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Title: TEMPERATURE EFFECTS ON GROWTH AND NUTRIENT CONCENTRATION IN TALL FESCUE (FESTUCA ARUNDINACEA, SCHREB.) SELECTIONS DIFFERING IN FORAGE YIELD

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This study was undertaken to better understand plant characteristics related to high and low forage yield in tall fescue selections as affected by temperature. Dry matter distribution into yield components in three different temperature regimes was evaluated. Root growth, dark respiration and nutrient concentration were also examined.

The four diverse tall fescue selections grown under controlled environmental conditions exhibited yields similar to those noted in the field. Selection TFM 26 produced more forage yield at the low temperature while TFK 12 produced more at the high temperature indicating a seasonal growth response. However, TFM 26 was the highest yielding selection when averaged over the three temperature regimes. High yielding TFM 26 had the greatest leaf area and low yielding TFK 4 the least. Higher yielding TFM 26 and TFK 12 had more leaf area per tiller than the other selections and TFM 26 had the greatest number of tillers. Root volume had a closer association with forage yield than root dry matter (RDM). Winter-growing TFMs had greater RDM than

the summer-growing TFKs. Root density was higher for winter-growing TFM 16 which appeared to be partitioning more root dry matter into root 'bulk' than root volume. Winter-growing TFMs had higher root-to-shoot ratios than TFKs suggesting that winter-growing selections distribute their dry matter differently.

Growth analysis showed that relative growth rates were higher for high yielding selections. High yielding selections also had a higher relative leaf area growth rate (RLAGR). A rapid leaf area development may be producing more available photosynthate at an earlier growth stage giving high yielding selections their yield advantage. The relative root growth rate (RRGR) was greater for winter-growing TFMs than for TFKs. The high RRGR of TRM 26 may be related to its high RLAGR. The harvest index was higher for summer-growing TFKs than winter-growing TFMs.

Dark respiration rates in roots and leaves did not differ throughout the experiment.

Mineral analysis showed that K accumulation per unit of root volume was greater for winter-growing TFM 16 than TFM 26, however, TFM 26 had greater K per gram of root material. The data suggest that winter-growing TFM 16 may absorb and translocate more K than TFM 26. Summer-growing TFK 12 had low Mg at the low temperatures suggesting that animal consumption may induce a Mg deficiency (grass tetany) when grazed during low temperatures.

Temperature Effects on Growth and Nutrient Concentration in Tall Fescue (Festuca arundinacea, Schreb.) Selections Differing in Forage Yield

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TEMPERATURE EFFECTS ON GROWTH AND NUTRIENT CONCENTRATION IN TALL FESCUE (*Festuca arundinacea* Schreb.) SELECTIONS DIFFERING IN FORAGE YIELD

LITERATURE REVIEW

The components of forage yield have been the subject of several studies attempting to explain how high yielding cultivars produce their forage yield. In tall fescue the leaves, stem and roots are components working in continual interactive ways resulting in forage yield. However, the exact nature of their interaction as affected by temperature is not completely understood.

Differential partitioning of dry matter has been observed between high and low yield per tiller genotypes of tall fescue (Wilhelm and Nelson, 1978). High yield per tiller genotypes of tall fescue partitioned more dry matter into leaf dry weight, stem base dry weight and root dry weight than low yield per tiller genotypes. They concluded a larger stem base may have provided more carbohydrates resulting in the rapid relative leaf growth rate observed, thus allowing the high yield per tiller genotypes to develop their superior forage yield.

Temperature affects forage yield of tall fescue in different ways. At low temperatures tall fescue root growth has been accompanied by relatively little top growth. As the temperature was increased, top growth increased at a proportionally greater rate than roots; however, at high temperature root growth remained constant while top growth declined (Davidson, 1969).

In a continuing effort to characterize tall fescue forage production, Jones and Nelson (1979) investigated the physiological process of dark respiration in the leaves and root tips of high, medium and low yield per tiller genotypes of tall fescue. Dark respiration rates in leaves of the high yield per tiller genotype were greater than those rates observed in the medium and low yield per tiller genotypes. However, respiration rates in the root tips of the low yield per tiller genotype were higher than the other two genotypes. Thus, yield and dark respiration rates correspond in the leaves of tall fescue, but dry matter deposition and respiration rates were inversely associated in the roots. Perhaps energy resulting from respiration in the roots of the low yielding genotype was being utilized for other functions, such as nutrient uptake.

Nutrient uptake is an outstanding characteristic of the plant's root system. One mechanism for nutrient uptake has been characterized as an ATPase energy requiring active transport system (Fisher and Hodges, 1969; Leonard and Harrison, 1972; Sze and Hodges, 1977; Leonard and Hotchkiss, 1978). In tall fescue Fleming and Murphy (1968) observed a seasonal trend in nutrient concentration levels from late spring to early winter; potassium concentrations declined, and magnesium and calcium concentrations increased. Low magnesium concentration which is related to grass tetany problems in grazing animals has been observed in tall fescue pastures in early spring and late fall (Karlen et al., 1980). However, Leggett et al. (1977) observed no effect of the seasonal temperature on potassium, magnesium and calcium concentrations in tall fescue.

Lhamby (1978) conducted a two-year field study on four diverse tall fescue selections differing in forage yield. Of the four tall fescue selections studied, two were noted to be high and low yielding, late fall and winter growing, and two were high and low yielding, early spring and summer growing. The present study was undertaken to evaluate and describe dry matter distributions in the shoot and root as affected by temperature in the four tall fescue selections described by Lhamby (1978). Respiration and nutrient concentration in the roots and shoots were also examined.

MATERIALS AND METHODS

Plant Material and Environmental Chambers

Four diverse selections of tall fescue previously determined to be high and low yielding, late fall and winter growing (TFM 26 and TFM 16, respectively), and high and low yielding, early spring and summer growing (TFK 12 and TFK 4, respectively) were used (Lhamby, 1978). Sixteen samples of each selection were randomly selected from established swards in the late fall. Plant material was transplanted to 650 cm^3 plastic pots and grown in the greenhouse. To maintain a vegetative growth state, plants were supplied a 13 hour photoperiod by cool-white fluorescent lights. Plants were vegetatively propagated to establish a greenhouse population of 200 plants per selection. All plants were watered every other day with tap water and once weekly with 5 ml of a modified Hogland's complete nutrient solution.

Twenty vegetative tillers from each selection were quantified for root volume (Pinkas *et al*., 1963), root length and the tops were trimmed to a 10 cm stubble height; all leaf area was removed. Plants material was then transferred to aeroponic misting chambers where the same complete nutrient solution used in the greenhouse was applied at one-eight strength as a nutrient mist (Zobel *et al*., 1976).

Three aeroponic misting chambers were located in three controlled environmental chambers programmed at $13^{o}C/2^{o}C$, $18^{o}C/7^{o}C$ and $24^{o}C/13^{o}C$ (day/night, respectively) and nutrient mists were maintained at constant temperatures of $7^{o}C$, $13^{o}C$ and $18^{o}C$, respectively. A 13 hour photoperiod with a photosynthetic photon flux density of $350\mu E\ m^{-2}\ sec^{-1}$ was provided by cool-white fluorescent and incandescent bulbs.

During this study, plant identity was retained in a randomized complete block design and after analysis of variance was performed, when significant, an L.S.D. was used to make planned comparisons between high yielding and low yielding plants, and between winter growing and summer growing plants. The data presented are the means of up to 20 plants.

The sampling was initiated 40 days after transfer to the aeroponic misting chambers, when regrowth at the lowest temperature was sufficient for quantification.

Ten hours into the dark period, one fully expanded leaf from each plant was excised. A 3 cm section from the center of each leaf blade was excised for dark respiration measurements. This was done for one replication only.

Three hours into the light period root tips 3 cm long were excised from each plant and respiration measured.

The remainder of the plant was removed from the environmental chamber and evaluated for leaf area, leaf fresh weight, leaf height, tiller number, root volume, root length and root fresh weight. Three centimeters of the stem bases were excised for mineral analysis and their fresh weight taken; the stem base from the main tiller of the plant was evaluated for diameter.

Plant material was dried at 70°C for 48 hours and dry weights determined.

Root Surface Area

In a previous experiment we conducted (data not shown) tall fescue roots grown in an aeroponic misting chamber were excised, dried and their surface area calculated. With roots of known surface area a linear regression model was developed. Using a saturated $CaNo_3$ solution, dried roots were dipped for 10 seconds, allowed to drain for 30 seconds and $CaNo_3$ adhering to or absorbed by the roots was gravimetrically determined (Carley and Watson, 1966). The following equation was used to calculate root surface area:

$$A_r = 65.384\ (CaNo_{3-g}) + 4.05; \quad r^2 = 0.9981$$

Respiration

The rate of respiration was estimated by rate of O_2 uptake. Root tips were floated in the outer well of a 17 ml single sidearm Gilson respirometer flask containing 5 ml of distilled water.

A CO_2-free atmosphere was maintained by absorption of CO_2 by 0.2 ml 4N KOH placed in the center well of the flask, using a filter-paper-wick to enchance gas exchange. Leaf sections were placed upright in the center well of the flask with 0.2 ml distilled water and 0.2 ml 4N KOH in the outer well (Wilson, 1972). The respirometer was shielded from the light and flasks were equilibrated in the water bath at the appropriate root or leaf temperature for 30 minutes before the rate of O_2 uptake was measured at 30 minute intervals over a two hour period.

Mineral Analysis

Plant material was washed in a detergent solution (Ashby, 1969), dried at 70°C for 40 hours and ground to pass a 40 mesh screen. Potassium, Ca and Mg were determined on a Jarrel-Ask 3/4 Meter Direct Reading Photoelectric Spark emission Spectometer.

Growth Analysis

Relative growth rate (RGR), relative leaf area growth rate (RLAGR), relative root growth rate (RRGR) and relative root area growth rate (RRAGR) were calculated (Radford, 1967; Wilhelm and Nelson, 1978). In order to utilize Radford's (1967) calculations initial root weight and initial root area were evaluated by prediction equation using initial root volume.

Specific leaf weight was evaluated by dividing the total dry weight of the leaves by the total leaf area resulting in a value which integrated all the leaves of the plant. The root to shoot ratio (R:S) was evaluated by the following equation:

$$R:S = \frac{R_2 - R_1}{(L_2-L_1) + (S_2-S_1)}$$

where R_1 and R_2 are initial and final root dry weight, L_1 and L_2 are initial and final leaf dry weight and S_1 and S_2 are initial and final stem dry weight, respectively. The harvest index (HI) was evaluated from the following equation:

$$HI = \frac{L_2 - L_1}{(L_2-L_1) + (S_2-S_1) + (R_2-R_1)}$$

RESULTS AND DISCUSSION

Forage Yield

The four diverse tall fescue selections grown under controlled environmental conditions exhibited yield responses similar to those noted by Lhamby (1978) for these same fescue selections grown under field conditions. Lhamby (1978) observed that of these four tall fescue selections TFM 26 and TFM 16 were winter-growing with TFM 26 producing more forage yield than TFM 16. Similarly, Lhamby (1978) noted that the TFKs were summer-growing selections and TFK 12 produced somewhat more forage yield than TFK 4.

Under the controlled environmental conditions of this study winter-growing TFM 26 produced more forage yield than TFM 16 and summer-growing TFK 12 produced more forage yield than TFK 4 (Table 1).

This study partly confirms Lhamby's (1978) observations as to the seasonable growth response of the tall fescue selections. Under the low temperature regime winter-growing TFM 26 produced more forage yield than the summer-growing TFKs. At the high temperature regime summer-growing TFK 12 produced more forage yield than the winter-growing TFMs (Table 2). However, winter-growing TFM 26 was the highest yielding selection when averaged over the three temperature regimes, followed respectively by TFK 12, TFM 16 and TFK 4 (Table 1). This ranking does not exactly coincide with

Lhamby's (1978) findings, where he showed that TFM 26 was the highest yielding selection followed in rank order by TFK 12, TFK 4 and TFM 16. The reason for the improved performance of TFM 16 is not clear, but it could be due to the low stress environment provided by the controlled environmental chambers. Nevertheless, the data does indicate that between the two tall fescue selection groups, different seasonally optimum growing temperatures may exist.

The characteristics of forage yield observed in this study were leaf area (LA), tiller number (TN), yield per tiller (YT), leaf area per tiller (LAT), stem dry weight (SDW), stem size (SS) and plant height (H). Of these characteristics the four tall fescue selections were found to differ in LA, LAT, TN and H.

Leaf area (LA) exhibited the same trend noted in forage yield (Table 1), with high yielding winter-growing TFM 26 having the greatest LA and low yielding summer-growing TFK 4 the least. The significant difference observed in LAT (Table 2) does not correspond with Lhamby (1978), who found no significant difference in LAT or number of leaves per tiller for field-grown plants. Cohen (1979) observed a significant difference in the number of leaves per tiller among the tall fescue selections when grown under greenhouse conditions, but no significant difference was found for TN. In contrast, the present study showed that selections differed in LAT and TN when grown under controlled conditions. The high yielding selections in this study, TFM 26 and TFK 12, had significantly more LAT than the other selections when grown at the high temperature (Table 2). However, high yielding winter-growing TFM 26 had significantly greater TN than summer-growing TFK 12 (Table 1); with the greatest difference in TN occurring at the medium temperature (Table 2).

The selections differed in H with winter-growing TFM 16 being significantly taller than summer-growing TFK 4 (Table 1); however, the significant difference in H between winter-growing TFM 16 and summer-growing TFK 4 was only observed at the lower temperature (Table 2). These results are similar to Cohen (1979) and Lhamby (1978) for leaf elongation. If plant height is a function of leaf elongation, the data suggests that this process may be similar under controlled environmental and field conditions.

In conclusion, winter-growing TFM 26, shown to be high yielding under competitive field conditions (Lhamby, 1978), also is high yielding under noncompetitive, controlled environmental conditions.

Table 1. Average forage yield, leaf area (LA), tiller number (TN) and plant height (H)[§] over temperatures for four diverse tall fescue selections.

Selection	Forage Yield (g)	LA (cm^2)	TN (unit/plant)	H (cm)
TFK 4	0.551	55.5	7.3	22.5
TFK 12	0.643	63.4	6.8	24.5
TFK 16	0.613	62.9	7.4	27.7
TFM 26	0.674	73.7	8.2	27.4
L.S.D.	0.081^{+}	12.0*	0.9*	3.8^{+}

+, * Significant at the 0.10 and 0.05 levels, respectively.

§ Expressed on a per plant bases, mean of 20 plants.

Table 2. The effect of temperature on forage yield, leaf area (LA), tiller number (TN), leaf area per tiller (LAT) and plant height (H)§ of four diverse tall fescue selections.

Temperature Regime	Selection	Forage Yield (g)	LA (cm^2)	TN (unit/plant)	LAT (cm^2/unit)	H (cm)
Low	TFK 4	0.253	11.8	7.0	1.7	6.1
	TFK 12	0.250	13.4	7.0	1.9	9.9
	TFM 16	0.233	14.4	6.3	2.4	14.5
	TFM 26	0.273	18.5	7.7	2.4	16.6
Medium	TFK 4	0.763	94.1	8.3	11.3	34.0
	TFK 12	0.707	75.1	6.7	11.2	27.7
	TFM 16	0.800	100.0	8.3	12.2	40.3
	TFM 26	0.910	110.2	10.3	10.7	35.3
High	TFM 4	0.637	60.6	6.7	9.1	27.3
	TFM 12	0.973	101.6	6.7	15.3	35.7
	TFM 16	0.807	74.2	7.7	9.6	28.4
	TFM 26	0.840	92.4	6.7	14.2	30.3
	L.S.D.	0.170*	28.2**	1.5*	3.4*	7.9*

*,**Significant at the 0.05 and 0.01 levels, respectively.

§Expressed on a per plant basis, mean of 20 plants.

Root Growth

Root volume (RV) may have a closer association with forage yield than root dry matter (RDM). Root volume (RV) was significantly different among the four tall fescue selections (Table 3). When averaged across the three temperature regimes both winter-growing TFM 26 and summer-growing TFK 12 had higher forage yield and RV than TFM 16 and TFK 4. Also, at the medium temperature both of the winter-growing TFMs had higher RV and forage yield than the summer-growing TFKS (Table 4). These data suggest that RV and forage yield may be interrelated.

Winter-growing TFMs developed greater RDM than the summer-growing TFKs (Table 3). This association was consistent, though not always significant, between the two groups at each temperature regime. The RDM accumulation increased as the temperature increased (Table 4); the increase was typical for cool season grasses (Smoliak and Johnson, 1968). Root density (RD) (RDM divided by RV) was higher for winter-growing TFM 16; however, RD was not significantly different among the other tall fescue selections (Table 3). Winter-growing TFM 16 appeared to be partitioning more root dry matter into root 'bulk' than into root volume, resulting in the thicker, less filamentous root system observed in this study. In part, this coincides with preliminary observations in the field that TFM 16's root system was shallower in depth and smaller in biomass than the root systems of the other tall fescue selections (Lhamby, 1978).

Further evidence for differential partitioning among the four tall fescue selections may be observed in the root-to-shoot ratio (R:S). The R:S may be an expression of the plants' ability to simultanuously partition dry matter to the roots and the shoots. In this study the winter-growing TFMs had a significantly higher R:S than the summer-growing TFKs (Table 3), when averaged across the three temperature regimes. However, no significant difference was noted among the four tall fescue selections within each temperature (Table 4). Collectively these data suggest that the winter-growing selections distribute their dry matter in different ways from the summer-growing selections.

An attempt was made to assess the root area (RA) and root length (RL) of the four tall fescue selections. Upon statistical analysis these measurements were found to be significantly different among the selections; however, the variation observed was considered to be mostly the product of the multibranching root system and the sampling techniques. Garwood (1968) demonstrated that perennial ryegrass increased in its root branching at higher root zone temperatures. Corn grown at cool temperatures has thicker and less branching roots, whereas, at higher temperatures the roots are more filamentous, thinner and more branching (Galligar, 1938). These effects were also observed in this study, affecting the RA and RL measurements. Root area (RA) was measured by coating the entire root system with a saturated solution of Ca NO_3, after Carly and Watson (1966). This technique does not allow for morphological changes in the root structures as affected by changes in temperature. Consequently, there was an observed increase in the amount of Ca NO_3 solution remaining within those filamentous multibranching root systems grown at the higher temperature. This increase was not observed in those root systems grown at the lower temperature, suggesting that the technique and its effects were not consistent enough to compare roots grown at different temperatures. Root length may not accurately reflect root activity because it fails to measure dry matter partitioning in volume; i.e. the kind of growth which contributes to the multibranching effect. Therefore, RV was deemed a more consistent assessment of root activity when comparing root growth at different temperatures.

Table 3. Average root dry matter (RDM), root volume (RV), root density (RD) and root to shoot ratio (R:S)§ over temperatures for four diverse tall fescue selections.

Selection	RDM (g)	RV (cm^3)	RD# (g/cm^3)	R:S
TFK 4	0.181	3.76	4.89	0.258
TFK 12	0.233	4.83	5.13	0.279
TFM 16	0.285	3.69	7.46	0.356
TFM 26	0.281	4.64	5.90	0.341
L.S.D.	0.062**	0.85**	2.54**	0.064*

*, ** Significant at the 0.05 and 0.01 levels, respectively.

Root density x 10^2

§ Expressed on a per plant basis, mean of 20 plants.

Table 4. The effect of temperature on root dry matter (RDM), root volume (RV), root density (RD) and root to shoot ratio (R:S)§ of four diverse tall fescue selections.

Temperature Regime	Selection	RDM (g)	RV (cm^3)	RD# (g/cm^3)	R:S
Low	TFK 4	0.031	0.62	4.94	0.096
	TFK 12	0.039	0.68	5.84	0.120
	TFM 16	0.041	0.67	6.51	0.136
	TFM 26	0.043	0.78	5.49	0.137
Medium	TFK 4	0.260	5.14	5.10	0.321
	TFK 12	0.239	5.00	4.78	0.315
	TFM 16	0.359	5.61	6.32	0.412
	TFM 26	0.319	5.55	5.80	0.336
High	TFK 4	0.252	5.51	4.62	0.356
	TFK 12	0.421	8.82	4.77	0.404
	TFM 16	0.456	4.79	9.56	0.521
	TFM 26	0.481	7.59	6.40	0.551
	L.S.D.	0.104**	1.47**	n.s.	n.s.

**Significant at the 0.01 level of probability

n.s. Not significant

#Root density x 10^2

§Expressed on a per plant basis; mean of 20 plants

Growth Analysis

The relative growth rate (RGR) was greater for winter-growing TFM 16 than for low yielding summer-growing TFK 4; however, no significant difference was noted between the high yielding selections or within the summer and winter-growing groups (Table 5). Temperature affected the trend in the rate of growth for the various plant parts in similar ways among the four tall fescue selections; the RGR is indicative of this trend (Figure 1). At the lower temperature there was no noted difference among the tall fescue selections. However, at the medium temperature high yielding winter-growing TFM 26 had a higher RGR than summer-growing TFK 12. At the high temperature no significant difference was observed between the high yielding selections, TFM 26 and TFK 12, but there was a difference noted between the low yielding selections with winter-growing TFM 16 having a significantly higher RGR than summer-growing TFK 4 (Table 6). As the temperature increased from medium to high the rate of change in the RGR of the four tall fescue selections differed. The TFMs remained relatively unchanged while the TFKs responded in opposite directions with the slope of the line for the RGR of summer-growing TFK 12 increasing at a greater rate than the winter-growing TFMs (Figure 1).

The relative leaf area growth rate (RLAGR) was significantly higher for high yielding winter-growing TFM 26 than for high yielding summer-growing TFK 12. Although no significant difference was observed in the RLAGR between the summer-growing selections, TFM 26 of the winter-growing selection had a significantly higher RLAGR than TFM 16 (Table 5), this may account for TFM 26's superior yield potential due to the rapid development of photosynthetic leaf material during early stages of development.

Differences in the RLAGR were significant among selections within temperatures (Table 6). At the low and medium temperature, high yielding winter-growing TFM 26 had a higher RLAGR than high yielding summer-growing TFK 12. However, at the high temperature TFK 12 had a significantly higher RLAGR than low yielding TFK 4, but no significant differences were noted among other comparisons.

The RRGR was consistently higher for the winter-growing TFMs than the summer-growing TFKs. But there was no significant difference noted for RRGR within either the TFMs or TFKs (Table 5). The RRGR for the four tall fescue selections was not different at the low temperature. At the medium temperature high yielding winter-growing TFM 26 had a significantly higher RRGR than high yielding summer-growing TFK 12; the high RRGR of TFM 26 may be related to TFM 26's high RLAGR. At the high temperature summer-growing TFK 12 had a higher RRGR than summer-growing TFK 4 .

The significant difference observed in TFK 12's RRGR corresponds to the significant difference observed in TFK 12's RLAGR (Table 6).

In a continuing effort to evaluate dry matter partitioning into forage yield among the four diverse tall fescue selections, specific leaf weight (SLW) and harvest index (HI) were determined. Specific leaf weight (SLW) is the dry weight of the leaf per unit of leaf area, reflecting the amount of dry matter partitioned into leaf tissue. The harvest index (HI) is the proportion of biological yield represented by economic yield, which reflects the differential partitioning of plant dry matter into harvestable forage yield (i.e. leaf production).

No significant difference in SLW among the four tall fescue selections was observed. These results are not surprising, for Lhamby (1978) and Cohen (1979) found no significant difference in SLW among these same four tall fescue selections.

A significant difference in the HI was noted among the selections. Winter-growing TFM 16 had a significantly lower HI than low yielding summer-growing TFK 4 (Table 5), suggesting that the low yielding winter-growing selection partitioned less dry matter into forage production. At the same time, there was no significant difference between the high yielding selections, nor was there a difference noted as the temperature varied (Table 6).

Many factors may be working together to enable the higher yielding tall fescue selections to produce their superior forage yield. Among the four tall fescue selections, high yielding winter-growing TFM 26 produced more total dry matter and had a higher RLAGR than the other selections. The more rapid expansion of TFM 26's leaf area may give it a yield advantage by increasing its photosynthetic leaf area more rapidly (Simons et al., 1973). Consequently, TFM 26 may have more available photosynthate at an earlier growth stage. Thus, in conjunction with a higher RLAGR, this would provide a compounding effect resulting in greater forage yield and root production.

Table 5. Average relative plant growth rate (RGR), relative leaf area growth rate (RLAGR), relative root growth rate (RRGR) and harvest index (HI)§ over temperature for four diverse tall fescue selections.

Selection	RGR# ($g\ g^{-1}\ day^{-1}$)	RLAGR ($cm^2\ cm^{-2}\ day^{-1}$)	RRGR# ($g\ g^{-1}\ day^{-1}$)	HI ($g\ g^{-1}$)
TFK 4	1.578	0.092	1.334	0.80
TFK 12	1.807	0.096	1.502	0.79
TFM 16	1.815	0.096	1.685	0.75
TFM 26	1.959	0.101	1.786	0.76
L.S.D.	0.229	0.004**	0.218**	0.04*

*, ** Significant at the 0.05 and 0.01 levels, respectively.

RGR x 10^2 and RRGR x 10^2

§ Expressed on a per plant basis, mean of 20 plants.

Table 6. The effect of temperature on relative plant growth rate (RGR), relative leaf area growth rate (RLAGR) and relative root growth rate (RRGR)§ of four diverse tall fescue selections.

Temperature Regime	Selection	RGR# ($g\ g^{-1}\ day^{-1}$)	RLAGR ($cm^2\ cm^{-2}\ day^{-2}$)	RRGR# ($g\ g^{-1}\ day^{-1}$)
Low	TFK 4	0.0337	0.061	0.320
	TFK 12	0.365	0.065	0.374
	TFM 16	0.250	0.066	0.357
	TFM 26	0.377	0.073	0.454
Medium	TFK 4	2.298	0.114	1.832
	TFK 12	2.122	0.107	1.666
	TFM 16	2.487	0.115	2.125
	TFM 26	2.658	0.117	2.137
High	TFK 4	2.098	0.102	1.849
	TFK 12	2.936	0.115	2.466
	TFM 16	2.709	0.107	2.575
	TFM 26	2.841	0.113	2.767
	L.S.D.	0.397*	0.007*	0.378**

*,**Significant at the 0.05 and 0.01 levels, respectively.

#RGR x 10^2 and RRGR x 10^2

§Expressed on a per plant basis, mean of 20 plants.

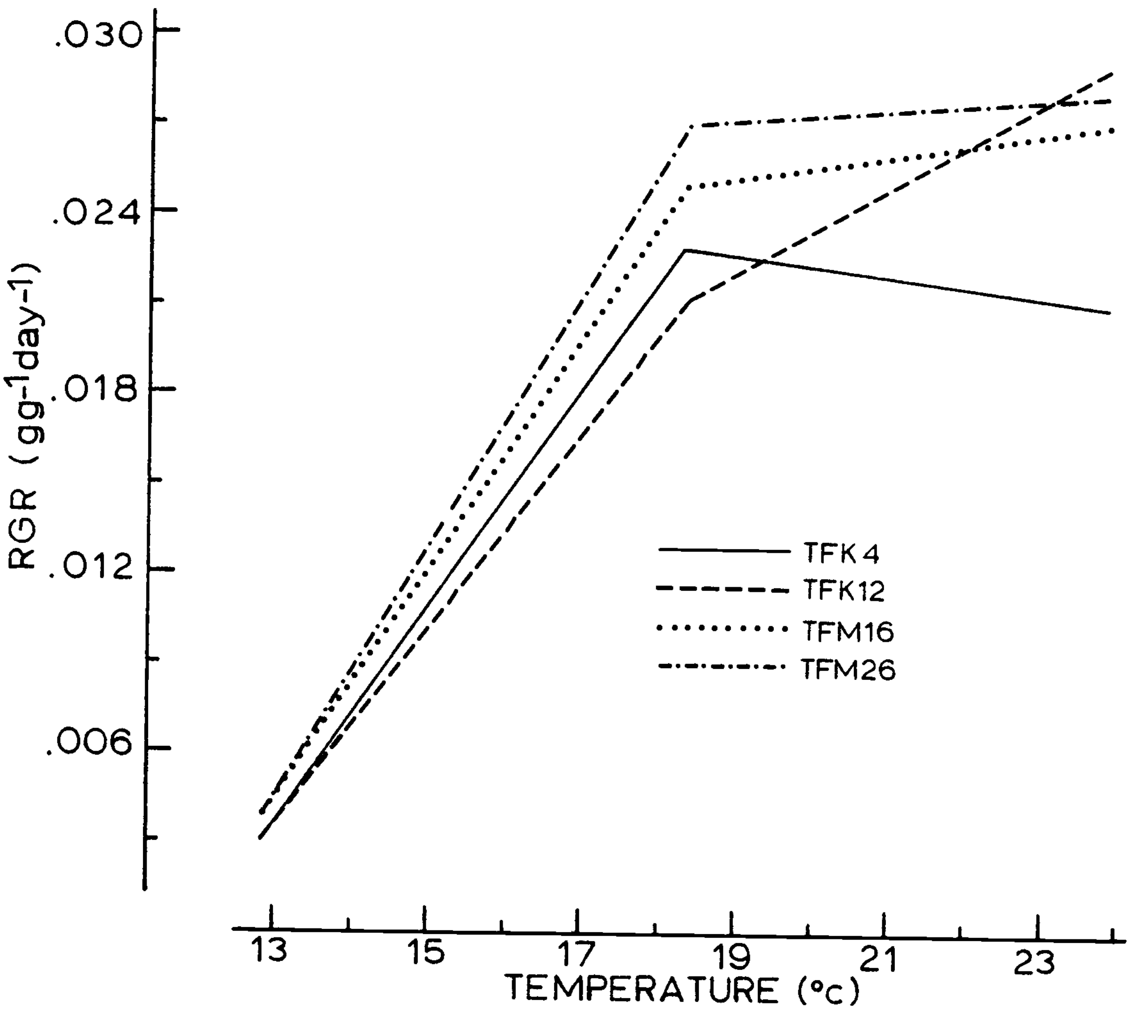

Figure 1. The trend over temperature of the relative growth rate (RGR) for four diverse tall fescue selections.

Respiration

Dark respiration (Rd) rates in excised root tips from the four tall fescue selections did not differ significantly throughout the experiment. Maintenance Rd rates in fully expanded leaves were quite variable and are the results of only one observation. However, as the temperature was increased the Rd rates in both leaves and root tips tended to increase (Table 7).

Minimal maintenance Rd may be desirable in mature plant parts to reduce respiratory losses during crop production (Wilson, 1972), however, high respiratory rates in the roots may be needed to supply energy for active ion uptake (Mengel and Kirkby , 1978). Jones and Nelson (1979) found that Rd rates of excised root tips did not correspond to their low and high yield per tiller genotypes of tall fescue. In this study, Rd rates of excised root tips corresponded to their root dry matter production but not to their top dry matter production (Table 7). Further work is needed on root respiration and root production in order to understand possible relationships to forage yield.

Nutrient Concentration

Plant parts, including roots, stems and leaves, were evaluated for their concentration of potassium, calcium and magnesium.

Table 7. Leaf and root respiration§ of tall fescue selections grown in three temperature regimes.

Temperature Regime	Selection	Leaves+		Roots++	
		O_2	CO_2	O_2	CO_2
		---------- $\mu/g^{-1}hr^{-1}$ ----------			
Low	TFK 4	818	744	1189	1059
	TFK 12	534	455	1760	1437
	TFM 16	879	585	4990	3422
	TFM 26	633	630	2520	1994
Medium	TFK 4	1203	1095	2136	1505
	TFK 12	816	773	3768	2601
	TFM 16	976	857	2571	2078
	TFM 26	1142	1015	2468	1673
High	TFK 4	1300	1120	4989	3793
	TFK 12	1604	1441	2584	1802
	TFM 16	1200	1083	3027	2203
	TFM 26	1200	1086	4259	3310
	L.S.D.			N.S.	N.S.

+, ++ Results of one observation and two observations, respectively.

§ Expressed on a per plant basis, mean of 20 plants.

The concentration of potassium was significantly different in the roots among the four tall fescue selections, while all three nutrient concentrations were significantly different in the stems and leaves. The potassium accumulation per unit of root volume was significantly greater for winter-growing TFM 16 than for high yielding winter-growing TFM 26 (Table 8). However, TFM 26 had significantly greater concentration of potassium per gram of plant material in its roots than low yielding TFM 16 or high yielding summer-growing TFK 12 (Table 9).

The availability of nutrients to the plant is interrelated with root volume via the nutrient supply mechanisms of passive and active transport (Mengel and Kirkby, 1978). The concentration of nutrients in the leaves of the four tall fescue selections grown under these controlled conditions may be limited only by the physiological capacity of the roots to absorb and transport nutrients. Therefore, the nutrient concentrations in the leaves of the tall fescue plant per unit of root volume may measure or reflect the nutrient absorption and transport capacity of the root system.

The potassium accumulation in the stems of the winter-growing TFMs was significantly higher than the accumulation of potassium in the stems of summer growing TFKs. However, high yielding winter-growing TFM 26 had a considerably greater accumulation of calcium and magnesium than low yielding winter-growing TFM 16 (Table 10). Potassium concentration in the leaves of low yielding winter-growing TFM 16 was significantly greater than the other tall fescue selections, while it was significantly lower in calcium and magnesium than high yielding winter-growing TFM 26 (Table 11). These data suggest that low yielding winter-growing TFM 16 may possess a greater capacity to absorb and translocate potassium than the other tall fescue selections, and high yielding winter-growing TFM 26 may have a greater capacity to absorb and translocate calcium and magnesium.

In this study, temperature had an effect on nutrient concentration among the tall fescue selections, with magnesium increasing as the temperature increased (Table 12). This trend corresponds with Gross and Jung (1978) who observed that the magnesium concentration in the forage of tall fescue, K 31, increased as the mean air temperature increased. This response has been attributed to lower magnesium accumulation at lower temperatures.

Hypomagnesema (grass tetany) has been associated with low Mg concentrations in tall fescue forage (Grunes et al., 1970; Wilkinson, 1976; Gross, 1973). Differential accumulation of potassium, calcium and magnesium is often expressed as a K/(Ca + Mg) meliequivalent ratio (Gross, 1973). High K/(Ca + Mg) meliequivalent ratios are associated with cool temperatures corresponding to low magnesium concentrations in the forage (Elkins and Hoveland, 1977). Gross (1973) suggested that consumption of forage with a potassium concentration greater than 2.5% and magnesium concentration less than 0.15% with a K/(Ca + Mg) meliequivalent ratio greater than 2.2 would result in the metabolic disorder identified as grass tetany.

These data suggest that high yielding summer-growing TFK 12 may induce grass tetany if consumed after growing at low temperatures.

Table 8. Average nutrient concentration in leaves per unit of root volume§ over temperatures for four diverse tall fescue selections.

Selection	K	Ca	Mg
	(Percent nutrient concentration/unit of root volume)		
TFK 4	1.90	0.24	0.18
TFK 12	1.80	0.17	0.11
TFM 16	2.09	0.27	0.13
TFM 26	1.01	0.29	0.11
L.S.D.	0.36*	0.07*	0.05**

*,**Significant at the 0.05 and 0.01 levels, respectively.

§ Expressed on a per plant basis, mean of 20 plants.

Table 9. Nutrient concentration in roots[§] averaged over temperatures for four diverse tall fescue selections.

Selection	K	Ca	Mg
		%	
TFK 4	0.70	0.57	0.08
TFK 12	0.66	0.58	0.08
TFM 16	0.72	0.59	0.07
TFM 26	0.87	0.65	0.08
L.S.D.	0.13**	N.S.	N.S.

** Significant at the 0.01 level of probability.

N.S. Not significant

§ Expressed on a per plant basis, mean of 20 plants.

Table 10. Average nutrient concentration§ over temperatures in stems of four diverse tall fescue selections.

Selection	K	Ca	Mg
	-----------------	%	-----------------
TFK 4	2.25	0.15	0.29
TFK 12	2.14	0.16	0.28
TFM 16	2.62	0.11	0.15
TFM 26	2.54	0.32	0.31
L.S.D.	0.29**	0.03**	0.06**

** Significant at the 0.01 level of probability.

§ Expressed on a per plant basis, mean of 20 plants.

Table 11. Average nutrient concentration and the $K^{+}/(Ca^{2+} + Mg^{2+})$ meliequivalent ratio§ over temperatures in leaves of four diverse tall fescue selections.

Selection	K	Ca	Mg	$K^{+}/(Ca^{2+} + Mg^{2++})$
	----------------	%	----------------	(Meq/100g)
TFK 4	2.93	0.51	0.32	1.59
TFK 12	2.91	0.44	0.26	2.00
TFM 16	3.42	0.55	0.26	1.91
TFM 26	2.95	0.71	0.33	1.35
L.S.D.	0.31**	0.10**	0.06^{+}	0.33**

+, ** Significant at the 0.10 and 0.01 levels, respectively.

§ Expressed on a per plant basis, mean of 20 plants.

Table 12. The effect of temperature on nutrient concentration and the $K^+/(Ca^{2+} + Mg^{2+})$ meliequivalent ratio§ in leaves of four diverse tall fescue selections.

Temperature Regime	Selection	K	Ca	Mg	$K^+/(Ca^{2+} + Mg^{2+})$ (Meq/100g)
Low	TFK 4	2.82	0.30	0.24	2.10
	TFK 12	3.00	0.23	0.15	3.24
	TFM 16	3.17	0.37	0.17	2.48
	TFM 26	2.77	0.46	0.16	1.93
Medium	TFK 4	3.47	0.56	0.30	1.71
	TFK 12	3.14	0.55	0.28	1.59
	TFM 16	3.55	0.53	0.24	1.94
	TFM 26	3.35	0.76	0.31	1.35
High	TFK 4	2.49	0.66	0.43	0.95
	TFK 12	2.60	0.54	0.36	1.17
	TFM 16	3.54	0.76	0.37	1.32
	TFM 26	2.72	0.92	0.53	0.78
	L.S.D.	0.39*	N.S.	N.S.	0.57**

*, ** Significant at the 0.05 and 0.01 levels, respectively.

N. S. Not significant

§ Expressed on a per plant basis, mean of 20 plants.

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APPENDIX I

LITERATURE REVIEW

Forage yield and nutritive value of tall fescue forage grass is a principle concern of the forage breeder. However, there is a lack of definitive work regarding the simultaneous dry matter distribution into forage yield and mineral distribution into plant parts of diverse selections of tall fescue as affected by temperature. Recent studies conducted on diverse genotypes of tall fescue have shown that temperature affects forage yield in different ways (Robson, 1972; Wilhelm and Nelson, 1978a), and forage yield differs among diverse selections of tall fescue as temperature changes (Lhamby, 1978). Where whole plant data were considered, high-yielding genotypes tended to have greater dry matter increase and leaf area development than low-yielding genotypes (Wilhelm and Nelson, 1978) and nutrient composition has been shown to vary with the size of the plant and the environmental conditions under which it was grown (Fleming and Murphy, 1968).

Most aspects of plant growth are very temperature dependent. Robson (1972) studying S.170 tall fescue observing that its relative growth rate (RGR) increased from 0.08 g g^{-1} day^{-1} at $10^{o}C$ to 0.21 g g^{-1} day^{-1} at $25^{o}C$ but fell to 0.15 g g^{-1} day^{-1} at $30^{o}C$.

The relative leaf area development of S.170 demonstrated a similar trend, it rose from 0.08 cm^2 cm^{-2} day^{-1} at 10^oC to 0.18 cm^2 cm^{-2} day^{-1} at 25^oC then fell to 0.12cm^2 cm^{-2} day^{-1} at 30^oC. However, the amount of leaf dry weight per unit of whole plant dry weight continually increased over the range of temperatures, but the amount of root dry weight per unit of whole plant dry weight decreased over the same range of temperatures, suggesting that S.170's root to shoot ratio decreased consistently as the temperature increased.

The root to shoot ratio is the relative weight of the root to the shoot and may be an expression of the differential partitioning of dry matter to the roots and the shoots. Since plant growth is influenced by environmental factors, it has been suggested the plant alters its root to shoot ratio according to the environment under which it is grown (Troughton, 1960; Luckwill, 1960). Davidson (1969) observed that tall fescue root growth at low temperatures is accompanied by relatively little top growth resulting in a root to shoot ratio of 1.33 at 5^oC. As the temperature was increased from 5^oC to 27.7^oC the top growth increased resulting in a root to shoot ratio of 0.87; however, as the temperature was increased to 35^oC top growth decreased, increasing the root to shoot ratio to 1.07.

Rising temperatures have affected a decrease in the root to shoot ratio for bentgrass (Stucky, 1942) and bromegrass (Nielsen _et al._, 1961). However, in bromegrass root growth declined while top growth continued as temperatures were increased (Smoliak and Johnston, 1968). The decrease in root growth as the temperature increased has been ascribed to higher respiration rates in the roots resulting in less carbohydrates being available for growth (Davidson, 1969). In contrast to the root shoot relationship in bromegrass, the top and root growth in bentgrass followed the same trend as the temperature increased (Stucky, 1942).

Temperature has been shown to affect the morphological response of root growth. It was observed in perennial ryegrass that there is an increase in root branching and a decrease in root diameter as the temperature increased (Garwood, 1968), and in corn the roots are thicker and less branched when grown at cool temperatures while at higher temperatures the roots were more filamentous and branching (Galligar, 1968).

Morphological characteristics of tall fescue have been studied as a selection criteria to increase forage yield. Growth analysis of leaves, stem bases and roots from high and low yield per tiller genotypes of tall fescue were evaluated, along with their harvest index, by Wilhelm and Nelson (1978).

The high yield per tiller genotypes had a low harvest index at 0.26 whereas the low yield per tiller genotypes had a higher harvest index of 0.33, suggesting to Wilhelm and Nelson (1978) that the genotypes were using 'different mechanism' to develop their forage yield. The 'different mechanisms' were thought to be exemplified by the high yield per tiller genotypes producing a greater stem and root mass of 3.79 g than the low yield per tiller genotypes at 2.34 g. Also, the high yield per tiller genotypes total leaf tissue was greater than the low yield per tiller genotypes; 2.87 g and 1.47 g, respectively.

Wilhelm and Nelson (1978) reported the relative growth rate and the relative leaf area growth rate for the low and high yield per tiller genotypes of tall fescue. The relative growth rate of high and low yield per tiller genotypes were similar at 0.023 $g\,g^{-1}$ day^{-1} and 0.022 $g\,g^{-1}$ day^{-1}, respectively. These values are lower than Robson (1972) reported for S.170 tall fescue which ranged from 0.08 $g\,g^{-1}$ day^{-1} to 0.21 $g\,g^{-1}$ day^{-1} depending on the temperature. The relative leaf area growth rate evaluated by Wilhelm and Nelson (1978) indicated that the high yield per tiller genotypes produced their leaf area faster than the low yield per tiller genotypes. The high yield per tiller genotype had a relative leaf area growth rate of 0.70 cm^2 cm^{-2} day^{-1}, whereas, the low yield per tiller genotypes had a relative leaf area growth rate of 0.45 cm^2 cm^{-2} day^{-1}.

These values are noticeably higher than Robson (1972) evaluated for S.170 tall fescue which ranged from 0.08 cm^2 cm^{-2} day^{-1} to 0.18 cm^2 cm^{-2} day^{-1} depending on the temperature.

It was concluded by Wilhelm and Nelson (1978) that more carbohydrate reserve was made available to the high yield per tiller genotype because of its larger stem base. The larger stem base may have provided more carbohydrates resulting in a rapid initial leaf growth rate thus allowing the high yield per tiller genotype to achieve a larger leaf area index sooner, resulting in a greater amount of photosynthate being available for growth.

In a continuing effort to characterize tall fescue's forage production, Jones and Nelson (1979) investigated the physiological process of dark respiration in the leaves and root tips of high, medium and low yield per tiller genotypes of tall fescue. Dark respiration rates in leaves of low and medium yield per tiller genotypes were 52% and 77% of those from the high yield per tiller genotype. Rates of respiration in the root tips of medium and high yield per tiller genotypes were 99% and 88% of the rate of respiration in the low yield per tiller genotype's root tips, and respiration rates in the root tips were shown to be from 1.8 to 5 times higher than dark respiration rates of the leaves.

Jones and Nelson (1979) demonstrated that yield and dark respiration rates corresponded with each other in the leaves of the high, medium and low yield per tiller genotypes of tall fescue. In contrast, Heichel (1971) observed that low dark respiration rates were associated with high relative growth rates in the leaves and roots of beans and corn. However, Jones and Nelson (1979) did observe that dry matter deposition and respiration were inversely related in the roots of the tall fescue genotypes. It may be reasonable to suppose that more energy was being used for maintenance in the roots of the low yield per tiller genotypes, and that energy in the roots of the high yield per tiller genotype was perhaps being used for other functions such as nutrient uptake.

Nutrient uptake is an outstanding characteristic of the plants' root system. One mechanism for nutrient uptake has been characterized as an energy requiring active transport system. ATPase is the primary enzyme associated with active nutrient uptake.

Observations made on isolated fractions of ion-stimulated ATPase from the plasmalema of oat roots indicated that sufficient membrane-associated ATPase existed to account for K transport (Fisher and Hodges, 1969). Further work done on isolated plasma membranes of oat roots showed that the kenetics of ion-stimulated ATPase was similar to the kinetics of Rb and Cs uptake (Sze and Hodges, 1977). Using excised corn roots Leonard and Harrison (1972) showed a close parallel between increases in ATPase and P absorption. Plasmalema fractions from the cortex and stele of corn roots were found to have similar levels of ATPase and similar kinetic data for ion-stimulated ATPase and K flux (Leonard and Hotchkiss, 1978).

These results support the concept that active transport via the root is a function of energy requiring ATPase.

Mineral distribution and composition in tall fescue has a distinct bearing on mineral consumption of the grazing animal. There are many genetic and environmental factors working in continual and varying degrees of interaction which affect the uptake and utilization of these elements by the plant. Therefore, an understanding of the distribution and composition of these elements may be important in achieving forage quality.

It is reasonable to assume that root growth and nutrient absorption are a function of root and shoot activity which has been shown to be temperature dependent. The yield and nutrient composition of bromegrass grown at various temperatures indicates that the uptake of K and Ca increases with an increased top growth in proportion to root growth (Nielsen et al., 1961). Therefore, temperature affects nutrient concentration in forage grasses and there have been appreciable differences observed in the nutrient concentration between plant parts and between forage grass species (Fleming and Murphy, 1968; Fleming, 1973; Gross and Young, 1978).

Red fescue has been shown to be relatively low in Mg, while the Mg concentration in tall fescue is noticeably higher. But Mg and Ca are both low in chewings fescue (Cooppenet and Calvez, 1962). Fleming and Murphy (1968) observed a seasonal trend from April to December for K, Ca and Mg concentration in tall fescue; potassium declined from 4.7% to 2.5%;and Ca and Mg increased from 0.6% to 0.8% and 0.24% to 0.35%, respectively. However, Leggett et al. (1977) observed no effect on tall fescue's K, Ca or Mg concentration as the temperature varied. In contrast, Italian ryegrass has been shown to increase in K, Ca and Mg as the temperature increased (Nielsen and Cunningham, 1964), but the concentration of K, Ca and Mg declined in bromegrass as the temperature increased (Nielsen et al., 1961).

Hypomagnesemia (grass tetany) has been identified as a problem in Oregon (Wilkinson, 1976). Differential accumulation of K, Ca and Mg is often expressed as a K/(Ca + Mg) meliequivalent ratio. Values of 2.2 have been identified, above which danger of grass tetany greatly increases (Kemp, 1971). This ratio varies widely within forage species when grown at different temperatures, and differences are not related to forage yield (Gross and Jung, 1978). For example, tall fescue showed a decline in its K/(Ca + Mg) meliequivalent ratio from 5.6 in April to 2.17 in Decmeber (Fleming and Murphy, 1968); Gross and Jung (1978) observed a similar seasonal fluctuation in K31 tall fescue with the highest K/(Ca + Mg) meliequivalent ratio being 1.76.

High K/(ca + Mg) meliequivalent ratios are associated with cool temperatures corresponding to low magnesium concentrations in the forage (Elkins and Hoveland, 1977). Gross (1973) suggests consumption of forage with a K concentration greater than 2.5% and Mg concentration less than 0.15% with a K/(Ca + Mg) meliequivalent ratio greater than 2.2 would result in the metabolic disorder identified as grass tetany.

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APPENDIX II.

Table 1. Average leaf moisture (LM), stem moisture (SM), stem dry weight (SDW) and stem size (SS)§ over temperatures for four diverse tall fescue selections.

Selection	LM (%)	SM (%)	SDW (g)	SS (mm)
TFK 4	77	76	0.06	5
TFK 12	77	76	0.07	5
TFM 16	79	72	0.07	5
TFM 26	79	80	0.06	5

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX II.

Table 2. The effect of temperature on leaf moisture (LM), stem moisture (SM), stem dry weight (SDW) and stem size (SS)§ of four diverse tall fescue selections.

Temperature Regime	Selection	LM (%)	SM (%)	SDW (g)	SS (mm)
Low	TFK 4	69	70	0.07	5
	TFK 12	73	72	0.08	5
	TFM 16	75	67	0.07	4
	TFM 26	78	79	0.06	5
Medium	TFK 4	82	81	0.05	5
	TFK 12	78	78	0.06	5
	TFM 16	83	77	0.06	5
	TFM 26	79	83	0.05	4
High	TFK 4	80	76	0.07	5
	TFK 12	80	78	0.08	5
	TFM 16	78	73	0.07	5
	TFM 26	79	78	0.07	5

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX II.

Table 3. Average yield per tiller (YPT), leaf area per tiller (LAT) and leaf weight (SLW)§ over temperatures for four diverse tall fescue selections.

Selection	YPT (g/unit)	LAT (cm^2/unit)	SLW (g/cm^2)
TFK 4	0.075	7.4	0.014
TFK 12	0.096	9.5	0.013
TFM 16	0.081	8.1	0.012
TFM 26	0.084	9.1	0.011

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX II.

Table 4. The effect of temperature on yield per tiller (YPT), specific leaf weight (SLW) and harvest index (HI)§ of four diverse tall fescue selections.

Temperature Regime	Selection	YPT (g/unit)	SLW (g/cm^2)	HI (g/g)
Low	TFK 4	0.036	0.022	0.91
	TFK 12	0.036	0.019	0.89
	TFM 16	0.038	0.016	0.88
	TFM 26	0.036	0.015	0.88
Medium	TFK 4	0.092	0.008	0.76
	TFK 12	0.106	0.010	0.76
	TFM 16	0.098	0.008	0.71
	TFM 26	0.088	0.008	0.75
High	TFK 4	0.096	0.011	0.74
	TFK 12	0.146	0.010	0.71
	TFM 16	0.107	0.011	0.66
	TFM 26	0.129	0.009	0.65

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX II.

Table 5. Average root area (RA), root length, (RL), relative root area growth rate (RRAGR) and relative root volume growth rate (RRVGR)§ over temperatures for four diverse tall fescue selections.

Selection	RA (cm^2)	RL (cm)	RRAGR (cm^2 cm^{-2} day^{-1})	RRVGR (cm^3 cm^{-3} day)
TFK 4	59.1	22.7	0.013	0.033
TFK 12	88.9	23.0	0.025	0.029
TFM 16	77.3	27.8	0.020	0.025
TFM 26	99.4	28.7	0.027	0.034

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX II.

Table 6. The effect of temperature on root area (RA), root length (RL), and relative root area growth rate (RRAGR)§ of four diverse tall fescue selections.

Temperature Regime	Selection	RA (cm^2)	RL (cm)	RRAGR§ (cm^2 cm^{-2} day)
Low	TFK 4	11.6	5.1	0.004
	TFK 12	19.6	4.6	0.010
	TFM 16	15.3	4.0	0.006
	TFM 26	17.3	6.1	0.010
Medium	TFK 4	64.3	32.6	0.015
	TFK 12	83.4	25.2	0.027
	TFM 16	94.1	41.8	0.025
	TFM 26	119.0	36.8	0.032
High	TFK 4	101.3	30.3	0.021
	TFK 12	163.6	39.2	0.039
	TFM 16	122.6	37.5	0.030
	TFM 26	162.0	43.2	0.038

§Expressed on a per plant basis, mean of 20 plants

APPENDIX II.

Table 7. The effect of temperature on nutrient concentration[§] in the roots of four diverse tall fescue selections.

Temperature Regimes	Selection	K	Ca	Mg
			%	
Low	TFK 4	0.44	0.45	0.07
	TFK 12	0.44	0.41	0.04
	TFM 16	0.45	0.48	0.05
	TFM 26	0.59	0.38	0.07
Medium	TFK 4	0.85	0.61	0.10
	TFK 12	0.83	0.66	0.13
	TFM 16	0.98	0.68	0.09
	TFM 26	1.77	0.76	0.11
High	TFK 4	0.80	0.65	0.07
	TFK 12	0.70	0.66	0.07
	TFM 16	0.73	0.60	0.08
	TFM 26	0.86	0.80	0.07

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX II.

Table 8. The effect of temperature on the nutrient accumulation per unit of root volume§ of four diverse tall fescue selections.

Temperature Regime	Selection	K	Ca (nutrient accumulation/cm^3)	Mg
Low	TFK 4	4.56	0.49	0.39
	TFK 12	4.49	0.35	0.24
	TFM 16	4.88	0.57	0.26
	TFM 26	3.55	0.59	0.21
Medium	TFK 4	0.68	0.11	0.06
	TFK 12	0.63	0.11	0.06
	TFM 16	0.63	0.10	0.04
	TFM 26	0.61	0.14	0.06
High	TFK 4	0.46	0.12	0.08
	TFK 12	0.30	0.06	0.04
	TFM 16	0.75	0.16	0.08
	TFM 26	0.37	0.13	0.07

§ Expressed on a per plant basis, mean of 20 plants.

APPENDIX III.

Table 1. Analysis of variance for forage yield components including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means (S_d) and coefficient of variability (CV%).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Forage Yield					
Blocks	2	0.244			
Selections	3	0.025	2.519^{+}	0.047	
Temperatures	2	1.220			
S x T	6	0.078	2.810*	0.082	
Error	22	0.010			16.00
Leaf Area					
Blocks	2	477.605			
Selections	3	506.553	3.378*	5.773	
Temperatures	2	22384.055			
S x T	6	594.571	3.965**	9.998	
Error	22	149.953			19.18
Plant Height					
Blocks	2	63.979			
Selections	3	56.233	2.555^{+}	2.211	
Temperatures	2	1745.429			
S x T	6	66.719	3.032*	3.830	
Error	22	22.005			18.38

APPENDIX III.

Table 1. Analysis of variance for forage yield components including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%)(continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Leaf Moisture %#					
Blocks	2	6.479			
Selections	3	10.181	0.884	.016	
Temperatures	2	157.588			
S x T	6	24.283	2.107+	.277	
Error	22	11.523			13.8
Stem Dry Weight#					
Blocks	2	10.361			
Selections	3	3.185	1.055	.009	
Temperatures	2	11.444			
S x T	6	.630	0.187	.015	
Error	22	3.361			28.45
Stem Size					
Blocks	2	0.250			
Selections	3	0.250	0.733	.275	
Temperatures	2	0.583			
S x T	6	0.139	0.408	.477	
Error	22	0.341			12.29

APPENDIX III.

Table 1. Analysis of variance for forage yield components including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F). standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Stem Moisture % #					
Blocks	2	50.171			
Selections	3	84.050	1.701	.033	
Temperatures	2	168.867			
S x T	6	15.407	0.312	.057	
Error	22	49.425			9.25
Tiller Number					
Blocks	2	0.861			
Selections	3	3.185	4.135*	0.414	
Temperatures	2	8.528			
S x T	6	2.602	3.378*	0.717	
Error	22	0.770			11.79
Yield Per Tiller#					
Blocks	2	0.630			
Selections	3	7.360	2.313	0.008	
Temperatures	2	231.318			
S x T	6	5.115	1.608	0.015	
Error	22	3.182			21.26

APPENDIX III.

Table 1. Analysis of variance for forage yield components including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means (S_d) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
<u>Leaf Area Per Tiller</u>					
Blocks	2	6.075			
Selections	3	8.221	0.495	0.951	
Temperatures	2	369.459			
S x T	6	11.561	2.838*	1.648	
Error	22	4.073			23.76
<u>Specific Leaf Weight#</u>					
Blocks	2	0.003			
Selections	3	0.130	2.163	0.001	
Temperatures	2	2.982			
S x T	6	0.093	1.554	0.002	
Error	22	0.060			20.05

+, *, * Significant at the 0.1, 0.05 and 0.01 levels, respectively.

\# MS x 10^4

APPENDIX III.

Table 2. Analysis of variance for components of root growth including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
<u>Root Dry Matter</u>					
Blocks	2	0.008			
Selections	3	0.022	10.522**	0.022	
Temperatures	2	0.420			
S x T	6	0.010	4.783**	0.037	
Error	22	0.002			18.67
<u>Root Volume</u>					
Blocks	2	0.646			
Selections	3	3.144	7.763**	0.300	
Temperatures	2	118.293			
S x T	6	3.735	9.222**	0.520	
Error	22	0.405			15.05
<u>Root Density</u>[#]					
Blocks	2	2.676			
Selections	3	12.177	3.558*	0.009	
Temperatures	2	2.302			
S x T	6	3.192	0.933	0.015	
Error	22	3.422			31.67

APPENDIX III.

Table 2. Analysis of variance for componets of root growth including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio, standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Root Area					
Blocks	2	933.420			
Selections	3	2685.808	9.016**	8.136	
Temperatures	2	44957.091			
S x T	6	861.591	2.892*	14.092	
Error	22	297.885			21.26
Root Length					
Blocks	2	2.954			
Selections	3	88.873	3.469*	2.386	
Temperatures	2	3844.145			
S x T	6	74.088	2.892*	4.133	
Error	22	25.619			19.83
Root to Shoot Ratio					
Blocks	2	0.011			
Selections	3	0.020	4.536*	0.031	
Temperatures	2	0.351			
S x T	6	0.006	1.361	0.054	
Error	22	0.004			21.52

*, ** Significant at the 0.05 and 0.01 levels, respectively.

MS x 10^4

APPENDIX III.

Table 3. Analysis of variance for analysis of growth components including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Relative Growth Rate[#]					
Blocks	2	0.009			
Selections	3	0.223	4.055*	0.001	
Temperatures	2	19.318			
S x T	6	0.187	3.400*	0.002	
Error	22	0.055			13.13
Relative Leaf Area Growth Rate[#]					
Blocks	2	0.253			
Selections	3	1.100	6.433**	0.002	
Temperatures	2	81.199			
S x T	6	0.569	3.327*	0.003	
Error	22	0.171			4.29
Relative Root Growth Rate[#]					
Blocks	2	0.188			
Selections	3	0.361	13.370**	0.0008	
Temperatures	2	13.648			
S x T	6	0.141	5.222**	0.0013	
Error	22	0.027			10.42

APPENDIX III.

Table 3. Analysis of variance for analysis of growth components including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
<u>Relative Root Area Growth Rate#</u>					
Blocks	2	0.420			
Selections	3	3.432	33.320**	0.002	
Temperatures	2	19.354			
S x T	6	0.320	3.107*	0.003	
Error	22	0.103			15.07
<u>Harvest Index</u>					
Blocks	2	0.004			
Selections	3	0.005	4.046*	0.017	
Temperatures	2	0.133			
S x T	6	0.001	0.885	0.003	
Error	22	0.001			4.68

*,**Significant at the 0.05 and 0.01 levels, respectively.

MS x 104

APPENDIX III.

Table 5. Analysis of variance for respiration including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Root O_2 #					
Blocks	1	92.293			
Selections	3	84.947	0.404	683.515	
Temperatures	2	291.000			
S x T	6	411.000	1.955	1183.883	
Error	11	210.237			47.99
Root CO_2 #					
Blocks	1	45.907			
Selections	3	43.134	0.405	486.224	
Temperatures	2	173.000			
S x T	6	196.000	1.842	842.165	
Error	11	106.386			46.05

MS x 10^4

APPENDIX III.

Table 4. Analysis of variance for nutrient concentration including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
<u>Leaf Potassium</u>					
Blocks	2	0.060			
Selections	3	0.543	9.988**	0.110	
Temperatures	2	0.976			
S x T	6	0.166	3.054*	0.190	
Error	22	0.054			7.64
<u>Leaf Calcium</u>					
Blocks	2	0.008			
Selections	3	0.121	20.015**	0.037	
Temperatures	2	0.454			
S x T	6	0.009	1.489	0.063	
Error	22	0.006			14.02
<u>Leaf Magnesium</u>					
Blocks	2	0.007			
Selections	3	0.013	2.403^{+}	0.033	
Temperatures	2	0.174			
S x T	6	0.006	1.109	0.060	
Error	22	0.005			24.86

APPENDIX III.

Table 4. Analysis of variance for nutrient concentration including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Stem Potassium					
Blocks	2	0.043			
Selections	3	0.474	9.989**	0.103	
Temperatures	2	6.982			
S x T	6	0.227	4.784**	0.178	
Error	22	0.047			9.12
Stem Calcium#					
Blocks	2	0.861			
Selections	3	771.065	125.089**	0.012	
Temperatures	2	964.194			
S x T	6	136.120	22.083**	0.020	
Error	22	6.164			13.56
Stem Magnesium					
Blocks	2	0.006			
Selections	3	0.046	24.683**	0.020	
Temperatures	2	0.100			
S x T	6	0.005	2.683*	0.035	
Error	22	0.002			16.78

APPENDIX III.

Table 4. Analysis of variance for nutrient concentration including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Root Potassium					
Blocks	2	0.010			
Selections	3	0.081	8.137**	0.047	
Temperatures	2	0.697			
S x T	6	0.012	1.205	0.081	
Error	22	0.010			13.56
Root Calcium					
Blocks	2	0.018			
Selections	3	0.011	1.729	0.038	
Temperatures	2	0.248			
S x T	6	0.014	2.200^{+}	0.065	
Error	22	0.006			13.41
Root Magnesium					
Blocks	2	9.083			
Selections	3	1.926	0.952	0.007	
Temperatures	2	70.750			
S x T	6	7.009	3.465*	0.012	
Error	22	2.023			17.78

APPENDIX III.

Table 4. Analysis of variance for nutrient concentration including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Leaf $K^+(Ca^{2+} + Mg^{2+})$					
Blocks	2	0.015			
Selections	3	0.800	12.894**	0.117	
Temperatures	2	5.793			
S x T	6	0.286	4.610**	0.203	
Error	22	0.062			14.54
Leaf K^+ Per Root Area					
Blocks	2	0.035			
Selections	3	0.524	3.834*	0.174	
Temperatures	2	58.348			
S x T	6	0.286	2.092^+	0.302	
Error	22	0.137			20.26
Leaf Ca^2 Per Root Area					
Blocks	2	0.003			
Selections	3	0.022	4.283*	0.034	
Temperatures	2	0.588			
S x T	6	0.010	1.947	0.059	
Error	22	0.005			35.59

APPENDIX III.

Table 4. Analysis of variance for nutrient concentration including variable tested, source of variation (SV), degrees of freedom (df), mean square (MS), F-ratio (F), standard difference between treatment means ($S_{\bar{d}}$) and coefficient of variability (CV%) (continued).

Variable and SV	df	MS	F	$S_{\bar{d}}$	CV%
Leaf Mg^{2+} Per Root Area					
Blocks	2	0.001			
Selections	3	0.008	5.333**	0.018	
Temperatures	2	0.183			
S x T	6	0.006	4.000**	0.032	
Error	22	0.002			29.30

+, *, ** Significant at the 0.10, 0.05 and 0.01 levels, respectively.

MS x 10^4