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Seasonal and diurnal relationship of forage nutritive value and mass in a tall fescue pasture under continuous stocking

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Abstract

Monitoring forage mass and nutritive value of pastures are encouraged to ensure adequate and efficient grazing management. For on-farm monitoring, reliable instruments such as the rising plate meter (RPM) are useful and easy to achieve. The objective of this research was to verify the relationship between measurements of RPM (MRPM) to forage nutritive value based on seasonal and diurnal changes within a tall fescue sward under continuous stocking management. The study was conducted at the Plateau AgResearch and Education Center in Crossville, TN, from January 2015 to December 2016. The experiment was conducted in two 9-hectare pastures consisting of a tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons., formerly *Festuca arundinacea* Schreb.] sward. During the 12-month grazing period each year, total aboveground available forage was measured monthly in each pasture with a calibrated RPM. In addition, each month, several randomly placed 1-m^2 sample areas were collected at 7 a.m., 9 a.m., 12 p.m. and 4 p.m. to characterize forage nutritive value. Neutral detergent fiber, crude protein and in vitro total dry matter digestibility (IVTDMD) were predicted by means of near-infrared spectroscopy. During the entire year of 2015, all correlation coefficients of forage nutritive value variables with MRPM were significant. However, in 2016, only IVTDMD showed a significant correlation with MRPM. Of the nutritive value variables, we chose to focus on the IVTDMD and MRPM relationship because it had one of the highest correlations for most seasons and different times of day, especially in 2015. There was a strong relationship between RPM measurements of herbage mass with IVTDMD, and this relationship is especially useful during the spring, where rapid growth is occurring. The same relationship was not found to be consistent during periods of slow forage growth, especially if recovering from a drought event.

KEYWORDS
forage nutritive value, grazing, rising plate meter, tall fescue

1 | INTRODUCTION

Ruminants tend to be selective, grazing forage that is higher in digestibility and protein, with a lower percentage of fiber than the remaining residue (Bryant, Blaser, Hammes, & Hardison, 1961). Consequently, high daily fluctuations in animal input occur, due to rapid changes in selectivity within a pasture (Blaser et al., 1960). These diurnal variations in nutritive value of the pasture affect animal selectivity and animal performance (Burns, Fisher, & Mayland, 2007). Selectivity has been observed on a daily basis with the progress of summer grazing (Hirata & Ogura, 2001); therefore, it is important to measure or estimate forage mass and nutritive value of forages and its association with grazing behavior (Ogura, Hasegawa, & Hirate, 2002).

The majority of the total seasonal growth of cool-season grasses occurs during spring. As temperatures rise and rainfall decreases, these grasses tend to show significant yield reduction, and this poor seasonal growth distribution can be a challenge for most forage managers (Riesterer, Casler, Undersander, & Combs, 1999). Tall fescue [*Lolium arundinaceum* (Schreb.) Darbyish] shows an active and intensive growth from early April to June in the southeastern United States (Read, Lang, & Adeli, 2014), and if producers can better manage spring yields, there could be an opportunity to better utilize vegetative growth efficiently (Riesterer et al., 1999).

Most of the plant's photosynthetic activity occurs in the leaves, while grasses stems serve mostly as intermediate storage sites (Mayland et al., 2005). Nutritive value of leaves has shown diurnal cycling where it increases in starch and total non-structural carbohydrates (TNC) during the day accompanied by a significant decrease in neutral detergent fiber (NDF) simply because of dilution by the extra sugar (Mayland et al., 2005).

Monitoring forage quality and mass of pastures are encouraged so adequate and efficient planning on stocking schedules can occur. Fiber digestibility of a mixed cool-season grass canopy has proven to be highly correlated with herbage mass, and researchers were able to develop a model to estimate NDF digestibility (NDFD) from herbage mass present consistently over two growing seasons across two consecutive years (Nave, Sulc, & Barker, 2013). Many tools for quickly and easily measuring forage quality and forage mass have been developed, but there is a need to investigate the relationship between the measurements provided by these tools (Watanabe, Sakanoue, Lee, Yoshitoshi, & Kawamura, 2014). The efficiency of pasture-based animal production systems is dependent on the seasonality of forage accumulation and growth, and measurements of forage mass in these pasture-based systems are required to determine the appropriate forage management to enhance animal performance and reduce feed costs (Ferraro, Nave, Sulc, & Barker, 2012).

Indirect non-destructive methods for quick estimation of forage mass in grazed pastures are useful for producers and researchers to effectively manage grazing systems (Frame, 1981). For on-farm monitoring, reliable instruments such as the rising plate meter (RPM) are useful and can be done quickly and easily over extensive areas (Ferraro et al., 2012). However, limited attention has been given to developing methods for field assessment of forage nutritive value (Nave et al., 2013). The use of conventional laboratory analyses of forage nutritive value for making instantaneous grazing decisions can be time-consuming and costly (Starks, Zhao, Phillips, & Coleman, 2006).

There is a need to develop quick and accurate methods to estimate forage nutritive value in the field, to provide accurate results while being cost-effective (Cherney & Sulc, 1997) and also to validate previous findings from harvested forage to grazing pastures (Nave et al., 2013). Therefore, the objective of this research was to verify the relationship between measurements of RPM (MRPM) to forage nutritive value variables based on seasonal and diurnal changes within a tall fescue sward under continuous stocking management, so that forage nutritive value can be rapidly estimated based on field measurements. The hypothesis is that MRPM can help estimate the nutritive value of the forage on offer, independently of time of day or season, even though variations in forage mass can be observed throughout the year.

2 | MATERIALS AND METHODS

2.1 | Study site

The study was conducted at the Plateau AgResearch and Education Center (PREC) in Crossville, TN (36°0′N, 85°7′W, 580-m elevation) from January 2015 to December 2016.

The experiment was conducted in two nine-hectare pastures consisting of a tall fescue sward (more than 10-year old). Soil conditions on location were Lonewood loam (fine-loamy, siliceous, semiactive, mesic Typic Hapludult) (loamy residuum weathered from sandstone, 2%–5% slopes, well drained, 100–200 cm to paralithic bedrock) and Ramsey loam (loamy, siliceous, subactive, mesic Lithic Dystrudept) (loamy residuum weathered from sandstone, 5%–12% slopes, somewhat excessively drained) (Natural Resources and Conservation Service, 2014). Initial soil nutrient levels of the experiment site were pH = 6.1, medium levels of P and K, and sufficient levels of Ca and Mg.

Nitrogen fertilizer (urea) was applied in March of each year at the rate of 67 kg/ha. An average of twenty Black Angus cows (*Bos taurus*) and their calves were stocked in each pasture during the experimental period. The put-and-take methodology (Mott & Lucas, 1952) was used during periods of rapid forage accumulation to avoid under grazing conditions.

2.2 | Measurements

During the 12-month grazing period each year, total aboveground dry matter available forage was measured at each sampling time in each pasture with a calibrated RPM. The RPM used consisted of a 0.1-m^2 ascendant disk, and the MRPM was made by a mechanical counter that measured the partially compressed sward height, in 5-mm increments (Ferraro et al., 2012). Forty points were measured at random across each pasture each sampling time. To calibrate the RPM, ten randomly placed 1-m^2 sample areas were measured with the RPM, and after recording these individual MRPM, the forage under the plate was hand-clipped to ground level within a 0.1-m^2 quadrat and dried at 60°C to constant weight. The calibration was developed by a regression equation for converting the MRPM to the total aboveground dry weight. In order to ensure accuracy of forage mass estimates determined by MRPM, we have made calibrations every sampling time with individual calibrations for each of the sampled pastures, totaling eight calibrations monthly. Significant variation across time in the slope coefficients of forage mass regressed on RPM suggests these should be made frequently enough to define the trend line for RPM slope coefficients (Ferraro et al., 2012).

Five spots in the pastures were randomly selected to collect forage samples for nutritive value analyses. Samples were collected at 7 a.m., 9 a.m., 12 p.m. and 4 p.m. to characterize forage nutritive value from a 1-m^2 area selected at random within each pasture four times a day on a monthly basis for 24 consecutive months. Forage samples for nutritive value analyses were collected above a 7-cm stubble height, then dried at 60°C to constant weight. Samples were then ground through a 1-mm screen in a shear mill (Thomas-Wiley Laboratory Mill Model 4, H. Thomas Co., Philadelphia, PA, USA) for laboratory analyses. NDF, crude protein (CP) and in vitro total dry matter digestibility (IVTDMD) were predicted by means of near-infrared spectroscopy (NIRS) (FOSS 5000, FOSS NIRSystems, Laurel, MD, USA). Equations for the forage nutritive analyses were standardized and checked for accuracy with the 2013 mixed hay equation developed by the NIRS Forage and Feed Consortium (NIRSC, Hillsboro, WI, USA). Software used for NIRS analysis was Win ISI II supplied by Infrasoft International (State College, PA, USA). The Global *H* statistical test compared the samples against the model and samples from distinct data sets within the database for accurate results, in which all forage samples fit the equation ($H < 3.0$) and are reported accordingly (Murray & Cowe, 2004).

2.3 | Statistical analysis

All statistical analyses were based on the averages of the forty points taken with the RPM and averages of the five random spots collected monthly in both pastures. Several procedures of SAS 9.4 (SAS 9.4 SAS Institute, 2008) were used to test the relationship between nutritive value and MRPM. The CORR procedure was used to determine simple correlations between MRPM versus forage nutritive value (CP, NDF and IVTDMD). The REG procedure was used to develop a linear regression equation between the highly correlated variables based on the CORR analyses.

3 | RESULTS AND DISCUSSION

3.1 | Weather data

In 2015, winter (January through March) rainfall averaged 85.6 mm, which was 47.7 mm lower than the 30-year average, and in 2016, it did not differ from the 30-year average of that period (Figure 1).

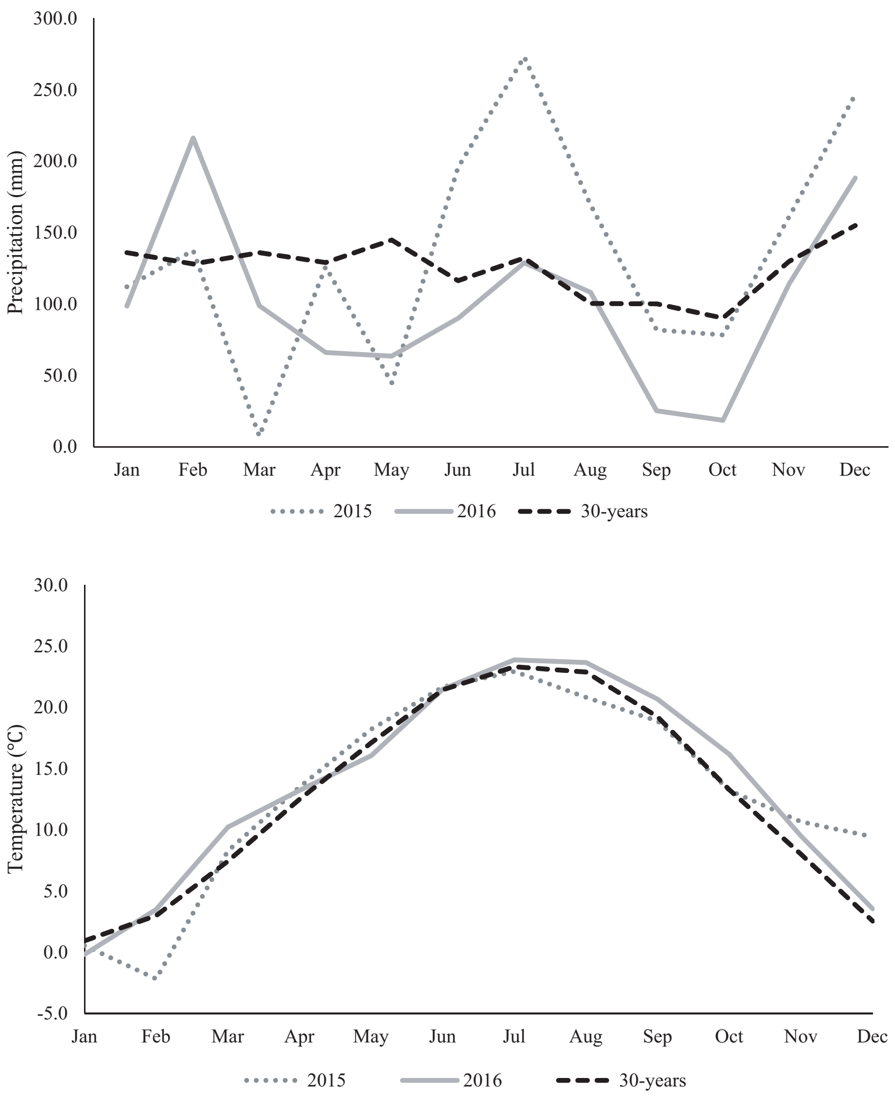

FIGURE 1 Weather for Crossville, TN, including 30-year average for growing season of 2015 and 2016

Spring of 2015 (April through June) rainfall was the same as the 30-year average and in 2016 averaged 73.1 mm, which was 56.9 mm lower than the 30-year average for spring. Summer (July through September) rainfall in 2015 averaged 174.8 mm and in 2016 averaged 87.4 mm, which were, respectively, 64 mm higher and 23.4 mm lower than the 30-year average. In 2015, fall (October through December) rainfall averaged 161.9 mm, which was 36.9 mm higher than the 30-year average during these months, and in 2016 averaged 106.9 mm (18.1 mm lower than the 30-year average) (Figure 1).

The mean air temperature during winter was 0.6°C lower than the 30-year average in 2015 and 0.5°C higher in 2016. In spring and summer of both years, mean air temperature did not differ from the 30-year average, and in the fall, it was 1.8 and 1.7°C higher than the 30-year average of 2015 and 2016, respectively (Figure 1).

3.2 | Correlations between MRPM and forage nutritive value

Overall correlations between MRPM and nutritive value variables are shown in Figure 2. In 2015, MRPM ranged from 464 to 4,508 kg/ha, CP ranged from 115 to 234 g/kg, NDF was 380–694 g/kg and IVTDMD ranged from 651 to 929 g/kg (Table 1). In 2016, MRPM ranged from 259 to 3,530 kg/ha, CP was 86–275 g/kg, NDF was 424–767 g/kg and IVTDMD ranged from 576 to 928 g/kg (Table 1). Changes in MRPM values and nutritive value were attributed to changes in age and maturity of the forage, as

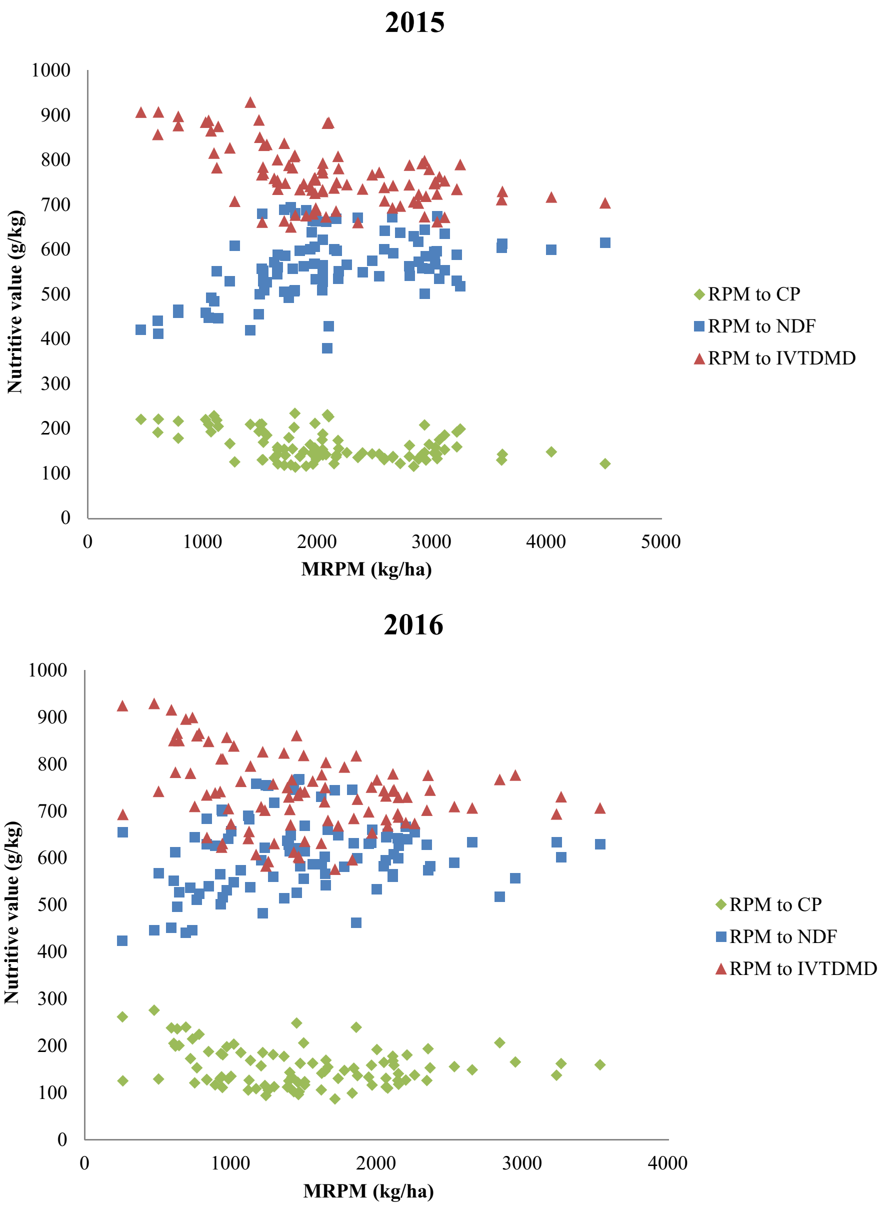

FIGURE 2 Scatter plots of overall relationship between MRPM with CP, NDF and IVTDMD in 2015 and 2016 of a continuous stocked tall fescue pasture in Tennessee. CP, crude protein; IVTDMD, in vitro true dry matter digestibility; MRPM, measurements of rising plate meter; NDF, neutral detergent fiber; RPM, rising plate meter

TABLE 1 Summary statistics for all variables analyzed of a tall fescue pasture under continuous stocking in two consecutive years (2015 and 2016)

Variable	*n*	MIN	MAX	Mean	*SD*	CV (%)
2015						
MRPM[§] (kg/ha)	96	464	4,508	2,132	775.21	36.35
CP (g/kg)	96	115	234	161	3.28	20.33
NDF (g/kg)	96	380	694	564	7.10	12.59
IVTDMD (g/kg)	96	651	929	763	6.62	8.68
2016						
MRPM (kg/ha)	96	259	3,530	1509	676.93	44.86
CP (g/kg)	96	86	275	153	4.13	26.96
NDF (g/kg)	96	424	767	603	7.84	13.00
IVTDMD (g/kg)	96	576	928	736	8.26	11.23

[§]CP, crude protein; IVTDMD, in vitro dry matter digestibility; *n*: number of observations; MAX: maximum observation; MIN: minimum observation; MRPM, measurements of rising plate meter; NDF, neutral detergent fiber. Significant at $p < 0.05$.

TABLE 2 Pearson correlation coefficients between forage nutritive value variables and measurements of rising plate meter (MRPM) of tall fescue pastures under continuous stocking during 2015 and 2016

Year	*n*	MRPM to CP[§]	MRPM to NDF	MRPM to IVTDMD
2015	96	−0.51	0.39	−0.46
p		<0.0001	<0.0001	<0.0001
2016	96	−0.18	0.12	−0.23
p		0.0814	0.2477	0.0272

[§]CP: crude protein; IVTDMD: in vitro dry matter digestibility; *n*: number of observations; NDF: neutral detergent fiber. Significant at $p < 0.05$.

TABLE 3 Pearson correlation coefficients between forage nutritive value variables and measurements of rising plate meter (MRPM) of tall fescue pastures under continuous stocking per season in 2015 and 2016

Season	*n*	MRPM to CP[§]	MRPM to NDF	MRPM to IVTDMD
Winter 2015	24	−0.40	0.42	−0.44
p		0.0555	0.0390	0.0327
Spring 2015	24	−0.67	0.74	−0.70
p		0.0003	<0.0001	<0.0001
Summer 2015	24	−0.20	0.49	−0.49
p		0.3370	0.0139	0.0140
Fall 2015	24	−0.62	0.21	−0.24
p		0.0014	0.3359	0.2520
Winter 2016	24	−0.51	0.49	−0.65
p		0.0101	0.0158	0.0006
Spring 2016	24	−0.57	0.59	−0.70
p		0.0040	0.0022	0.0002
Summer 2016	24	−0.11	0.24	−0.16
p		0.6161	0.2594	0.4558
Fall 2016	24	−0.13	−0.01	−0.03
p		0.5395	0.9475	0.8979

[§]CP: crude protein; IVTDMD: in vitro dry matter digestibility; *n*: number of observations; NDF: neutral detergent fiber. Significant at $p < 0.05$.

the samples were collected throughout the entire year of 2015 and 2016. Overall, MRPM and forage nutritive value variables were higher in 2015 than 2016. These results can be explained by the unusual drought that occurred in 2016 (Figure 1). Assessing forage mass is very helpful when making grazing management decisions and it can be easily achieved by taking MRPM along with calibration samples to ensure accurate results (Ferraro et al., 2012). The significance of these correlations is highly dependent

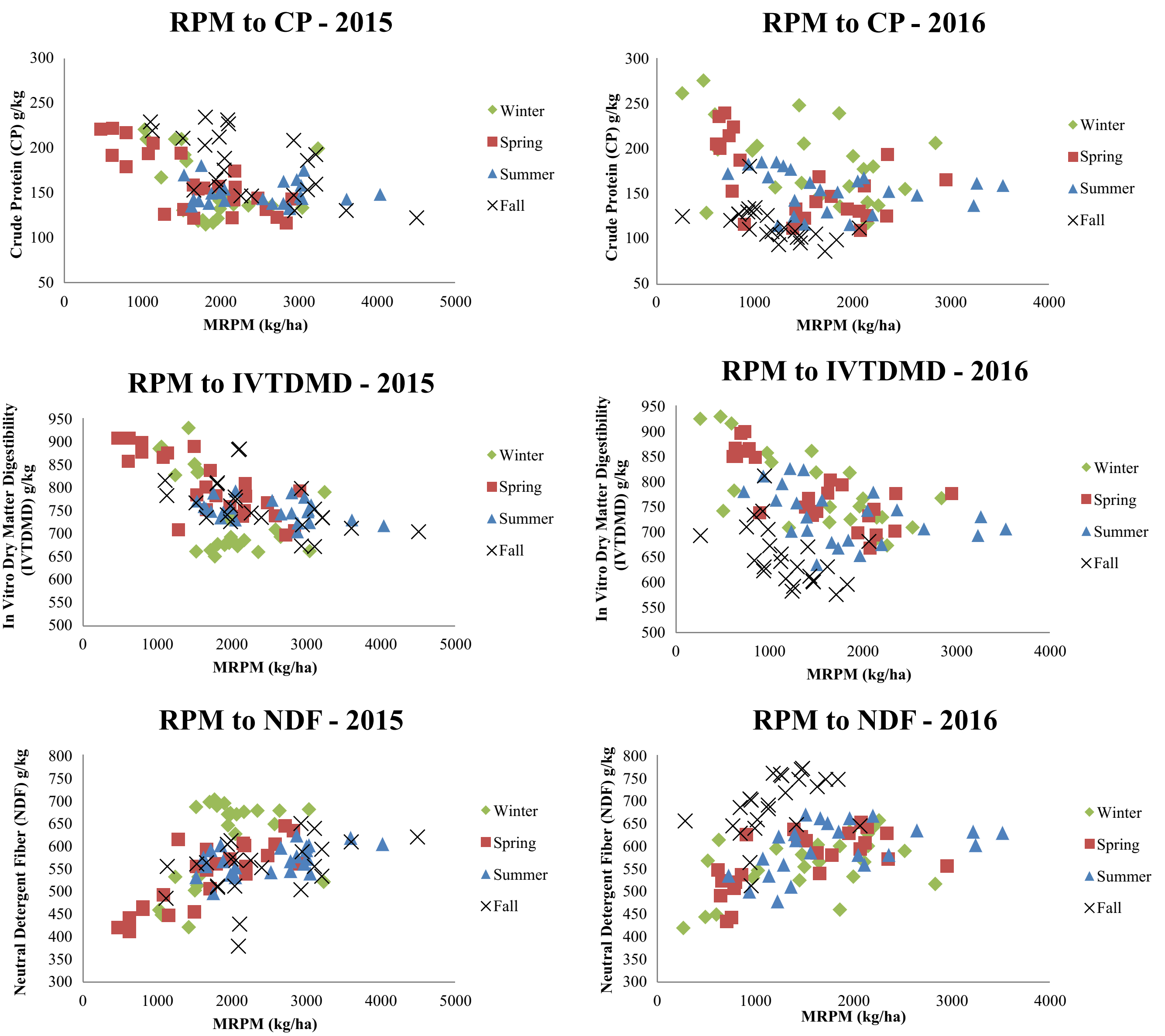

FIGURE 3 Scatter plots of relationship between measurements of rising plate meter (MRPM) with CP, NDF and IVTDMD during the seasons (winter, spring, summer and fall) in 2015 and 2016 of a continuous stocked tall fescue pasture in Tennessee. RPM, rising plate meter

on the accuracy of the RPM calibration equations. Environmental variables can influence the DM forage mass without changing the overall forage height. Also, the seasonal variation in the morphological composition combined with the density of the sward being measured can be highly variable according to stocking rate (Matthew et al., 1996).

Among all variables, MRPM showed the highest variation with CV of 36.35 in 2015 and 44.86 in 2016 (Table 1). The variable showing the lowest variation was IVTDMD with CV of 8.68 in 2015 and 11.23 in 2016. Similar results can be found on a study assessing bermudagrass parameters using canopy reflectance, with total biomass showing highest CV and NDF showing lowest CV (Zhao, Starks, Brown, Phillips, & Coleman, 2007). One of the reasons for the high variation in 2016 can be attributed to weather data, with lower precipitation accompanied by high temperatures (Figure 1). Severe drought has an impact on yield and nutritive value of forage crops, leading to a decrease in total mass, CP content and increase in fiber content (Liu, Wu, Ge, Han, & Jia, 2018). Scheneiter, Camarasa, Carrete, and Amendola (2014) showed that estimating forage nutritive value based on accumulated forage mass has limitations throughout the year due to influences by environmental variables such as mean air temperature and rainfall.

During the entire year of 2015, all correlation coefficients of forage nutritive value variables with MRPM were significant ($p < 0.05$; Table 2; Figure 2). However, in 2016, only IVTDMD showed a significant correlation with MRPM (Table 2; Figure 2). These results can also be explained by the drought that has occurred in 2016, affecting especially CP and NDF. In a study evaluating relationships of forage nutritive value to forage characteristics, the most consistent correlation occurred between NDFD and herbage mass, helping producers

TABLE 4 Pearson correlation coefficients between forage nutritive value variables and measurements of rising plate meter (MRPM) of tall fescue pastures under continuous stocking at different times of the day in 2015 and 2016

Time of day	*n*	MRPM to CP	MRPM to NDF	MRPM to IVTDMD
7 a.m. 2015	24	−0.44	0.32	−0.40
p[§]		0.0333	0.1296	0.0570
9 a.m. 2015	24	−0.57	0.37	−0.46
p		0.0039	0.0751	0.0248
12 p.m. 2015	24	−0.77	0.59	−0.58
p		<0.0001	0.0024	0.0028
4 p.m. 2015	24	−0.42	0.34	−0.39
p		0.0393	0.1017	0.0582
7 a.m. 2016	24	−0.22	0.03	−0.22
p		0.2975	0.8769	0.3074
9 a.m. 2016	24	−0.24	0.22	−0.28
p		0.2684	0.3029	0.1781
12 p.m. 2016	24	−0.19	0.18	−0.28
p		0.3726	0.4112	0.1822
4 p.m. 2016	24	−0.05	0.02	−0.12
p		0.8285	0.9159	0.5847

CP: crude protein; IVTDMD: in vitro dry matter digestibility; *n*: number of observations; NDF: neutral detergent fiber.
[§]Significant at $p < 0.05$.

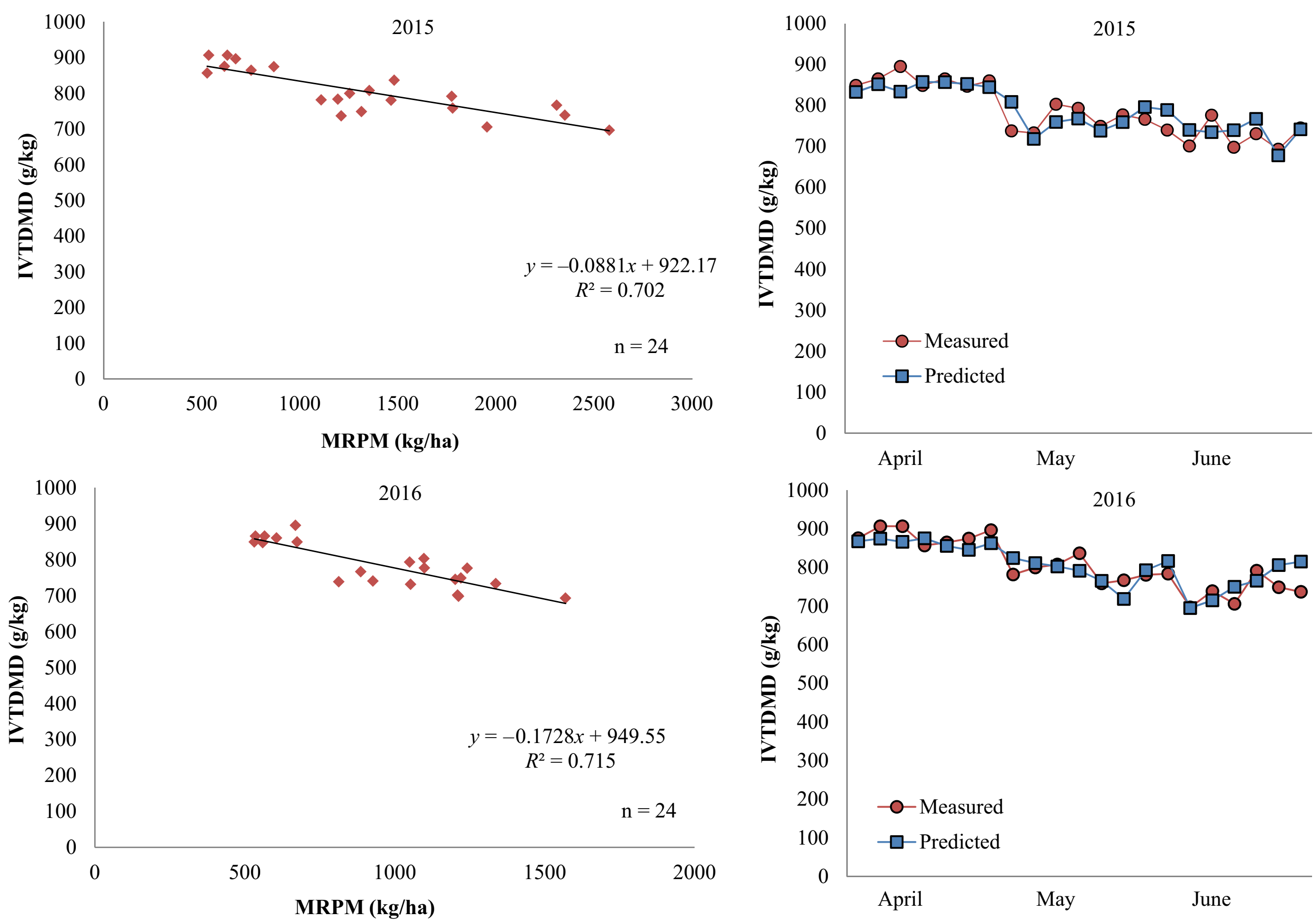

FIGURE 4 Measured and predicted relationship between MRPM and IVTDMD during spring season (April, May and June) in 2015 and 2016 of a continuous stocked tall fescue pasture in Tennessee. IVTDMD, in vitro true dry matter digestibility; MRPM, measurements of rising plate meter

to better manage their pastures and grazing routines (Nave et al., 2013).

When correlations were made seasonally each year (Table 3; Figure 3), MRPM was correlated to CP only in spring and fall of 2015, and winter and spring of 2016. Similar results can be observed in a study focusing on forage nutritive value of cool-season grass correlations to forage removal by dairy cattle (Billman, Goff, Baldwin, Prince, & Phillips, 2017). CP changes indicated that CP levels fluctuated seasonally possibly due to varying levels of N uptake and showed no dilution effect, therefore with increased CP content as forage mass increased (Billman et al., 2017). Another study investigating the relationship of quantity and quality of forage during a grazing season in tropical pastures showed that CP tended to be similar at different forage masses during spring, but decreased as forage mass increased during summer and fall (Ogura et al., 2002). With these inconsistencies shown in CP levels throughout the year, MRPM does not seem to be a good predictor of CP content in tall fescue swards.

Correlations between MRPM and NDF were significant on winter, spring and summer of 2015, and winter and spring of 2016 (Table 3; Figure 3). The MRPM were correlated to IVTDMD in winter, spring and summer of 2015, and winter and spring of 2016. The seasonal pattern of forage mass and nutritive value can be observed, where a stronger energy conversion to forage mass and an increase in nutritive value occurs in early spring, corresponding to changes in morphological stage (Pontes, Carrere, Andueza, Louault, & Soussana, 2007).

When analyzing these correlations at different times of the day (Table 4), only 2015 showed significant correlations. In 2016, severe drought was observed especially during spring, corresponding to the period of rapid rate of growth in tall fescue swards. Also, overall mean air temperature was higher in 2016, which can highly influence growth rate and nutritive value of cool-season grasses. Higher evapotranspiration due to the increase in temperature can cause a decrease in productivity of cool-season grasses, also affecting TNC concentration, resulting in higher variability of forage nutritive value throughout the day (Bertrand, Tremblay, Pelletier, Castonguay, & Belanger, 2008). The RPM was correlated to CP at all different sampling times in 2015, MRPM and NDF were significant for the 12 p.m. sampling time in 2015, and MRPM was correlated to IVTDMD at 9 a.m. and 12 p.m. in 2015. The impact of time of day on forage nutritive value does not appear to be as important, and only a small increase in the concentration of IVTDMD can occur in the afternoon due to an increase in TNC (Pelletier et al., 2010). This can explain the lack of correlation between herbage mass and IVTDMD in the later part of the day in 2015 (Table 4).

3.3 | Forage IVTDMD and relationship with MRPM

Of the nutritive value variables, we chose to focus on the IVTDMD and MRPM relationship. Based on our results and recent literature, the relationship between MRPM and nutritive value variables appears to be more consistent during different seasons than different times of day (Tables 3 and 4), and IVTDMD had one of the highest correlations for most seasons during both years (Table 3; Figure 3).

Regression equations were developed to describe the relationship between IVTDMD and MRPM (Figure 4). Based on the highest correlations above, it became clear that during spring is when the most reliable and accurate predictions of forage nutritive value from MRPM may occur. The growth rate of tall fescue is usually highest in the spring (Denison and Perry, 1990), reaching its highest IVTDMD, with very few differences during the spring months if the sward is kept under vegetative stage (Nave, Sulc, Barker, & St-Pierre, 2014). However, tall fescue tends to decrease IVTDMD with advanced maturity in the spring (Minson, Raymond, & Harris, 1960).

Also, per our results, there was not a clear time of the day to be focused on this relationship and the results were not consistent based on time. There was a strong relationship between MRPM and IVTDMD during spring in both years generating the following regression equations: IVTDMD (g/kg) = −0.0881 MRPM + 922.17, $r^2 = 0.70$, and $p > 0.001$, in 2015 and IVTDMD (g/kg) = −0.1728 MRPM + 949.55, $r^2 = 0.71$, and $p > 0.001$ (Figure 4). These results are in agreement with past literature, suggesting the importance of maintaining tall fescue swards in a vegetative stage in periods of rapid forage accumulation such as spring (Nave et al., 2014). The strong relationship found between MRPM and IVTDMD can facilitate management during this crucial period. Relationships between forage nutritive value and forage mass are highly dependent on the time of the year, and significant relationships found during periods other than spring are more likely due to synthesis of non-digestible compounds rather than forage mass (Scheneiter et al., 2014).

4 | CONCLUSIONS

The results of the present study show that a RPM can be used to estimate forage nutritive value of tall fescue during spring in the field. There was a strong relationship between RPM measurements of herbage mass with IVTDMD, and this relationship is especially useful during the spring, where rapid growth is occurring. However, it was not possible to create an estimation formula to predict nutritive value from RPM in different seasons for grazed tall fescue pastures. These results could serve as a useful management guide to forage producers in order to easily estimate forage nutritive value in the field at the beginning of the growing season, when a most intensive management is needed. There was not a strong relationship between MRPM and nutritive value at different times of the day during grazing. Also, the same relationship was not found to be consistent during periods of slow forage growth, especially if recovering from a drought event.

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