EKOLOGIA POLSKA (Ekol. pol.)	22	2	417–440	1974

Ewa SYMONIDES

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MORPHOLOGICAL VARIABILITY OF *SPERGULA VERNALIS* WILLD. FROM DIFFERENT DUNE BIOTOPES OF THE TORUŃ BASIN

ABSTRACT: This paper is concerned with the morphological variability of *Spergula vernalis* Willd, and the effect of different habitat conditions on the variability of different organs. Biometric analysis was made of 5000 plants, taking 11 morphological characters into consideration, over a period of three years differing as to weather conditions, on five stands, each of which formed a separate stage in the spread of vegetation over the dune. The analysis revealed which characters are distinguished by the greatest variability and correlation. The study also contains the results of growing *Spergula vernalis* for the purpose of checking the correctness of the assumption that such variability is phenotypic in character.

Contents

1. INTRODUCTION

The attention of a large number of researchers has been concentrated for a long time on the problem of the morphological variability of plants. A considerable percentage of biometric studies in this field deals with questions of taxonomy and systematics but there is a disproportionately small number of papers concerned with the morphological variability of plants from the aspect of causal connections with the habitat (cf. J e n t y s - S z a f e r o w a 1971).

An analysis of the morphological variability of *Spergula vernalis* Willd. was made during the period from 1969 to 1971 in five populations from different dune biotopes. The stands from which material was taken for the studies differed not only in respect of the degree of plant cover and floristic composition, but also in respect of differing physical and chemical properties of the soils.

Stand 1. A sandbank continually eroded by wind, within the initial patch of *Spergulo-Corynephoretum.* The soil has an unformed profile, is very infertile and dry. Humus content at a depth of 10 cm – 0.24%, most frequently recorded soil moisture– about 2.9%.

Stand 2. A sandbank continually eroded by wind in a local depression in the area, within a typical patch of *Spergulo-Corynephoretum.* The dominating species is *Spergula vernalis.* Under the layer of windborne sand there is a weakly formed humus horizon. Humus content at a depth of 10 cm – 0.55%, most frequently recorded soil moisture – 3.7%.

Stand 3. Sands stabilized to a considerable degree, covered by a patch of *Spergulo-Corynephoretum*, with a large percentage of *Polytrichum piliferum* Schreb. (60%). A humus horizon (3 cm) can be seen in the soil profile, lying on unchanged parent rock. Humus content at a depth of 10 cm – 0.38%, most frequently recorded soil moisture – 4.2%.

Stand 4. Extensive moorland *(Arctostaphyllo-Callunetum)* with a large percentage of *Cladonia rangiferina* (L.) Web. (75%). Distinct humus horizon (6 cm) in the soil profile, lying on weakly changed parent rock. Humus contents at a depth of 10 cm – 1.40%, most frequently recorded soil moisture – 6.1%.

Stand 5. Part of dune densely covered by grassy vegetation, with *Calamagrostis epigeios* Roth. as the dominating species. Soil profile – as on stand 4. Humus content at a depth of 10 cm – 1.20%, most frequently recorded soil moisture – 5.4%.

A more detailed description of the stands and also of the climatic conditions during the study period are to be found in the study by S y m o n i d e s (1974).

On account of biotope differences individuals of *Spergula vernalis* from one area are treated in this paper as a separate population and given the same number as the stand from which they were taken.

2. GENERAL PREMISES

The usefulness of undertaking biometric studies on *Spergula vernalis* was suggested by the differences, very distinct even at a first glance, in the growth of individuals representing different biotopes. The question then arose as to whether they also apply to other characters of the plant. On account of the somewhat small and open area and the consequently easy spread of winged seeds it could be assumed that the differences discovered form the expression of the complex and different effect of the habitat of the different areas compared. In order to check the correctness of the assumption that such variability is phenotypic in character, comparison was made on three stands of progeny cultivated from the seeds of a different population from the parent individuals. Two variants of such cultures, one with greater and the other with lesser density, were intended to define the effect of intraspecies competition on the morphological characters of the plants.

Comparison of results obtained from biometric analysis of the morphological characters of a plant with the abiotic and biotic factors of the chosen stands was aimed at indicating those characters of the habitat which exert the greatest influence on variability of the different organs of *Spergula vernalis.* In order to grasp the possible effect of climatic conditions each population was analyzed in three consecutive years.

Finally, it appeared interesting to investigate whether variation in one character brings about variation in a second, and to define the character of the correlations between different pairs of characters.

3. METHODS

Biometric studies were made of a total of 5000 individuals chosen at random. During the first year measurements were first made of 100 individuals on each stand, then the numbers of samples were increased by several hundred more. Initial calculations showed that a series consisting of 100 individuals is sufficiently representative and this number was adhered to in subsequent measurements.

A further character, namely root length, was added in the two subsequent years to the 10 characters taken into consideration in 1969.

The following is a list of these characters: (1) length of stem, (2) length of root (not taken into consideration in 1969), (3) length of leaf from the first whorl, (4) length of leaf from the third whorl, (5) number of capsules, (6) number of seeds in the first capsule, (7) length of seed, (8) width of seed, (9) width of the seed wing opposite the incision, (10) maximal width of the seed wing, (11) relation of maximal width of the seed wing to length of the seed.

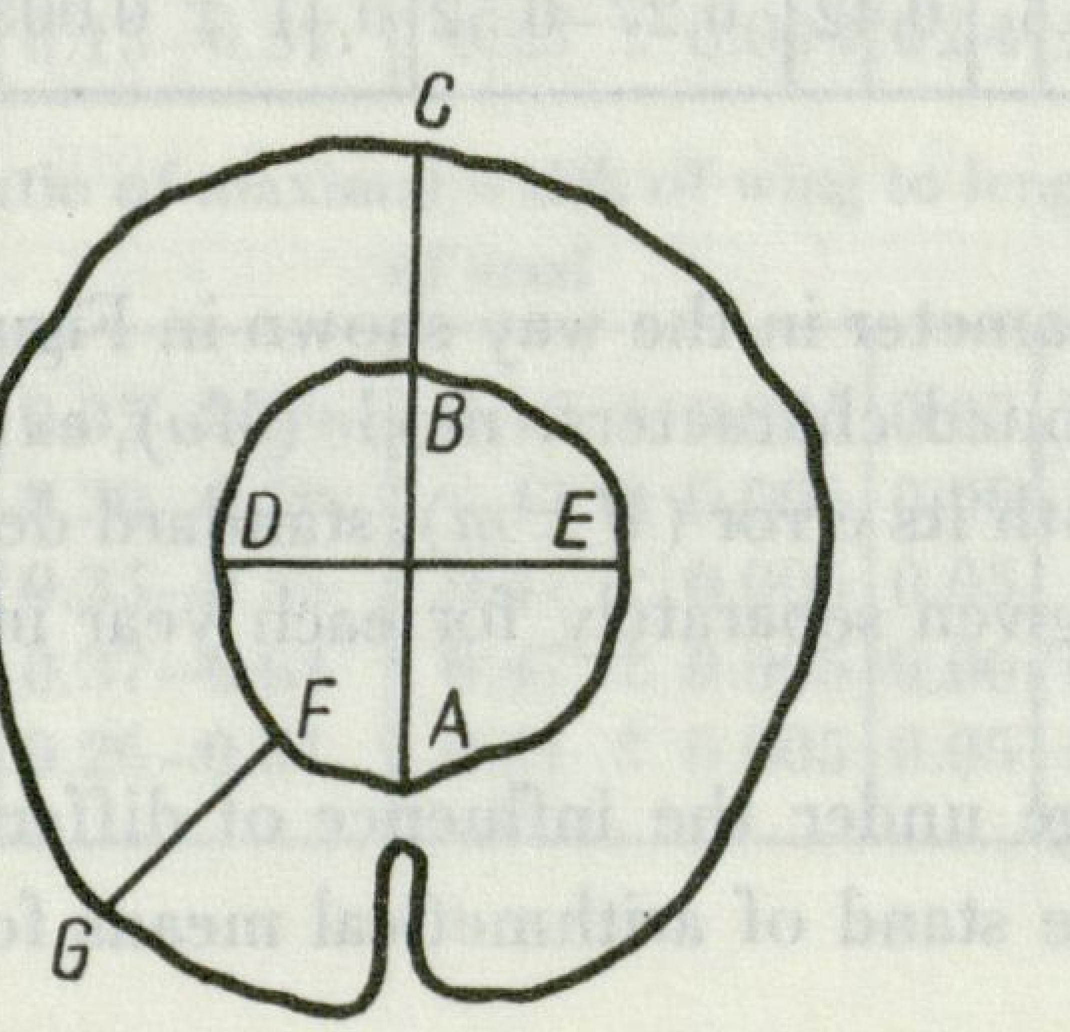

Fig. 1. Way in which seeds were measured

***A–B* – length of seed, *D–E* – width of seed, *B–C* – width of seed wing opposite incision, *F–G* – maximal width of wing, *F–G*/*A–B* – ratio of maximal width of wing to length of seed**

Tab. 1. Comparison of morphological characters of five populations (1969)
(explanations in text – Section 3)

Population	Mo	Min.-Max.	$M \pm m$	σ	V	Mo	Min.-Max.	$M \pm m$	σ	V
	1. length of stem (cm)					3. length of leaf from first whorl (mm)				
1	6.1	3.8–11.4	6.0 ± 0.067	0.96	15.9	1.1	0.7–1.6	1.13 ± 0.008	0.13	11.5
2	8.3	5.4–13.9	8.5 ± 0.050	1.77	20.8	1.3	0.8–1.8	1.31 ± 0.003	0.11	8.5
3	8.3	5.1–18.3	9.1 ± 0.011	2.28	25.1	1.2	0.6–1.7	1.14 ± 0.008	0.18	15.4
4	11.6	6.3–23.9	12.9 ± 0.011	3.64	28.2	1.7	0.8–2.4	1.56 ± 0.010	0.28	17.8
5	7.2	3.6–11.4	7.2 ± 0.060	1.22	17.0	0.8	0.4–1.5	0.76 ± 0.008	0.17	21.8
	4. length of leaf from third whorl (mm)					5. number of capsules				
1	0.5	0.3–0.9	0.50 ± 0.007	0.11	20.0	4	2–10	4.7 ± 0.10	1.77	37.1
2	0.6	0.4–0.9	0.60 ± 0.003	0.10	15.9	6	1–12	6.4 ± 0.05	1.77	27.5
3	0.5	0.4–0.9	0.60 ± 0.009	0.17	28.7	6	2–14	6.2 ± 0.09	2.07	32.1
4	0.7	0.3–1.0	0.68 ± 0.004	0.13	19.6	7	3–15	7.8 ± 0.08	2.25	28.6
5	0.4	0.2–0.8	0.40 ± 0.005	0.10	22.8	4	1–8	3.9 ± 0.06	1.26	31.8
	6. number of seeds in 1 capsule					7. length of seed (mm)				
1	24	16–37	26 ± 0.31	4.35	16.9	0.90	0.74–1.00	0.92 ± 0.004	0.063	6.89
2	39	24–49	39 ± 0.27	3.88	9.9	0.90	0.82–1.02	0.91 ± 0.002	0.032	3.50
3	36	20–47	35 ± 0.33	4.74	13.6	0.90	0.74–0.99	0.88 ± 0.004	0.046	6.36
4	39	21–48	37 ± 0.41	5.76	15.6	0.90	0.64–1.01	0.87 ± 0.004	0.062	7.19
5	24	15–37	24 ± 0.33	4.71	19.6	0.90	0.64–0.99	0.87 ± 0.004	0.064	7.35
	8. width of seed (mm)					9. width of wing opposite incision (mm)				
1	0.90	0.74–1.03	0.89 ± 0.004	0.054	6.06	0.30	0.16–0.42	0.27 ± 0.003	0.048	17.8
2	0.90	0.74–0.99	0.87 ± 0.003	0.047	5.40	0.30	0.19–0.39	0.28 ± 0.003	0.038	13.7
3	0.85	0.66–0.96	0.84 ± 0.004	0.052	6.20	0.30	0.16–0.42	0.28 ± 0.004	0.062	22.1
4	0.85	0.64–1.00	0.83 ± 0.003	0.052	6.26	0.30	0.21–0.49	0.31 ± 0.004	0.055	18.2
5	0.85	0.64–1.01	0.86 ± 0.004	0.058	6.74	0.25	0.14–0.34	0.25 ± 0.003	0.043	17.1
	10. maximal width of wing (mm)					11. ratio of maximal width of wing to length of seed				
1	0.40	0.31–0.56	0.43 ± 0.004	0.052	11.9	0.45	0.34–0.58	0.47 ± 0.005	0.050	10.9
2	0.40	0.28–0.53	0.41 ± 0.005	0.063	15.3	0.38	0.30–0.58	0.42 ± 0.006	0.060	13.9
3	0.40	0.31–0.56	0.43 ± 0.003	0.043	10.0	0.48	0.36–0.55	0.47 ± 0.005	0.047	9.8
4	0.40	0.32–0.54	0.41 ± 0.004	0.052	12.7	0.47	0.38–0.63	0.47 ± 0.005	0.054	11.3
5	0.35	0.26–0.48	0.35 ± 0.003	0.048	13.5	0.42	0.27–0.52	0.41 ± 0.005	0.052	12.5

The seeds were measured with an MP 4 lanameter in the way shown in Figure 1.

Characteristic figures for the above-mentioned characters: mode (Mo), extreme values (max. – min.), arithmetical mean together with its error ($M \pm m$), standard deviation (σ) and coefficient of variability (V) have been given separately for each year in Tables I, II and III.

In order to show which characters change under the influence of different climatic conditions, comparison was made within one stand of arithmetical means for 1969 and

Tab. II. Comparison of morphological characters of five populations (1970) (explanations in text – Section 3)

Population	*Mo*	Min.-Max.	*M* ± *m*	σ	*V*	*Mo*	Min.-Max.	*M* ± *m*	σ	*V*
	1. length of stem (cm)					2. length of root (cm)				
1	6.1	3.4–10.6	5.9 ± 0.11	1.06	17.8	10.5	5.9–12.9	9.8 ± 0.15	1.49	15.1
2	8.3	5.2–13.4	8.3 ± 0.15	1.45	17.4	12.7	9.0–17.3	13.2 ± 0.17	1.75	13.3
3	8.3	4.6–19.8	9.4 ± 0.25	2.50	26.5	10.5	6.7–13.4	10.5 ± 0.14	1.38	13.2
4	11.6	5.9–23.9	19.9 ± 0.35	3.54	27.3	7.2	6.1–11.9	7.9 ± 0.15	1.51	19.1
5	7.2	4.3–10.9	7.2 ± 0.13	1.30	18.2	9.4	5.6–13.1	9.5 ± 0.15	1.52	15.9
	3. length of leaf from first whorl (mm)					4. length of leaf from third whorl (mm)				
1	1.1	0.6–1.7	1.11 ± 0.017	0.17	15.6	0.5	0.3–0.8	0.5 ± 0.012	0.12	22.9
2	1.2	0.9–1.9	1.24 ± 0.020	0.20	16.4	0.6	0.3–0.9	0.6 ± 0.015	0.15	25.3
3	1.1	0.6–1.6	1.05 ± 0.019	0.19	18.2	0.5	0.3–0.9	0.6 ± 0.014	0.14	24.1
4	1.7	0.7–2.2	1.54 ± 0.033	0.33	21.3	0.7	0.3–0.9	0.7 ± 0.013	0.13	19.6
5	0.8	0.4–1.4	0.82 ± 0.022	0.22	26.4	0.4	0.2–0.7	0.4 ± 0.012	0.12	28.2
	5. number of capsules					6. number of seeds in 1 capsule				
1	4	1–9	4.4 ± 0.18	1.78	40.3	24	15–34	25 ± 0.38	3.84	15.2
2	6	2–13	6.4 ± 0.19	1.86	42.1	39	23–48	38 ± 0.52	5.25	13.9
3	5	1–13	5.7 ± 0.21	2.12	37.1	36	19–44	33 ± 0.55	5.54	16.8
4	7	2–13	7.5 ± 0.27	2.67	35.4	39	21–46	37 ± 0.56	5.65	15.4
5	4	1–7	4.0 ± 0.13	1.27	31.9	24	14–36	24 ± 0.46	4.65	19.5
	7. length of seed (mm)					8. width of seed (mm)				
1	0.90	0.75–1.14	0.91 ± 0.007	0.07	8.17	0.80	0.65–1.00	0.82 ± 0.007	0.07	8.54
2	0.90	0.78–1.02	0.92 ± 0.006	0.06	6.55	0.90	0.77–1.05	0.88 ± 0.006	0.06	6.40
3	0.90	0.77–1.02	0.88 ± 0.005	0.05	6.25	0.85	0.63–0.94	0.84 ± 0.004	0.04	5.19
4	0.90	0.69–0.97	0.87 ± 0.005	0.06	6.35	0.85	0.65–1.00	0.83 ± 0.005	0.05	5.88
5	0.90	0.65–1.00	0.89 ± 0.006	0.06	6.90	0.90	0.60–1.03	0.86 ± 0.006	0.06	7.14
	9. width of wing opposite incision (mm)					10. maximal width of wing (mm)				
1	0.25	0.14–0.40	0.26 ± 0.005	0.05	17.9	0.45	0.32–0.51	0.43 ± 0.005	0.05	10.9
2	0.25	0.17–0.36	0.26 ± 0.004	0.04	15.8	0.35	0.26–0.52	0.40 ± 0.006	0.06	14.1
3	0.30	0.15–0.40	0.29 ± 0.006	0.06	20.8	0.40	0.29–0.51	0.42 ± 0.004	0.04	10.2
4	0.30	0.18–0.46	0.31 ± 0.005	0.05	17.3	0.40	0.31–0.51	0.42 ± 0.005	0.05	11.5
5	0.25	0.15–0.31	0.25 ± 0.004	0.04	15.4	0.35	0.25–0.46	0.36 ± 0.005	0.05	12.7
	11. ratio of maximal width of wing to length of seed									
1	0.45	0.35–0.59	0.47 ± 0.005	0.05	10.9					
2	0.39	0.30–0.59	0.43 ± 0.006	0.06	13.9					
3	0.48	0.35–0.55	0.47 ± 0.005	0.05	9.8					
4	0.48	0.37–0.64	0.47 ± 0.005	0.06	11.5					
5	0.42	0.26–0.51	0.41 ± 0.005	0.05	12.6					

Tab. III. Comparison of morphological characters of five populations (1971) (explanations in text – Section 3)

Population	*Mo*	Min.-Max.	*M* ± *m*	σ	*V*	*Mo*	Min.-Max	*M* ± *m*	σ	*V*
	1. length of stem (cm)					2. length of root (cm)				
1	7.2	4.1–10.9	6.4 ± 0.12	1.21	18.7	11.6	7.1–13.7	10.6 ± 0.15	1.54	14.5
2	9.4	5.3–14.7	9.1 ± 0.15	1.50	16.5	13.8	9.1–19.4	13.7 ± 0.21	2.07	15.1
3	9.4	5.4–19.6	10.0 ± 0.27	2.70	27.0	9.4	5.2–19.7	10.6 ± 0.26	2.65	25.0
4	12.7	7.8–24.9	13.9 ± 0.31	3.13	22.5	8.3	6.9–12.4	9.1 ± 0.16	1.57	17.3
5	7.2	4.2–11.7	7.2 ± 0.17	1.67	22.8	9.4	6.2–13.3	10.1 ± 0.15	1.54	15.4
	3. length of leaf from first whorl (mm)					4. length of leaf from third whorl (mm)				
1	1.2	0.6–1.9	1.21 ± 0.016	0.16	13.5	0.6	0.3–0.9	0.6 ± 0.013	0.13	24.1
2	1.3	0.9–1.9	1.31 ± 0.017	0.17	13.0	0.6	0.2–0.9	0.6 ± 0.014	0.14	20.9
3	1.2	0.7–1.8	1.20 ± 0.020	0.19	15.5	0.5	0.4–1.0	0.7 ± 0.015	0.15	22.4
4	1.8	0.8–2.3	1.66 ± 0.028	0.28	16.8	0.7	0.3–1.0	0.7 ± 0.014	0.14	20.1
5	0.9	0.4–1.8	0.93 ± 0.027	0.27	29.5	0.5	0.2–0.8	0.5 ± 0.014	0.14	30.3
	5. number of capsules					6. number of seeds in 1 capsule				
1	5	2–10	5.3 ± 0.16	1.57	29.6	27	16–38	26 ± 0.36	3.6	14.0
2	6	2–13	7.0 ± 0.20	1.96	27.9	39	24–49	39 ± 0.43	4.3	11.0
3	6	2–13	6.2 ± 0.17	1.72	27.6	36	21–43	34 ± 0.52	5.2	15.2
4	9	5–16	9.5 ± 0.22	2.19	22.9	39	23–47	38 ± 0.45	4.5	11.8
5	5	1–8	4.3 ± 0.16	1.64	37.7	24	13–35	24 ± 0.51	5.1	20.7
	7. length of seed (mm)					8. width of seed (mm)				
1	0.90	0.74–1.10	0.91 ± 0.007	0.07	8.16	0.80	0.64–1.00	0.82 ± 0.005	0.07	8.53
2	0.90	0.78–1.02	0.93 ± 0.006	0.06	6.56	0.90	0.78–1.06	0.88 ± 0.006	0.06	6.40
3	0.90	0.78–1.02	0.89 ± 0.005	0.06	6.25	0.85	0.62–0.93	0.84 ± 0.004	0.04	5.19
4	0.90	0.69–0.97	0.87 ± 0.005	0.06	6.34	0.85	0.65–1.00	0.83 ± 0.005	0.05	5.87
5	0.90	0.64–1.00	0.88 ± 0.006	0.06	6.88	0.90	0.60–1.04	0.86 ± 0.006	0.06	7.19
	9. width of wing opposite incision (mm)					10. maximal width of wing (mm)				
1	0.25	0.15–0.41	0.26 ± 0.005	0.05	17.9	0.45	0.33–0.51	0.43 ± 0.005	0.05	10.9
2	0.25	0.16–0.38	0.26 ± 0.004	0.04	15.7	0.35	0.25–0.51	0.40 ± 0.006	0.06	14.2
3	0.30	0.14–0.39	0.29 ± 0.006	0.06	20.9	0.40	0.29–0.52	0.43 ± 0.004	0.04	10.1
4	0.30	0.17–0.45	0.30 ± 0.005	0.05	17.2	0.40	0.29–0.49	0.42 ± 0.005	0.05	11.6
5	0.25	0.14–0.32	0.25 ± 0.004	0.04	15.5	0.35	0.26–0.46	0.36 ± 0.005	0.05	12.7
	11. ratio of maximal width of wing to length of seed									
1	0.45	0.35–0.59	0.47 ± 0.005	0.05	10.9					
2	0.39	0.29–0.59	0.43 ± 0.006	0.06	14.0					
3	0.48	0.34–0.56	0.47 ± 0.005	0.05	9.8					
4	0.45	0.36–0.64	0.46 ± 0.005	0.05	11.4					
5	0.42	0.25–0.50	0.41 ± 0.005	0.05	12.5					

1971 with the arithmetical means of analogical characters for 1970, using the J e n t y s-- S z a f e r o w a (1959) diagram method.

The experimental plots for cultivation were set up on stands 1, 4 and 5. The flowering individuals were first removed and seeds sown in August 1970 in the following combinations: (1) on stand 4 seeds from population 5, (2) on stand 1 seeds from population 4, (3) on stand 2 seeds from population 5.

Two variants of the above were made: scanty (1 seed per 1 cm^2) and dense sowing (1 seed per 0.2 cm^2). The following year in May the plants obtained were compared with the parent plants for the given stand in respect of four characters: length of stem, length of root, length of leaf from first whorl and number of capsules. The arithmetical means of these characters, together with their mean errors, have been given in Table IV.

Comparison of populations was in principle made in two ways: the diagram method for comparing size and shape (J e n t y s - S z a f e r o w a 1959) and Wanke's index

Tab. IV. Morphological characters of individuals cultivated

A – individuals grown from seeds from population 5 on stand 4, *B* – individuals grown from seeds from population 4 on stand 1, *C* – individuals grown from seeds of population 2 on stand 5, *a* – grown from spaced sowing, *b* – grown from dense sowing, $M \pm m$ arithmetical mean together with its error

Characters		Variants of cultivation		
		A	*B*	*C*
Stem length (cm) ($M \pm m$)	*a*	13.3 ± 0.30	7.0 ± 0.19	7.1 ± 0.22
	b	12.8 ± 0.27	6.5 ± 0.6	7.1 ± 0.19
Root length (cm) ($M \pm m$)	*a*	8.8 ± 0.19	9.4 ± 0.21	10.0 ± 0.23
	b	9.5 ± 0.16	9.9 ± 0.17	10.3 ± 0.18
Length of leaf from first whorl (mm) ($M \pm m$)	*a*	1.7 ± 0.022	1.3 ± 0.019	1.1 ± 0.018
	b	1.6 ± 0.029	1.3 ± 0.014	0.9 ± 0.011
Number of capsules ($M \pm m$)	*a*	9.9 ± 1.7	6.1 ± 1.5	4.8 ± 1.1
	b	8.7 ± 1.1	5.7 ± 1.0	4.6 ± 0.9

method (W a n k e 1954, O l e k i e w i c z 1956), primarily in order to check its suitability for differentiation of this type of series.

Differences between the various characters for all populations are illustrated in diagram form on polygonal graphs, taking into consideration the standard values of characters (P e r k a l 1958) and on frequency diagrams.

4. DISCUSSION OF RESULTS

4.1. Effect of climatic factors on morphological variability

The picture of the relation of analogical characters in the years compared is given in diagram form in Figure 2. The reversed order of the two first characters on the diagram in relation to those given in section 3 was due to the lack of measurements of root length for the first study year.

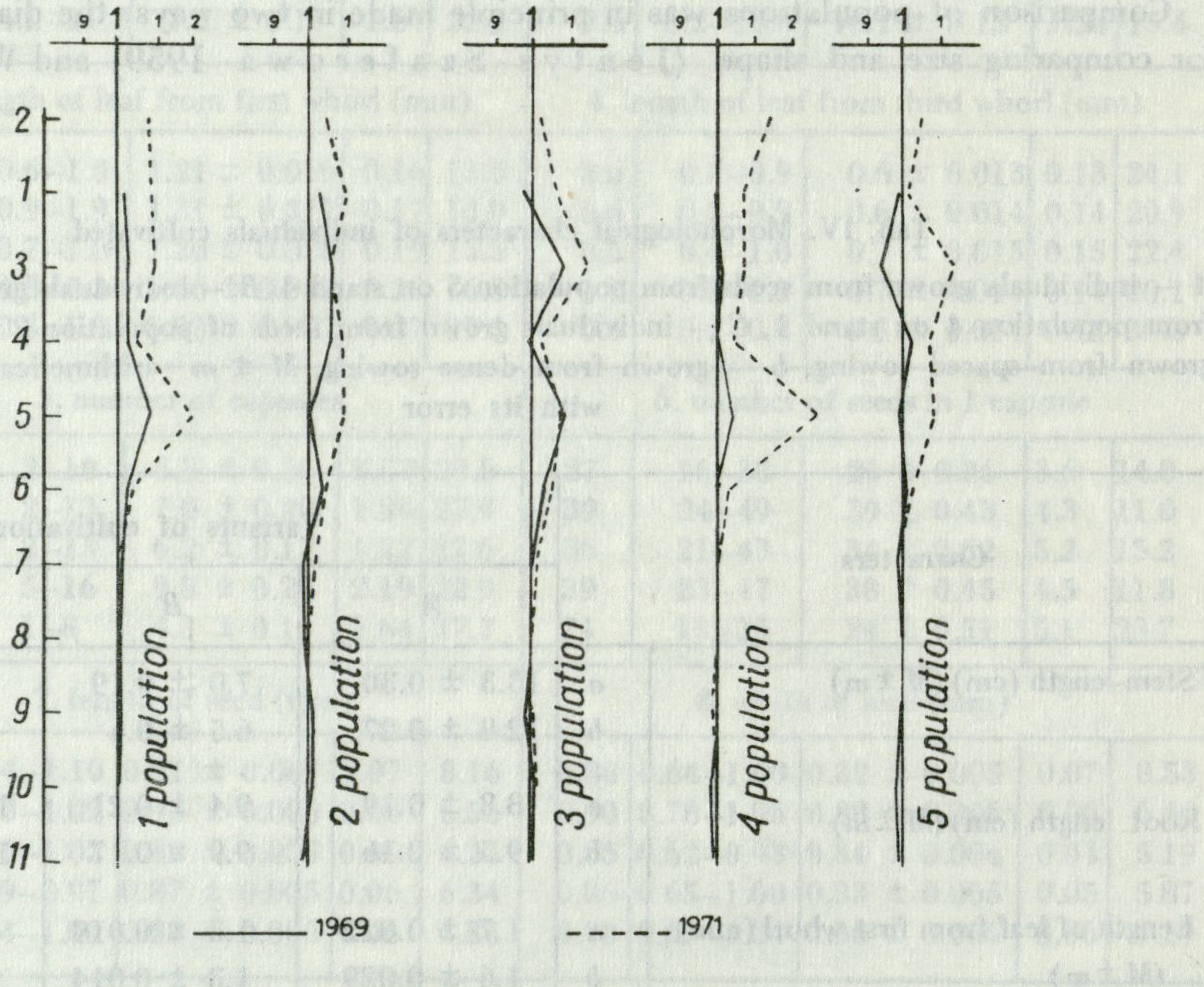

Fig. 2. Comparison of individuals from 1969 and 1971 (angular lines) with individuals from 1970 (vertical lines) within one population

Figures on horizontal scale indicate the values of the ratio of arithmetical means for characters of the populations in the years compared (after Jentys-Szaferowa 1959). Numbers of characters as in Tables I, II, III

It can be seen from Figure 2 that differences found within one population are generally slight, particularly in relation to results for 1969 and 1970. In principle it is only characters 1–5 which are subject to variation, the greatest fluctuations being in respect of number of capsules (5), then leaf length (3 and 4). The number of seeds in a capsule, and especially their size and shape (6–11), are distinguished by exceptionally great stability. The minimum differences found in the years compared permit of considering the characters of seeds as constant for the given population (and biotope) and not subject to the effect of climatic conditions.

When analysis is made of the results illustrated in Figure 2 from the aspect of differing weather factors in different years, it may be concluded that the most favourable conditions for the plants' development were those during the growing season 1970/1971 (abundant rainfall in autumn and fairly high temperature in spring). On all the stands the plants were taller that year, had longer roots and leaves, and fruited more abundantly (Tab. I, II, III).

4.2. Effect of biotope factors on morphological variability

Among the 11 morphological characters of *Spergula vernalis* taken into consideration in biometric analysis certain give a distinct reflection of the more or less favourable biotope conditions for the species. This is shown primarily by differences, proved to be statistically significant, between the arithmetical means of characters in the study populations (Fig. 3).

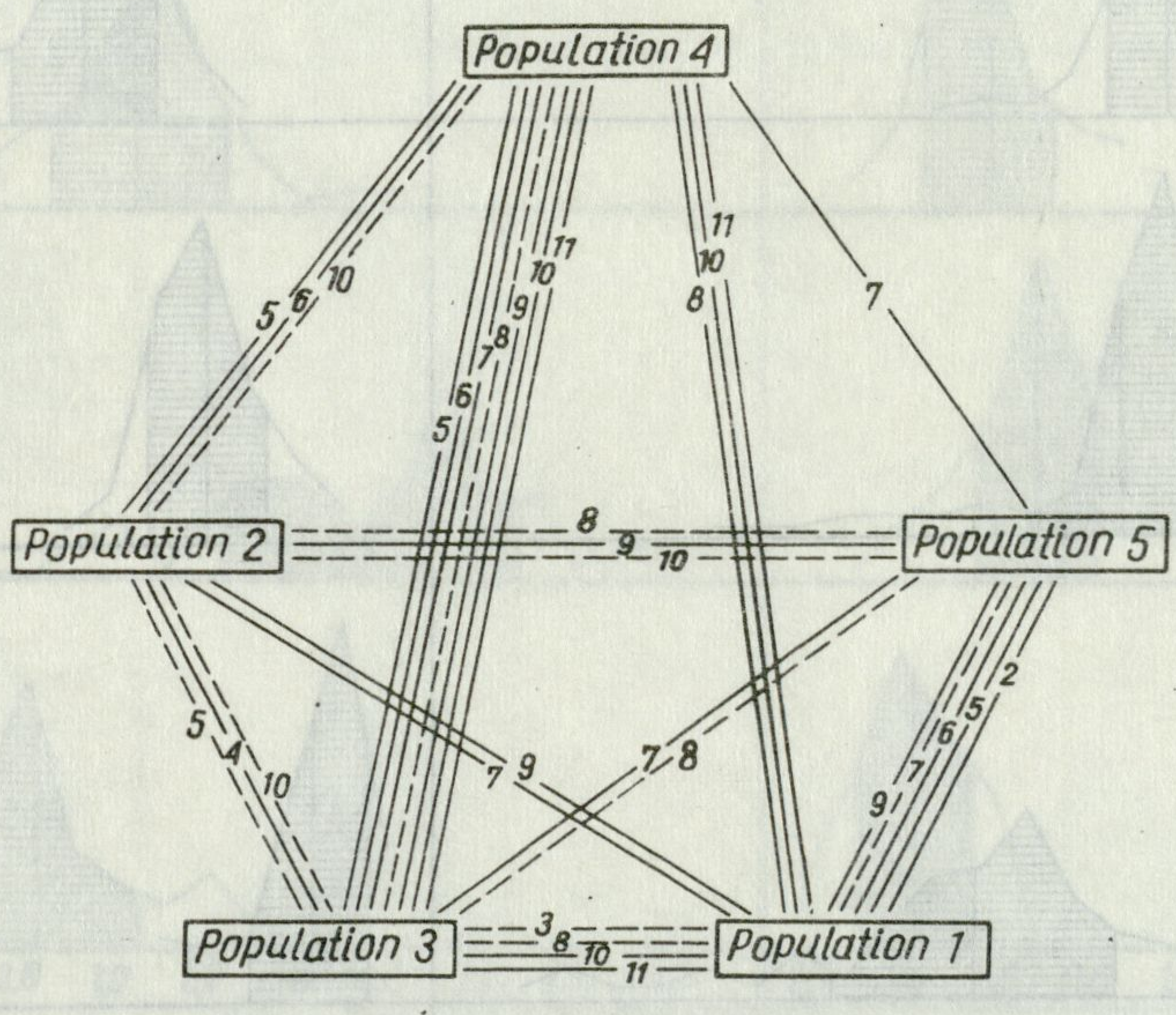

Fig. 3. List of characters which do not exhibit significant differences between arithmetical means for the study populations (continuous line) and which differ on a level of 5% (broken line)

Numbers of characters as in Tables I, II, III

Data show that length of root, stem and leaves and number of capsules and seeds depends to the greatest degree on the effect of the biotope, and therefore the populations differ from each other most in respect of these characters (Fig. 4, 5, 6). Confirmation of these observations is provided by results of the cultivation operations presented in Figure 7. The diagram shows the distinct similarity of the cultivated individuals – from seeds of a different population to the parent plants on the given stand. They are particularly clearly evident in comparison with the average individuals on the stand from

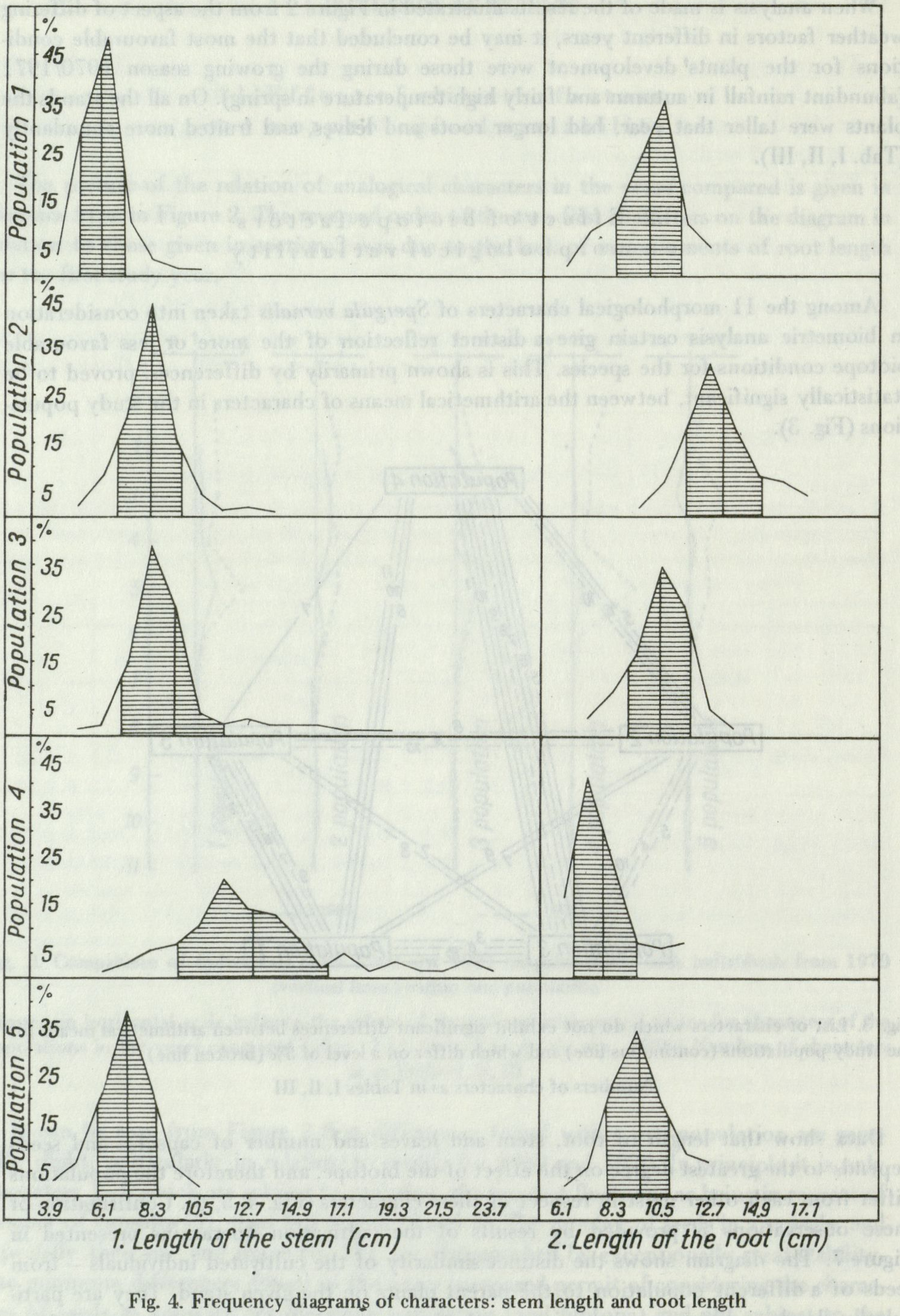

Fig. 4. Frequency diagrams of characters: stem length and root length

Shaded field indicates value of arithmetical mean together with its standard deviation

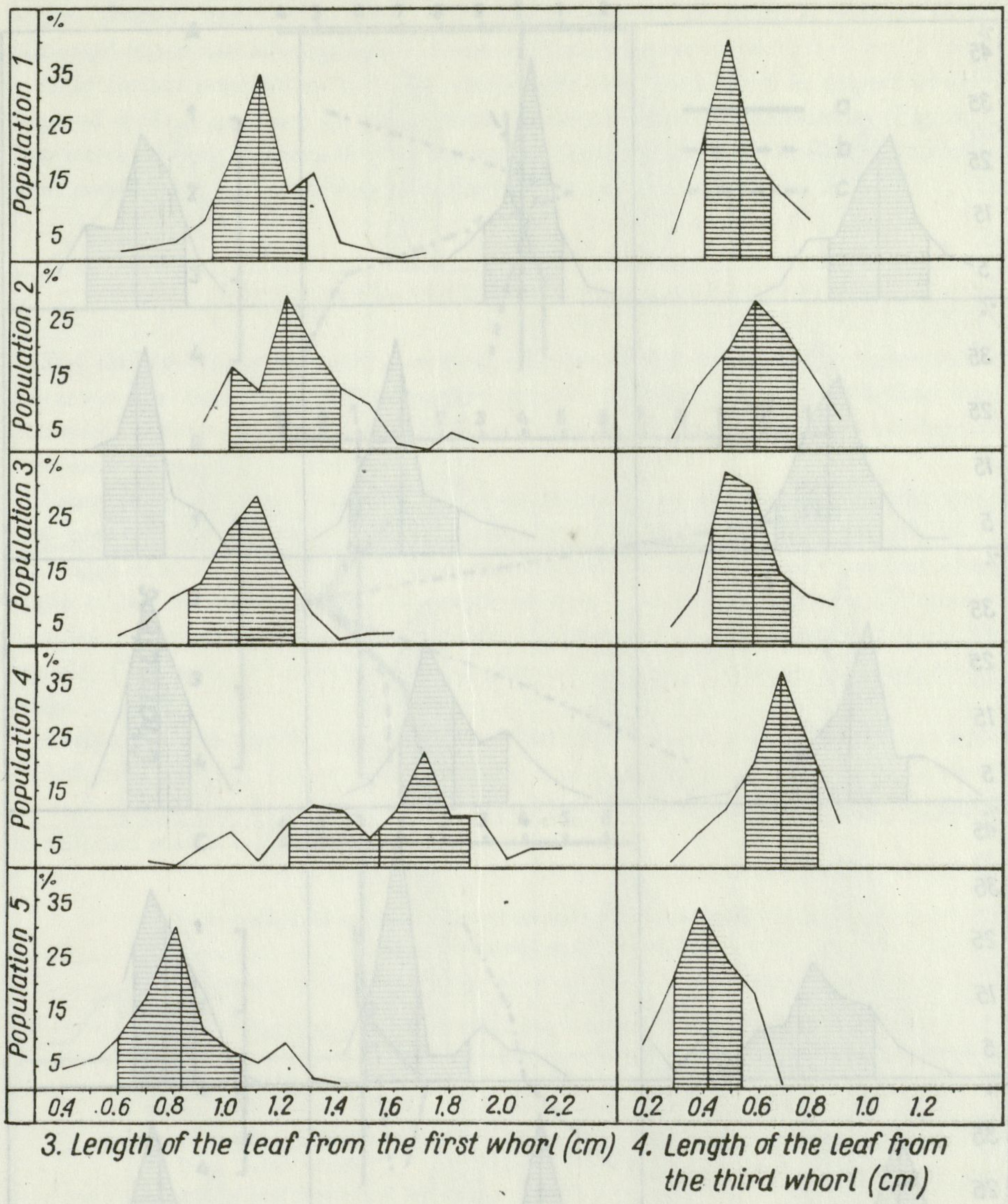

Fig. 5. Frequency diagrams of characters: length of leaf from first whorl and length of leaf from third whorl

Shaded field indicates value of arithmetical mean together with its standard deviation

which seeds were taken. Undoubtedly such results form evidence of the effect of local biotope conditions on formation of the plant and therefore confirm the assumption as to the phenotypic character of variability. It can also be concluded from Figure 7 that the characters most susceptible to the effect of the biotope are length of stem and abundance of fruiting.

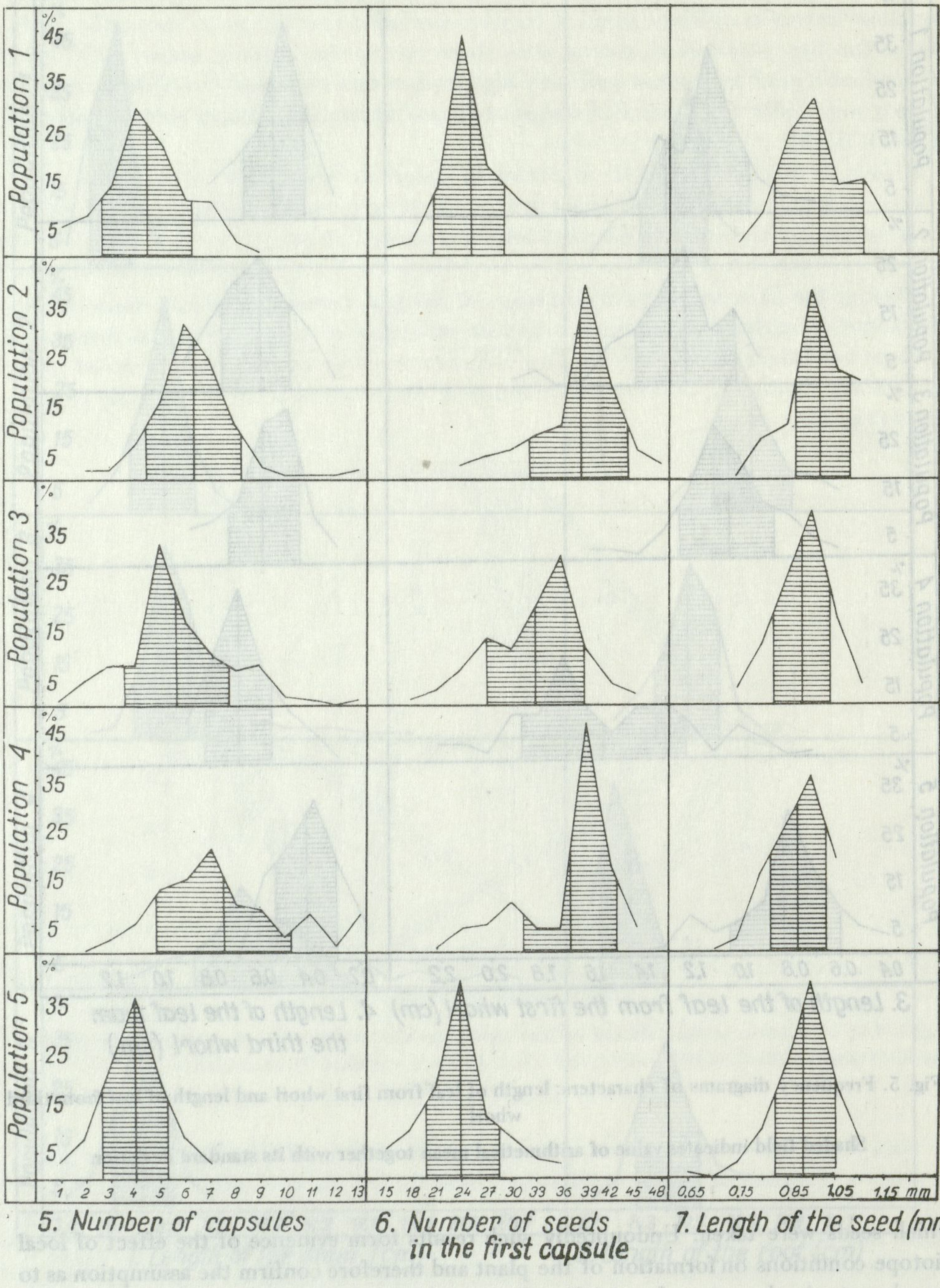

Fig. 6. Frequency diagrams of characters: number of capsules, number of seeds in 1 capsule and length of seed

Shaded field indicates value of arithmetical mean together with its standard deviation

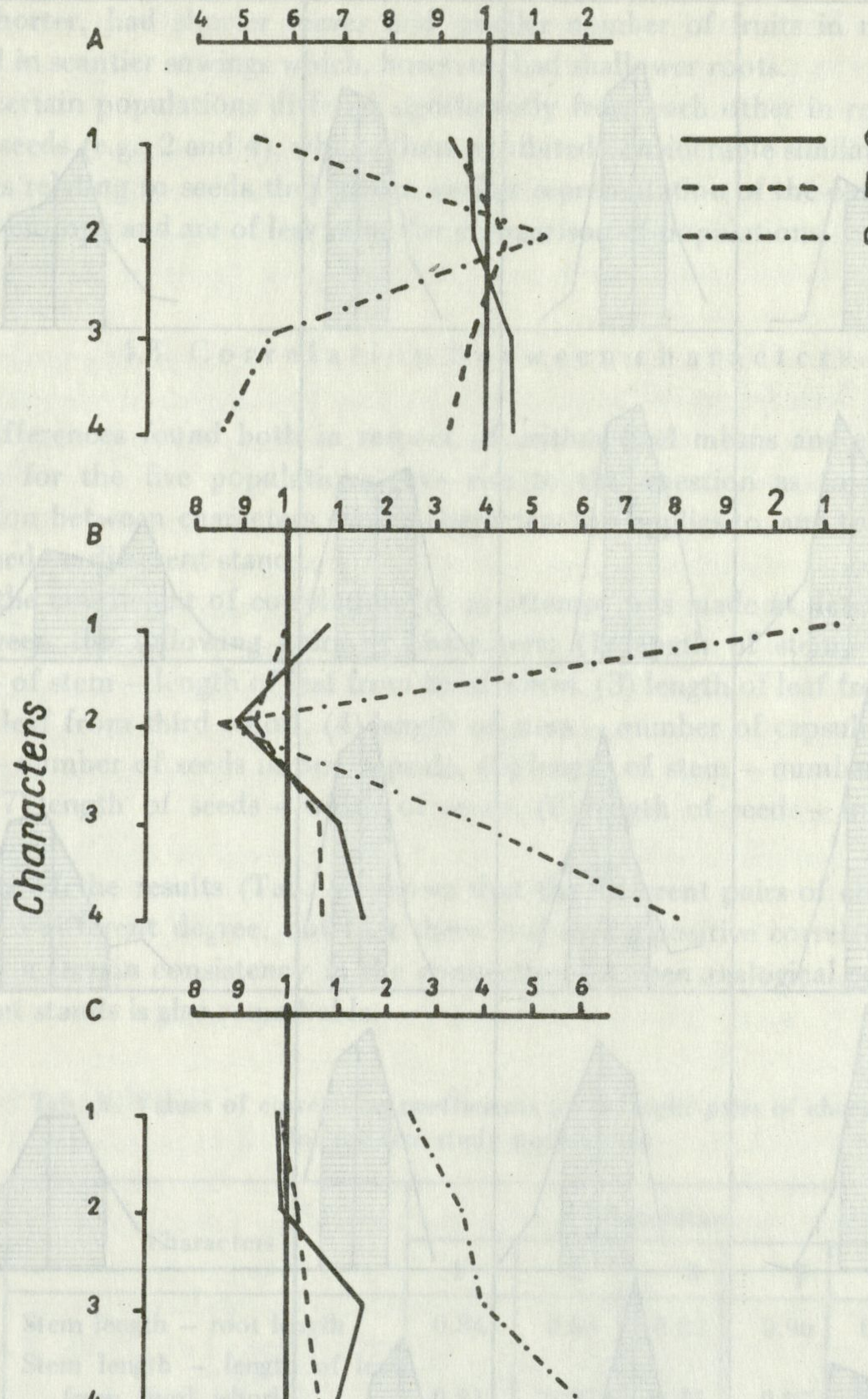

Fig. 7. Comparison of individuals grown on stand 4 from seeds from population 5 *(A)*, on stand 1 from seeds from population 4 *(B)* and on stand 2 from seeds from population 5 *(C)* with parent plants for the given stand

a – plants grown from spaced sowing, *b* – plants grown from dense sowing, *c* – plants from parent stand for the given seeds. Figures on horizontal scale indicate values of the ratio of arithmetical means for characters of the individuals compared (after J e n t y s - S z a f e r o w a 1959). Characters *1–4* as in Table IV

Differences between individuals originating from scanty and from dense sowing are not so great as might have been expected. It must, however, be emphasised that on account of the high mortality among the seedlings it proved impossible to cultivate very densely sown plants. In general, fully grown individuals in a very dense sowing were more even in

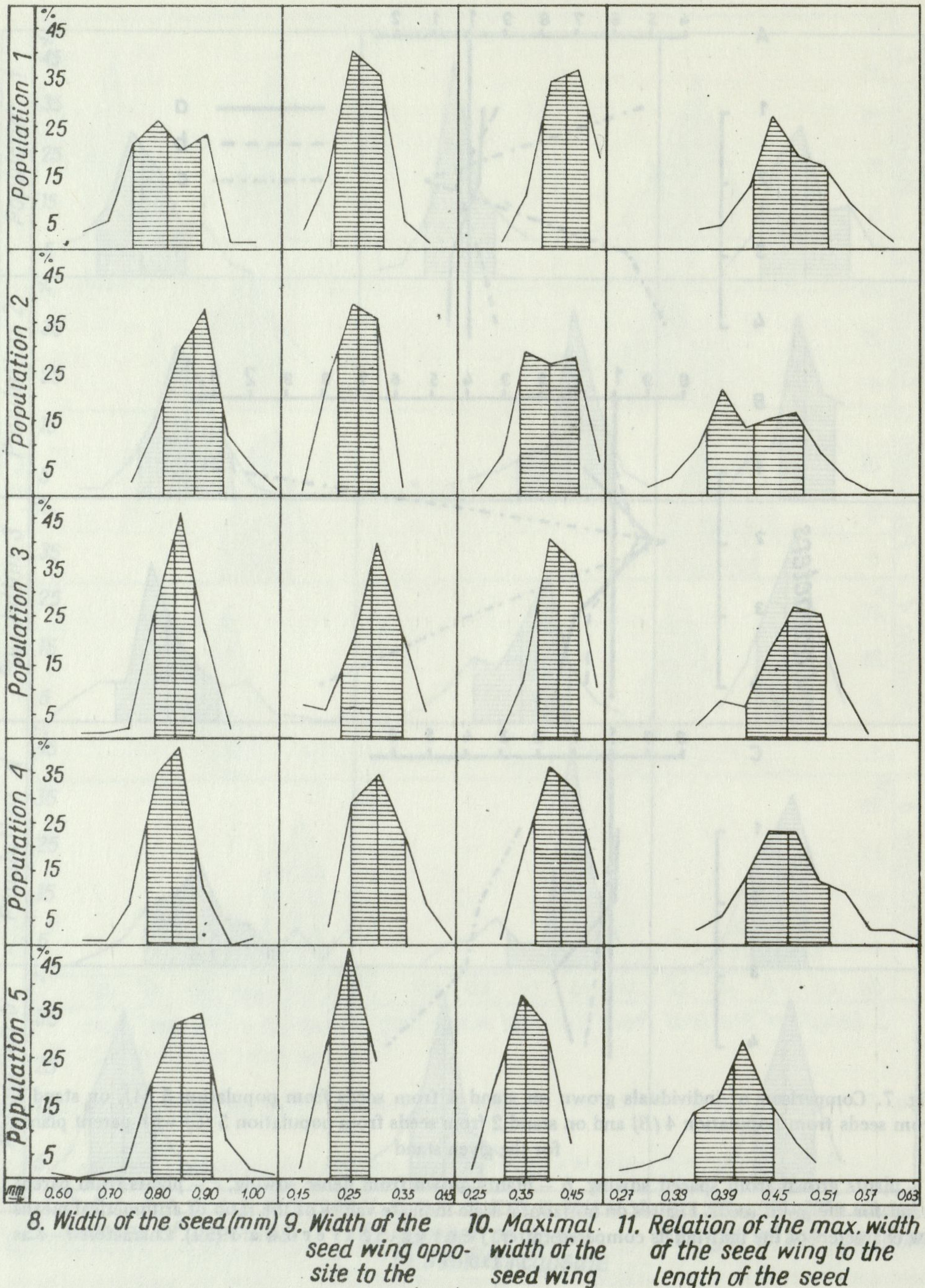

Fig. 8. Frequency diagrams for characters: width of seed, width of seed wing opposite incision, maximal width of wing and ratio of maximal breadth of wing to length of seed

Shaded field indicates value of arithmetical mean together with its standard deviation height, shorter, had shorter leaves and smaller number of fruits in relation to plants cultivated in scantier sowings which, however, had shallower roots.

Only certain populations differed significantly from each other in respect of size and shape of seeds (e.g., 2 and 4), while others exhibited considerable similarity (Fig. 3, 6, 8). Characters relating to seeds thus give a weaker representation of the connection between plant and biotope and are of less value for comparison of populations.

4.3. Correlation between characters

The differences found both in respect of arithmetical means and extreme values of characters for the five populations gave rise to the question as to whether there is a correlation between characters, which characters this applies to, and to what degree this is confirmed on different stands.

Using the coefficient of correlation (*r*) an attempt was made at determining correlations between the following pairs of characters: (1) length of stem – length of root, (2) length of stem – length of leaf from third whorl, (3) length of leaf from first whorl – length of leaf from third whorl, (4) length of stem – number of capsules, (5) number of capsules – number of seeds in one capsule, (6) length of stem – number of seeds in one capsule, (7) length of seeds – width of seeds, (8) length of seeds – maximal width of wings.

Analysis of the results (Tab. V) shows that the different pairs of characters are correlated to a different degree, but that there is always a positive correlation. In addition the fact of a certain consistency in the connection between analogical pairs of characters on different stands is also remarkable.

Tab. V. Values of correlation coefficients (*r*) for eight pairs of characters for the five study populations

Characters	Population				
	1	2	3	4	5
Stem length – root length	0.84	0.63	0.82	0.96	0.82
Stem length – length of leaf from third whorl	0.81	0.87	0.85	0.87	0.84
Length of leaf from first whorl length of leaf from third whorl	0.93	0.94	0.94	0.96	0.94
Stem length – numer of capsules	0.79	0.91	0.80	0.93	0.80
Stem length – number of seeds in 1 capsule	0.15	0.33	0.57	0.60	0.42
Number of capsules – number of seeds in 1 capsule	0.23	0.46	0.43	0.53	0.46
Length of seed – width of seed	0.64	0.45	0.39	0.51	0.75
Length of seed – maximal width of wing	0.25	0.22	0.22	0.16	0.24

Stem length is fairly closely connected with root length although not to a uniform degree on all areas, which is due to a great extent to their character. On desely covered stands which are consequently usually moister in the upper layers (as it is difficult for water to evaporate from the soil) root length is in proportion to stem length (stands 3, 4 and 5). On bare sands (stands 1 and 2), where water evaporates unusually rapidly from the superficial layers of soil, it often happens that insignificant plants have a strongly developed deep root system, better adapted both to holding the plant firmly on labile dune sands and to taking water from deeper levels.

Stem length is also closely correlated with leaf length. Although only leaves from the third whorl were included in the calculations, the very high degree of correlation shown for leaves from the first and third whorl permits of concluding indirectly that, in general, there is correlation between stem length and leaf length.

Values of correlation coefficients for length of leaf from the first and third whorls are maintained within a very narrow range when the populations are compared in this respect. As shown in Table V, this pair of characters exhibits the closest connection.

The data given above show that within one population, the higher the stems, the longer the roots and leaves, and the greater the number of capsules on these plants.

No such close correlation, nor consequences in this respect in the series examined, were found for the other pairs of characters. It must be emphasised that correlation was taken as significant in the present study where $r > 0.4$.

4.4. Comparison of populations by the Jentys-Szaferowa (1959) diagram and Wanke's (1954) index method

In analysing samples by the Jentys-Szaferowa (1959) diagram method the arithmetical means of characters and their standard deviation in population 4 was taken as the unit for comparison, comparing with them in turn the arithmetical means of characters and their standard deviation for the other four populations. Choice of the comparative unit was made on the strength of the fact that the average individual from stand 4 corresponds most closely with the description of the species in literature (Bock 1908, Oberdorfer 1949, Dostál 1950, Rothmaler 1958, Fournier 1961, Szafer, Kulczyński and Pawłowski 1967).

Calculation of the relation of arithmetical means of characters with reference unit shows that the picture of similarity and difference between the series compared is not subject to general changes in time. On this account, in order to avoid unnecessary increase in the volume of this study, diagrams relating to similarity of populations are presented only in relation to results for one year (1970).

The results illustrated in Figure 9 show that in comparison with the comparative unit the other populations are characterized by a shorter stem and shorter leaves, but a longer root. In each case differences are significant at a level of 1%. The populations compared are in addition characterized by a smaller number of capsules and – apart from sample 2 – a smaller number of seeds per capsule. The length of seeds in relation to unit of reference is slightly greater, although it is only on stands 1 and 2 that the seeds differ

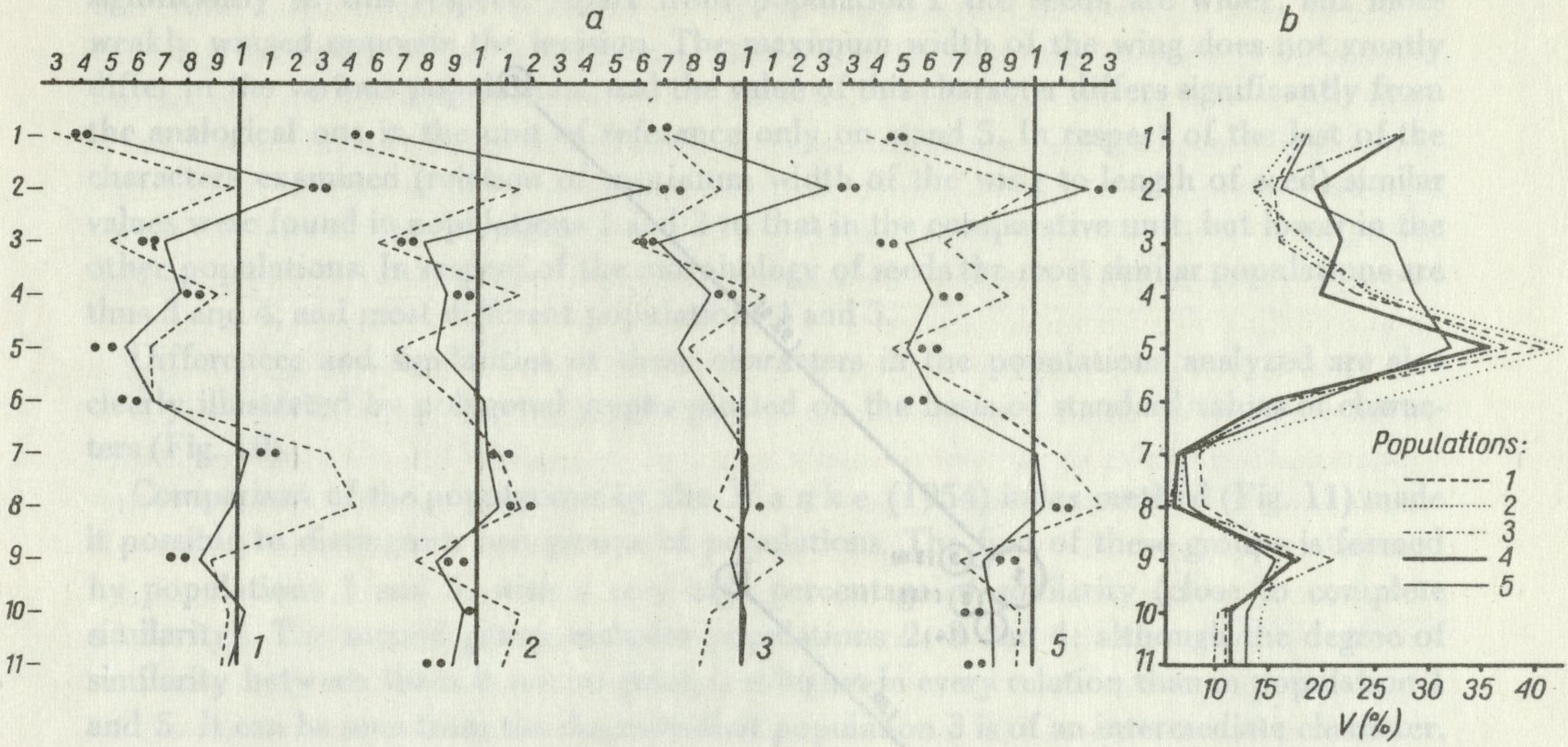

Fig. 9. *a* – Comparison of 11 characters (continuous angular curves) and their variability (broken curves) of populations 1, 2, 3 and 5 with population 4 (vertical lines), *b* – diagram of coefficients of variation *(V)* for the characters examined

On the horizontal scale the figures indicate the value of the ratio of arithmetical means and dispersion of characters of the populations compared (after Jentys-Szaferowa 1959). Characters *1–11* as in Tables I, II, III, (..) – difference significant on level of 1%, (.) – difference significant on level of 5%

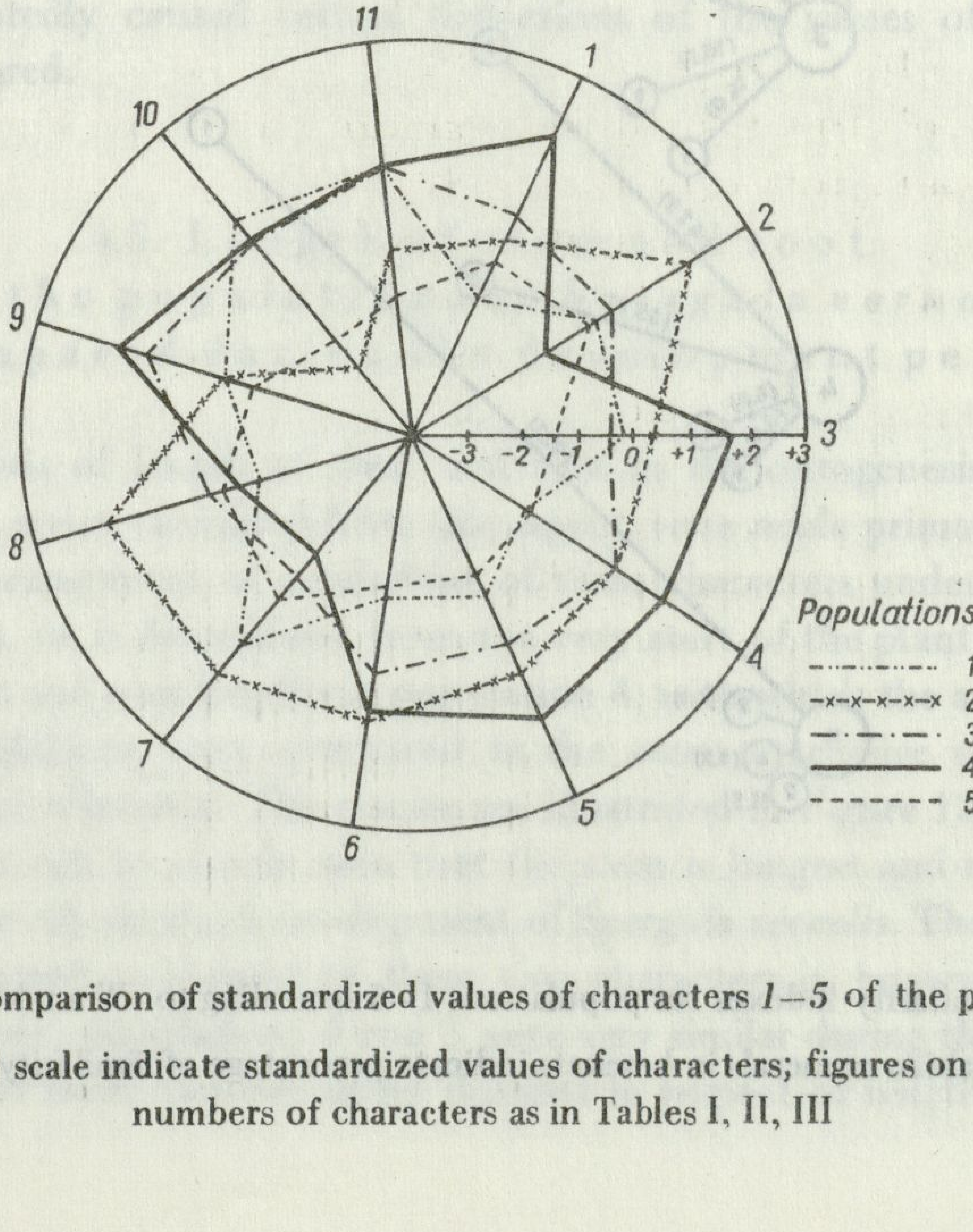

Fig. 10. Comparison of standardized values of characters *1–5* of the populations

Figures on horizontal scale indicate standardized values of characters; figures on periphery of circle – numbers of characters as in Tables I, II, III

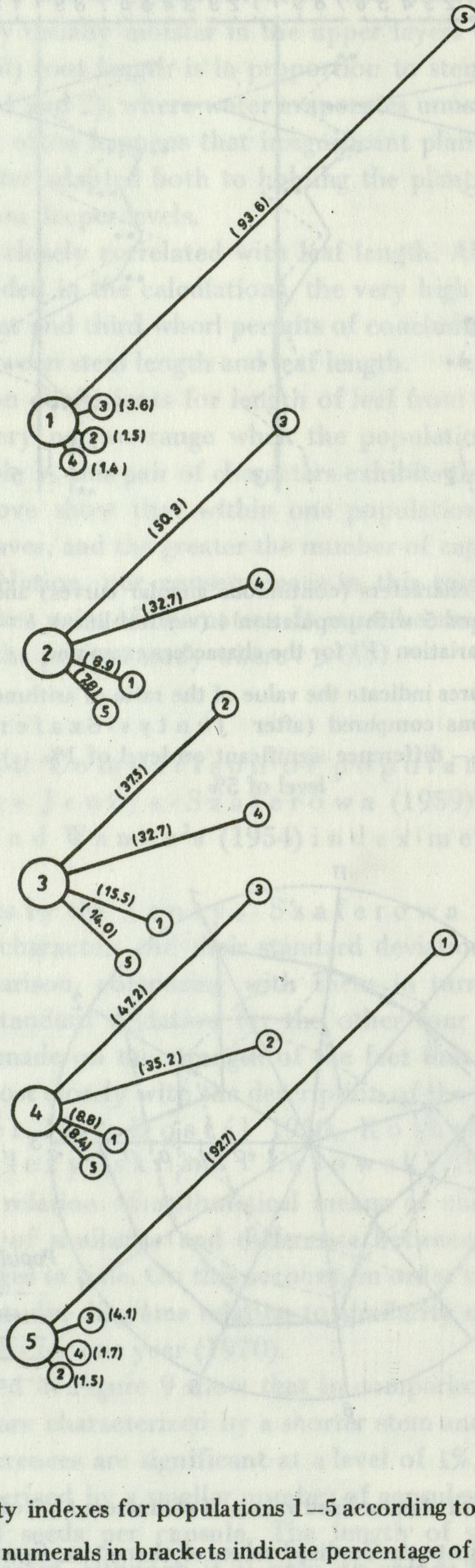

Fig. 11. Diagram of similarity indexes for populations 1–5 according to W a n k e ' s (1954) method

Arabian numerals in brackets indicate percentage of similarity significantly in this respect. Apart from population 1 the seeds are wider, but more weakly winged opposite the incision. The maximum width of the wing does not greatly differ in the various populations, and the value of this character differs significantly from the analogical one in the unit of reference only on stand 5. In respect of the last of the characters examined (relation of maximum width of the wing to length of seed) similar values were found in populations 1 and 3 to that in the comparative unit, but lower in the other populations. In respect of the morphology of seeds the most similar populations are thus 3 and 4, and most different populations 4 and 5.

Differences and similarities of these characters in the populations analyzed are also clearly illustrated by polygonal graphs plotted on the basis of standard values of characters (Fig. 10).

Comparison of the populations by the W a n k e (1954) index method (Fig. 11) made it possible to distinguish two groups of populations. The first of these groups is formed by populations 1 and 5, with a very high percentage of similarity (close to complete similarity). The second group includes populations 2, 3 and 4: although the degree of similarity between them is not so great, it is higher in every relation than in population 1 and 5. It can be seen from the diagrams that population 3 is of an intermediate character, as the distribution of similarities in the compared series is the most equal in this case.

The results obtained by the diagram method and W a n k e's (1954) method are thus almost identical, nevertheless the similarity of populations 1 and 5, according to W a n k e's (1954) indexes would appear exaggerated due to the inaccuracies of the method. The values of the indexes are determined to the greatest extent by characters, the absolute value of which is expressed by a large number, in this case the number of seeds, or number of capsules. The participation of all other characters, particularly size of seeds and wings, is disproportionately small. The lack of equivalent treatment of the characters undoubtedly caused certain distortions of the values of similarity for the populations compared.

4.5. Length of stem and root in the populations of *Spergula vernalis* compared during the development period

Biometric analysis of length of stem and root in the ontogenesis of the plant, and comparison of the series examined from this aspect, were made primarily in order to find out whether the arrangement of similarities of these characters undergoes change during the growing season, or is determined from the very start of the plant's life. The arithmetical means of stem and root lengths in population 4, with which the analogical characters of the other populations were compared in the seven successive measurements, were taken as the unit of reference. The results are illustrated in Figure 12, and would appear interesting, since it can be clearly seen that the stem is longest and root shortest in the comparative unit in all stages of development of *Spergula vernalis*. The value of similarity of the series compared in respect of these two characters is, however, subject to basic changes. For instance, populations 4 and 5 were very similar during the juvenile period in respect of length of stem, but decidedly differed in respect of length of root. The final effect of growth of the two organs gave a differing picture of similarity: the two populations were characterized by similar root length and basic difference in stem length. The same can be said of the remaining populations, except for population 2. In the last case the root was always longer, not only in relation to the comparative population but also to the others.

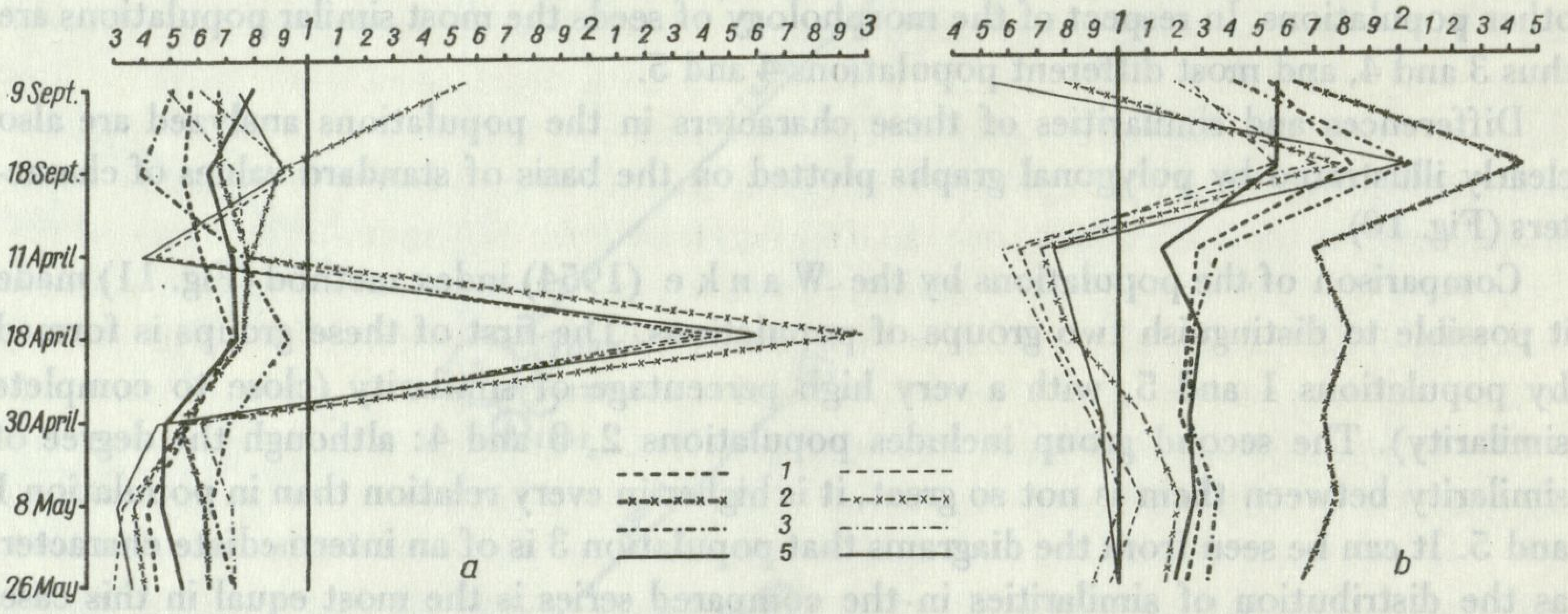

Fig. 12. Comparison of stem length *(a)* and root length *(b)* and variability of these characters for populations 1, 2, 3 and 5 (angular lines) with population 4 (vertical lines) during the growing season

Figures on horizontal scale indicate values of ratio of arithmetical means and dispersion of characters for the populations compared (after Jentys-Szaferowa 1959). Thicker line indicates characters, thinner line — variability of characters

The curves of variation for these two characters are also interesting (Fig. 12). During the period of intensive growth of the roots (September) and stems (April) the coefficients of variation are particularly large but later decrease considerably in comparison with population 4.

5. CONCLUSIONS

1. Biometric analysis of a large number of morphological characters of *Spergula vernalis* from different biotopes points to the phenotypic character of variability. Stem length is most influenced by the habitat, as are also length of root and leaves and number of capsules. The number and shape of seeds are among the more stabilized characters.

2. Morphological variability of the species depends primarily on edaphic factors, while the part played by the microclimate is less distinct. This is shown by: (a) the similarity of individuals in three years differing as to weather conditions and (b) distinct differences between individuals cultivated in a different biotope from that from which the seeds were obtained, and individuals coming from the parent stand of the seeds.

3. Analysis of the morphological characters of *Spergula vernalis* and the properties of the biotopes of the stands compared led to the conclusion that none of these characters exhibit direct dependence on any one factor, but are the result of the coaction of several linked parameters (cf. Matuszkiewicz 1948).

4. The most variable character proved to be stem length. According to Sulma, Tokarz and Wierzchowska-Renke (1967), this property distinguishes particularly plants with a wide ecological scale.

5. The nutrient components and moisture contents in the soil have a distinct effect on the height of the plant. A striking example of this is on the one hand the luxuriant growth of individuals in population 4 (coming from a stand relatively rich in moisture and humus), and on the other the moderate growth of individuals in population 1 (growing on outstandingly infertile and dry sands). These data are confirmed by the results given by a large number of researchers (Gore 1961, Marshall 1965, Willis 1965).

6. The factor of interspecies competition, particularly in relation to the most plastic characters – stem and leaf length and abundance of fruits – is of no less importance than moisture and nutrient components in the soil. This is shown by comparison in respect of the above characters between populations 4 and 5 and – correspondingly – stands 4 and 5, where the soil properties are similar, but the density and in particular the species composition of the accompanying vegetation differ. The generally weak formation of individuals in population 5 would appear to be due to the greater competitive strength of species growing with *Spergula vernalis* (Ellenberg 1952, Zarzycki 1965). In this particular case an important role in competition can be attributed to the unusually dynamic *Calamagrostis epigeios* (Nowinski 1967), which is capable of "starving" the other species.

7. The size of the roots is primarily the function of soil moisture in the superficial layers. On wetter soils the root systems of plants are shallower (stand 4) than on drier stands (stands 1 and 2). This regularity is confirmed in relation to all species which use chiefly precipitation as a source of water (Salisbury 1952, Król 1963, Coupland and Johnston 1965).

8. Abundant fruiting is not always accompanied by well-shaped and large seeds (Bartkowiak and Gostyńska-Jakuszewska 1965). Considerable production of very small seeds is most distinctly characteristic of population 4, although it applies in general to plants of so-called open communities (Salisbury 1942).

9. Maximum reciprocal co-variability is exhibited by such characters as stem length, root length, leaf length and number of capsules. The results of calculations of correlation coefficients, to a great degree similar in all populations confirm the assumption made by Sych (1967) that usually a superior factor of a genetic nature affects the correlation of two variables.

10. In comparison with the description of the species in literature and in particular with the data given by Bock (1908) plants from the study area are, apart from population 4, lower and have shorter leaves. The dimensions of seeds and width of wings do not in principle differ from those given by Kulpa (1958) and Kowal (1966).

11. On account of the complex effect exerted by the biotope on a plant it appeared useful to carry out cultivation experiments on a wider scale, during which, by means of elimination and choice of certain factors only, it would be possible more easily and accurately to define their influence on the various morphological characters of the species examined.

I must express my grateful thanks to Professor Dr. K. Zarzycki, Professor Dr. J. Szweykowski and Docent Dr. J. Staszkiewicz for their assistance and guidance during the course of this study.

6. SUMMARY

The paper contains the results of studies on the variability of 11 morphological characters of *Spergula vernalis* Willd. from different dune biotopes of the Toruń Basin. The biometric analysis, made three times for each population during the period from 1969 to 1971, covered a total number of 5000 individuals chosen at random from five stands differing from the floristic and edaphic aspects.

The main purpose of the analysis was to establish which morphological characters of *Spergula vernalis* are most subject to the effect of climatic and biotope factors and whether there is a correlation between characters and if so, what is the character of this correlation. *Spergula vernalis* was grown in different biotopes from those from which seeds were taken, in order to obtain confirmation of the view that variability is phenotypic in character, after which grown individuals were analysed in respect of 4 characters.

The studies showed the following:

1. Populations representing different biotopes differ fairly considerably in extreme cases in respect of a large number of morphological characters (Tab. I, II, III).

2. The role of climatic factors in relation to morphological variability of the study species is far less important than that of biotope factors. This is shown primarily by the great similarity of individuals within one population in three years differing as to weather conditions. The influence of the climate is distinct only in relation to the number of capsules and, to a lesser degree, to length of leaves (Fig. 2).

3. Confirmation of the assumption that morphological variation of the study populations is of a phenotypic character is provided by the results of analysis of individuals grown in a different biotope from that from which the seeds were obtained. They exhibited a decided similarity to the parent population for the given stand and clearly differed – in respect of the characters examined – from the parent population for seeds (Fig. 7).

4. Among the most plastic characters, that is, those most closely connected with the biotope, are length of stem, root and leaf, and abundance of fruits produced (Fig. 4, 5, 6). In respect of these characters the study populations differed most markedly (Fig. 3).

5. The number of seeds and their size and shape depend to the least extent on biotope (and climatic) conditions (Fig. 6, 8).

6. None of the characters examined exhibits a direct dependence on any one habitat factor, but is the result of the coaction of several linked parameters.

7. The water and nutrient component contents in the soil exert a distinct influence on the growth of the plant. This is shown by the great differences in height of individuals in population 4 (coming from a stand relatively well supplied with water and humus) in comparison with individuals of population 1 (growing in an outstandingly infertile and dry biotope). These results confirm data given in literature (G o r e 1961, M a r s h a l l 1965, W i l l i s 1965).

8. An important role in the general sturdy appearance of the plant is played by the factor of interspecies competition, particularly in relation to the most plastic characters – length of stem and leaf, number of fruits. This conclusion is reached after comparing populations 4 and 5, which differ greatly in respect of these characters; these populations come from stands with similar soil properties, but differing species composition of accompanying vegetation (cf. S y m o n i d e s 1974). The weak formation of individuals in population 5 results from the greater competitive power of *Calamagrostis epigeios*, which dominates on stand 5, and which is capable of "starving" other species (N o w i ń - s k i 1967).

9. The results of calculations of the coefficients of correlation for 8 pairs of characters showed that stem length, root length, leaf length and number of capsules are characterized by the greatest co--variability. No negative correlation was found in any of the relations (Tab. V).

10. On account of the complex action of the biotope on a plant it would appear necessary to carry out cultivation operations, in addition to field studies, by means of which, through elimination and choice of only certain factors, it would be possible accurately to define their influence on the various morphological characters of the species examined.

7. POLISH SUMMARY (STRESZCZENIE)

W pracy podano wyniki badań zmienności 11 cech morfologicznych *Spergula vernalis* Willd. z różnych siedlisk wydmowych Kotliny Toruńskiej. Analiza biometryczna, przeprowadzona dla każdej populacji trzykrotnie w latach 1969–1971, objęła w sumie ponad 5000 losowo pobieranych osobników z pięciu odmiennych pod względem florystyczno-edaficznym stanowisk.

Zasadniczym celem analizy było ustalenie, które cechy morfologiczne *Spergula vernalis* podlegają w największym stopniu wpływowi czynników klimatycznych i siedliskowych oraz czy istnieje współzależność między cechami i jaki jest charakter tej współzależności. Dla potwierdzenia tezy o fenotypowym charakterze zmienności prowadzono także hodowle *Spergula vernalis* na siedliskach innych niż te, z których pobierano nasiona, po czym analizowano pod względem 4 cech wyrosłe osobniki.

W wyniku przeprowadzonych badań stwierdzono:

1. Populacje reprezentujące odmienne siedliska różnią się w skrajnych przypadkach dość znacznie pod względem szeregu cech morfologicznych (tab. I, II, III).

2. Rola czynników klimatycznych w stosunku do zmienności morfologicznej badanej rośliny jest znacznie mniejsza, niż czynników siedliskowych. Świadczy o tym przede wszystkim duże podobieństwo osobników w obrębie jednej populacji w trzech latach, różniących się warunkami pogody. Wpływ klimatu zaznacza się wyraźniej jedynie w stosunku do liczby torebek, w mniejszym zaś stopniu do długości liści (fig. 2).

3. Potwierdzeniem tezy o fenotypowym charakterze zmienności morfologicznej badanych populacji są wyniki analizy osobników wyhodowanych na innym siedlisku niż to, z którego pobrano nasiona. Wykazywały one zdecydowane podobieństwo do populacji macierzystej dla danego stanowiska i wyraźnie odbiegały – w zakresie uwzględnionych cech – od populacji macierzystej dla nasion (fig. 7).

4. Do cech najbardziej plastycznych, a więc najsilniej związanych z siedliskiem, należy długość łodygi, korzenia i liści oraz obfitość produkowanych owoców (fig. 4, 5, 6). Pod względem wymienionych cech badane populacje różniły się najbardziej (fig. 3).

5. W najmniejszym stopniu uzależnione od czynników siedliskowych (i klimatycznych) są liczba nasion oraz ich wielkość i kształt (fig. 6, 8).

6. Żadna z badanych cech nie wykazuje prostej zależności od jakiegoś jednego czynnika środowiska, jest natomiast wynikiem współdziałania kilku sprzężonych parametrów.

7. Na wzrost rośliny wyraźny wpływ wywiera zasobność gleby w wodę i składniki pokarmowe. Świadczą o tym duże różnice w wysokości osobników populacji 4 (pochodzącej ze stanowiska stosunkowo zasobnego w wodę i próchnicę) w porównaniu z osobnikami populacji 1 (zajmującej wybitnie jałowe i suche siedlisko). Wyniki te potwierdzają dane z literatury (G o r e 1961, M a r s h a l l 1965, W i l l i s 1965).

8. Ważną rolę w ogólnej dorodności rośliny spełnia czynnik konkurencji międzygatunkowej, zwłaszcza w stosunku do cech najbardziej plastycznych – długości łodygi, liści, liczby owoców. Do wniosku tego prowadzi porównanie populacji 4 i 5, znacznie odbiegających pod względem tych cech; populacje te pochodzą ze stanowisk o podobnych właściwościach gleb ale o odmiennym składzie gatunkowym towarzyszącej roślinności (por. S y m o n i d e s 1974). Słabe wykształcenie osobników populacji 5 wynika z większej siły konkurencyjnej dominującego na stanowisku 5 *Calamagrostis epigeios*, zdolnego do „ogładzania" innych gatunków (N o w i ń s k i 1967).

9. Wyniki obliczeń współczynników korelacji dla 8 par cech wykazały, że największą współzmiennością charakteryzują się: długość łodygi, długość korzenia, długość liści i liczba torebek. W żadnej relacji nie stwierdzono korelacji ujemnej (tab. V).

10. Z uwagi na kompleksowe oddziaływanie siedliska na roślinę właściwym wydaje się prowadzenie, oprócz badań w terenie, hodowli, w których drogą eliminacji i doboru pewnych tylko czynników można by precyzyjniej określić ich wpływ na poszczególne cechy morfologiczne badanego gatunku.

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