CHAPTER II

GROWTH AND SOIL MOISTURE DEPLETION RESPONSES OF MOWED TALL FESCUE CLONES.

ABSTRACT

A field study was conducted to investigate soil moisture depletion and plant growth of mowed tall fescue clones (Festuca arundinacea Schreb.). These clones were previously screened for seedling shoot and root growth responses in controlled environment studies. Divergent seedling selections were made for extreme root growth and root/shoot ratio, while directional selections were made for maximum rooting depth. These 17 divergent and directional selections combined with 19 randomly selected clones were reproduced as vegetative propagules. These propagules were established as mowed space plants in a Sharpsburg silty clay loam (fine montmorlillontic mesic Typic Argiudoll).

Clonal differences occurred in root and shoot growth and coefficients of genetic determination were high, indicating that individual clonal performance was relatively stable. Clones differed for soil moisture depletion rates, total water extraction and expression of visible wilt symptoms. Soil water content and total root production were correlated ($r= -0.78$, $p \geq 0.01$). Random sampling at the end of August showed the presence of viable white roots at the 120 cm soil depth. These facts suggested that soil moisture content and depletion

were root growth related. Approximately two-thirds of the clonal wilt response were related to soil moisture content indicating superior soil moisture extraction was one mechanism for avoiding wilt under drought. This mechanism alone could not explain low wilt values of other clones which had low soil moisture depletion rates and higher soil moisture contents.

Root/shoot ratios were significant among clones in the field, but were unrelated to seedling performance. Divergent root/shoot seedling selections failed in anticipated field response. Based on the correlation matrix for all response variables measured, no seedling growth parameters could be used to predict field growth. The positive growth correlation between root and shoot production ($r = 0.68$, $p \geq 0.01$) among seedlings grown in controlled environment was different among clones in the field ($r = 0.26$, $p \geq 0.13$). Divergent selections based on seedling root growth differed significantly ($p \geq 0.01$) for field root production. Seedlings with large root mass values had large field root production. This indicated that seedling and field root production were related among plants when selected for extremes in root growth.

Introduction

Tall fescue (*Festuca arundinacea* Schreb.) is a cool season turfgrass used for both forage and turf. This species has superior summer growth responses compared to other cool season grasses (Beard, 1973). Its superior performance may be attributed to tall fescues ability to produce a deep and extensive root system (Youngner et al., 1981) which allows greater soil moisture extraction on a volume and depth basis (Sheffer, 1979). This characteristic would be considered a drought avoidance mechanism. Drought avoidance is defined as those plant properties which allow plants to avoid internal water deficits, maintain high relative water contents and have less negative water potentials (Turner, 1979). These components were found to be responsible for tall fescue's superior growth when compared to orchardgrass and perennial ryegrass under identical test conditions (Garwood and Sinclair, 1979). The development of turf-type tall fescue cultivars is increasing the acceptance of this grass for use in home lawns both for intensively and low managed turfs. These new cultivars have greater shoot density, finer leaf texture, darker and more uniform color, and greater persistence under close frequent mowing than forage types.

A mowed turfgrass plant must produce enough leaf area to maintain adequate shoot and root growth. Plants with a greater root system for a given amount of top growth should maintain active growth longer, be capable of extracting more soil moisture (Burton, 1959) and perhaps be more competitive than plants with a lesser root system (Hofman and Ennik, 1980). This concept is important in tall fescue swards subjected to frequent defoliation and its subsequent root growth limitation effects (Garwood and Sinclair, 1979; Crider, 1954). Identification of such plants with a large root system would be desirable in breeding programs designed to develop tall fescue germplasm which has superior root growth when mowed.

The objectives of this experiment were to determine soil moisture extraction of mowed tall fescue clones under non-irrigated turf conditions, to determine if field growth characteristics were similar to those observed of seedlings grown in controlled environment, and to evaluate field root and shoot growth of divergent and directional seedling selections of tall fescue.

Materials and Methods

The procedure was as follows for seedlings. Tall fescue seeds were germinated in washed vermiculite in the greenhouse. One week old seedlings were transplanted into 38 mm diameter X 2.0 mm deep plastic tubes with a rooting medium of washed silica sand. They were fertilized twice weekly with 1/3 strength Hoaglands solution till saturation and free drainage occurred (Hoagland and Arnon, 1950).

Seedlings were mowed twice weekly at 33 mm. The seedling study was terminated 5 weeks after transplanting and growth parameters evaluated were: shoot dry weight (mg plant^{-1}), leaf area (mm plant^{-1}), root dry weight (mg plant^{-1}), number of nodal roots (roots plant^{-1}), and the length of the single deepest root (mm plant^{-1}). Dry weights were estimated from the regression of dry weight on fresh weight from a previous experiment (r= 0.98). Individual selections were identified from 96 mowed seedlings that were two standard deviations from the grand mean for the respective growth variables (Table 1). Divergent selections were made for seedling dry root weight (mg plant^{-1}) and root/shoot ratio. Directional selection was made for seedling deep root response. These 17 divergent and directional selections were combined with 19 randomly chosen seedlings. The 36 selections were propagated from single bladeless tillers at the end of the controlled environment study for replicated field evaluation. Seedlings originated from turf-type germplasm Rebel, Mustang, SynGa, the forage cultivars Kenhy, Pastuca and Kentucky 31, and the experimental DT-294. The other 19 were composed of turf and forage seedlings from these and other commercially available turf-type cultivars.

Each seedling selection was transplanted into a 1:1:1 medium (v/v) of peat, vermiculite and perlite. After 6 weeks, each clone was separated into 6 vegetative propagules. Clones were again divided into thirds producing 18 propagules per clone for a total of 108 plants. The 108 plants were transplanted in mid July 1983 after six weeks of establishment at the University of Nebraska Agricultural Research and Development Center located near, Mead. The soil type was Sharpsburg silty clay loam (fine montmorlillontic mesic Typic Argiudoll).

The experimental design was a 6 X 6 triple lattice with one replicate of the basic design. Each experimental unit consisted of 6 vegetative propagules of the same clone. Four propagules were transplanted 120 mm apart from each other on a 120 mmradius from the center of a 50 mm diameter X 2.15 m deep neutron probe access tube. Propagules were arranged at a 45 ^{o} angle from the centerline so the border effect was the same for each propagule. Two propagules, located 600 mm apart on a 180 ^{o} vector from each access tube, were included for destructive root and shoot growth determinations.

Alleyways 0.9 m wide were seeded to a blend of K-31, Jaguar and Falcon in September at 30 g m^{-2}. Irrigation was applied for establishment the first summer. Starter fertilizer (18N-10P-5K) was applied in July and September at the rate of 7.5 g N m^{-2} over the entire experiment. Space plants and alleyways were mowed regularly at 76 mm. Weeds were removed by hand when necessary. In the spring of 1984, a total of 10.0 g N m^{-2} of methylene urea (41N-0P-0K) was applied in two equal applications to promote uniform spring green up. Oftanol (O-ethyl--O-[isopropoxy-carbonyl]-phenyl isopropyl phosphoramidothiate) was applied at 7.5 g m^{-2} to control any carryover population of white grubs. A total of 134 mm of precipitation fell from 1 to 17 June, and soil moisture was exceptionally high during the spring.

Soil samples were taken in 1983 with 51 mm Tempe cells and 76 mm Uhland rings every 15 cm to a depth of 137 cm to determine bulk density, soil moisture depletion, and saturated conductivity values. Bulk density increased with depth, and did not interact with sampling method. Saturated conductivity could not be determined due to extreme swelling of the soil.

One propagule from each experimental unit (for the 17 selections) was harvested on 17 July, so valid comparisons of unstressed plant growth could be made. Propagules were harvested with a tractor-mounted hydraulically driven 76 mm soil coring tube. Tillers and leaves were removed from the crown base, rinsed over a screen and dried at 35 ° C for 5 days. Soil cores were taken to a depth of 90 cm and were divided into 6 successive 15 cm segments. Individual cores were washed in a stainless steel root washer by repeated submersion and misting for 25 to 30 minutes. Root samples were dried at 35 ° C for 4 days and weighed. Field shoot growth was expressed in g m^{-2}. Root growth was expressed as root density on a dry weight basis with depth (kg m^{-3}), and as total root production (g m^{-2}). Root/shoot ratio was determined on a total dry weight basis. Degree of genetic determination (DGD) (Falconer, 1981) and the genetic coefficient of variability (GCV) (Burton, 1953) were calculated from components of variance. DGD and GCV were used as relative measures of genetic control and genetic variability about the mean, respectively.

Soil moisture determinations were made on 30 June, 14 July, and 4 and 29 August using a 10 uC. neutron probe. A 120 mm long 50 mm X 50 mm I/O diameter adapter was used to interface the probe and the access tube. Standard counts were made for each incomplete block. Measured counts were 30 seconds and were taken in 8 successive 15 cm depths beginning at 15 cm from the soil surface. Count ratios were expressed in mm water. Probe calibration produced correlation values of r= 0.96 and all measured counts occurred within the sampling range eliminating extrapolation. The experiment was covered nightly with heavy plastic to eliminate precipitation and to promote a progressive soil moisture stress. Wilt ratings were made based on frequency and severity of leaf roll using a 1 to 9 scale with 1=none, 2=trace, 3=slight, 4=slight-moderate, 5=moderate, 6=moderate-severe, 7=severe, 8=very severe, 9=total wilt-chlorophyll degradation. Ratings were made between 1200 and 1450 solar hours on 21 and 27 July, and on 10, 15 and 28 August. Plants with wilt scores of 6 or greater remained rolled the following morning.

Analysis of variance was used to determine overall clonal effects for plant growth response, wilt and soil moisture variables. Unadjusted treatment means are reported since intra-block errors were usually large or gain of efficiency was less than 5 to 7% . Pearsons Product moment correlations were used to compare seedling performance of the 17 selections with the respective means of the 3 propagules per clone in the field. Partial correlation coefficients were used to compare variables measured among all 36 clones. Contrasts were used to test mean performance of diverse seedling selections. Bonferroni's protection values were computed to maintain the experimental error rate of 0.05 when non-orthogonal contrasts were used.

Results and Discussion

Mean SMD rates were significant with time and depth, (Table 2). DGD values for SMD rates were low to moderate and increased with depth as the experiment progressed in time (Table 2). Mean soil water content (mm) for each time period illustrated that soil moisture was first extracted in the upper soil profile from 30 June to 14 July (Figure 1). Soil moisture was generally depleted equally in all depths between 15 July to 4 August, with the same trend between 4 to 29 August. The largest SMD rates occurred between 15 July to 4 August, when potential evapotranspiration estimates were high. SMD rates were low during 2 to 29 August, when over 70 percent of the clones expressed moderate to severe leaf rolling symptoms. DGD values were moderate at lower depths initially, but increased with depth as the season progressed. This trend indicated that clones responded differently to soil moisture depletion with increased depth.

Clonal analysis for total water use for the period 30 June to 29 August was significant for the entire profile and all depths but 60 cm (Table 3). The low GCV value for soil moisture content of the total profile was due to the cumulative stress during the experiment.

Partial correlations between root densities of plants on 17 July and the corresponding soil moisture depletion rates early in the season were low and inconsistant. The low correlation was most likely due to soil water previously extracted before 30 June and to low root densities at harvest time. The partial correlation between total root production on 17 July and total soil moisture content (mm) on 29 August was $r = -0.78$, $p \geq 0.03$. This indicated that tall fescue clones with greater total root production on a dry weight basis were capable of extracting a relatively greater volume of soil moisture.

Contrasts were formulated by grouping the 6 upper and lower clones in mean root and shoot production rank on 17 July to investigate which growth parameter had the greater effect on SMD rates. Only two of the clones with high root production had high shoot production, indicating that no definite relationship existed between root and shoot growth when clones were mowed regularly.

Clones which had the greatest total root production on 17 July had larger SMD rates for 15, 30, 45 and 60 cm depths from 30 June to 14 July (Table 4). The reverse was true at mid season when clones with high initial root production had significantly lower SMD rates for the 15, 30, 45, 60 and 75 cm depths (Table 4). This may have been due to the low soil moisture content of the upper profile because of previous extraction.

SMD rates for clones differing for high and low root production were 1.17 and 1.35 mm per day respectively, as decreasing soil water content severely limited soil moisture uptake between 4 to 29 August. The shoot production was not significant for any SMD rate throughout the summer (Table 4). Clones with the largest shoot production at harvest had large SMD rates early in the season. These rates were not significant (Table 4).

Visual wilt symptoms are commonly used as an indicator of drought stress in turf, and provide a relative assessment of plant water content. Clonal wilt response was highly significant for all measurement dates (data not shown). The mean soil water content (mm) in the 120 cm profile and mean time till clones reached a mean wilt score of 5 indicated that tall fescue differed in the wilt response expression with time and soil water uptake (Figure 2). This trend agrees with another tall fescue study where interspecific tall fescue hybrids with diminished leaf rolling characteristics extracted greater amounts of soil moisture as opposed to those that wilted (King et al., 1982). Additional contrasts were devised by grouping 6 clones each having the upper and lower mean values for wilt on 21 June, and on 5 and 29 August to investigate any potential relationship between SMD rates and the leaf rolling response (Table 5). There was no association between clones differing in wilt values on 21 July and SMD rates between 30 June to 14 July. This was due to the relatively high soil moisture content at the onset of the first wilt symptoms by those clones wilting early in the study.

Contrasts based on extreme wilt values on 5 August with SMD rates showed a definite relationship. Wilted clones had higher SMD rates from 15 to 90 cm, with significant differences at 30, 45, 60 cm and for the entire profile (Table 5). This trend continued from 5 to 29 August with the exception of the 105 and 120 cm depths. Wilted clones produced significantly lower dry clipping weights during midsummer stress, than clones which did not wilt. This agreed with a previous tall fescue study that showed leaf extension was influenced by drought and soil moisture content (Horst and Nelson, 1979).

Although the contrast for clones with extreme wilt values on 29 August was not significant for SMD rates between 5 to 29 August, clones that wilted severely had lower SMD rates at all but the 120 cm depths. The actual mean soil water content (mm) on 29 August for the high and low wilt contrast was not more than 1.5 mm in difference for each depth or the entire profile. The ability to avoid leaf rolling by maintaining adequate soil water uptake was due in part to other mechanisms (such as heat tolerance) once soil water availability became limiting and soil temperatures exceed root growth optimum. It has been demonstrated that forage tall fescue plants wilted even when roots were present between

100 and 120 cm (Bennett and Doss, 1960).

Partial correlation coefficients among clones based on field growth responses were low (Table 6), with essentially no relationship between field root and shoot production with the July harvest. This does not agree with the correlations of root and shoot growth among mowed seedlings (Table 6). The root/shoot ratio was probably affected more by shoot growth since the correlation between root/shoot ratio and shoot growth was $r = 0.51$ ($p \geq 0.01$), since shoot growth was much greater on a dry weight basis at harvest.

There were no seedling variables which could serve to predict field growth performance based on Pearsons Product moment correlations for seedling and clonal field growth performance (Table 6). Seedling root production was poorly correlated ($r = 0.18$, $p \geq 0.01$) with field root production. Seedling root number was not strongly correlated with field shoot weight ($r = 0.31$, $p \geq 0.21$) or root weight ($r = 0.44$, $p \geq 0.08$). More importantly, divergent selections for high or low root dry weights had field means of 433 and 312 g m^{-2}, respectively ($p \geq 0.02$). This fact showed that plants selected for extreme root production in the seedling stage had large field root production.

Clonal shoot production (g m^{-2}) on a dry wt. basis was significant ($p \geq 0.01$), with approximately a five fold difference in clonal means ranging from 1.62 to

7.41 kg m^{-2}. Turf-type seedlings produced significantly greater ($p \geq 0.01$) mean topgrowth (3.8 kg m^{-2}) than forage types (2.9 kg m^{-2}).

Significant clonal root production ($p \geq 0.01$) indicated that the genetic differences existed in mowed tall fescue. The "turf vs. forage" contrast (based on the 17 selections) was significant ($p \geq 0.01$) with means of 377 and 267 g m^{-2}, respectively. Clonal variation within perennial ryegrass for root growth occurred as 3 fold differences were detected for root weight among clones with similar shoot production (Ennik and Hofman, 1984). In this study, clones 2, 5, and 22 had the greatest root production as seedlings and field plants (Table 7). Root production of clone 19 was above the grand mean of field root production, but clone 32 which was selected for large root production had little field root growth. Of the clones selected for low root production, clones 18 and 29 had mean root production values lower than the grand mean, while clones 26 and 31 had above average performance. These results may be due to effects of potential seedling vigor and the expression of mowing adaptation.

The DGD values for field shoot and root gowth were high (0.77 and 0.84 respectively). The high DGD values indicated that clones exhibited stable field performance.

Clones differed for root weight densities with depth, but distribution was constant (Table 8). An unirrigated tall fescue sward produced twice as much root mass and had different root distribution when compared to a well watered sward (Bennett and Doss, 1960). Selection for root distribution may not be feasible as selection for total root production under non-stress conditions based on results obtained in this study. It has been demonstrated that mowed tall fescue root redistribution takes place under conditions of decreasing levels of plant available water (Kopec et al.,1984).

The root/shoot ratio for tall fescue clones was significant ($p \geq 0.01$) but no relationship existed between seedling and field performance. DGD for root/shoot ratio (0.38) was low compared to those of shoot and root growth (0.77 and 0.84 respectively), noting that shoot production was greater than root production in this test. Although clones 5 and 25 had high root/shoot ratio values in both the seedling and field studies, clones 15 and 22 did not (Table 7). The overall seedling-field relationship for this variable further deteriorated as clones 18, 31, 26, and 29 had root/shoot ratio values in the field which were moderate or large. The low values for the root/shoot ratio could be attributed to high spring soil moisture content which limited root growth. It has been demonstrated that the root/shoot ratio among interspecific tall fescue hybrids was low under high soil moisture conditions (King et al.,1982). A light application of N in June would also favor shoot over root growth, and decrease the root/shoot ratio (Beard, 1973). Adaptation to mowing stress and seedling vigor may be additional factors contributing to the poor relationships between seedling and field growth responses.

The seedling-field performance of deep roots could not be fully analyzed since the 90 cm sampling depth was not sufficient to separate maximum rooting, even though root densities at this depth were extremely low. Five of the deep rooted seedlings did produce roots in excess of 90 cm, although other clones did the same. This rooting parameter warrants further clonal study.

Conclusions and Summary

Tall fescue clones differed significantly in SMD rates throughout the summer of 1984 when soil moisture was initially high followed by progressive soil moisture stress . DGD values were moderate to high for field growth responses and low to moderate for SMD rates. SMD rates were under genetic control to various degrees, depending on time and depth of measurement.

The correlation between total root production in mid July with soil moisture in the 120 cm profile in late August was r= -0.78 and significant at the 0.01 probability level. This shows that root production is probably related to soil moisture depletion in tall fescue plants under mowed conditions. Tall fescue can produce roots to a depth of 120 cm or more under mowing and summer stress conditions. This has been previously documented in forages (Ash et al., 1975; Garwood and Sinclair, 1979) but not in turfs.

Mowed tall fescue germplasm grown in the field differed in root and shoot growth parameters for unstressed seedlings and replicated clonal material. In most cases, seedlings selected for extreme root growth produced large field root values. Divergent selections had significantly different field root responses.

Tall fescue had different correlation structures among plants for seedling and field growth response parameters. No seedling variables could be used to predict field responses under the conditions of these experiments. Seedling-field plant correlations based on 17 clones were poor, but divergent seedling selections tended to produce expected field results showing that seedlings selected for extreme root growth had superior root production in the field.

Tall fescue clones differed in the expression of visible wilt in a prolonged soil drought. This was in part accomplished by the plant's ability to meet evaporative demand through root water uptake and as other stress response mechanisms which were not identified. Based on the evaluation of vegetatively propagated clonal material mowed at 76 mm under field conditions, there appeared to be adequate genetic variability and genetic effects for shoot, root growth, soil water depletion and visible wilt. Further experimentation designed to study plant growth and stress respons of this germplasm under various environmental conditions would allow judicious selection and formulation of suitable mating schemes designed to improve the turf performance of tall fescue.

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Table II.1. Tall fescue growth parameter statistics, based on performance of 96 mowed seedlings from a growth chamber experiment.

		Number of plants
Dry root mass (mg plant-1)		
Mean	56.2	
Standard deviation	2.9	
Critical value		
High selection (+)	62.1	5
Low selection (-)	43.4	4
Root/shoot ratio		
Mean	.86	
Standard deviation	.06	
Critical value		
High selection (+)	1.0	6
Low selection (-)	0.7	5
Deep root (mm plant-1)		
Mean	129.0	
Standard deviation	5.5	
Critical value		
High selection (+)	140.0	5

Table II.2. Soil moisture depletion rates (mm day -1), degree of genetic determination, coefficient of genetic variability and probability values based on performance of 36 mowed tall fescue clones under field conditions.

	June 30 to July 14					July 15 to August 4.					August 5 to August 29.				
Depth (cm)	Grand mean† (mm)	Range‡ (mm)	(DGD)§	(GCV)¶	P>F value	Grand mean (mm)	Range (mm)	(DGD)	(GCV)	P>F value	Grand mean (mm)	Range (mm)	(DGD)	(GCV)	P>F value
0–15	0.19	0.53–0.02	21.56	45.54	0.01	0.68	0.84–0.42	27.03	8.45	0.01	0.24	0.34–0.10	28.61	14.97	0.02
15–30	0.70	1.00–0.43	19.37	12.80	0.02	0.77	1.06–0.58	32.40	9.54	0.01	0.16	0.24–0.11	—	—	0.67
30–45	0.75	1.17–0.33	39.15	18.59	0.01	0.83	1.07–0.60	54.45	9.12	0.02	0.17	0.23–0.07	17.43	12.34	0.04
45–60	0.66	0.87–0.30	41.41	20.20	0.01	0.87	1.04–0.74	33.97	7.47	0.01	0.16	0.26–0.08	7.15	8.54	0.22
60–75	0.37	0.77–0.12	77.35	45.57	0.01	0.89	1.04–0.74	19.05	5.32	0.02	0.15	0.24–0.09	20.96	17.50	0.02
75–90	0.28	0.64–0.01	41.76	57.73	0.01	0.96	1.05–0.77	—	—	0.51	0.14	0.24–0.07	49.61	56.73	0.01
90–105	0.12	0.58–0.01	38.95	99.55	0.01	1.01	1.28–0.87	14.32	8.49	0.31	0.16	0.29–0.03	10.23	18.32	0.14
105–120	0.23	0.43–0.02	14.97	25.11	0.06	0.98	1.23–0.73	31.76	8.38	0.01	0.18	0.28–0.08	12.53	17.49	0.10
Total profile	3.30	5.06–0.88	49.31	23.25	0.01	6.98	7.89–6.15	19.32	3.08	0.02	1.3442	1.76–0.89	9.86	7.49	0.15

† Grand mean is mean of 108 measurements (3 replications of 36 clones).
‡ Range is high and low value based on performance of 36 tall fescue clones.
§ (DGD) derived from components of variance (ANOVA).
¶ (GCV) derived from components of variance.

Table II.3. Response of 36 tall fescue clones for soil water content (mm) extracted for each 15 cm increment and the entire 120 cm profile.

Depth (cm)	Grand mean† (mm)	Range ‡ (mm)	(DGD)§	(GCV)π	P>F # value
0-15	22.57	27.2 - 19.5	19.65	5.36	0.02
15-30	29.83	33.5 - 26.7	86.72	16.91	0.01
30-45	31.70	34.9 - 28.6	16.70	2.86	0.04
45-60	31.45	33.9 - 29.4	8.67	1.81	0.18
60-75	27.47	30.4 - 24.5	29.80	4.68	0.01
75-90	27.32	29.8 - 19.9	28.03	5.54	0.01
90-105	26.82	30.0 - 18.9	15.93	4.98	0.05
105-120	28.06	32.3 - 18.9	30.92	11.09	0.01
Total profile	225.22	205.6 - 235.8	23.90	2.35	0.01

† Grand mean is mean of 108 observations (3 replications of 36 clones).
‡ Range is extreme values for 36 clones.
§ (DGD) is degree of genetic determination derived from varaiance components (ANOVA).
π (GCV) is genetic coeficient of variabilty derived from variance components (ANOVA).
P>F value. Experimental error rate = 0.05

Table I.4. Contrast significance and mean soil moisture depletion (SMD) rates for tall fescue clones having high or low root or shoot production. Rates are in (mm day-1).

Period	Depth (cm)	P>F value	High roots†	Low roots	Depth (cm)	P>F‡ value	High shoot	Low shoot
June 30 to July 14.	0-15	0.02	0.27	0.14	0-15	0.53	0.23	0.19
	15-30	0.16	0.73	0.65	15-30	0.87	0.68	0.69
	30-45	0.01	0.91	0.64	30-45	0.21	0.74	0.66
	45-60	0.01	0.78	0.54	45-60	0.13	0.66	0.58
	60-75	0.01	0.59	0.24	60-75	0.04	0.46	0.31
	75-90	0.01	0.42	0.19	75-90	0.57	0.29	0.26
	90-105	0.63	0.17	0.14	90-105	0.16	0.19	0.11
	105-120	0.94	0.23	0.23	105-120	0.14	0.31	0.27
	Total	0.01	4.10	2.79	Total	0.06	3.59	3.05
July 15 to August 4.	Depth (cm)	P>F value	High roots	Low roots	Depth (cm)	P>F value	High shoot	Low shoot
	0-15	0.02	0.60	0.72	0-15	0.43	0.65	0.67
	15-30	0.01	0.68	0.83	15-30	0.70	0.76	0.75
	30-45	0.01	0.73	0.90	30-45	0.41	0.83	0.84
	45-60	0.01	0.81	0.91	45-60	0.61	0.88	0.89
	60-75	0.03	0.85	0.92	60-75	0.31	0.86	0.89
	75-90	0.92	0.94	0.95	75-90	0.62	0.97	0.92
	90-105	0.01	1.06	0.95	90-105	0.60	1.02	0.99
	105-120	0.04	1.04	0.96	105-120	0.57	0.97	0.95
	Total	0.01	6.71	7.15	Total	0.87	6.94	6.96
August 5 to August 29	Depth (cm)	P>F value	High roots	Low roots	Depth (cm)	P>F value	High shoot	Low shoot
	0-15	0.09	0.20	0.23	0-15	0.35	0.21	0.22
	15-30	0.24	0.14	0.16	15-30	0.70	0.15	0.16
	30-45	0.64	0.15	0.16	30-45	0.33	0.16	0.15
	45-60	0.49	0.15	0.16	45-60	0.25	0.18	0.16
	60-75	0.03	0.12	0.15	60-75	0.23	0.14	0.17
	75-90	0.07	0.11	0.15	75-90	0.55	0.14	0.12
	90-105	0.09	0.13	0.17	90-105	0.13	0.16	0.15
	105-120	0.24	0.18	0.14	105-120	0.81	0.17	0.16
	Total	0.19	1.17	1.22	Total	0.89	1.31	1.29

† Contrast formulated by grouping 6 upper and lower clones for each effect.
‡ Experimental error rate 0.05. Contrast significance level = 0.01 (Bonferroni).

Table II.5. Contrast significance and mean soil moisture depletion (SMD) rates (mm day -1) for tall fescue clones having high or low wilt values during the summer of 1984, Mead Nebraska.

	June 30 to July 14.				July 15 to August 4.				August 5 to 29		
Depth	P>F value	High wilt	Low wilt	Depth	P>F	High wilt	Low wilt	Depth	P>F	High wilt	Low wilt
0-15	0.22	0.24	0.18	0-15	0.01	0.62	0.71	0-15	0.05	0.24	0.27
15-30	0.43	0.71	0.65	15-30	0.01	0.72	0.81	15-30	0.31	0.16	0.18
30-45	0.96	0.74	0.74	30-45	0.01	0.79	0.86	30-45	0.28	0.16	0.17
45-60	0.32	0.64	0.69	45-60	0.55	0.85	0.85	45-60	0.11	0.14	0.17
60-75	0.74	0.35	0.37	60-75	0.49	0.86	0.87	60-75	0.28	0.12	0.15
75-90	0.21	0.22	0.29	75-90	0.94	0.97	0.97	75-90	0.32	0.11	0.13
90-105	0.42	0.05	0.09	90-105	0.71	1.04	1.01	90-105	0.32	0.15	0.13
105-120	0.59	0.19	0.21	105-120	0.41	0.99	0.95	105-120	0.08	0.21	0.16
Total	0.68	3.14	3.23	Total	0.05	6.83	7.04	Total	0.06	1.29	1.37

Values are means of 3 replicates of 6 clones in extreme rank for plant wilt response.
Experimental error rate = 0.05. Contrast significance level = 0.05.

Table II.6. Correlations of root and shoot growth variables for mowed tall fescue seedlings and mowed plants in the field, summer 1984, Mead Nebraska.

	Seedling tillers†	Seedling leaves	Seedling roots	Seedling shoot wt	Seedling root wt	Seedling leaf area	Seedling R/S ratio	Field shoot wt‡	Field root wt††	Field R/S ratio§
Seedling§ tillers		0.08 (0.10)	0.16 (0.01)	0.62 (0.01)	0.46 (0.01)	0.44 (0.01)	-0.08 (0.18)	0.15 (0.54)	0.16 (0.32)	0.05 (0.84)
Seedling leaves			0.36 (0.01)	0.70 (0.01)	0.51 (0.01)	0.54 (0.01)	-0.08 (0.18)	0.45 (0.06)	0.37 (0.13)	-0.08 (0.75)
Seedling root no.				0.36 (0.01)	0.39 (0.01)	0.31 (0.01)	0.04 (0.49)	0.31 (0.21)	0.43 (0.08)	-0.06 (0.81)
Seedling¶ shoot wt.					0.68 (0.01)	0.73 (0.01)	-0.16 (0.09)	0.21 (0.42)	0.36 (0.15)	-0.03 (0.90)
Seedling¶ root wt						0.52 (0.01)	0.54 (0.01)	0.36 (0.15)	0.18 (0.47)	-0.31 (0.22)
Seedling# leaf area							-0.05 (0.35)	0.08 (0.74)	0.09 (0.70)	-0.04 (0.85)
Seedling R/S R/S ratio								0.28 (0.26)	-0.02 (0.91)	-0.33 (0.18)
Field shoot wt									0.26 (0.13)	-0.45 (0.01)
Field root wt										0.51 (0.01)
Field R/S ratio										

†Amoung seedlings, partial correlations, Df=245.
‡Amoung clones in field, partial correleations, Df=77.
§Between seedling and field plants, Pearson's Product moment, Df=17.
¶Seedling shoot and root wt, mg plant .
#Seedling leaf area, cm .
††Field shoot and root weight, g m .

Table II.7. Root and shoot growth of 17 tall fescue clones grown in the field[ψ] as replicated propagules and as individual seedlings.[†]

Clone	Origin	Seedling roots (gm plant^{-1})	Seedling Contrast[‡]	Field roots (g plant^{-1})		Seedling shoots (mg plant^{-1})	Field shoots (g m^{-1})		Seedling R/S ratio	Seedling Contrast[‡]	Field R/S ratio	Seedling Deep Root mm		Seedling Contrast[§]	Field Roots >120 cm
2	Turf	65.1	+	519	a[#]	41.1	4981	a-b	1.21	+	0.068		a-f[#]		
5	K-31	51.0		263	c-f	30.3	1868	g-h	1.08	+	0.094	124	a-b	+	
14	Forage	44.9		338	b-e	39.8	3612	c-e	0.72	-	0.067		a-f		
15	Turf	62.3		257	c-f	39.5	7412	a	1.06	+	0.024	132	f	+	
18	Forage	37.0	-	218	d-f	29.0	1619	h	0.77		0.090		a-d		
19	K-31	73.9	-	341	b-e	58.5	3363	c-f	0.84		0.073	148	a-f	+	+
20	DP-294	50.5		210	e-f	41.6	2740	e-h	0.78		0.051	160	d-f		
21	Forage	60.5		152	f	42.1	1930	g-h	0.95		0.042	144	c-f	+	
22	Forage	61.2	+	457	a-b	62.7	4484	b-c	0.64	-	0.071		a-f		
24	DP-294	57.1		272	e-f	42.1	3612	c-e	0.89		0.050	160	d-f	+	+
25	Turf	65.1	+	405	a-c	41.4	2865	d-g	1.05	+	0.112		a-e		
26	Turf	38.9	-	349	b-e	34.4	1806	g-h	0.69	-	0.101		a		
27	Turf	60.4		351	b-e	33.6	4106	g-h	1.18	+	0.045	160	b-f	+	+
29	DP-294	38.6	-	289	c-f	30.7	4564	b-d	0.76		0.042	150	e-f	+	+
31	Turf	40.3	-	394	a-c	36.8	2304	b-c	0.68	-	0.135		a-c		
32	Forage	62.4	+	173	f	38.8	2678	e-h	1.06	+	0.039		e-f		
33	Turf	60.0		366	b-d	55.0	2989	d-f	0.74	-	0.086		a-f		

† Seedlings selected on individual plant basis.

‡ Seedling contrast based on divergent selection (+ = high, - = low).

§ Seedling contrast based on directional selection (+ = high).

ψ Field plant performance based on mean of three replicates per clone.

Duncans Multiple range test. Values with the same letter in common not significantly from each other at the 0.05 probability level.

Table II.8. Mean root density (kg m^{-3}) of tall fescue clones with depth for 17 tall fescue selections field harvested July 17, 1984 Mead Nebraska.

Soil depth (cm)	Mean†	Std. error of mean	Clonal Significance P > F
0 -15	1.79	0.34	0.01
15-30	0.85	0.12	0.01
30-45	0.17	0.12	0.62
45-60	0.08	0.03	0.16
60-75	0.05	0.01	0.01
75-100	0.03	0.01	0.20

†Grand mean of 51 observations, 3 replicates per clone, 17 selections.

Figure 1.

MEAN SOIL WATER WITH DEPTH AND TIME

FOR 36 MOWED TALL FESCUE CLONES

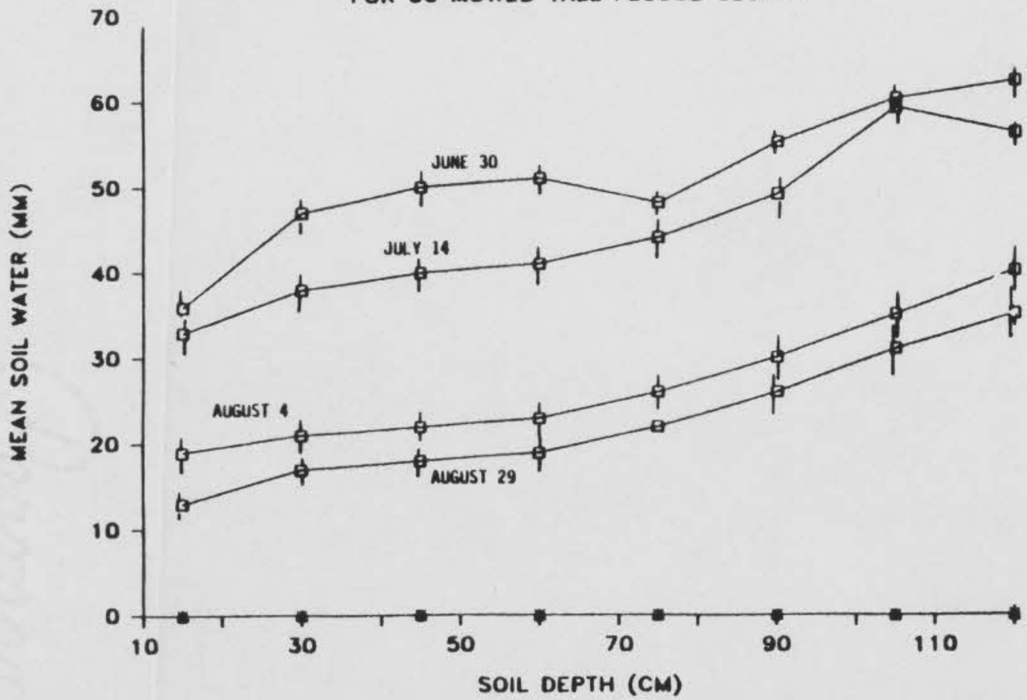


Figure 2.

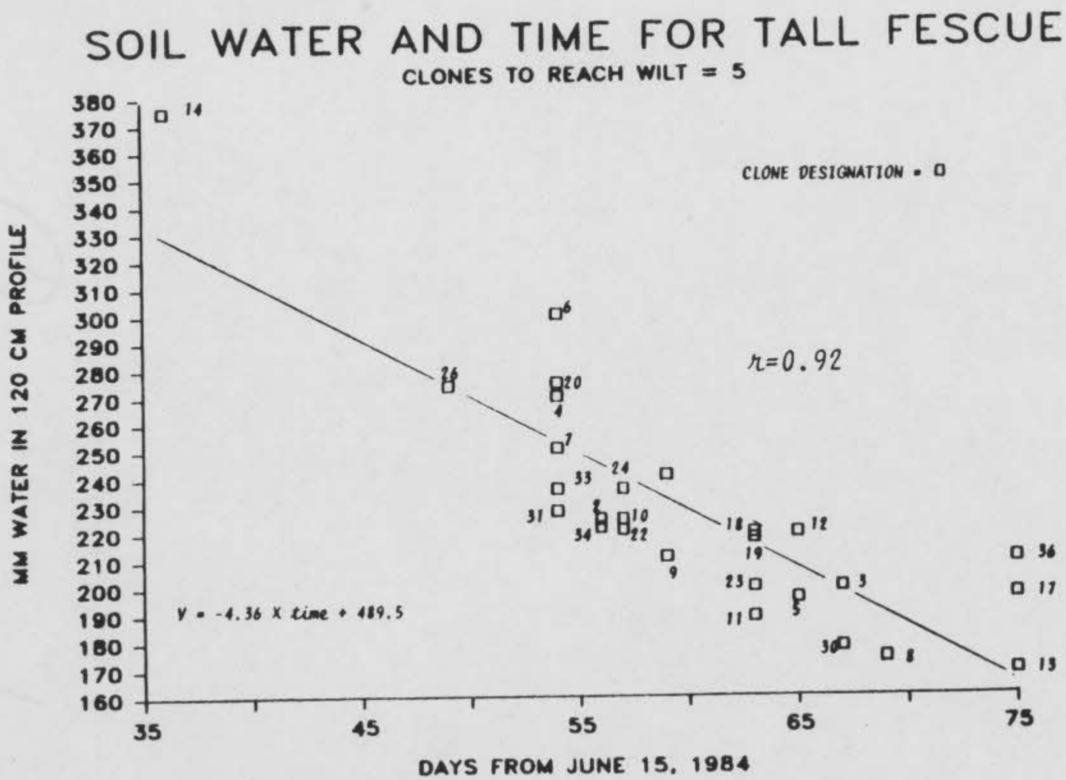
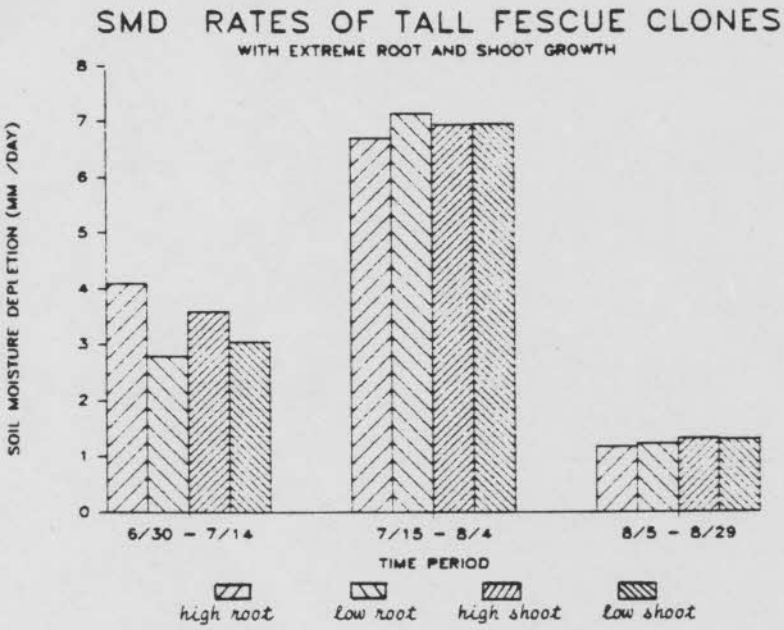

SOIL WATER AND TIME FOR TALL FESCUE
CLONES TO REACH WILT = 5
CLONE DESIGNATION = □
r=0.92
Y = -4.36 X time + 489.5
MM WATER IN 120 CM PROFILE
DAYS FROM JUNE 15, 1984

Figure 3.


SMD RATES OF TALL FESCUE CLONES
WITH EXTREME ROOT AND SHOOT GROWTH
SOIL MOISTURE DEPLETION (MM /DAY)
8
7
6
5
4
3
2
1
0
6/30 - 7/14
7/15 - 8/4
8/5 - 8/29
TIME PERIOD
high root
low root
high shoot
low shoot