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Correlations and path analysis of the components of *Festuca pratensis* seed yield

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Abstract. Seed yield and yield components were investigated using single meadow fescue plants (*Festuca pratensis* Huds.) grown in widely spaced rows. Plants of four cultivars (Cykada, Skawa, Skiba and Skra), entered into the EU catalogue, made the representative sample. On the basis of observations and measurements of 20 plants from two harvest dates and three vegetation seasons, the number of days till heading, number of panicles, seed weight per panicle, degree of panicle axis maturity, weight of fallen seeds, the shedding being induced under laboratory conditions, and gross seed yield. For these traits mean values, coefficients of variation, simple correlation coefficients and Wright's path coefficients were calculated. Over the period of the three-year experiments the greatest variation was found for seed weight per panicle, seed yield per plant and number of panicles, especially in the first harvest year. From among the investigated traits, seed yield per plant was most correlated with the number of panicles per plant (r = 0.480** to r = 0.829**) and seed weight per panicle (r = 0.336* to r = 0.820**). As the number of panicles per plant increased, the weight of fallen seeds increased as well (r = 0.432** to r = 0.620**). The path analysis confirmed the finding that the number of panicles per plant, increasing in successive years, determined the seed yield by 12–23%, 40–46% and 63–74% respectively. The greatest direct effects of the number of panicles and seed weight per panicle on seed yield were observed in the second harvest year.

K e y w o r d s: correlations, *Festuca pratensis,* path analysis, seed yield, yield components

1. Introduction

Meadow fescue (*Festuca pratensis* Huds.) is one of the important species of fodder crops that adapts to varied ecological conditions. It is medium-early, winter grass, in the year of sowing it develops slowly and it is susceptible to drought; when grown for seed, it shows a tendency toward lodging and seed shedding.

The production of generative shoots and the yield of seeds in spot-planted meadow fescue are varied, depending on the date of sowing, especially in the first harvest year. The favourable effect of early spring sowing on the total productivity was observed for two years (Lewis, 1963). Considering the traits connected with seed yield, special attention was drawn to heading date, plant height, number of fertile shoots, weight of seeds per panicle, weight of 1,000 seeds, length and width of the flag leaf. For certain traits the heritability coefficient h^2 was estimated (Ray and Harms, 1994), and DNA markers were used for the analysis of quantitative traits (QTL) and linkages (STUDER *et al.*, 2008).

The evaluation of simple relationships between the traits determining the seed yield, if made using correlation coefficients, is not satisfactory because of the possible effect of the third variable or a group of variables. The partial correlation coefficients, enabling the elimination of the effects of single variables, point to the complex character of the correlation coefficients. To analyze the complex cause-and-effect system we can use Wright's path analysis (1921). This method was used to explain the interrelationships between the components of seed yield of many grass species (DEWEY and LU, 1959; FANG *et al.*, 2004; WOLFF *et al.*, 2006; ABBOTT *et al.*, 2007; GOZDOWSKI *et al.*, 2008). On the basis of the importance of direct and indirect causal variable effects on the yield, as a resulting trait, certain procedures for selection works were proposed. In the publications on grasses special attention was focused on *Festuca arundinacea* (BEAN, 1972), *Bromus catharticus* (PISTORALE et al, 1998; WOLFF *et al.*, 2006; ABBOTT *et al.*, 2007) and *Lolium perenne* (ELGERSMA *et al.*, 1994; STUDER *et al.*, 2008; GOZDOWSKI *et al.*, 2008). In meadow fescue the path analysis showed that the fertility of panicles measured by the weight of seeds per unit of panicle length was the most important component determining the yield of seeds. The number of fertile shoots, plant height and flag leaf width were also significant. Moreover, flag leaf width and plant height influenced indirectly, through panicle fertility, the yield of seeds (FANG *et al.*, 2004).

The objective of the research was to estimate the relationship between the yield of meadow fescue seeds and the yield components, special attention being focused on the susceptibility to seed shedding and the direct and indirect effects of the components on seed yield over the period of three vegetation seasons with two harvest dates.

2. Materials and methods

Reproductive capacity of meadow fescue was evaluated over the period of three vegetation seasons. Observations were made on single plants of four cultivars: Cykada, Skawa, Skiba and Skra. Field experiments were started in the year 2005. Sixty plants of each of the cultivars (6 rows with 10 plants each) were planted on August 23, the spacing being 50 cm × 60 cm. In three successive years, i.e. 2006, 2007 and 2008, observations of heading and flowering phases, as well as plant height were made. The number of days till heading was counted from May 1 of a given year, following the principles of making observations according to the OECD system (1968). Harvest was made each year, on three dates; 20 successive plants in a row were cut. When analyzing the results, only two dates were considered because of substantial percentage of seeds lost due to shedding on the third harvest date. The panicles obtained from single plants were subjected to induced seed shedding, using a modified laboratory shaker, and the weight of the fallen seeds was determined. The panicles were divided into 3 maturity groups, on the basis of their colour. For evaluation of maturation degrees a score system was used, according to modified ANDERSON'S (1981) scale:

– Degree 1 – the axis and the lower part of the panicle are green,

– Degree 2 – the axis and the upper part of the panicle are yellow,
– Degree 3 – the axis and the panicle are yellow.

The colour of the panicle having been assessed, the seeds were threshed and weighed. Then, the fallen seeds were added and the gross yield was calculated. The degree of panicle maturity was calculated as a sum of the product of the number of panicles multiplied by bonitation values of maturity degrees divided by the total number of panicles. On the basis of the observations and measurements made, the following was determined: number of days till heading (starting from May 1), number of panicles, weight of seeds per panicle, degree of maturity, weight of fallen seeds and gross seed yield.

The results obtained over the period of three years, relating to 20 single plants of each cultivar and two harvest dates, were used to calculate mean values and variability coefficients for each trait. For all the possible trait pairs phenotypical Pearson's simple correlation coefficients were calculated. The analysis of path coefficients for 3 successive vegetation seasons of individual plants and for six traits was carried out according to Wright's guidelines (1921) and the procedure applied by DEWEY and LU (1959). On the basis of the coefficients of direct effect of independent variables multiplied by the coefficients of correlation with seed yield, partial determination coefficients (R^2) were calculated.

3. Results and Discussion

In the carried out variance analyses no significant differences between the tested cultivars were found; thus, in the discussion of the results attention was focused on the characterization of the species. The mean values of seed yield and yield components compiled for years and harvest dates showed considerable seasonal variability. The average potential seed yield (gross) per plant ranged from 17.0 g to 24.5 g and increased in successive vegetation seasons (Table 1). Seed yield variability coefficients, attaining on harvest dates I and II the values 45.5–58.5% and 57.2–67.7% respectively, point to great individual variability of this trait. The higher values obtained for the second harvest date resulted from varied tendency toward seed shedding. The greater weight of fallen seeds observed for the second harvest date resulted from the degree of panicle maturity which increased from 1.79–2.27 on the first date to 2.12–2.41 on the second date. The number of panicles per plant ranged from 99 to 236, the maximum being reached in the second harvest year. That trait was negatively correlated with the weight of seeds per panicle. In the first harvest year the weight of seeds per panicle was most variable (50.4–107.6%). In next years the variability of that trait decreased (30.2–35.7%). Heading time of the tested cultivars (6.6–8.4%) and plant height (6.8–8.5%) were the most stable traits.

The analysis of phenotypical correlation coefficients showed a tendency toward negative interrelationship between the number of days till heading and maturity degree and the weight of fallen seeds (Table 2). Statistically significant correlation coefficients attained, however, rather low values (r = –0.313** to r = –0.499**). The height of plant was significantly correlated with the number of panicles, weight of fallen seeds and potential seed yield only in the third year and only for the first harvest date. The number

Table 1. Mean values for the traits of single plants (n = 40) related to harvest dates and meadow fescue vegetation seasons

Trait	Harvest date	Mean values			Standard deviation			CV%		
		Vegetation season			Vegetation season			Vegetation season		
		1	2	3	1	2	3	1	2	3
Days till heading	I II	18.0 17.7	17.6 17.4	19.4 19.4	1.35 1.34	1.41 1.46	1.28 1.45	7.5 7.5	8.0 8.4	6.6 7.5
Plant height (cm)	I II	– –	114.6 113.2	116.6 112.2	– –	8.77 7.66	9.05 9.48	– –	7.6 6.8	7.8 8.5
Number of panicles	I II	98.9 103.2	235.7 218.8	140.5 128.0	30.11 39.27	96.39 88.28	59.48 69.52	30.4 38.1	40.9 40.3	42.3 54.3
Seeds/panicle (g)	I II	0.173 0.197	0.096 0.085	0.173 0.197	0.087 0.212	0.042 0.041	0.052 0.071	50.4 107.6	43.8 48.5	30.2 35.7
Degree of maturity	I II	2.27 2.41	1.79 2.27	1.96 2.12	0.48 0.44	0.41 0.40	0.51 0.45	21.2 18.1	23.2 17.5	26.0 21.4
Fallen seeds (g)	I II	4.81 6.81	2.79 3.75	4.49 6.90	3.09 5.22	2.05 2.44	3.85 5.03	64.3 76.6	73.2 65.0	85.8 73.0
Gross seed yield	I II	16.99 18.96	21.21 17.55	23.91 24.35	9.94 12.84	9.65 10.51	11.39 13.94	58.5 67.7	45.5 59.9	47.6 57.2

of panicles per plant was the trait which determined seed yield per plant to the highest extent (r = 0.480** to r = 0.829**), and it increased as the plants grew older. The number of generative shoots was positively correlated with the weight of fallen seeds (r = 0.432** to r = 0.620**), especially for the second harvest date. In the second vegetation season an increase in the number of panicles per plant was accompanied by a decrease in the weight of seeds per panicle (r = –0.317* to r = –0.340*), calculated on the basis of gross yield. The correlation between the weight of seeds per panicle and the degree of seed maturity was negative in the first harvest year (r = –367* to r = –0.488**) when the degree of panicle maturity was greater (2.34). The positive correlation (r = 0.399*) was noted in the third year, for the second harvest date, when the degree of panicle maturity was lesser (2.04).

High positive correlations between the yield of seeds and the weight of seeds per panicle (r = 0.566** to r = 0.820**), observed in the first harvest year, decreased in successive years to r = 0.455** and r = 0.336 for the first and second harvest dates respectively. The correlation between the yield of seeds and the weight of fallen seeds was not so strong; it was significant only for the first harvest date. The degree of maturity showed a negative correlation with gross yield, except for the third vegetation season when the correlation was positive. Considering seed production, the highly significant correlation between the potential yield of seeds per plant and the weight of fallen seeds (r = 0.531** to 0.778) was especially unfavourable. The observed interrelationships between the traits indicate that as the number of generative shoots increases, uneven maturity of seeds on a plant increases as well, which, in turn, increases the tendency toward seed shedding.

The results of Wright's path analysis, taking into account the years and two harvest dates, are presented in Table 3. The calculated coefficients of the direct effects of traits, as well as the partial coefficients of determination (R^2), in spite of the variability observed for years and evaluation dates, point to certain regularities. From among the five investigated components of yield, the greatest direct effect on seed yield was exerted by

Table 2. Phenotypical coefficients of simple correlations between meadow fescue traits for two vegetations seasons and two harvest dates

Trait	Vegetation season	Harvest date	Plant height	Number of panicles	Seeds/ panicle	Degree of maturity	Fallen seeds	Seed yield (gross)
Days till heading	1	I II	– –	–0.249 –0.148	–0.077 –0.091	–0.292 0.092	–0.219 –0.324*	–0.068 –0.254
	2	I II	0.303 0.312*	–0.073 –0.215	0.101 0.398*	–0.393* –0.499**	–0.260 –0.034	0.005 0.176
	3	I II	–0.028 –0.136	–0.119 –0.077	–0.311 –0.259	–0.326* –0.313*	–0.357* –0.339*	–0.268 –0.158
Plant height	2	I II		–0.111 –0.162	0.309 0.202	–0.342 –0.190	–0.037 0.070	0.206 0.131
	3	I II		0.388* 0.115	0.190 0.209	0.309 0.224	0.462** 0.202	0.491** 0.193
Number of panicles	1	I II			–0.037 –0.166	0.116 0.166	0.432** 0.548**	0.480** 0.465**
	2	I II			–0.340* –0.317*	–0.064 0.033	0.274 0.489**	0.518** 0.602**
	3	I II			–0.136 –0.190	0.344* 0.097	0.462** 0.620**	0.789** 0.829**
Seeds/ panicle	1	I II				–0.367* –0.488**	0.509** 0.277	0.820** 0.566**
	2	I II				0.013 –0.286	0.334* 0.198	0.567** 0.452**
	3	I II				0.227 0.399*	0.371* 0.107	0.455** 0.336*
Degree of maturity	1	I II					0.215 0.066	–0.242 –0.284
	2	I II					0.256 0.138	–0.032 –0.186
	3	I II					0.331* 0.365*	0.451** 0.297
Fallen seeds	1	I II						0.675** 0.778**
	2	I II						0.531** 0.635**
	3	I II						0.669** 0.652**

*/ **/ significant at p = 0.05 and p = 0.01 (n = 40) respectively

Table 3. Coefficients of correlation (r), direct trait effects (P_nx_n) and determination (R^2 %) for the yield of meadow fescue seeds for three vegetation seasons and two harvest dates

Trait	Harvest date	Vegetation season								
		1			2			3		
		r	P_nx_n	R^2%	r	P_nx_n	R^2%	r	P_nx_n	R^2%
Days till heading	I II	–0.068 –0.254	–0.000 0.025	0.0 –0.6	0.005 0.176	–0.022 0.067	0.0 1.2	–0.268 –0.158	0.034 0.067	–0.9 –1.1
Plant height#	I II	– –	– –	– –	0.206 0.131	0.055 0.099	1.1 1.3	0.491** 0.193	0.030 –0.024	1.5 –0.5
Number of panicles	I II	0.480** 0.465**	0.486 0.254	23.3 11.8	0.518** 0.602**	0.786 0.764	40.7 46.0	0.789** 0.829**	0.802 0.892	63.3 73.9
Seeds/panicle	I II	0.820** 0.566**	0.803 0.364	65.8 20.6	0.567** 0.452**	0.805 0.621	45.6 28.1	0.455** 0.336*	0.529 0.519	24.1 17.4
Degree of maturity	I II	–0.242 –0.284	–0.014 –0.188	0.3 5.3	–0.032 –0.186	0.007 0.000	0.0 0.0	0.451* 0.297	0.027 0.005	1.1 0.1
Fallen seeds	I II	0.675** 0.778**	0.059 0.559	4.0 43.5	0.531** 0.635**	0.041 0.134	2.2 8.5	0.669** 0.652**	0.092 0.069	6.2 4.5
Residual factors (P_e)	I II	x x	0.255 0.441	x x	x x	0.161 0.398	x x	x x	0.220 0.235	x x
Total trait determination R^2 (%)	I II	x x	x x	93.4 80.6	x x	x x	89.6 85.1	x x	x x	95.3 94.3

*/ ** significant at $p < 0.05$ and 0.01 respectively
#/ data for the second and third vegetation seasons

the number of generative shoots, the share of which increased in successive vegetation seasons. This trait determined the yield of seeds to 12–23%, 39–45% and 64–74% in the third harvest year. The direct effect of the weight of seeds per panicle showed a different direction of changes in successive years; in addition, a greater effect on the yield was found for the first harvest date. Partial coefficients of determination of that trait, for the first harvest date, decreased in successive years and amounted to 64, 40% and 24% respectively. However, for the second harvest date this direction of changes was not confirmed, the values being 20, 28% and 17% respectively. FANG *et al.* (2004) also found that in meadow fescue the yield was affected most by the fertility of panicles, measured by the weight of seeds per unit of the panicle length, and the number of generative shoots. In ray grass the yield of seeds per plant was equally determined by the number of generative shoots and the weight of seeds per spike (GOZDOWSKI *et al.*, 2008), or even to a greater extent by the weight of seeds per spike (STUDER *et al.*, 2008). The variability of the effects of the investigated components results from the modifying effects of other independent variables and environmental factors. Beside the effects of agrotechnical factors, pollination, fertilization and formation of seeds are of great significance (ABBOTT *et al.*, 2007).

Table 4. Path coefficients for three meadow fescue vegetation seasons

Trait	Vegetation season		
	1	2	3
(1) Heading – gross yield (7) r [1,7]	0.177	0.109	–0.204
Direct effect P [1,7]	0.012	0.012	0.037
Indirect through (2)		0.025	0.000
Indirect through (3)	–0.067	–0.100	–0.081
Indirect through (4)	–0.020	0.182	–0.142
Indirect through (5)	0.022	0.008	0.001
Indirect through (6)	–0.125	–0.016	–0.018
(2) Plant height – gross yield r [2,7]	–	0.180	0.310
Direct effect P [2,7]	–	0.079	0.000
Indirect through (1)	–	0.004	–0.003
Indirect through (3)	–	–0.094	0.218
Indirect through (4)	–	0.187	0.077
Indirect through (5)	–	0.005	0.000
Indirect through (6)		0.000	0.018
(3) Number of panicles – gross yield r [2,7]	0.473**	0.563**	0.807**
Direct effect P [2,7]	0.344	0.755	0.867
Indirect through (1)	–0.002	–0.002	–0.003
Indirect through (2)	–	–0.010	0.000
Indirect through (4)	–0.056	–0.220	–0.096
Indirect through (5)	–0.027	0.001	0.000
Indirect through (6)	0.215	0.039	0.040
(4) Seeds/panicle – gross yield r [3,7]	0.607**	0.517**	0.377**
Direct effect P [3,7]	0.448	0.702	0.527
Indirect through (1)	–0.001	0.003	–0.010
Indirect through (2)	–0.043	0.021	0.000
Indirect through (3)	–	–0.237	–0.159
Indirect through (5)	0.071	0.003	–0.001
Indirect through (6)	0.132	0.025	0.019
(5) Degree of maturity – gross yield r [4,7]	–0.244*	–0.186	0.364**
Direct effect P [4,7]	–0.181	–0.018	–0.002
Indirect through (1)	–0.001	–0.005	–0.011
Indirect through (2)	0.051	–0.023	0.000
Indirect through (3)	–	–0.048	0.171
Indirect through (4)	–0.174	–0.123	0.176

Trait	Vegetation season		
	1	2	3
Indirect through (6)	0.062	0.030	0.030
(6) Fallen seeds – gross yield r [5,7]	0.707**	0.529**	0.640**
Direct effect P [5,7]	0.424	0.111	0.079
Indirect through (1)	–0.003	–0.002	–0.008
Indirect through (2)	0.174	0.000	0.000
Indirect through (3)	–	0.266	0.442
Indirect through (4)	0.139	0.159	0.127
Indirect through (5)	–0.027	–0.005	–0.001
Residual factors P [x,7]	0.473	0.367	0.243
Coefficient of determination (R^2%)	77.6	86.3	94.9

The direct effect of fallen seeds on the yield of seeds did not become apparent in the investigated system of cause-effect variables, although the coefficients of correlations between these traits were high. A significant direct effect of the weight of fallen seeds on the yield of seeds was noted only in the first year, for the second harvest date. The degree of panicle maturity did not affect significantly the yield of seeds per plant. Low values of residual factors ($P_{e)}$, found for the first harvest date, were higher for the second harvest date. The total value of partial coefficients of determination (R^2), ranging from 93% to 97% for the first harvest date and from 80% to 94% for the second harvest date, show that the analyzed components explain well the phenotypical variability of meadow fescue seed yield.

The path analysis carried out for 80 plants harvested on two dates, in spite of non-additiveness of the correlation coefficients, showed similar results for the cause-effect relationships (Table 4). The direct effects of the investigated traits showed good conformity with the data presented in the former Table. The highest coefficients of the direct effects of the number of panicles and the weight of seeds per panicle, observed in the second harvest year, indicate that this may be the best time to start direct plant selection aimed at the yield of seeds. The tabulated data made it possible to examine generally small indirect effects of the investigated yield components. A negative trend of the indirect effect was found for the weight of seeds per panicle, through the number of panicles, on the yield of seeds. The indirect effect of the degree of panicle maturity, through the weight of seeds per panicle, was rather weak and varied from year to year. The positive indirect effect of the weight of fallen seeds, through the number of panicles, on the yield of seeds became evident especially in the third harvest year.

4. Conclusions

- A significant, direct effect of number of generative shoots per plant determining the yield of seeds per plant was reduced by indirect negative effects of the weight of seeds per panicle and the weight of fallen seeds.

- The greatest direct effect of the number of generative shoots on the yield of seeds, noted in the third year, suggests that the selection made in later vegetation seasons is a right action.
- The number of generative shoots positively correlated with the weight of fallen seeds points to the necessity for their optimization, because the excessive number of generative shoots per plant increases the unevenness of panicle maturity and, in consequence, the tendency toward seed shedding and losses in the yield of seeds.

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Korelacje i analiza ścieżek komponentów plonu nasion
Festuca pratensis

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Streszczenie

Plon nasion i komponenty plonu badano na pojedynczych roślinach kostrzewy łąkowej wysadzonych w szerokiej rozstawie. Próbę reprezentatywną stanowiły rośliny 4 odmian (Cykada, Skawa, Skiba i Skra) wpisanych do katalogu UE. Na podstawie obserwacji i pomiarów 20 roślin z dwóch terminów zbioru i trzech lat wegetacji roślin określono liczbę dni do kłoszenia, liczbę wiech, masę nasion/wiechę, stopień dojrzałości osadek wiechy, masę nasion osypanych indukowaną w warunkach laboratoryjnych oraz plon nasion brutto. Dla wymienionych cech obliczono wartości średnie, współczynniki zmienności, proste współczynniki korelacji oraz współczynniki ścieżek Wrighta. W okresie trzech lat doświadczeń największą zmienność wykazała masa nasion z wiechy, plon nasion z rośliny oraz liczba wiech zwłaszcza w pierwszym roku zbioru nasion. Spośród badanych cech plon nasion z rośliny był najsilniej skorelowany z liczbą wiech na roślinie (r = 0,480** do r = 0,829**) oraz masą nasion z wiechy (r = 0,336* do r = 0,820**). Ze wzrostem liczby wiech na roślinie zwiększała się masa nasion osypanych (r = 0,432** do r = 0,620**). Analiza ścieżek potwierdziła, że zwiększająca się w kolejnych latach wegetacji liczba wiech na roślinie determinowała plon nasion odpowiednio w 12–23%, 40–46% oraz 63–74% w trzecim roku zbioru kostrzewy łąkowej. Największy bezpośredni wpływ liczby wiech i masy nasion z wiechy na plon nasion obserwowano w drugim roku zbioru nasion. Negatywny trend pośredniego wpływu wykazała masa nasion poprzez liczbę wiech na plon nasion. Pozytywny pośredni wpływ masy nasion poprzez liczbę wiech na plon nasion ujawnił się w trzecim roku zbioru i wskazuje, że wraz z zwiększeniem liczby wiech na roślinie zwiększa się nierównomierne ich dojrzewanie powodujące większą skłonność do osypywania nasion.

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