Chapter 4

Relationship of Shoot Morphology Between Seedlings and Established Turf in Creeping Bentgrass

ABSTRACT

Shoot morphological characteristics are important determinants of turf quality in creeping bentgrass. The objectives of this research were to determine differences for tiller and stolon characteristics among creeping bentgrass cultivars and lines and compare and relate these characteristics between seedlings and established turf. Two experiments involving 10 and 15 entries were grown in controlled environment chambers and harvested as seedlings at 21, 35 and 49 d and 21, 28 and 35 d after transplanting, respectively. Nine and fifteen creeping bentgrass entries were grown in two separate field experiments on sand-based golf greens and core samples were taken for subsequent measurements at 3 yr and 1 yr, respectively. Tiller and stolon measurements included seedling tillers plant^{-1} in the controlled environment; tillers m^{-2} on established turf; and leaf number, leaf width, plant height/stolon length, internode length, internode number, and stolon diameter in all experiments. The correlation coefficients for seedling tillers plant^{-1} at 35 d between the two controlled environment experiments was r = 0.835 and for tiller density between the two field experiments was r = 0.930. There were differences among the creeping bentgrass entries for tiller number plant^{-1} (9.7 to 20.2) and internode length (20 to 54 mm) when measured at 35 d and for tiller density (67 to 227 x 10^3 m^{-2}) in established turf. Correlation coefficients between seedling tillers plant $^{-1}$ at 35 d and tiller number m^{-2} in established turf ranged from r = 0.701 to r = 0.826. There was also a high correlation for stolon internode length between seedling and established turf, with r values ranging from r = 0.725 to r = 0.948. These results document differences for tiller and stolon characteristics between creeping bentgrass cultivars and lines and indicate the potential for plant improvement of these characteristics in creeping bentgrass using 35 d old seedlings in a controlled environment.

Key words: Creeping bentgrass, tiller number, tiller density, stolons, turf, seedling

Abbreviations: RCBD, randomised complete block design

INTRODUCTION

Creeping bentgrass (*Agrostis stolonifera* L.) is a turfgrass used predominantly in high-maintenance, close-mown situations, such as required for golf putting turf. Tiller density (tiller number per unit area) is an important shoot morphological characteristic in creeping bentgrass and is positively related to wear stress recovery (Hawes and Decker 1977) and potential wear stress resistance in turf (Lush 1990). Shildrick and Peel (1984) found a positive relationship between tiller density and wear stress resistance in Kentucky bluegrass (*Poa pratensis* L.). In Chapter 6 we report differences for tiller density in golf putting green turf among six creeping bentgrass entries. We noted that higher tiller densities were associated with higher aboveground biomass and improved wear stress resistance potential. Previous research indicated that plant tiller and leaf number were positively associated with each other ($r = 0.97$) and with visual turf density ratings (Cattani and Clark 1991). Lehman and Engelke (1991) found narrow-sense heritabilities for plant tiller number of 0.31 to 0.41 with creeping bentgrass.

Currently, progress in turfgrass breeding is limited as each cycle of selection requires the establishment and maintenance of turfgrass plots. The ability to relate shoot morphological characteristics of seedlings to established turf would be useful for plant breeders. Important shoot morphological characteristics include higher tiller densities for improved golf putting green wear-stress tolerance and increased stolon length for quicker colonisation of bare spots in golf fairway and tee-box turfs. Selecting superior creeping bentgrass plants in the seedling stage would provide an improved methodology for generation advance. This methodology would allow selection of plants with desired shoot morphological attributes at an early stage, enabling earlier transplanting of seedlings to field or greenhouse crossing blocks. If selection for one characteristic can be achieved at an early growth stage and selection for another characteristic at a later stage (e.g., disease tolerance), advancement for both characteristics may be possible without extending the time for generation advancement. The objectives of this research were: (1) to demonstrate cultivar differences for shoot morphological traits in creeping bentgrass seedlings, and (2) to compare seedling shoot morphological traits to mature plant shoot morphological traits in established turf.

Table 4.1. Creeping bentgrass cultivars and lines planted in controlled environment growth rooms and under field conditions on golf putting greens in Winnipeg, MB, Canada.

Cultivar	Origin	Year	Growth room Studies		Putting Green Studies	
			1[z]	2	3	4
18th Green	University of Manitoba, MB, Canada	1990[y]	x	x	x	x
Cobra	International Seeds Inc., OR, USA	1987	x	x		x
Emerald	W. Weibull AB, Sweden	1965	x	x	x	x
National	Pickseed West Inc., , OR, USA	1987	x	x	x	x
Penncross	Penn State Univ., PA, USA	1955		x	x	x
Penneagle	Penn State Univ., PA, USA	1978	x	x	x	x
Pennlinks	Penn State Univ., , PA, USA	1986	x	x	x	x
Providence	Seed Research of Oregon, Inc., OR, USA	1988		x		x
Putter	Jacklin Seed Co., ID, USA	1988	x	x		x
Regent	Willamette Valley Breeders, OR, USA	1990		x		x
Seaside	University of Oregon	1923		x	x	x
Southshore	Rutgers University, NJ, USA	1992	x	x		x
SR1020	Seed Research of Oregon, Inc., OR, USA	1987		x		x
UM86-01	University of Manitoba, MB, Canada	exp.	x	x	x	x
UM86-02	University of Manitoba, MB, Canada	1998	x	x	x	x

[z] 1 - Experiment 1, 10 cultivar seedling study in the growth room; 2 - Experiment 2, 15 cultivar seedling study in the growth room; 3 - Experiment 3, 9 cultivar golf putting green turf study seeded in 1986; 4 - Experiment 4, 15 cultivar golf putting green turf study seeded in 1992.
[y] exp. - experimental line developed at the University of Manitoba.

MATERIALS AND METHODS

Controlled Environment Experiments

Experiment 1. The initial growth room experiment was designed to allow measurements of shoot morphological characteristics at the seedling stage for 10 creeping bentgrass cultivars and lines (entries) (Table 4.1). Certified seed was used for all entries except University of Manitoba experimental germplasms (Syn_1) and "18th Green" (breeders seed, Syn_3). All seed was pre-germinated for 4 d in petri dishes containing moistened filter paper at

Table 4.2. Nutrient application and harvest schedule for two controlled environment growth room experiments designed to measure creeping bentgrass morphological characteristics.

Days	Experiment 1[z]	Experiment 2[y]
0	Transplanting	Transplanting
2	Fertilise @[x] 14g N/100 m^2 [w]	-
7	Fertilise @ 75g N/100 m^2	Fertilise @ 56g N/100 m^2
10	Fertilise @ 75g N/100 m^2	Fertilise @ 112g N/100 m^2
14	Fertilise @ 150g N/100 m^2	Fertilise @ 112g N/100 m^2
17	Fertilise @ 300g N/100 m^2	Fertilise @ 225g N/100 m^2
21	1st Harvest	1st Harvest
		Fertilise @ 225g N/100 m^2
24	Fertilise @ 300g N/100 m^2	Fertilise @ 450g N/100 m^2
28	-	2nd Harvest
		Fertilise @ 450g N/100 m^2
31	Fertilise @ 450g N/100 m^2	Fertilise @ 450g N/100 m^2
35	2nd Harvest	3rd Harvest
38	Fertilise @ 450g N/100 m^2	-
45	Fertilise @ 450g N/100 m^2	-
49	3rd Harvest	-

[z] Experiment 1: study of 10 entries.
[y] Experiment 2: study of 15 entries.
[x] @ indicates at the rate of.
[w] Fertiliser source was Peter's 20-20-20 water soluble formulation.

approximately 20 °C and transplanted at the coleoptile stage into 500-mL containers with a 9:1 (vol/vol) sand:peat mixture. The transplanting date will be subsequently referred to as day 0. The soil mixture exhibited soil physical properties within acceptable ranges for all parameters, as recommended for United States Golf Association (USGA) putting greens (USGA Green Section 1993). The plants were grown in a controlled environment at 20/15 °C with a photoperiod of 16/8 h light/dark (approx. 300 $\mu E\ m^{-2}\ s^{-1}$). All containers were watered daily and fertilised with N:P:K (20–20–20 Peter's water soluble formulation, manufactured by W.R. Grace Co., Vogelsville, PA) according to the schedule in Table 4.2. The experimental design was a RCBD with four replicates and four plants per experimental unit, for a total of 16 plants per creeping bentgrass entry mean at each sampling date. Occasionally sample size was reduced to three plants due to plant mortality. Plants were sampled at 21, 35 and 49 d by removing them from the containers and carefully washing soil from the roots.

The number of tillers plant^{-1} was determined at each sampling date. A tiller was counted when a fully emerged leaf was visible. The number of leaves plant^{-1} were determined at 21 d, longest internode on the longest stolon was measured at 35 and 49 d and the number of internodes on the longest stolon was counted at 35 d. A leaf was counted when its length equalled or exceeded the length of the previous leaf on that tiller. All length and width measurements were made to the nearest 0.5 mm.

Experiment 2. The second growth room experiment included 15 creeping bentgrass entries at the seedling stage (Table 4.1). Seed classification, germination conditions, soil mixture, potting containers and transplant procedures were consistent to Exp. 1, but the cultivar Penncross was also included which is a first generation, 3 clone hybrid and therefore marketed seed is from the Syn_1 generation. The plants were grown in a controlled environment at 24/16 °C during 16/8 h light/dark (≈ 300 $\mu E\ m^{-2}\ s^{-1}$) conditions. All containers were watered daily and fertilised with the same formulation as in Exp. 1 according to the schedule recorded in Table 4.2. The experimental design was a RCBD with three replicates and eight plants per experimental unit, for a total of 24 plants per creeping bentgrass entry mean at each sampling date. Occasionally an experimental unit was reduced to seven plants, and once to six plants, due to plant mortality. Plants were destructively sampled at 21, 28, and 35 d after seeding as described in Exp. 1. The 49-d sampling date was not conducted since results from Exp. 1 indicated that tillers had developed on stolon nodes by this date.

The numbers of tillers and leaves plant^{-1} were determined at each sampling date as in Exp. 1. All length and width measurements were made to the nearest 0.5 mm. Plant height was measured at 21 d, and length of the longest stolon was measured at 28 and 35 d. The following measurements were made using the longest stolon at 35 d; (i) the length of the longest internode; (ii) the number of nodes; and (iii) the width of the 4th leaf from the stolon terminus.

Established Turf Studies

Experiments 3 and 4: On 2 September 1986 and 18 August 1992, Exps. 3 and 4 were established on a sand base putting green at the Department of Plant Science Winnipeg Field Research Laboratory. The soil particle size distribution was within the soil particle size guidelines as recommended by the USGA (1993). The 1986 experiment (Exp. 3) included nine creeping bentgrass entries, and the 1992 experiment (Exp. 4) included 15 creeping bentgrass entries (Table 4.1). Seed classes were the same as for Exps. 1 and 2 with the exception of Syn_1 seed for 18th Green in Exp. 3.

Experiment 3. The experimental design for Exp. 3 was a RCBD with four replicates and 1 m^2 plots. The plots were irrigated frequently to prevent wilting and to maintain vigorous turf growth. Mowing was at a 5 mm height with all clippings removed. Aeration and topdressing operations were performed in June of 1988 and 1989 for Exp. 3. The topdressing material was identical in composition to the base media. This experiment received two applications of a 19-25-4 (N:P:K) fertiliser (O.M. Scotts, Marysville, OH) in 1986 with a total application of 1.0 kg N 100 m^{-2}. Fertilisation levels were 2.0 kg N 100 m^{-2} in 1987, 1.95 kg N 100 m^{-2} in 1988 and 1.0 kg N 100 m^{-2} in 1989 prior to sampling (Chapter 6). Phosphorous (P_2O_5) was not applied again until June 1989 at the rate of 250 g 100 m^{-2}. Potassium (K_2O) was included at each fertilisation application at approximately 75% of the nitrogen rate, with the exception of 1989. On 12 July 1989, core samples (6.25 cm in diameter) were taken for tiller density measurements. The perimeter:area ratio for these samples was 0.64:1, well within the 1.1:1 limit for the ratio as established by Lush and Franz (1991). Tiller number was counted for the entire core sample and expressed as functional tillers m^{-2} (Madison 1962).

Experiment 4. The experimental design for Exp. 4 was a RCBD with six replicates and 0.5 m x 1 m plots. In 1993, all plots received irrigation to prevent wilting and produce vigorous turf growth, and mowing height was at 5 mm with all clippings removed. This experiment did not receive aeration or topdressing treatments. The seeding year fertility levels were equivalent to the ones in Exp. 3. Prior to sampling in 1993 fertilisation was 2.5 kg N 100 m^{-2}, 500 g P_2O_5 100 m^{-2} and 1.85 kg K_20 100 m^{-2}. On 29 September 1993, core samples were taken for tiller number m^{-2} and plant morphological measurements.

Tillers m^{-2} were determined as in Exp. 3. Stolon diameter was measured with a dial caliper (Mitutoyo Corporation, Tokyo, Japan) to the nearest 0.05 mm. The length of the 4th internode from the terminus was measured to the nearest 0.05 mm using the ridge of tissue left by the sheath attachment as to determine the internode termini. These detailed measurements were conducted on five stolons per core. Dry weight of live aboveground biomass for each core sample was determined as follows: (1) 100 tillers were randomly selected from each core and dried at 85 °C for 72 h to determine 100-tiller total dry weight; (2) these 100-tiller samples were placed in an ashing oven at 560 °C for 6 h to determine the weight of non-organic matter; (3) ashed weights were subtracted from initial dry weights; and (4) the biomass $tiller^{-1}$ was multiplied by total tiller number $core^{-1}$. To estimate potential wear stress resistance, tiller number m^{-2} and live above ground biomass measurements were used to calculate log *c*:

Solving for log *c*: $$\log10B = \log10c - 0.5 \log10N \qquad (1)$$

where *B* is dry weight of live tillers m^{-2}, *N* is tiller number m^{-2}, and log *c* is an estimate of potential turf wear stress resistance (Lush 1990).

All data were analysed using SAS Institute, Inc. (1988). Cultivar and line means were compared using Duncan's new multiple range test. Spearman's correlation coefficients were calculated between the entry means.

RESULTS AND DISCUSSION

Seedling Experiments 1 and 2

There were entry differences for a number of seedling morphological traits in Exps. 1 and 2 including tillers $plant^{-1}$ and leaves $plant^{-1}$ at all dates, stolon internode length at 35 d and 49 d and leaf width at 35 d (Tables 4.3 and 4.4). There was no entry effect for stolon length at 28 d (Table 4.4) and nodes $stolon^{-1}$ at 35 d (Tables 4.3 and 4.4). Leaves $plant^{-1}$ across entries ranged from 4.59 to 37.8 for the 21 to 35 d sampling dates in Exp. 2. 18th Green, UM86-01 and UM86-02 ranked the highest for leaves $plant^{-1}$ for all measurement dates in both experiments. National, Pennlinks, Penneagle and Emerald (except at 35 d in Exp. 2) had the fewest leaves $plant^{-1}$ on all dates in both experiments and Seaside had few

Table 4.3. Seedling morphological attributes in a controlled environment growth room (Experiment 1) for 10 creeping bentgrass entries measured at 21 d, 35 d and 49 d after transplanting.

	Leaves	Tiller			Internode Length		Node Number
Cultivar	21 d	21 d	35 d	49 d	35 d	49 d	35 d
Syn1	no. plant^{-1}	--------------no. plant^{-1}--------------			---------cm--------		Stolon^{-1}
UM86-02	10.1 a[z]	4.7 a	15.6 ab	29.8 abc	3.1 cd	4.8 b	4.8 a
UM86-01	9.1 abc	3.9 bc	15.1 abc	31.8 ab	3.2 cd	4.7 b	4.8 a
Syn2 or Later							
18th Green	9.7 ab	4.5 ab	17.4 a	33.8 a	2.4 d	3.7 b	4.3 a
Cobra	9.1 abc	4.3 ab	12.5 bcd	26.2 bcd	5.4 a	7.0 a	4.9 a
Southshore	8.5 abc	3.9 bc	12.1 cd	24.6 cd	4.8 ab	6.6 a	4.8 a
Pennlinks	7.5 cd	3.6 cd	9.9 d	26.9 bcd	4.1 bc	7.1 a	4.5 a
Penneagle	8.1 bcd	3.5 cd	12.6 bcd	26.3 bcd	4.9 ab	7.1 a	4.8 a
Putter	7.8 cd	3.4 cd	10.2 d	29.5 abc	4.8 ab	7.2 a	3.9 a
National	7.9 cd	3.3 cd	11.0 d	23.3 d	4.3 ab	7.3 a	3.8 a
Emerald	7.0 d	2.9 d	12.1 cd	23.0 d	4.6 ab	7.4 a	3.8 a

[z] Means in each column followed by the same letter within each column are not significantly different ($P \leq 0.05$) using Duncan's New Multiple Range Test.

leaves plant^{-1} in Exp. 2.

UM86-01, UM86-02 and 18th Green consistently expressed the highest tillers plant^{-1} at all three observation dates in both experiments while National and Emerald were in the lowest grouping in Exp. 1 and Seaside and Penneagle in Exp. 2 (Tables 4.3 and 4.4).

Tillers plant^{-1} over all entries ranged from 2.9 to 33.8 from the 21 d to the 49 d sampling date in Exp. 1 (Table 4.3) and 2.0 to 20.2 from the 21 to the 35 d sampling date in Exp. 2 (Table 4.4). Tillers plant^{-1} at 35 d was highly correlated between Exps. 1 and 2 (r = 0.835), indicating a consistent expression for this trait in the controlled environment experiments. The difference in actual tillers plant^{-1} between Exps. 1 and 2 was likely due to the difference in fertility (Madison 1962) and temperature regimes between the two experiments and the fact that *A. stolonifera* L. is an obligate out-crosser (Bradshaw 1958) resulting in plant to plant variation within entries.

Stolon development was not visible at the 21 d measurement date, but by 35 d all entries had initiated stolons. At 49 d stolon development was extensive and tillering was taking place at the nodes. National and Regent had the longest stolons at 35 d in Exp. 2 and 18^{th} Green, UM86-01 and UM86-02 had the shortest. The other entries tested were not significantly different for internode length for any measurement date with the exception of Pennlinks which was shorter than Putter at 35 d in Exp. 1 (Table 4.3). Although the University of Manitoba entries expressed the shortest internode lengths at 35 d, they produced the same number of nodes stolon^{-1} as the other entries, indicating a dwarf-type growth habit. Furthermore, correlation coefficients for internode length and tiller number within Exps. 1 and 2 were $r = -0.772$ and $r = -0.730$, respectively (data not shown). These results indicate that the increase in tiller number may be due to the shortening of internode length and thus stolon length, resulting in a more compact plant.

Stolon elongation occurred between the 21 d and 28 d measurement dates. Therefore, to allow for simultaneous selection for tiller number and stolon elongation plants should be allowed to develop for 28 d or until stolon expression. The appearance of tillers at the stolon nodes by 49 d complicated the measurements and increased the time required for measurements.

Heterotic effects for tillers plant^{-1} may have been present in these experiments since different seed generations were used across entries. The expression of heterosis is usually evidenced by increased biomass through the enlargement of the plant structures (Poehlman 1987). Since 18^{th} Green was of the Syn_3 generation (in all but Exp. 3) and Penncross seed is of the Syn_1 generation, then the expression of tillers plant^{-1} for 18^{th} Green is probably not heterotic in nature. The high tiller number for 18^{th} Green is most likely the result of selection for this trait (Cattani *et al.* 1992).

Experiments 3 and 4

Entry differences for tillers m^{-2} were present in 3-yr-old turf in Exp. 3 and in 1-yr-old turf in Exp. 4 (Table 4.5). There was a high correlation for tillers m^{-2} between entries in Exps. 3 and 4 ($r = 0.930$). This high correlation and the consistent entry performance for tiller number m^{-2} across both experiments, indicated that differences were stable over time and

Table 4.4. Seedling morphological attributes in a controlled environment growth room (Experiment 2) for 15 creeping bentgrass cultivars and lines, measured at 21 d, 28 d and 35 d after transplanting.

Entry	Leaves 21 d	Leaves 28 d	Leaves 35 d	Tillers 21 d	Tillers 28 d	Tillers 35 d	Plant Height 21 d	Stolon Length 28 d	Stolon Length 35 d	Internode Length 35 d	Leaf Width 35 d	Node Number 35 d
	-----no. plant^{-1}------			-------no. plant^{-1}-------			---mm---					stolon^{-1}
Syn1												
UM86-01	5.85 a-c[z]	14.5 b	32.2 ab	2.67 a-c	8.1 a	15.2 b	51 a	75 a	165 bc	27 cd	3.02 cd	3.4 a
UM86-02	6.25 a	14.4 b	29.8 bc	2.84 a	7.8 a	14.7 b	52 a	88 a	167 bc	27 cd	3.04 b-d	3.3 a
Penncross	4.92 cd	10.3 cd	27.2 b-d	2.37 a-d	6.3 b	13.5 bc	60 a	87 a	230 a	40 a	3.58 a	3.1 a
Syn2 or Later												
18th Green	6.20 ab	16.4 a	37.8 a	2.80 ab	8.7 a	20.2 a	42 a	57 a	139 c	20 d	2.90 d	2.8 a
Emerald	4.70 d	9.4 d	27.2 b-d	2.13 cd	5.4 b	11.6 c-e	61 a	81 a	202 ab	41 a	3.45 a-c	2.7 a
Southshore	4.79 d	10.0 cd	26.1 b-d	2.15 cd	5.9 b	13.0 b-d	52 a	86 a	220 a	38 ab	3.50 ab	3.4 a
Providence	5.06 cd	11.2 cd	25.1 c-e	2.27 b-d	6.4 b	12.6 b-d	56 a	104 a	228 a	40 a	3.58 a	3.2 a
Regent	4.71 d	11.5 cd	24.9 c-e	2.21 cd	5.9 b	12.4 b-d	52 a	102 a	234 a	38 ab	3.69 a	3.3 a
SR1020	5.09 cd	12.0 c	24.5 c-e	2.27 b-d	6.3 b	12.8 b-d	60 a	123 a	216 ab	37 a-c	3.50 ab	3.0 a
Putter	4.99 cd	9.8 d	24.1 c-e	2.38 a-d	5.8 b	11.6 c-e	59 a	101 a	202 ab	38 ab	3.58 a	3.3 a
National	4.59 d	9.4 d	23.1 c-e	2.06 d	5.8 b	11.3 c-e	60 a	81 a	243 a	42 a	3.54 a	3.1 a
Pennlinks	5.51 a-d	9.5 d	22.7 c-e	2.63 a-c	5.7 b	11.3 c-e	62 a	80 a	204 ab	34 a-c	3.56 a	2.7 a
Cobra	5.42 a-d	10.7 cd	22.2 de	2.48 a-d	6.1 b	10.4 de	60 a	83 a	216 ab	37 a-c	3.42 a-c	3.0 a
Penneagle	4.65 d	9.7 d	20.3 de	1.95 d	5.6 b	9.7 e	58 a	76 a	201 ab	35 a-c	3.48 a-c	2.9 a
Seaside	5.27 b-d	9.9 d	18.6 e	2.38 a-d	5.5 b	9.7 e	64 a	81 a	206 ab	34 a-c	3.33 a-c	2.3 a

[z] Means followed by the same letter within columns are not significantly different according to Duncan's New Multiple Range Test ($P \leq 0.05$)

Table 4.5. Morphological attributes for nine creeping bentgrass entries in Experiment 3 and fifteen entries in Experiment 4 in golf putting green turf at Winnipeg, MB, Canada.

	Exp. 3	Experiment 4					
Entry	Tiller Density		Stolon Diameter	Internode Length	Above Ground Biomass	100 Tiller Weight	Log *c*
	---- x 1,000 ----		---------- mm	---------	-- g m^{-2} --	--- mg ---	
Syn 1							
UM86-02	154 ab[z]	227 a	0.29 a	3.5 bcd	277 a	125 bcd	5.11 a
UM86-01	147 b	227 a	0.27 a	3.1 d	254 abc	112 d	5.07 a
Penncross	100 d	155 de	0.31 a	5.3 ab	198 d	128 bcd	4.89 b
18th Green	168 a	-	-	-	-	-	-
Syn 2 or Later							
18th Green	-	221 a	0.29 a	3.3 cd	259 ab	114 d	5.09 a
Southshore	-	188 b	0.33 a	4.9 abcd	218 cd	116 cd	4.97 b
SR1020	-	182 bc	0.39 a	6.0 a	204 d	112 d	4.93 b
Pennlinks	124 c	176 bc	0.35 a	5.1 abc	207 d	118 c	4.94 b
Regent	-	176 bc	0.31 a	5.4 ab	229 bcd	131 abcd	4.97 b
Penneagle	109 cd	171 bcd	0.37 a	6.3 a	200 d	117 cd	4.92 b
Providence	-	170 bcd	0.31 a	4.8 abcd	206 d	121 cd	4.92 b
Putter	-	168 cd	0.38 a	6.4 a	218 cd	129 abcd	4.95 b
Cobra	-	165 cd	0.34 a	5.6 a	228 bcd	137 abc	4.96 b
Emerald	93 d	143 e	0.37 a	5.9 a	204 d	144 ab	4.88 b
National	108 cd	117 f	0.33 a	5.3 ab	159 e	137 abc	4.73 c
Seaside	67 e	82 g	0.29 a	6.3 a	123 f	150 a	4.54 d

[z] Means followed by the same letter within columns are not significantly different according to Duncan's New Multiple Range Test ($P \leq 0.05$)

environment (Table 4.5). In both experiments, 18th Green, UM86-01, and UM86-02 expressed the highest tillers m^{-2} in comparison to all other entries and Seaside, National, Emerald and Penncross consistently expressed the lowest tillers m^{-2}.

Entry differences were also observed for internode length, aboveground biomass, 100-tiller weight and log *c* (estimate of potential wear stress resistance) in Exp. 4 (Table 4.5). 18th Green, UM86-01, and UM86-02 ranked lowest for internode length and there were no differences between the other entries. In general, entries with higher 100 tiller weights expressed lower for tillers m^{-2} as evidenced by the negative correlation (r = -0.79) between these two traits in Exp. 4. Similar results were reported by Cattani (1987).

Entry differences for log c in Exp. 4 indicated that the entries differed for potential turf wear stress resistance (Lush 1990). These results were consistent with those reported in Chapter 6. Log c estimates were highest for 18th Green and UM86-01 and lowest for Seaside. Creeping bentgrass entries that express high tiller numbers and reduced stolon extension have higher potential wear stress resistance under golf putting green management. Therefore, these characteristics are desirable traits for inclusion in the development of new creeping bentgrass cultivars.

Selection for high tillers plant^{-1} and/or tillers m^{-2} should increase wear stress resistance. Although characteristics that improve wear stress resistance are important for golf putting green conditions, rapid stolon elongation may be a more important characteristic for fairway and tee-box turf conditions allowing the turf to fill in damaged areas. There are a number of plant characteristics which also influence turf quality (e.g. disease resistance) and all should be considered when choosing a creeping bentgrass cultivar.

Seedling vs. Established Turf

Pearson correlation coefficients were calculated to compare seedling tillers plant^{-1} under controlled environmental conditions in Exps. 1 and 2 and tillers m^{-2} from established putting green turf for Exps. 3 and 4 (Table 4.6). Tillers plant^{-1} at 35 d in Exps. 1 and 2 was highly correlated with tillers m^{-2} on established turf in Exp. 3 ($r = 0.824$ and 0.826) and in Exp. 4 ($r = 0.762$ and 0.701), respectively.

The consistently high correlations that were observed between seedling tillers plant^{-1} and tillers m^{-2} on established turf suggest that turf density characteristics can be accurately identified and selected using 35-d-old seedlings. The consistently lower correlation coefficients for Exp. 4 were likely influenced by the higher number of entries in this experiment. Also, stand age may have resulted in greater between plant competition in the 1-yr-old turf in Exp. 4 as compared to the 3-yr-old turf in Exp. 3.

The correlation coefficient for stolon internode length was higher ($r = 0.919$) between Exp. 4 and Exp. 1 at 49 d as compared to the correlation coefficients between Exp. 4 and Exp. 1 at 35 d ($r = 0.883$) and Exp. 2 at 35 d (0.725) (Table 4.6). The lower correlation value between Exp. 4 and Exp. 2 at 35 d can be partially explained by the greater number of entries (15) thereby encompassing a greater amount of the variation in the population. For

Table 4.6. Pearson correlation coefficients among creeping bentgrass seedlings and established turf for tiller number and internode length.

	Experiment 1[z]			Experiment 2		
	21 d	35 d	49 d	21 d	28 d	35 d
			Tiller Number			
Exp. 3	0.944**[y] n = 7	0.824* n = 7	0.955** n = 7	0.711* n = 9	0.885** n = 9	0.826** n = 9
Exp. 4	0.760* n = 10	0.762* n = 10	0.832** n = 10	0.566* n = 15	0.759** n = 15	0.701* n = 15
			Internode Length			
Exp. 1 - 49d		0.901** n = 10				
Exp. 2 - 35d		0.863** n = 10	0.948** n = 10			
Exp. 4		0.883** n = 10	0.919** n = 10			0.725** n = 15

[z] Experiment 1 - 10 entry growth room experiment; Experiment 2 - 15 entry growth room experiment; Experiment 3 - 9 entry golf putting green experiment seeded in 1986; Experiment 4 – 15 entry golf putting green experiment seeded in 1992.

[y] *,** Significant at the 0.05 and 0.01 probability levels.

example, when only the 10 entries from Exp. 1 were compared the *r* value increased to 0.825.

These results suggest that there may be an upper limit for improvement in turf tiller density through selection for seedling tiller number. Other traits, such as stolon length and internode length, are also affected by selection for tiller number. Internode length is negatively related to increasing tiller number; therefore, both traits must be taken into consideration during creeping bentgrass cultivar development.

The ability to select plants based on shoot morphological characteristics provides an opportunity for creeping bentgrass breeders to improve tiller density for putting greens or to increase stolon length to promote rapid colonisation of damaged areas in fairway or tee-box turf. The potential to select in the seedling stage offers a number of advantages including a reduction in the time required to assess shoot morphology and a reduction in the amount of plant material that requires field testing.

Conclusions

There are measurable cultivar and line differences for shoot morphological traits in creeping bentgrass seedlings. These seedling differences are closely associated with the differences observed in established turf. This research suggests that turf tiller density may be improved by selecting seedlings with high tiller numbers at 35 d under controlled conditions.

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