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Factors Affecting Seed Yield in Breeding Material of Kentucky bluegrass (*Poa pratensis* L.)

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ABSTRACT

Factors affecting seed yield, including seed yield components, were determined in two breeding populations of Kentucky bluegrass (*Poa pratensis* L.). In both populations a higher number of inflorescences and spikelets had a positive effect on seed yield, but their effect was reduced by a smaller seed weight. It was concluded that the seed yield per plant could be used as a breeding objective when selecting for seed yield.

Additional index words: **seed yield components, path coefficients, multiple regression.**

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INTRODUCTION

Kentucky bluegrass (*Poa pratensis* L.) is widely used as a turf grass in temperate areas and possesses favorable turf characteristics. However good the turf quality is, the ultimate commercial success of a cultivar will be determined by the economics of its seed production. Numerous cultivars have been developed that excelled in turf quality but were never marketed because of their inability to produce seed in large enough quantities. Examples are also known of cultivars that are high in seed production but poor in turf quality.

The breeder, therefore, is challenged to combine both turf quality and seed productivity in one and the same cultivar - two characteristics that act adversely on each other.

Various studies have been undertaken to define the components determining seed yield and therefore should be the objectives in a selection program for higher seed yield (Dewey and Lu, 1959; Lewis, 1966; Knowles et al., 1970; Bugge, 1981; Wilson et al., 1981; Nguyen and Sleper, 1983). Often such studies have been based on a limited number of plants and on refined observations. In a large scale breeding program however, thousands of plants have to be screened for seed productivity and simple screening characteristics are required in order to cope with these numbers.

The present study was set up to define the factors affecting seed yield which could be determined for a large number of plants.

MATERIALS AND METHODS

The bluegrass material studied originated from two hybridization programs between cultivars, that were crossed in 1976 and 1977 respectively as described by Hintzen and van Wijk (1985).

The F1-plants that deviated positively (i.e. vigorous and healthy growth with an adequate number of inflorescences) from the mother plant were selected. In 1979 2.9% of the F1-plants were selected; in 1980 this percentage was 1.2%. The origin and number of the selected plants is given in Table 1.

The selected plants were multiplied vegetatively. Of the clones selected in 1979, 15 plants per clone were planted at a distance of 30 x 30 cm on 9 August 1979. Of the 1980-selected clones, 20 plants per clone were planted at the same distance on 19 August 1980. The distance between plots was 90 cm. At time of planting in 1979, 100 kg N ha^{-1} was applied as calcium ammonium nitrate, while the 1980 planting received 40 kg N ha^{-1} at time of planting and 40 kg N ha^{-1} on 20 October 1980. The grass was not cut during autumn. On 28 February 1980 and 19 February 1981 respectively, 60 kg N ha^{-1} was applied.

Table 1. Origin and number of plants studied.

Origin		No.
1979		
Parade	*Continental	24
Parade	*Aquila	9
Parade	*Entopper	2
Parade	*Baron	4
Fylking	*Aquila	9
Continental	*Parade	1
Aquila	*Parade	1
1980		
Pion	*Mentor	5
Pion	*Aquila	5
Pion	*Parade	1
Entopper	*Mentor	3
Entopper	*Aquila	4
Entopper	*Parade	3
Parade	*Entopper	3
Parade	*Pion	1
Parade	*Mentor	2
Parade	*Aquila	1
Aquila	*Bristol	2
Aquila	*Baron	2
Aquila	*Parade	2
Aquila	*Enwarto	1
Aquila	*Entopper	3
Mentor	*Bristol	1
Mentor	*Baron	1
Mentor	*Entopper	1
Mentor	*Pion	1
Enwarto	*Pion	1
Baron	*Mentor	2

In the 1979- and 1980- program 50 and 45 F1-plants were chosen at random for making the observations described below. The cultivars Aquila, Continental, Fylking and Parade were included as standards in the 1979- program; Aquila, Baron, Birka, Entopper, Enwarto, Parade and Pion for the 1980-program. The standard cultivars were planted as the F1-plants were. Observations made in 1980 and 1981 are listed in Table 2.

One week before harvesting, an area of 30 x 30 cm of the treated plants in the vegetative stage was cut at ground level. Observations made on the material harvested are listed in Table 2.

The remaining 14 (1980) or 19 plants (1981) were harvested when the seed was ripe. After threshing and cleaning, the following was determined or calculated: seed yield per plant, seed yield per inflorescence, and 1000 grain weight.

The measured and calculated characteristics were subjected to a regression analysis. Path coefficients were calculated according to Dewey and Lu (1959) between number of inflorescences, number of florets, 1000 grain weight and floret utilization (1980), or number of germinating seeds (1981) with seed yield per plant and seed yield per inflorescence as dependent variables (excluding number of inflorescences for the latter). The variables with the highest predictability of the dependent variables were selected according to Daniel and Wood (1971), as described by van Wijk (1977). Of each characteristic, the relative influence on the dependent variable was calculated. The relative influence describes the fraction of the total change in the dependent variable that can be accounted for by the accompanying total change in the i^{th} independent variable and is defined as: relative influence = $(|b_i| w_i)/w_y$ in which

b_i = the partial regression coefficient of the i^{th} independent variable x
w_i = the range of the i^{th} independent variable x
w_y = the range of the dependent variable y

RESULTS

Though the plants studied were selected for high growth vigor and number of inflorescences, a wide variation in the measured characteristics still occurred. In Table 3 the means, the coefficients of variation and the ranges of the measured characteristics are presented (standard cultivars are included). In spite of their different genetic background, the 1979- and 1980- plants showed a fair agreement in these values.

In both years, plant height and 1000-grain weight had the lowest coefficients of variation, while increase in culm num-

Table 2. Observations during plant development and at harvest.

Growth Stage	Observations	Date 1980	Date 1981
Vegetative stage			
-tiller number	the number of tillers in an area of 30 x 30 cm around one plant	19/3	21/3
-growth stage	1=vegetative, 9=fully emerged inflorescence	-	12/5
-lodging	1=none, 9=heavy	-	1/6
-mildew	1=none, 9=present	3/6	-
-increase in number of inflorescences	the number of inflorescences was determined every 4 days till it remained constant - the regression coefficient between time and number of inflorescences was a measure for theincrease		
-plant height	measured on the longest culm at full head emergence	3/6	3/6
Reproductive stage			
-number of inflorescences			
-number of spikelets per culm	determined on 10 culms (1980) and 5 culms (1981) respectively		
-% vegetative tillers	the number of tillers that had not produced an inflorescence was expressed as a percentage of the total number of harvested tillers		
-% generative tillers	the percentage tillers, present on 19/3/1980 or 21/3/1981 that produced inflorescences		
-% floret utilization in 1980	the weight of filled florets, as determined with a seed blower, was expressed as a percentage of the weight of all florets		
-number of germinating seeds per inflorescence in 1981	15 inflorescences were laid out for germination (7 months after harvesting) and the number of germinating seeds was counted		

ber, seed yield per plant and per inflorescence had the highest.

The percentage generative tillers was in some cases higher than 100, which meant that more tillers than the ones counted in March produced inflorescences. This was partly caused by inaccuracies at counting and by the fact that later developed tillers became generative as well.

The determination of floret utilization and number of germinating seeds per culm showed diverging results. The variation in floret utilization as determined by the weights of the filled and non-filled florets was much smaller than the number of germinating seeds per culm, which was a measure of floret utilization as well.

Table 3. Means, coefficients of variation and ranges of the measured characteristics.

	1980			1981		
Characteristic	Mean	CV%	Range	Mean	CV%	Range
Number of tillers	189	42	40-379	184	33	60-345
Growth stage	-	-	-	4.2	43	1-7
Lodging	-	-	-	2.3	92	1-9
Mildew	5.5	51	1-9	-	-	-
Increase	8.4	46	2.3-16.3	10.0	47	2.5-22.9
Plant height (cm)	60	17	40-90	74	16	46-98
Nb. of inflorescences	131	38	40-262	177	42	52-364
Nb. of spikelets/infl.	170	22	105-283	139	25	76-220
% Vegetative tillers	40	36	13-74	38	45	4-80
% Generative tillers	75	37	31-159	105	13	84-170
% Floret utilization	86	9	64-94	-		-
Nb. germ. seeds/infl.	-	-	-	56	72	7-212
1000-grain weight (mg)	470	17	290-730	479	21	230-710
Seed yield/plant (g)	8.8	45	1.8-20.0	6.7	49	1.0-16.2
Seed yield/infl. (mg)	74	45	18-158	42	54	7-102

Table 4. Correlation coefficients between characteristics.

	Tiller number	Growth stage 1=vegetative 9=generative	Lodging 1=none 9=lodged	Mildew 1=none 9=present	Increase in inflo-rescence nb	Plant height	Nb of inflo-rescences	Nb of spike-lets/culm	% Veg. tillers	% Gen. tillers	Seedset-Nb. of germ. seeds	1000 Grain weight	Seed yield/ plant	Seed yield/ infl.
Tiller number	*	- 0.343*	- 0.237	0.364** -	0.521** 0.757**	0.125 0.135	0.597** 0.711**	0.033 -0.002	0.047 -0.161	-0.526** -0.381**	-0.211 -0.048	-0.300* -0.333*	0.003 0.154	-0.353** -0.368**
Growth stage		*	- 0.163	- -	- 0.592**	- 0.025	- 0.365**	- 0.151	- -0.501**	- -0.349**	- -0.156	- -0.233	- 0.083	- -0.214
Lodging			*	- -	- 0.078	- 0.394**	- -0.023	- 0.283*	- -0.103	- -0.312*	- -0.124	- -0.122	- 0.373**	- 0.276**
Mildew				*	0.079 -	0.326* -	0.114 -	0.083 -	0.108 -	-0.254 -	-0.198 -	-0.186 -	-0.011 -	-0.042 -
Increase in inflorescence nb					*	0.054 0.035	- -	-0.218 0.111	-0.316* -0.457**	-0.002 -0.405**	-0.032 0.004	-0.153 -0.373**	0.198 0.122	-0.171 -0.459**
Plant height						*	0.012 0.046	0.333* 0.226	-0.065 -0.250	-0.134 -0.354**	-0.020 -0.226	0.029 -0.028	0.182 0.355**	0.166 0.396**
Nb of inflorescences							*	-0.061 0.024	-0.340* -0.524**	0.284* -0.252	-0.152 0.033	-0.292* -0.338*	0.230 0.228	- -
Nb of spikelets/ culm								*	0.003 -0.186	-0.119 -0.014	-0.255 0.195	-0.276* -0.141	0.084 0.085	0.150 0.057
% Veg. tillers									*	-0.448** 0.232	0.048 0.122	0.110 0.139	-0.277* -0.382**	-0.009 -0.012
% Gen. tillers										*	-0.097 0.310*	-0.004 0.164	0.186 -0.264	-0.124 -0.048
Seedset-Nb germ. seeds											*	0.505** 0.257	0.525** 0.080	0.546** 0.035
1000 Grain weight												*	0.180 0.200	0.304* 0.378*
Seed yield/ plant													*	- -
Seed yield/ infl.														*

first line: 1979 plants
second line: 1980 plants

**P < 0.01 *P < 0.05

In Table 4 the correlation coefficients between the various characteristics are presented. The only characteristic that showed a significant correlation with seed yield per plant in both years was the percent vegetative tillers at harvest time. The more vegetative tillers were present, the lower the seed yield. Inflorescence number and percent vegetative tillers were negatively correlated as can be expected. The correlation between inflorescence number and seed yield was positive, but not significant.

The higher inflorescence number resulted in a lower 1000-grain weight as can be seen from the negative correlation between both characteristics. This contributed to the absence of a significant relationship between inflorescence number and seed yield.

A high tiller number in spring was a good indication of the number of inflorescences that could be expected, as can be seen from the positive correlation between both characteristics. However, too many tillers, and consequently too many culms, led to a low 1000-grain weight, adversely affecting seed yield per plant.

For the 1979-plants the number of spikelets per culm had a negative significant correlation with 1000-grain weight -- the same trend existed for the 1980-plants though not significantly.

Floret utilization as determined by the weight of the filled and non-filled florets had a positive correlation with 1000-grain weight and seed yield. These relatively high, significant correlations were partly a consequence of the method of determination. The number of germinating seeds did not show a significant relationship with 1000-grain weight or seed yield per plant.

Plants that had lodged more, which were the tall plants, had a significantly higher seed yield than the not lodged, shorter plants as can be seen from the positive correlations between these characteristics. The plants that showed heavier lodging also had less generative tillers developed as compared to the March count. Also more mildew occurred on the densely tillering plants.

In view of the negative correlations between tiller and culm number with 1000-grain weight it followed that seed yield per culm was negatively correlated with tiller number.

In Table 5, the path coefficients between seed yield per plant and its components for both years are presented. In spite of the fact that a large part of the variation observed in seed yield was not explained by the measured seed components (residual factors amounted to 0.747 and 0.925 in 1980 and 1981 respectively), similar trends existed in both years

Table 5. Path coefficients between seed yield per plant and its components.

	1980	1981
Number of inflorescences		
Direct effect	0.355	0.344
Indirect effect via 1000-grain weight	-0.013	-0.117
Indirect effect via spikelet number	-0.017	0.003
Indirect effect via floret util/germ seeds	-0.095	-0.002
	r=0.230	r=0.228
Number of spikelets		
Direct effect	0.278	0.135
Indirect effect via infl. number	-0.022	0.008
Indirect effect via 1000-grain weight	-0.012	-0.049
Indirect effect via floret util/germ seeds	-0.160	-0.009
	r=0.084	r=0.085
1000-grain weight		
Direct effect	0.043	0.347
Indirect effect via infl. number	-0.104	-0.116
Indirect effect via spikelet number	-0.076	-0.019
Indirect effect via floret util/germ seeds	0.317	-0.012
	r=0.180	r=0.200
Floret utilization/number of germ seeds per infl.		
Direct effect	0.628	-0.047
Indirect effect via infl. number	-0.054	0.012
Indirect effect via 1000-grain weight	0.022	0.089
Indirect effect via spikelet number	-0.071	0.026
	r=0.525	r=0.080
Unexplained	0.747	0.925

Table 6. Path coefficients for seed yield per inflorescence and its components.

	1980	1981
Number of spikelets		
Direct effect	0.325	0.136
Indirect effect via 1000-grain weight	-0.028	-0.060
Indirect effect via floret util/germ seeds	-0.147	-0.019
	r=0.150	r=0.057
1000-Grain weight		
Direct effect	0.102	0.423
Indirect effect via spikelet number	-0.090	-0.019
Indirect effect via floret util/germ seeds	0.292	-0.026
	r=0.304	r=0.378
Floret utilization/Number of germinating seeds		
Direct effect	0.577	-0.100
Indirect effect via spikelet number	-0.083	0.026
Indirect effect via 1000-grain weight	0.052	0.109
	r=0.546	r=0.035
Unexplained	0.778	0.914

within the two (genetically different) populations.

In 1980, the largest influence on seed yield was exerted by floret utilization, but, as mentioned before, this might have been caused by its method of determination. Indirect effects through the other components did not influence the direct effect a great deal, resulting in a high correlation between seed yield and floret utilization. The second highest effect in 1980 came from inflorescence number, which was high in 1981 as well. But contrary to 1980, the effect of inflorescence number in 1981 was reduced by a negative, indirect effect via 1000-grain weight, while the two other indirect effects were negligible.

The direct and indirect effects of the number of germinating seeds per inflorescence in 1981 was very small giving evidence that this characteristic was in no way related to seed yield.

The highest effect in 1981 was given by 1000-grain weight - an indirect negative effect via inflorescence number made that the correlation between 1000-grain weight and seed yield was small. The same correlation in 1980 was largely composed of the indirect effect of floret utilization.

Spikelet number had a relatively large influence in 1980, but the indirect effects via inflorescence number and floret utilization, made the correlation nil. The presence of many spikelets had a positive effect on seed yield, but due to the lower weight of seeds, overall yield was smaller. A path analysis was also done for seed yield per inflorescence (Table 6).

In 1980, the largest direct effect on seed yield per inflorescence was exerted by percent floret utilization. The second largest effect came from number of spikelets: a high number contributed towards a higher yield per inflorescence, but at the same time seed weight and floret utilization were reduced as can be seen from the negative effects of these characteristics. Thousand-grain weight influenced seed yield positively. A larger influence than this effect was exerted by the indirect effect via percent floret utilization.

Thousand-grain weight had the largest direct effect on seed yield per inflorescence in 1981. Spikelet number exerted some influence. Though the influence of the number of germinating seeds per inflorescence was small, it is interesting to note that the direct, negative effect was compensated by the indirect, positive effect via 1000-grain weight resulting in the absence of a clear correlation between both characteristics. Therefore, many germinating seeds per inflorescence did not contribute to a higher seed yield per inflorescence as these seeds had a low weight.

The multiple regression of seed yield per plant is given in Table 7.

Respectively 57 and 46% of the variation observed in seed yield per plant was explained by the independent variables, which was significant at P=0.01.

In 1980, the largest relative influence was exerted by percent generative tillers, percent floret utilization and tiller number. These variables were not completely independent from each other. The squared multiple correlation coefficient with the other 9 variables was 0.882, 0.446 and 0.916, respectively. Only subset equations with 7 independent vari-

Table 7. Multiple regression with seed yield per plant as dependent variable.

Variable	1980			1981		
	1	**2**	**3**	**1**	**2**	**3**
Tiller number	0.318	1.8	0.59	0.020	0.2	0.04
Mildew	0.123	0.7	0.05	-	-	-
Growth stage	-	-	-	-0.001	0.0	0.00
Increase infl. no.	0.126	0.9	0.10	-3.434	1.4	0.46
Plant height	0.243	0.5	0.07	0.388	0.9	0.12
Lodging	-	-	-	5.249	2.4	0.28
Infl. number	-0.258	1.1	0.31	0.230	1.6	0.47
1000-grain weight	0.009	0.2	0.02	0.085	2.0	0.27
Spikelet number	0.348	2.7	0.34	-0.046	0.4	0.04
Floret util./germ. seeds	4.077	5.8	0.67	0.139	1.2	0.19
% Veg. tillers	-0.029	0.9	0.10	-0.535	1.5	0.27
% Gen. tillers	0.996	2.4	0.70	-0.465	1.3	0.26
Constant	-44.684			46.578		
F	5.6 (10/43)			3.1 (11/40)		
R^2	0.565			0.461		

1 = partial regression coefficient
2 = t-value
3 = relative influence
F-value - between brackets: degrees of freedom
R^2 = squared multiple correlation coefficient

ables could be selected that approached the fit of the data to the equation with all variables included. A smaller number of variables increased bias and random error.

For the 1981 data, increase in number of inflorescences and inflorescence number had the largest influence. Their squared multiple correlation coefficients were 0.889 and 0.871, respectively. A subset equation was selected that predicted the dependent variable with the same precision as the full equation. The subset consisted of the variables lodging, inflorescence number, 1000-grain weight and percent vegetative tillers.

DISCUSSION

Seed yield in Kentucky bluegrass is a most unpredictable characteristic. Within one cultivar, yield levels between fields in the same year can vary to a great extent and differences up to 200 - 300% can be obtained. Besides the genetical determination, seed yield is largely affected by environmental factors, climate and management. In a survey on possible factors determining seed yield of two cultivars in two consecutive years with 87 and 107 growers respectively (van Wijk, unpublished data) no apparent factor could be defined explaining the large yield differences. In general it was found that the high yielding fields were those that were given the recommended growing practices for bluegrass seed production.

The factors studied here were thought to affect seed yield. Observations were made on yield and its components and on certain characteristics (e.g. lodging and mildew) if clones showed differences for the expression of these characteristics. Increase in inflorescence number was thought to reflect synchronization of flowering and thus affect floret utilization and seed yield. Floret utilization was determined in two different ways in order to find a method that could be applied on a large scale in relatively simple way.

The present study revealed information on the variation in the size of the reproductive system but failed to give some indication of its efficiency. This was largely caused by the absence of a suitable method to determine floret utilization.

In both years and for both populations, it was evident that a higher number of inflorescences and spikelets had a positive effect on seed yield but their effects were reduced by a smaller 1000-grain weight.

Thus, it appears that selecting for a high inflorescence number will not indiscriminately increase seed yield because of a negative response in seed weight. The same trend was observed in seed yield trials with Kentucky bluegrass and red fescue (*Festuca rubra* L.) sown at different times in the same year (van Wijk, unpublished data). Sowing dates were mid June, mid July and mid August. The later sowing date reduced the inflorescence number and increased 1000-grain weight. Hebblethwaite and Pierson (1983) also reported the effect of sowing time on seed weight. A later sowing time increased 1000-grain weight and, floret utilization was less, giving florets already utilized more chance to develop.

In 1980 percent floret utilization was determined by separating filled and non-filled florets with a seed blower, which was calibrated for the actual amount of filled and non-filled florets. However, percent floret utilization displayed such a strong correlation with seed yield, that the method has probably separated heavy and light seeds. Seed cleaning, which was applied to determine the amount of seed per plant has the same effect. On the other hand, the method is easy to apply and for that reason more research is needed with a varying range of seed samples to assess its applicability.

In 1981 the number of germinating seeds per inflorescence was determined. This characteristic did not show any correlation with seed yield and could not be used as a measure of floret utilization. Seed dormancy did not play a role as the determination was made seven months after harvest. A possible cause for the low correlation between this characteristic and seed yield might have been that the seeds of the harvested culms were immature as these were sampled one week before harvest in order not to lose any seeds. The number of germinating seeds showed a positive correlation with 1000-grain weight, determined from mature seeds. The number of germinating seeds per inflorescence showed a negative, though not significant, correlation with lodging and plant height. Shorter plants that lodged less had more germinating seeds per inflorescence suggesting that those plants have a better flower utilization.

Based on these results, it is concluded that the yield per plant is the best determinant for seed yield, irrespective of how the components contribute to the resulting yield. It could be questioned whether there is an optimum between number of inflorescences (number of spikelets and florets), seed weight and floret utilization. Can seed yield be increased by improving floret utilization (either through selection or management) or do correlated responses counteract resulting in no improvement?

Once single plants with a high seed yield have been selected, their yield capability in rows has to be investigated. A trial set-up is therefore required that gives the closest correlation with the actual field growing conditions.

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