Winter forage producers must choose an optimal stocking rate amid uncertainty about how much forage is available. Adjusting stocking rates can be costly since it can require moving, purchasing, or selling cattle. As stocking rates go up, profits per unit area of land initially increase. However, at some point, there is not enough to eat, so gains and profits decrease (Fales et al., 1995). Overstocking requires supplemental feeding, which is usually expensive (Macdonald et al., 2008). A low stocking rate can lead to poor pasture utilization and low nutritional value of forage if the forage matures. To maximize profit, farmers need to optimally stock each individual field (Fales et al., 1995).

When selecting a stocking rate, farmers are implicitly estimating forage availability (Cuykendall and Casler, 1973). While farmers can use visual assessment to make rough estimates, accurate assessment of forage mass would help in optimally managing grazing systems (Balehegn and Berhe, 2016; Sanderson et al., 2001). Researchers often hand clip and weigh the forage, which is accurate but costly. Hand clipping is labor intensive and takes at least 2 d for the leaves to dry (O’Donovan et al., 2002). A rising plate meter, alternatively, can quickly measure forage mass. The rising plate meter measures compressed height and so a calibration equation is needed to convert its measurement to a prediction of forage mass, and predictions can vary across crops, seasons, and locations. Our research objective was to derive new calibration equations for wheat (Triticum aestivum L.) and rye (Secale cereale L.). Most past literature used a linear model, but recent literature has suggested that using a quadratic model without an intercept could improve predictions. A non-nested test was used to test among these two non-nested models for wheat and rye calibration equations. The results favored the more encompassing model of a quadratic with an intercept; however, with wheat the quadratic with no intercept was not rejected. A pooling test indicated different equations were needed for species, seasonality (winter and non-winter), and tillage type (tilled or no-till).

Abstract: Estimating forage availability is important in optimizing livestock stocking rates. The rising plate meter was developed to estimate forage availability. It needs a calibration equation to convert its measurement to a prediction of forage mass, and predictions can vary across crops, seasons, and locations. Our research objective was to derive new calibration equations for wheat (Triticum aestivum L.) and rye (Secale cereale L.). Most past literature used a linear model, but recent literature has suggested that using a quadratic model without an intercept could improve predictions. A non-nested test was used to test among these two non-nested models for wheat and rye calibration equations. The results favored the more encompassing model of a quadratic with an intercept; however, with wheat the quadratic with no intercept was not rejected. A pooling test indicated different equations were needed for species, seasonality (winter and non-winter), and tillage type (tilled or no-till).

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Core Ideas
- The rising plate meter was useful in predicting forage mass.
- A quadratic functional form is favored for predicting forage mass using the rising plate meter.
- Relationships differed by species, season, and tillage

Abbreviations: PMU, rising plate meter units.
percentage of dead matter. If the rising plate meter is to be widely adopted, calibration equations are needed for other species and environmental conditions.

As the physical composition of the plants is significantly different, the calibration equations for other forages may not be accurate for wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.). Since the rye forage cycle is typically a little ahead of wheat (Edmisten et al., 1998; Evers et al., 1998), rye and wheat may need different calibration equations. In winter months (December to mid-March), forage has lower water content, and so calibration equations may also need to differ by season (Gusta and Fowler, 1976).

Therefore, this study estimates wheat and rye calibration equations for a rising plate meter. These equations will help quickly and accurately estimate forage availability. Specifically, we consider crop species, winter seasonality, and tillage effect to estimate forage mass. To achieve our objectives, we used a linear regression model and data from field trials in which the rising plate meter and classical methods (hand clipping and forage weighing) were used.

**Data Collection and Statistical Analysis**

Data were collected during the 2012 and 2014 to 2017 production seasons on the Noble Research Institute’s Pasture Research and Demonstration Farm (34°22' N; 97°21' W) in Ardmore, OK, and the Red River Research Farm (33°52' N; 97°16' W) near Burneyville, OK. From December to January, average temperatures were below 10°C. Total precipitation was adequate to produce good yields during these years. Winter months (December–February) were drier than other months. Wheat and rye were planted using 125 to 135 kg ha⁻¹ of wheat (Edmisten et al., 1998; Evers et al., 1998), rye and wheat may need different calibration equations. In winter months (December to mid-March), forage has lower water content, and so calibration equations may also need to differ by season (Gusta and Fowler, 1976).

Results

Total observations were 734: 435 wheat and 299 rye. With the overall non-nested tests, both the linear model (*F* = 3.89) and the quadratic model with no intercept (*F* = 3.29) were rejected in favor of the more general model (*P* < 0.05). With wheat only, however, the null hypothesis of a zero intercept was not rejected (*F* = 1.49). The null hypothesis of no difference between wheat and rye was rejected (*P* < 0.05). Thus, separate equations were needed for wheat and rye. The pooling tests of seasonality and tillage were done after separating wheat and rye data. Seasons were modeled as winter and nonwinter. The winter period is from December to mid-March for wheat and December to January for rye. The *F*-tests of no seasonal difference for wheat (*F* = 16.04) and rye (*F* = 28.94) were rejected (*P* < 0.05). Tillage also affects wheat (*F* = 8.42) and rye (*F* = 27.68) (*P* < 0.05). Therefore, eight calibration equations were estimated.

The winter calibration equation had a higher intercept and slope than the nonwinter equation (Table 1), reflecting the lower water content in winter. Also, tillage showed more forage mass than no-till for given PMUs. The difference in till and no-till may reflect some carryover of plant material on the surface. These regressions, except for the rye nonwinter till case, have *R²* values above 0.5 (Table 1). The rye nonwinter till case had a major outlier where PMU was low yet forage mass was high; thus, this equation is less reliable than the others (Fig. 1–2).

**Discussion and Conclusion**

Based on non-nested test results, the preferred functional form was a quadratic with an intercept. With wheat, however, the intercept was not significant, which matches Rayburn et
al. (2017), who argued for a quadratic with no intercept. The no-till rye parameters had a lower intercept than the model with tillage. The rye no-till had organic matter on the soil surface that was not included in the clippings but did affect the rising plate meter measurements. Calibration equations differed by species, season, and tillage. The conclusions about functional form are based on joint tests. The individual models have less statistical power and show varied responses, with only four of the eight intercepts being significant and only three of the eight quadratic terms significant. As Fig. 1 and 2 show, most of the regressions are close to being linear and many of the intercepts are close to zero. The $R^2$ values were similar to those of previous research such as L’Huillier and Thomson (1988). The rye nonwinter till had an $R^2$ that was low enough to suggest it might not be useful. The other calibration equations can be used along with the rising plate meter to provide more accurate estimates of forage availability than previous estimates that were for different forages and different locations. Field clipping will still be considerably more accurate than the rising plate meter, but the calibration equations used here can help when clipping data are economically infeasible.

### Table 1. Wheat and rye calibration equations.

<table>
<thead>
<tr>
<th></th>
<th>Winter Till</th>
<th>No-till</th>
<th>Winter Nonwinter</th>
<th>No-till</th>
</tr>
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<tr>
<td><strong>Wheat calibration equations</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Intercept</td>
<td>311.8*</td>
<td>67.98</td>
<td>131.13</td>
<td>–198.76</td>
</tr>
<tr>
<td>(159.45)</td>
<td>(412.31)</td>
<td>(372.58)</td>
<td>(404.26)</td>
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</tr>
<tr>
<td>PMU</td>
<td>74.29***</td>
<td>120.23***</td>
<td>41.13***</td>
<td>102.96***</td>
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<td>(16.67)</td>
<td>(46.61)</td>
<td>(39.02)</td>
<td>(46.94)</td>
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</tr>
<tr>
<td>PMU*</td>
<td>0.36</td>
<td>–1.12</td>
<td>0.75**</td>
<td>–0.76</td>
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<tr>
<td>(0.38)</td>
<td>(1.19)</td>
<td>(0.88)</td>
<td>(1.24)</td>
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<tr>
<td>$R^2$</td>
<td>0.6562</td>
<td>0.5686</td>
<td>0.8513</td>
<td>0.5681</td>
</tr>
</tbody>
</table>

| **Rye calibration equations** |         |         |                  |         |
| Intercept      | 717.45***  | –448.8**| 1463.78***       | –121.04 |
| (814.72)       | (367.07)   | (723.35)| (412.79)         |         |
| PMU            | 70.45***   | 181.56***| 28.35***         | 86.52***|
| (108.63)       | (40.35)    | (71.65) | (49.07)          |         |
| PMU*           | 2.47*      | –2.13***| 0.74             | –0.26   |
| (3.41)         | (0.99)     | (1.64)  | (1.34)           |         |
| $R^2$          | 0.6613      | 0.7644  | 0.2610           | 0.6913  |

* *, **, *** Significant at $P = 0.05, 0.01$ and 0.001, respectively.
† The dependent variable is kilograms of forage dry matter per hectare. The numbers in parentheses are standard errors.
‡ PMU, rising plate meter unit.

Fig. 1. Wheat forage mass versus rising plate meter unit (PMU) reading.
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Conflict of Interest
The authors declare no conflict of interest.

References

Fig. 2. Rye forage mass versus rising plate meter unit (PMU) reading.