

Forage yield of winter rye increases quadratically with maturity. The yield response is variable over environment with ranges at boot (Zadok 41) of 1.2 to 2.7 tons/acre, at heading (Zadok 51) 1.4 to 4.2 tons/acre, and at dough (Zadok 81) of 4.4 to 9.5 tons/acre. Forage quality as measured by CP, DDM, or NDF digestibility generally decreased with maturity.

Winter rye has a potential as a forage crop but the yield and quality will vary with environment and harvest maturity. Winter rye can be effectively used as small grain forage as it has similar forage quality and higher yield than other small grain forages. Producers will have to assess the relative value of forage yield and quality in their operations. For example, rye grazed at early vegetative stages (Zadok 21 or 31) before planting of corn or soybean would provide high quality pasture in early spring (April or May) but yields would be low. We realize that planting date in the fall influences forage yield in the spring with earlier planting resulting in higher spring yields. However, we feel that the differences between growth stages would be the same regardless of planting date. For mechanical harvest as silage or hay, the highest quality forage would be at boot (Zadok 41); however, later growth stages would provide greater yield. Commonly grown cultivars of winter rye in Minnesota show little difference in forage quality or yield, indicating that most rye cultivars could be used to produce quality forage.

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