Phenotyping Summer Dormancy in Tall Fescue

S. Bhamidimarri, M. C. Saha,* M. E. Payton, and A. A. Hopkins

ABSTRACT
Summer dormancy enables tall fescue (*Festuca arundinacea* Schreb.) to survive hot and dry summers. Phenotyping summer dormancy in the field can be problematic owing to the confounding effects of heat and drought. The objective therefore was to develop a method for phenotyping summer dormancy in tall fescue. Three genotypes (summer active [SA], moderately summer dormant [MSD], and strongly summer dormant [SSD]) were grown in four growth chambers under long day (LD) and high temperature (HT), LD and optimum temperature (OT), short day (SD) and HT, and SD and OT conditions. Within each chamber, two levels of moisture (well watered [+W] or drought [–W]) and vernalization (vernalized [+V] or nonvernalized [–V]) were also tested. Under SD, OT, +W, and +V conditions, SSD had equal or greater growth compared to SA genotype, as measured by number of tillers, plant height, fresh weight, and dry weight. The SSD genotype grew less than the SA as measured by number of tillers (8.6 vs. 15.8), fresh weight (6.0 vs. 16.0 g), and dry weight (3.1 vs. 8.8 g) under LD, OT, +W, and +V conditions. The MSD genotype had intermediate responses. Plant height of genotypes followed a similar pattern during two consecutive regrowth periods. Dormancy of plants could not be classified under drought or without prior vernalization. Dormancy of genotypes could be differentiated by comparing growth under favorable (SD, OT, +W, and +V) versus LD, OT, +W, and +V conditions.

Tall fescue (*Festuca arundinacea* Schreb.) is an important cool-season perennial forage grass in the United States. Use of cool-season perennial grasses could decrease production costs and increase returns to producers who are currently relying on cool-season annual grasses for livestock production (Malinowski et al., 2005). Earlier studies have shown that cool-season perennial grasses may save the farmer up to US$100 ha–1 yr–1 over annual grasses (Redmon, 1997) apart from reducing water runoff and soil erosion (Brady and Weil, 1996), conserving soil water during periods of drought (Hanselka et al., 1994), and improving the physical and chemical properties of soil (Dormaar et al., 1995). Hot summers coupled with severe drought in the southern Great Plains adversely affect the persistence and productivity of many traditionally cultivated summer active cool-season perennial grasses including tall fescue (Malinowski et al., 2005; Nielsen-Gammon et al., 2005). Summer dormancy, an important drought adaptation trait evolved in the perennial species of Mediterranean...
climates, enables cool-season perennial grasses to survive harsh summer conditions (Vegis, 1964). Therefore, summer dormant plants of Mediterranean origin have better persistence and fall regrowth than summer active plants that may not even survive severe summer conditions (Malinowski et al., 2005; Norton et al., 2006a, b). Understanding the mechanisms and factors governing summer dormancy in tall fescue can help in developing cultivars that would not only benefit livestock producers but also contribute to environmental sustainability.

Defining summer dormancy is difficult due to its complexity and the influence of confounding environmental factors. Lang et al. (1987) defined dormancy as a “temporary suspension of visible growth of any plant structure containing a meristem.” Summer dormancy refers to plants that have little or no growth due to physiological preconditioning rather than to some specific stress (e.g., heat, drought) per se (Hopkins and Bhamidimarri, 2009). Summer dormancy is observed in species of Alliaceae, Orchidaceae, Poaceae, and Liliaceae including many geophytes (Volaire and Norton, 2006). Among the grasses, *Poa secunda* J. Presl [syn. *Poa scabrella* (Thurb.) Benth. ex Vasey] (Laude, 1953), *Poa bulbosa* L. (Ofir and Kigel, 2003; Volaire et al., 2001), *Hordeum bulbosum* L. (Ofir et al., 1967), orchardgrass (*Dactylis glomerata* L.) (Norton et al., 2006a; Volaire, 2002), hardinggrass (*Phalaris aquatica* L.) (Oram, 1984), and tall fescue (Norton et al., 2006b; Volaire et al., 2009) have exhibited summer dormancy.

Accurate and consistent measurement of summer dormancy is difficult because stress conditions in the field cannot be controlled and stress reduces growth rate of both summer dormant and summer active types. As dormancy induction is thought to be mediated through changes in plant hormones in response to environmental factors (Salisbury and Ross, 1985), the characteristics of summer dormancy may vary between grass species and between populations of the same species according to their place of origin. In general, considerable reduction of shoot growth, cessation of leaf growth, senescence of above ground herbage, dehydration of leaf bases of the youngest leaves of vegetative tillers, and in some cases formation of swollen leaf bases or swollen internodes are associated with summer dormancy irrespective of soil water availability (Volaire and Norton, 2006). Volaire and Norton, 2006 categorized temperate perennial grasses into three categories related to their behavior under fully irrigated conditions over summer. These are:

1. Populations having active growth in summers under irrigation, for example summer active Continental populations of orchardgrass (Volaire, 1995) and tall fescue (Norton et al., 2006b);
2. Populations that cease growth completely until onset of autumn conditions (declining temperature and shortening daylength), for example completely summer dormant *P. bulbosa*, *H. bulbosum*, and some populations of orchardgrass;
3. Populations exhibiting significant reduction in growth and associated with partial senescence of foliage, for example incompletely dormant tall fescue (Norton et al., 2006b).

Despite recent studies aimed at gaining a greater understanding of summer dormancy (Malinowski et al., 2007; Ofir and Kigel, 1999, 2006, 2007; Volaire and Norton, 2006; Volaire et al., 2009), confusion still exists regarding the role that various factors play in inducing summer dormancy. Ofir and Kigel (2007) reported the induction of summer dormancy in *P. bulbosa* by two alternative and probably additive pathways, namely photoperiodic induction under long days and water deficit under short days. In spring sown populations of ‘Kasbah’ orchardgrass and ‘Flecha’ tall fescue incomplete dormancy was observed in summer under drought (Norton et al., 2006a, b). Prior exposure to cool temperatures and shorter daylengths clearly enhanced the dormancy induction of *P. bulbosa* under subsequent long days (Ofir and Kigel, 1999).

Malinowski et al. (2008) have reported a method to differentiate summer dormant from summer active genotypes in tall fescue and orchardgrass based on germination response to various photoperiods. However, this method cannot be used in phenotyping established plants. Tall fescue is highly self-incompatible and exhibits a great deal of inbreeding depression. Thus, phenotyping summer dormancy in tall fescue based on germination response to photoperiod of selfed parental seed could be problematic. Phenotyping half-sib seed produced by outcrossing may be an alternative, but such seed will only contain half the genetic makeup of the female parental clone. Moreover, the method of Malinowski et al. (2008) was studied in cultivars with known summer dormancy expression and further investigations are needed to quantify its effectiveness in populations segregating for summer dormancy.

Thus, differential responses to photoperiod, temperature, vernalization, and drought in three tall fescue genotypes of known summer dormancy class were investigated in this study. The objective was to develop a method for phenotyping summer dormancy in tall fescue.

**MATERIALS AND METHODS**

**Plant Material**

The plant materials used in this study were R43-64, a Continental type summer active (SA) genotype, which was used as a parent to construct a tall fescue genetic linkage map (Saha et al., 2005). This genotype has been observed to grow actively in the field at Ardmore, OK (35°10' N, 97°04' W), during summer and was derived from 97TF1, a population collected in northwest Oklahoma (Mian et al., 2002). Genotypes SSD (strongly summer
dormant) and moderately summer dormant (MSD) were selected from Flecha, a summer dormant cultivar that traces back to Mediterranean germplasm (New Zealand Pastoral Agriculture Research Institute, 2000). Both SSD and MSD genotypes were selected because of a total lack of, or very little, growing plant tissue, respectively, in late summer at Overton, TX (32°19′ N, 94°59′ W), under rain-fed conditions. Summer active tall fescue at the same location had more growth than Flecha.

Treatments and Their Combinations
At the outset of each experiment, ramets of the three genotypes were either grown in the greenhouse under 24/16°C day/night temperature and 16 h photoperiod or were vernalized following the procedure of Wang et al. (2003). All plants were acclimatized for 7 d in growth chambers before treatments were imposed. Plants were approximately the same age at every stage of each cycle of the experiments. Photoperiod, air temperature, vernalization, and soil moisture treatments were imposed on genotypes in four Conviron (Controlled Environments Ltd., Winnipeg, MB, Canada) growth chambers. The long day (LD) and short day (SD) consisted of 16 h (0600–2200 h) and 10 h of day light (0600–1600 h), respectively, with the light intensity between 300 and 350 μmol m⁻² s⁻¹. The day/night air temperatures were 34/24°C for high temperature (HT) and 24/16°C for optimum temperature (OT) conditions. Selection of temperature and daylength conditions was based on average spring and summer climate data for southern Oklahoma. To mimic day and night conditions, growth chamber temperature was gradually decreased over 2 h at the end of the photoperiod and likewise increased after the dark period. Each growth chamber environment comprised one of the four combinations of daylength and temperature. Within a given growth chamber environment, two levels each of vernalization (vernalized [+V] and nonvernalized [–V]) and soil moisture status (well watered [+W] and drought [–W]) were studied. Genotypes in the +W and –W treatments were watered with 4 and 2 L of water twice a week, respectively. In this study, the treatment combination SD, OT, +W, and +V was considered most favorable for growth of cool-season perennial grasses.

Experimental Layout
The first cycle experiment was initiated in August 2007 and continued until March 2008. The second cycle experiment was conducted from April 2008 to September 2009. Three tillers per genotype were planted in an 11 by 10 cm pot filled with Sungro, Metro-Mix 300 series growing medium (Sungro Horticulture, Vancouver, BC, Canada) and either subjected to vernalization (+V) or not (–V). Three pots of each genotype were later placed in a 19-L (25 by 24 cm) pot filled with the same growing medium. Two 19-L pots were placed on a tray and water applied to the tray as needed (bottom watering). Each growth chamber consisted of six trays giving a total of 36 small pots consisting of three replications of a genotype for a given treatment combination. Genotypes did not differ for tiller number, regardless of vernalization treatment, on entering growth chambers for the first cycle of the experiment. For the second cycle of the experiment, all plants consisted of three tillers after the vernalization period and were arranged in the growth chambers as described above. Figure 1 shows the experimental layout for one replication for a given growth chamber environment.

Figure 1. Lay out of treatments and their combinations in four growth chambers. The growth chambers were set for long day (LD) and high temperature (HT), LD and optimum temperature (OT), short day (SD) and HT, and SD and OT. The vernalized (+V), nonvernalized (–V), well-watered (+W), and drought (–W) treatments were distributed in each growth chamber following a split-split plot arrangement in a randomized complete block design.
Plant Management
The three youngest fully expanded leaves per ramet were noted and leaf length and leaf growth measured over a period of 8 wk. Leaf length was measured once a week until leaf growth ceased. A leaf was determined to have attained maximum length when it had the same reading for two consecutive weeks. Number of new tillers, number of green leaves (leaves with less than 25% senescence), leaf length, leaf growth duration (measured as number of days taken to reach maximum leaf length), percentage greenness (measured as (number of green leaves/total number of leaves) × 100), and plant height were measured after 8 wk, immediately before the first harvest. Genotypes were cut to a height of 5 cm (first harvest) and data on fresh and dry weight collected. The timelines of regrowth measurement and harvests are shown in Fig. 2. Regrowth was measured at an interval of 4 wk after the first (regrowth I), second (regrowth II), and third harvests (regrowth III). Regrowth of the genotypes was measured as change in tiller number, that is, the number of new tillers, number of new leaves, and plant height. Summer dormancy index was calculated on SSD and MSD genotypes based on the method given by Norton et al. (2008) where summer dormancy index = \{100 – [(summer yield of cultivar/summer yield of nondormant control) × 100]/10\}. The nondormant control genotype in this research was SA.

Immediately after the second harvest, all the genotypes, irrespective of their treatment combinations, were watered from the top to the point of saturation. Growth chamber conditions were not altered during this irrigation. Bottom watering was resumed for +W and –W watering treatments within a week. Four weeks after the top watering, the genotypes were harvested for the third time and the growing conditions in the growth chambers were returned to favorable conditions of SD and OT. One month after the return to the favorable conditions, measurements were taken again (Fig. 2).

The experiment was repeated a second time in the growth chambers. To avoid the possibility of any lingering treatment effects on the ramets from the first cycle of the experiment, a new set of clones of SA, SSD, and MSD genotypes that had been maintained in the greenhouse were used for the second experiment following the same procedures as outlined above.

Statistical Analysis
All the treatments and their corresponding combinations were laid out in a 3 × 2 × 2 × 2 × 2 split-split plot arrangement in a randomized complete block design with two replications. Replication was performed over time (i.e., cycles were considered replications). Each growth chamber comprising a specific combination of daylength and temperature formed the main plot. Within each growth chamber, the +W and –W groups formed the subplots. Each genotype in a single 11 by 10 cm pot formed the sub-subplot. Data were analyzed by the PROC MIXED procedure of SAS (SAS Institute, 2001) with photoperiod, temperature, vernalization, drought, and genotypes as fixed effects and replication, replication × photoperiod × temperature, and replication × photoperiod × temperature × water as random effects. Error terms and denominator degrees of freedom were specified by the DDFM = SATTERTH option. The interactions were evaluated using the SLICE option of the LSMEANS procedure. Differences between treatment least square means were compared using the diff option at \(p < 0.05\).

RESULTS AND DISCUSSION
The rationale behind including favorable conditions (SD, OT, +W, and +V) in this research is as follows. The SA genotype is capable of growing well under a wide range of conditions including summer environments. Reduced growth of the SA genotype in a given environment compared to growth under favorable conditions would therefore be a response to stress (e.g., drought, heat) and not summer dormancy. Such an environment would therefore not be useful for differentiating summer active from summer dormant genotypes. However, under a given set of conditions, if a genotype, such as SSD, grew less than when under favorable conditions while the SA genotype did not have reduced growth for the same comparison, then we surmise the plants can be differentiated as summer dormant and summer active genotypes, respectively.

Genotypes × trait means are listed for all the various treatment combinations in Table 1 and Supplemental Table S1. Under LD, HT, –W, and +V compared to favorable conditions, the SA genotype had significantly lower means for fresh weight (2.8 vs. 19.6 g), dry weight (1.3 vs. 6.9 g), number of green leaves (10.6 vs. 59.6), percentage greenness (30.1 vs. 63.6), plant height (23.6 vs. 56.6 cm), and leaf growth duration (36.1 vs. 42.0) (Table 1). Similar
results for many traits could be observed under –W conditions of LD and HT, LD and OT, and SD and HT (Table 1) implying that the lower means of the SA genotype in these environments could be a stress response to high temperature, drought, or their combination (Table 1; Fig. 1). Comparable results occurred for regrowth periods 1 and 2 (Table 2). Thus, high temperature under long day conditions and drought in any treatment combination were not useful in differentiating summer dormant from summer active genotypes and further discussion will be largely limited to well-watered (+W) and OT treatments.

All plants subjected to long days and vernalization flowered irrespective of the water and temperature conditions. The –V plants under long days and +V plants under short day conditions did not flower independent of water and temperature conditions. Hence, in these three genotypes, long days and vernalization treatments were effective in conditioning plants to shift from vegetative to reproductive growth.

Significant differences between the summer active and dormant genotypes could not be found for many traits under other treatment combinations in –V conditions (Supplemental Table S1). Also, growth of SSD and MSD was very similar for all –V conditions vs. favorable conditions. Our observation that the vernalization treatment could be necessary for differentiating dormant from active genotypes agrees with earlier results reported by Malinowski et al. (2007) and Norton et al. (2009). Norton et al. (2009) observed that Flecha sown in autumn (analogous to +V) exhibited summer dormancy whereas when sown in spring

Table 1. Comparison of trait means of a vernalized genotype with itself (rows) and between genotypes (columns) under various environmental conditions before first harvest.

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1HT, high temperature; LD, long day; OT, optimum temperature; SD, short day; +V, vernalized; +W, well watered; –W, drought.
2SA, summer active; SSD, strongly summer dormant; MSD, moderately summer dormant.
3Means followed by the same letter in a given column (uppercase) under a given treatment condition for the three genotypes are not significantly different at the 0.05 probability level.
4Means followed by the same letter (lowercase) in a given row for a genotype are not significantly different at the 0.05 probability level.
(analogous to \( -V \)), the summer active cultivar ‘Demeter’ and Flecha were similar in growth. Therefore, we have limited further discussion of our results to \(+V\) treatments.

Thus, in the present research, SD, HT, \(+W\), and \(+V\) and LD, OT, \(+W\), and \(+V\) are the only remaining treatment combinations that can potentially separate SA and SSD genotypes.

### Before Harvest

Under favorable conditions immediately before the first harvest, no differences were observed between the SA and SSD genotypes for tiller number (15.5 vs. 10.0), percentage greenness (63.6 vs. 59.8), fresh weight (19.6 vs. 18.6 g), and dry weight (6.9 vs. 6.3 g) (Table 1). On the other hand, SSD was taller (69.0 vs. 56.6 cm) and had longer...
leaves (35.0 vs. 29.0 cm) than SA under these conditions. The means of MSD for tiller number (16.8) and percentage greenness (73.0) were similar to SA (Table 1). No differences between the three genotypes were observed in fresh and dry weight (Table 1). Thus, SSD and MSD grew as much or more than SA under favorable conditions.

Earlier research by Norton et al. (2006b) suggested leaf senescence could be used to identify summer dormant plants. However, we found that the number of green leaves and percentage greenness were not helpful in differentiating dormancy of the three genotypes. The SSD genotype had significantly fewer green leaves compared to the SA and MSD genotypes under favorable conditions (35.5 vs. 59.6 and 65.1, respectively) (Table 1). In addition, relative to favorable conditions, SA had the same or more senescence under SD, HT, +W, and +V; LD, OT, –W, and +V; LD, HT, –W, and +V; and LD, HT, +W, and +V (Table 1), indicating that loss of greenness in tall fescue can be a general response to drought and/or heat stress rather than an indicator of summer dormancy. Therefore, senescence may not always be a reliable indicator of summer dormancy, which corresponds to our field observations in the south central United States (Hopkins and Bhamidimarri, 2009). Under LD, OT, +W, and +V conditions, significant differences between SA and SSD were observed for fresh (16.0 vs. 6.0 g) and dry weight (8.8 vs. 3.1 g) respectively (Table 1). Fresh and dry weights were greatest, intermediate, and least for SA, MSD, and SSD, respectively (Table 1).

Likewise, dry weight indicated that SA grew more under LD, OT, +W, +V versus favorable conditions whereas SSD grew less under LD, OT, +W, and +V compared to favorable conditions. Dry weight of MSD was equivalent under both conditions (Table 1). Leaves of SSD were longer under favorable compared to LD, OT, +W, and +V conditions (35.0 vs. 21.6 cm) whereas leaves of SA were comparable under both conditions (29.0 vs. 25.8 cm).

These differences in growth of genotypes, as measured by leaf length and fresh and dry weight under favorable compared to LD, OT, +W, and +V conditions appear to indicate active growth of SA under both types of conditions and dormancy of SSD under LD, OT, +W, and +V (Table 1; Fig. 3). Plant height, fresh weight, and dry weight of MSD indicated an intermediate dormancy response. There were no differences in tiller number or leaf growth of SSD under favorable compared to LD, OT, +W, and +V conditions (Table 1), indicating that these traits may have had limited value in differentiating dormancy of the three genotypes.

Under SD, HT, +W, and +V, the number of tillers, fresh weight, and dry weight were significantly less for SSD compared to SA while fresh and dry weights were less for MSD than SA (Table 1). When comparing growth under SD, HT, +W, and +V vs. favorable conditions, SSD had fewer tillers and shorter leaves while all genotypes were shorter and had less fresh and dry weight (Table 1).

We surmise that the reduced growth of all three genotypes under SD, HT, +W, and +V vs. favorable conditions indicates a response to heat stress, perhaps resulting from reduced availability of assimilates coupled with a higher respiration rate. Perhaps the greater reduction in growth of SSD and MSD compared to SA was an indication of greater sensitivity of these genotypes to high temperature stress under these conditions rather than expression of dormancy.

Summer dormancy indices were calculated for SSD and MSD under different combinations and are presented in Table 3. Index scores under LD, OT, +W, and +V were significantly greater for SSD than for MSD and SA (6.3 vs. 2.8). These results provide further evidence that summer dormancy can be differentiated among tall fescue genotypes under LD, OT, +W, and +V conditions. Interestingly, the indices were also greater for SSD and MSD than SA under SD, HT, +W, and +V conditions (4.4 vs. 3.2). We cannot rule out that SSD and MSD expressed dormancy under SD, HT, +W, and +V, but again we think that the tall fescue genotypes had reduced growth due to heat stress.

**Regrowth I**

Four weeks after first harvest, SSD was taller than SA under favorable conditions. In contrast, under LD, OT, +W, and +V and SD, HT, +W, and +V conditions, SA was taller than SSD (Table 2). This implies dormancy expression in SSD, although all three genotypes had less regrowth, as measured by height, under LD, OT, +W, and +V and SD, HT, +W, and +V than under favorable conditions. Tiller number and number of new leaves did not differ across these three environmental conditions for SA, SSD, or MSD (Table 2).

**After Top Watering, Regrowth II**

Research by Norton et al. (2006b) in tall fescue showed that complete dormancy could not be broken even after...
Table 3. Dormancy indices of strongly summer dormant (SSD) and moderately summer dormant (MSD) tall fescue genotypes grown in various environments. A greater number indicates a greater degree of dormancy.

<table>
<thead>
<tr>
<th>Growth environment†</th>
<th>SSD</th>
<th>MSD</th>
<th>SA‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD, HT, +W, and +V</td>
<td>–0.7a§</td>
<td>1.6a</td>
<td>0.0a</td>
</tr>
<tr>
<td>SD, HT, +W, and +V</td>
<td>4.4a</td>
<td>3.2a</td>
<td>0.0b</td>
</tr>
<tr>
<td>LD, OT, +W, and +V</td>
<td>6.3a</td>
<td>2.8b</td>
<td>0.0c</td>
</tr>
<tr>
<td>SD, OT, +W, and +V</td>
<td>0.7a</td>
<td>–1.0a</td>
<td>0.0a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>1.75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†LT, high temperature; LD, long day; OT, optimum temperature; SD, short day; +V, vernalized; +W, well watered.
‡SA, summer active.
§Means followed by the same letter in a given row are not significantly different at the 0.05 probability level.

In the present research plants were watered from the top immediately after the second harvest and growth measurements taken as regrowth II after 4 wk (Fig. 2). This was done to determine if growth would become less restrained due to a sudden change in some limiting factor (e.g., water, temperature); such a response or the lack thereof would provide further insight into methods for phenotyping summer dormancy in tall fescue. When comparing growth after top watering under favorable versus LD, OT, +W, and +V conditions, SA was equal in height in both environments whereas SSD and MSD grew almost 2 cm less under LD, OT, +W, and +V. Also, significant differences between SA and SSD in plant height and number of new leaves under LD, OT, +W, and +V continued after top watering. These results suggest that SSD remained dormant under LD, OT, +W, and +V despite any changes in growing conditions that may have occurred due to top watering.

After top watering under LD, OT, –W, and +V and LD, HT, –W, and +V conditions, SA grew more and became significantly taller than SSD (Table 2). No such differences were noticed for number of new leaves and tillers. This shows that under the drought conditions of LD, HT, –W, and +V and LD, OT, –W, and +V before top watering, any dormancy that might have been expressed by SSD could not be differentiated from the poor growth of SA under drought stress. Interestingly, the differences in plant height that were observed earlier in regrowth I between the three genotypes in the SD, HT, +W, and +V conditions could not be seen after top watering. This could be because under the SD, HT, +W, and +V conditions, lower rates of photosynthesis coupled with higher respiration rates could have reduced assimilates and available water. Hence, on top watering to the point of saturation, all genotypes grew equally tall. Therefore, the summer dormancy of the genotypes may not be accurately differentiated under SD, HT, +W, and +V.

Regrowth III
After the regrowth II period, the conditions in all the growth chambers were returned to the favorable conditions of SD and OT and all the treatments were irrigated equally. Plant height increased significantly with all genotypes becoming the same height (Table 2). Although the number of new leaves increased in the dormant genotypes, significant differences still existed between the dormant and active types. However, any dormancy of SSD and MSD was broken under SD, OT, and +W conditions as indicated by the resumed active growth of these genotypes.

Compared to favorable conditions, several measures indicated that growth of SA was not reduced under LD, OT, +W, and +V conditions whereas growth of SSD was reduced under these same conditions. For this same comparison, MSD showed intermediate growth. Differences between SSD and SA were observed in number of tillers, plant height, leaf length, and fresh and dry weights under SD, HT, +W, and +V compared to favorable conditions before the first harvest whereas SSD did (Table 1). Differences occurred for number of leaves in regrowth II (Table 2). Still, SA was shorter and had less fresh and dry weight under SD, HT, +W, and +V compared to favorable conditions before the first harvest. Thus, of the treatment combinations that we examined, genotypes could be most clearly separated into dormancy classes by comparing growth under LD, OT, +W, and +V versus favorable (SD, OT, +W, and +V) conditions.

The results from this study have shown that in the absence of drought, dormancy appears to have been induced in SSD (under LD, OT, +W, and +V conditions). Under drought stress the active and dormant genotypes could not be differentiated as the growth of SA was significantly reduced. A similar response was seen for high temperature conditions. Vernalization was also a prerequisite for differentiating summer dormant from summer active genotypes. Following a top watering treatment under LD, OT, +W, and +V conditions, the active genotype grew significantly taller than SSD but was not different from the MSD. Dormancy indices further confirmed that the level of dormancy was the highest in SSD followed by MSD.

CONCLUSIONS
In this investigation, we report the differentiation of summer dormant from summer active tall fescue plants under LD, OT, +W, and +V conditions. The complete expression of growth in the SA genotype was generally masked under HT and –W treatments. Such stresses would make differentiating between summer active and summer dormant types difficult. We conclude that summer dormancy is indicated when a genotype has vigorous growth under conditions of SD, OT, +W, and +V but significantly less growth under LD, OT, +W, and +V. Under both conditions, a summer active check genotype should grow vigorously. The traits leaf length, fresh and dry
weight, and particularly plant height are useful in quantifying growth differences between active and dormant plants. Further research is needed to verify that this same differentiation correlates with what happens in the field. We initiated a project to verify that this approach can differentiate summer active from dormant genotypes in a segregating population.

Supplemental Information Available

Supplemental material is available at http://www.crops.org/publications/cs.

Supplemental Table S1. Comparison of trait means of nonvernalized genotypes at various daylength, temperature, and water regimes.

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References


