Measuring Tiller Development and Mortality in Winter Wheat under Field Conditions

M. Scott Tilley,* Ronnie W. Heiniger, and Carl R. Crozier

Core Ideas
• Seeding rate is important for measuring phyllochron interval and maximum number leaf.
• As seeding rate increases, phyllochron interval increases; as seeding rate increases, maximum leaf number decreases.
• High seeding rate led to an increase in tiller production per m² compared with low seeding rate.
• Neither seeding rate nor N application timing increased tiller viability.

ABSTRACT
Vegetative growth in the form of tillers is crucial in development of wheat (Triticum aestivum L.). To better understand wheat development and tiller initiation, a study was conducted using two seeding rates (193 vs. 676 m⁻²) and two N application timings (single vs. split). Using a detailed marking technique to track leaf and tiller growth, tillers plant⁻¹, rate of leaf appearance tiller⁻¹, phyllochron interval (PI), accumulated heat units, and maximum leaf number (MLN) were measured. Although the timing of tiller initiation did not differ among the two seeding rates, results showed that at the low seeding rate (LSR) the frequency of leaf appearance on each tiller was increased, resulting in tillers having more leaves at decimal growth stage (DGS) 30. At the high seeding rate (HSR), leaf appearance among tillers was reduced, resulting in only fall tillers having enough leaf area to sustain growth from DGS 30 to harvest. The MLN was significantly greater at the LSR compared with the HSR. The MLN for the main stem was greater than those found on Tiller 1, and MLN for Tiller 1 was greater than those found on Tiller 2. There were no significant interactions or main effects involving the timing of N. It is difficult to determine the role that N application timing has on tiller and leaf development since there was not a consistent effect of N timing on PI and no effects of N timing on MLN.

Abbreviations: BC, Beaufort County; DGS, decimal growth stage; GDD, growing degree days; HSR, high seeding rate; LSR, low seeding rate; MLN, maximum leaf number; MS, main stem; PI, phyllochron interval; PRS, Piedmont Research Station; TRS, Tidewater Research Station; T0, tiller at the coleoptile node; T1, tiller 1; T2, tiller 2; T3, tiller 3; T4, tiller 4.

Tiller production is a key component in the growth and development of winter wheat (Triticum aestivum L.). To maximize wheat yields, producers must focus on maximizing the number of tillers, which ultimately lead to a greater number of spikes (Tilley et al., 2019). The number of tillers produced plant⁻¹ is controlled by the environment beginning at the three-leaf stage to jointing (decimal growth stage [DGS 13–30]) (Klepper et al., 1982; Tottman., 1987) and the amount of tiller mortality that occurs from jointing to anthesis (DGS 30–69) (Jewiss, 1972; Rawson, 1971). Recent research has shown the timing of tiller initiation and management factors such as planting date (Oakes et al., 2016) that promote leaf development could also influence yield components such as kernels spike⁻¹ and kernel weight (Tilley et al., 2019). An understanding of when most spikes are formed and the management factors that promote tiller formation during this critical period would help growers improve wheat yield. Therefore, the purpose of this work is to determine if seeding rate as well as current N application methods used in the southeast of the United States influence the pattern of tiller development of existing plant structures and mortality.

Tiller development is directly influenced by its environment, as illustrated by the work of Charles-Edwards (1984). This study suggested that a new tiller is formed whenever the amount of assimilate that is fixed by the plant surpasses the amount of assimilate that is required for growth and development. It is clear from this theory that many factors such as temperature, light, water, and nutrients can influence the growth and development of tillers, possibly by influencing the leaf area produced by the plant to help manufacture assimilate.

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Temperature strongly influences leaf growth (Baker et al., 1986), which in turn leads to the increase in tillers. One way of quantifying the effect of temperature on tiller generation is by computing the thermal units. Also known as growing degree days (GDD), thermal units are measured using the formula

\[ \text{GDD} = \frac{T_{\text{max}} + T_{\text{min}}}{2} - T_b \]

where \( T_{\text{max}} \) is the daily maximum temperature (°C), \( T_{\text{min}} \) is the daily minimum temperature (°C), and \( T_b \) is base temperature (Bauer et al., 1984; Khichar and Niwas, 2007). Baker et al. (1984) in measuring spring wheat found that GDD provided an excellent estimate of development rate, that leaves on the MS of a wheat plant appear in direct response to temperature, and that the relationship between leaf appearance and GDD are linear. Baker et al. (1986) developed a method based on the Haun scale (Haun, 1973) for measuring the linear response between leaf appearance and GDD using the term phyllochron interval (PI). Phyllochron interval is defined as the time it takes for elongation of successive leaves (Krenzer et al., 1991) and is measured by taking the reciprocal of the slope determined by regressing main stem leaf stage against GDD.

Many studies have characterized the development of leaves and tillers in wheat under field and growth chamber conditions (Klepper et al., 1982; Baker et al., 1986; Krenzer and Nipp, 1991; Krenzer et al., 1991). Using growth chamber studies, Klepper et al. (1982) postulated that after a wheat plant emerges from the soil, environmental stress does not influence the rate at which main stem (MS) leaves appear, except under severe stress. It was found that once initiated, the leaves on each tiller develop synchronously with the MS leaves and that it was possible to estimate number of leaves on a tiller based on MS leaf stage. Therefore, Klepper et al. (1983) proposed a system in which tillers are labeled according to the leaf node at which they develop with T0 designating a tiller at the coleoptile node and T1, a tiller at leaf number 1, and so forth. They found that when stress was severe the tiller normally developing during a specific morphological period will not form at all. The number of plants containing a specific tiller can be used as a measure of the presence, or absence, of stress during seedling emergence. Bauer et al. (1984), in a study using three N treatments of 0, 45, and 188 kg ha\(^{-1}\) applied to previously non-fertilized cultivars, demonstrated the importance of \( N \) fertilizer in sustaining tillers. Treatments of 118 kg ha\(^{-1}\) sustained tillers at a greater number compared with the 0 and 45 kg treatments. Nitrogen fertilization reduces tiller mortality, especially of the coleoptile tiller and tiller emerging from the axil of the second leaf on the MS (Fraser et al., 1982; Power and Alessi, 1978). These studies found that tillers that are sustained throughout the growing season will have greater influence on final yields. Plant populations have a major influence on tiller sustainability. Research conducted by Davidson and Chevalier (1990) examined tiller mortality at preanthesis stage using two populations of 225 and 450 plants m\(^{-2}\) under irrigated and non-irrigated treatments. Results indicated tiller mortality in all treatments; however, reduced irrigation and higher \( N \) treatments of 

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**MATERIALS AND METHODS**

**Field Experiment**

Field experiments were conducted at three sites in eastern North Carolina and one site in western North Carolina across a 2-yr period. At the Tidewater Research Station (TRS) in Plymouth, NC, experiments were conducted in 2010–2011 (35.8511 N, 76.6589 W) and 2011–2012 (35.8518 N, 76.6537 W). On a private farm in Beaufort County (BC), experiments were conducted in 2010–2011 (35.6162 N, 76.7310 W). On the third site in western North Carolina (Piedmont Research Station [PRS] in Salisbury, North Carolina and one site in western North Carolina across a 2-yr period. At the Tidewater Research Station (TRS) in Plymouth, NC, experiments were conducted in 2010–2011 (35.8511 N, 76.6589 W) and 2011–2012 (35.8518 N, 76.6537 W). On a private farm in Beaufort County (BC), experiments were conducted in 2010–2011 (35.6162 N, 76.7310 W). On the third site in western North Carolina (Piedmont Research Station [PRS] in Salisbury,
NC) a single trial was conducted in 2011–2012. (35.6832 N, 80.6047 W). The soil at TRS was a Cape Fear loam (clayey, mixed, thermic Typic Umbraquolls) soil. At the BC site in 2010–2011, the experiment was conducted on a Cape Fear fine sandy loam. The 2011–2012 experiment at PRS was conducted on a Mecklenburg clay loam (fine, mixed, thermic Ultic Haplustolls). In 2010–2011, plots were planted on 10 November at TRS and 11 November in BC. In 2011, plots were planted on 10 November at TRS and 15 November at PRS.

At each site, a high-yielding wheat variety in North Carolina (Pioneer ‘26R12’) was planted in a 16.9-cm row spacing into a conventional tilled field following corn (Zea mays L.). The experimental design at all sites was a split plot design with main plots consisting of two seeding rates, 193 and 676 m², and subplots consisting of 134 kg N ha⁻¹ applied either as a single application in March or a split application with half applied in late January or early February and the remaining half applied by late March. Current North Carolina recommendations suggest a total of 134 kg N ha⁻¹ to be applied to a winter wheat crop (Weisz et al., 2011). It is currently under debate whether the total application should be applied as a single or split application at different growth stages, particularly at the beginning of tiller development and just prior to jointing. In 2010–2011, the first N application was applied on 4 February whereas the remaining split and single applications were completed on 18 March. During the 2011–2012 growing season at TRS, the first split application was applied on 19 January with the final split and single N applications applied on 12 March. Applications at the PRS were applied 1 wk later on 26 Jan and 19 March. All treatments were replicated five times.

Disease pressure was minimum across all three site-years and did not reach current threshold recommendations for fungicides applications (Weisz et al., 2011). However, weed and insect control practices were applied. In 2010–2011 at both TRS and BC, thifensulfuron-methyl/tribenuron-methyl was applied post-emergence at 0.04 kg a.i. ha⁻¹ on 6 Dec. 2011 and thifensulfuron-methyl/tribenuron-methyl applied post-emergence at 0.05 kg a.i. ha⁻¹ on 1 Jan. 2012. At the PRS, chlorsulfuron/medsulfuron-methyl was applied pre-plant at 0.03 kg a.i. ha⁻¹ on 3 Nov. 2011 and thifensulfuron-methyl/tribenuron-methyl was applied post-emergence at 0.05 kg a.i. ha⁻¹ on 28 Feb. 2012.

Individual plots were 24.4 m long and 1.98 m wide, equaling a total of 48,313 m². Each plot was divided into three sections. The first 18.01-m² section was designated for grain yield and grain sampling. The second section equaling 9.12 m² was designated for marked samples. Five plants from each plot were marked and the number of full and partial leaves on each MS and tiller were recorded along with the total number of tillers once a month from planting to harvest. During the 2010–2011 growing season, observations were made on 7 December, 31 January, 4 March, 2 April, and 30 April. During the 2011 growing season, leaf and tiller counts were recorded on 9 December, 2 January, 11 February, and 3 April at TRS and 15 December, 9 January, 24 February, and 13 April at PRS. Each new and existing tiller was noted using either a black, silver, or red Sharpie to mark leaf number. Black markings represented tillers that were initiated from planting through the end of December. Silver markings represented early winter tillers that developed from the first of January to the beginning of March. Red markings represented late spring tillers produced from March till DGS 30. The three colors used to track tillers helped categorize each individual tiller and determined whether or not they initiated in the fall, winter, or spring. Furthermore, tillers were marked on each subsequent leaf to track the number of leaves produced throughout the growing season.

The last 21.18 m² of each plot was reserved for destructive sampling. Destructive samples were taken throughout the growing season on the same dates as marked samples to count leaves, tillers, and collect biomass (biomass data not shown). Sampling was performed by carefully digging all plants, to a depth of 15 cm, from a 2 m row length. Final destructive samples were taken on 17 June 2010, at TRS and BC and again on the 15 and 20 of June 2011 at TRS and PRS to measure final maximum leaf number (MLN) among individual tillers and yield data (Tilley et al., 2019). Due to repeated sampling and the large size of the destructive samples, the marking of individual tillers could not be made as was done in the second 19.2-m² section. This presented a problem in that each stem within the destructive samples needed to be classified for when each tiller initiated growth (fall, spring, winter). Therefore, the ratio of tillers initiated (black, silver, and red) within the second 19.2-m² marking section was used to classify tiller initiation within the destructive samples. This ratio was determined by counting the number of MS or tillers from each category (black, silver, and red) in the five marked plants described above and dividing that number by the total number of MS or tillers produced in these same plants. Using the ratio of MS or tillers that were initiated from planting to the end of December (black), the same ratio of plants with the highest leaf numbers in the destructive sample were designated as having been initiated during this period. Plants with the next highest leaf number were considered initiated during the period from 1 January to the end of February, and plants with the fewest leaves were considered initiated after 1 March.

**Statistical Procedures**

Because planting was done on different dates and sampling occurred at different periods, the data from all four site-years could not be combined and were analyzed separately. The Proc Mixed procedure in SAS (SAS Institute, Cary, NC) was used to determine if there were differences in either leaf number on main stems or main stem tillers among sampling dates, seeding rate, N application timings, and tiller classification (MS and tiller number). In all cases, seeding rate and N application timing were treated as fixed effects, whereas block and the block × seeding rate interaction were treated as random. Leaf number per the five individual plants per plot was averaged prior to statistical analysis. A spatial power covariate structure was used to account for repeated measures over time. When differences in leaf number among sampling dates, tiller classification within a sampling date, tiller classification within seeding rate and sampling date, and tiller classification within seeding rate, N application timing, and sampling date were detected least squares comparisons were used to separate means.

Growing degree days were calculated using the same formula found in Bauer et al. (1984). Daily $T_{\text{max}}$ and $T_{\text{min}}$ was collected with base temperature ($T_{\text{base}}$) equal to 0°C. When $T_{\text{min}}$ for the day was less than 0°C, $T_{\text{min}}$ equaled 0°C. The PI for leaf appearance on the MS and first two main stem tillers were calculated in a manner similar to that described by Krenzer and Nipp (1991). The PI for the growth period from the first sampling to 1400 GDD (the appearance of the flag leaf at this stage indicated the end of leaf development) was calculated by determining the change in leaf number GDD⁻¹ over this period and taking the reciprocal. This was done for each marked
RESULTS AND DISCUSSION

Leaf Number and Tiller Appearance

Across all site-years there were three-way interactions between sampling period, seeding rate, and tiller class for the number of leaves recorded at each sampling period (Table 1). In addition, there were two-way interactions between sampling period and seeding rate, and sampling period and tiller class along with significant main effects of sampling period, seeding rate, and tiller class. For the most part, these interactions were expected due to the nature of measuring tiller elongation over time. However, the interaction worth noting is the two-way interaction between seeding rate and tiller class. At BC 2010–2011 (Fig. 1) (TRS 2010–2011 data not shown), rate of leaf appearance for the MS was similar until the fifth sample at 1650 GDD. Main stem at the low seeding rate (LSR) had a significantly higher number of leaves compared with the HSR. The same pattern was observed for T1, except differences were seen earlier beginning at 1150 GDD. Tiller 2 began seeing significant differences in leaf number beginning at 800 GDD. Tillers able to develop more leaves earlier grew in a similar leaf pattern as the MS described by Klepper et al. (1982). Tidewater Research Station 2011–2012 (Fig. 2) (PRS 2011–2012 data not shown) saw difference in leaf number at the last sample period at roughly 1700 GDD. Once again, T1 saw approximately 11 leaves developed among the LSR compared with 8 in the HSR. Tiller 2 saw approximately nine leaves at 1700 GDD, with the HSR having four leaves. At both locations during the 2010–2011 growing season, wheat reached DGS 30 just after the fourth sample on 2 April. However, during the 2011–2012 growing season, GDD accumulated at a more rapid pace compared with the previous year due to warm weather over the winter months (climate data not shown). In 2011–2012, DGS 30 occurred at the beginning of March.

Similar to other work (Klepper et al., 1982; Krenzer et al., 1991), tillers did not appear until at least three leaves were present on the MS. To visualize timing of tiller initiation, vertical dashed lines in

Table 1. Analysis of variance table for leaf number at each location during the 2010–2011 and 2011–2012 growing seasons.†

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<td>8</td>
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* Significance at the 0.05 level.
** Significance at the 0.01 level.
*** Significance at the 0.001 level.
† BC, Beaufort County; NS, nonsignificant; PRS, Piedmont Research Station; TRS, Tidewater Research Station.
Fig. 1 and 2 were used to describe the beginning of winter and the beginning of spring. For example, at the TRS site in 2010–2011, the start of winter (21 December) began at 315 GDD and spring (20 March) began at 1017 GDD. At PRS and TRS in 2011–2012, some tillers were formed before the start of winter (Fig. 2). Although planting dates were similar, warm fall weather helped promote early tiller development in 2011–2012. Tillers that had six leaves or more were commonly initiated either in the fall or by the second sampling date in early January (Fig. 1). At BC 2010–2011 there was a significant interaction between split N and tiller class. At BC 2010–2011 average leaf number on the MS across sampling periods was significantly greater when split N was applied compared with a single N treatment (6.56 compared with 6.36 leaves MS⁻¹) (Fig. 3). In contrast, there were no significant differences in average leaf number across sampling periods for T1 through T3 between a single and split application of N.

At PRS 2011–2012, there was a significant three-way interaction for leaf number among sampling period, seeding rate, and split N, and a two-way interaction between seeding rate and split N (Table 1). At the LSR, there were small but significant differences in leaf number at 900 and 1712 GDD, with the single application of N having more leaves than the split N application. In contrast, there were large differences in leaf number at the last two sampling periods in the HSR with the split N application having significantly more leaves than the single N application.

At TRS 2011–2012, there was a three-way interaction among sampling periods, seeding rate, split N, and tiller class along with a three-way interaction among seeding rate, split N, and tiller class (Table 1). Depending on seeding rate, a split application of N affected leaf number differently (Fig. 2). In general, at the LSR, only small, insignificant differences in leaves on MS and tillers were found between N application timings, and at the HSR differences in leaf number between a single and split N application were found in T1. At the HSR, T1 had more leaves when split N was applied (Fig. 2). At the HSR the impact of a split N application was to increase growth of the first productive tiller, but it did not improve the leaf development in the higher order tillers.
Fig. 2. Leaf number of main stems and tillers due to accumulation in heat units at Tidewater Research Station in 2011–2012. Points with different letters within and between figures represent significant differences at $p < 0.05$. Vertical dashed lines indicate the beginning of fall, winter, and spring. Vertical dotted lines indicate when single or split N was applied.

Fig. 3. Leaf number averaged across sample periods for main stem, Tiller 1 (T1), Tiller 2 (T2), and Tiller 3 (T3) for single and split N treatments at Beaufort County in 2010–2011. Letters represent significant differences $P = 0.05$. 

134.4 kg N ha$^{-1}$ and 67.2 / 67.2 kg N ha$^{-1}$
Rate of Leaf Development

At TRS and BC in 2010–2011, four sampling periods were used to calculate PI for the MS and two to three sampling periods were available to calculate PI for T1 and T2 (Fig. 1, Table 2). At TRS and PRS 2011–2012, three sampling periods were used to calculate PI for MS and two to three sampling periods were used to calculate PI for T1 and T2. When $r^2$ values could be calculated from three or more sampling periods, they ranged across locations from 0.64 to 0.99. Analysis of variance for PI found a three-way interaction among site-year, seeding rate, and timing of N application (Table 3). In addition, there were two-way interactions between seeding rate and tiller class and site-year and tiller class along with a seeding rate main effect.

Across all sites, PI for the LSR treatment either with a single or split N application were shorter than the PI for the HSR (Fig. 4). At TRS 2011–2012, the key factor that resulted in the three-way interaction were the differences in PI for the single and split N treatments within the HSR. At both sites in 2010–2011, the split N application had longer PIs compared with the single application of N within the HSR. In contrast, TRS 2011–2012 had a longer PI with a significant difference in the single application of N compared with the split application of N. Though PRS 2011–2012 tended to follow the same pattern, there was no significant difference between N treatments.

An examination of PI across seeding rates and tiller classes indicated significant differences between seeding rates for the PI for leaves appearing on the MS, T1, and T2 with longer PI consistently found at HSR compared with LSR (Fig. 5). Within the HSR were significant differences in PI, with T1 having a significantly shorter PI than T2. Within both seeding rate treatments, T1 had a significantly longer PI than the MS.

Differences in Maximum Leaf Number

The differences in PI resulted in differences in MLN. Analysis of variance for MLN found significant two-way interactions between seeding rate and tiller class and site-year and tiller class,
along with significant main effects of tiller class, seeding rate, and site-year (Table 3). Within each tiller class, MLN were significantly greater at the LSR (Fig. 6) compared with the HSR. Likewise, within each tiller class MLN for the MS were greater than those found on T1, and MLN for T1 were greater than those found on T2. This trend was consistent across all site-years. Clearly the rate of leaf emergence influences the number of leaves that will develop on a stem or tiller, which in turn determines light interception and yield potential. There were no significant interactions or main effects involving the timing of N applied.

Factors Affecting Tiller Mortality

One of the objectives of this research was to determine what role seeding rate and timing of N application played in tiller mortality. The key measure of changes in tiller number was the use of destructive measurements taken over the growing season to count the number of live tillers m\(^{-2}\). At BC in 2010–2011 there were significant two-way interactions between both sampling period and seeding rate and sampling period and N timing, along with significant main effects for sampling period, seeding rate, and N timing (Table 4). By the third sampling period the HSR had over twice as many live tillers m\(^{-2}\) compared with the LSR (Fig. 7A). However, by the fourth sampling period, tiller mortality was noted at the HSR, resulting in a smaller difference in tillers m\(^{-2}\) between the HSR and LSR. At the
At the final sampling period, tiller mortality was observed in both seeding rates. Tiller mortality increased at the HSR, resulting in more tillers m$^{-2}$ in the LSR compared with the HSR. Willey and Holliday (1971) found similar results when evaluating tiller production in barley (*Hordeum vulgare* L.). As seeding rate increased, tiller numbers plant$^{-1}$ decreased. Among N timing treatments, tiller counts were similar until the fourth sampling period, where fewer tillers m$^{-2}$ were measured in the split N treatment compared with the single application of N (Fig. 7B). However, more tillers were lost in the single N application between the fourth and fifth sampling periods, resulting in no differences in tillers m$^{-2}$ prior to harvest.

The other three site years revealed a significant two-way interaction between sampling period and seeding rate along with significant main effects for sampling period and seeding rate (Table 4). In a pattern similar to that found at BC 2010–2011, the HSR always initially had more tillers m$^{-2}$ (Fig. 8). However, tiller mortality was noted at an earlier sampling period at the HSR, and tiller losses were usually (with the exception of PRS 2011–2012) greater at the HSR, resulting in no significant differences in tillers m$^{-2}$ at the final sampling period. In contrast to BC 2010–2011 (Fig. 7B), at TRS 2010–2011 and both sites in 2011–2012, N treatment was not significant for total tiller numbers (Table 4), indicating that no significant differences resulting from split applications could be detected. Measuring the effects of N on tiller production can be difficult to assess. Otteson et al. (2007) evaluated two N rates among three N timings. Results at the lowest N rate showed a reduction in tiller counts for all three N timing applications. Among the high N rate, tiller numbers remained unchanged among the preplant and two-split timing application. However, a 12% reduction in tillers occurred when the three-way split was applied. Clearly, the impact of N timing on tiller mortality depends on soil and environmental conditions and can vary across locations and seasons.

### CONCLUSION

Management practices such as seeding rate played a greater role in influencing rate of leaf appearance as measured by PI and MLN than did N application timing. The rate of leaf appearance was slower for the HSR compared with the LSR. Also, for each seeding rate, the rate of leaf appearance for T1 and T2 was significantly slower than the rate of leaf appearance on the MS. Furthermore, the rate of leaf appearance for T2 was slower than T1. The same pattern was observed when measuring MLN with the number of MS leaves > T1 leaves > T2 leaves. Clearly, competition for a limited resource has an influence on leaf development in a field setting that is not present in

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**Table 4. Analysis of variance for destructive tiller sampling at each location during the 2010–2011 and 2011–2012 growing seasons.†**

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<td>SP × Seeding rate</td>
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<td>Seedrt × Split N</td>
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<td>SP × Seedrt × Split N</td>
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* Significance at the 0.05 level.
** Significance at the 0.01 level.
*** Significance at the 0.001 level.
† BC, Beaufort County; NS, nonsignificant; PRS, Piedmont Research Station; TRS, Tidewater Research Station.
Fig. 7. Tiller number measured in destructive samples (A) at two seeding rates and (B) at two N application timings in Beaufort County in 2010–2011. Error bars represent significant difference $P = 0.05$. (B) Tiller number measured in destructive samples across N application timing in Beaufort County in 2010–2011. Error bars represent significant difference $P = 0.05$.

Fig. 8. Tiller number measured in destructive samples across seeding rates at the Tidewater Research Station in 2011–2012. Error bars represent significant differences $P = 0$. 
a growth chamber environment. It is difficult to determine the role that N application timing has on leaf development, because there was not a consistent effect of N timing on PI and no effects of N timing on MLN. At the LSR, N application timing did not significantly change PI at any site year. At the HSR, a split N application significantly reduced PI at TRS 2011–2012 but increased PI at BC in 2010–2011. Differences in fall and winter temperatures and rainfall could explain the lack of consistency in the response of PI to N application timing. All of these observations of the impact of seeding rate, N application timing, and climate on leaf number and rate of leaf appearance support the idea stress from nutrients, freeze events, or lack of light influences the rate of leaf appearance and, in turn, impacts the number of leaves that appear on each tiller and the number of tillers developed.

The number of tillers initiated differed across site-years and, within each site-year, were influenced by seeding rate. Although the rate of leaf appearance and number of leaves for each tiller was greater in the LSR treatments, the number of tillers initiated per unit area was greater at the HSR due to more MS available from which to produce tillers. The key difference in the rate of leaf appearance (PI) in the tillers between the LSR and HSR was found in the number of tillers that failed to reach maturity. At HSR tiller numbers m–2 did not change or declined during the period from DGS 30 to 37, whereas tiller numbers continued to increase at the LSR. This was likely due to the rapid rate of leaf appearance in the tillers at the LSR when compared with the HSR, which resulted in more leaves per tiller at the LSR. Therefore, these tillers had more leaf area capable of sustaining continued growth once the plant began to develop reproductively. This was even more evident during the period from DGS 37 (flag leaf) to maturity when, in most site-years, the rate of tiller mortality was greater at the HSR compared with the LSR. Tillers with more leaves had a better chance of sustaining growth and producing seeds than those with fewer leaves. Within the HSR, although the number of MS was high, the MS was not able to produce or sustain tillers leading to an increase in tiller mortality. As a result, only a few of the very first tillers produced developed enough leaf area to sustain growth from DGS 30 to harvest. Main stems within the LSR were not only able to sustain themselves but produced more tillers m–2 with less tiller mortality. This is the reason that, under field conditions, the number of productive plants at harvest is often independent of seeding rate. If stress during the period from emergence to DGS 30 could be reduced, then it is likely that the rate of leaf development in each tiller would become similar to that in the MS.

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REFERENCES


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