Colloquium Biometricum 41
2011, 103–113

ON THE DEPENDENCE OF THE SIZE OF GENOTYPE–ENVIRONMENT INTERACTION ON THE NUMBER OF LOCATIONS IN SERIES OF SPRING BARLEY TRIALS

Wiesław Pilarczyk[1,2] , Anna Fraś[2]

[1]Department of Mathematical and Statistical Methods,
Poznań University of Life Sciences,. Wojska Polskiego 28
60–637 Poznań, Poland
[2]The Research Center for Cultivar Testing, 63–022 Słupia Wielka, Poland
e–mail: wpilar@au.poznan.pl

Dedicated to the memory of Professor Wiktor Oktaba

Summary

Inference on the value for cultivation and use (VCU) of new varieties is usually based on results of series of trials performed in different environments (trial stations, locations) over a period of 3–4 years. Similar series are also performed for post–registration investigations. The size of series (number of locations) depends on economic importance of species and varies (in Poland) from a very few trials for less important species to several dozens for the most important ones. There is a permanent economical pressure on reduction of the size of series. In this paper the influence of the number of experiments on the size of genotype–environment interaction is investigated and also the contribution of particular experimental stations (locations) to the genotype–environment interaction is assessed. The results of three year series of 113 trials on spring barley conducted in a period between years 1993 and 1995 at 41 experimental stations form a basis for investigations.

Key words and phrases: genotype–environment interaction, number of locations, series of trials

Classification AMS 2010: 62P10

1. Introduction

In Poland**,** the value for cultivation and use (VCU) of new varieties of important species is tested in special VCU trials in which new (candidate) varieties are compared with the subset of registered (standard) varieties. Such trials are performed in a set of experimental stations belonging to the network of stations of the Research Centre for Cultivar Testing (COBORU) at Słupia Wielka. For economical reasons the number of experimental stations and the number of trials is systematically decreasing. For example, there were more than fifty VCU trials on spring barley conducted yearly in eighties of previous century while currently there are no more than twenty such trials. So it is of special interest to know the contribution of a particular location to the genotype–environment interaction as it could allow – at the stage of planning of a new series of trials – to avoid locations with a low contribution to the interaction. It is very important to have relevant estimates of the genotype–environment interaction as – in series of trials (under mixed model of observations) – the significance of differences between genotypes is tested against interaction. In this paper – using the results of numerous trials on spring barley conducted in the years 1993–1995 – the relationship between the number of trials and the size of genotype–environment interaction (expressed as mean square for that interaction) is investigated. And also the contribution of particular locations (experimental stations) to the interaction is assessed. Similar considerations concerning winter wheat trials were performed by Pilarczyk and Fraś (2010). They have shown that the size of trials series should be large enough (consisting of about 15 trials) to provide stable estimates of parameters describing the genotype–environment interaction.

2. Materials and method

The results of three year series (from 1993 to 1995) of trials on spring barley form the basis of all considerations. The list of locations (experimental stations) involved in experiments on barley is given in Table 1.

There were respectively 34 trials in the year 1993, 39 in 1994 and 40 in 1995, giving in total 113 trials. All trials were established in 1–resolvable incomplete blocks with four replicates (superblocks). Incomplete blocks consisted of 5 – 8 plots. Plot size for harvesting was 15 m^2 (1,5 m $\times$ 10m). All the analysis are performed for grain yield recalculated to standard moisture content of 15% and expressed in dt/ha. The list of tested varieties is given in Table 2.

Table 1. List of locations in which trials were performed in a period 1993–1995 and mean yield

No.	Location	1993	1994	1995	Mean	No.	Location	1993	1994	1995	Mean
1	**BEZEK**		80.9	64.9	72.9	22	**MASŁOWICE**	41.8	57.1	67.6	55.5
2	**BOBROWNIKI**	58.6	59.8	44.6	54.3	23	**NAROCZYCE**		52.5	64.3	58.4
3	**BUKÓWKA**		32.6	27.5	30.0	24	*POKÓJ*	42.7	25.7	36.9	35.1
4	**CICIBÓR DUŻY**	33.1	45.2	49.5	42.6	25	*PRUSIM*	56.5	36.4	69.4	54.1
5	**CZESŁAWICE**	55.4	67.5	61.3	61.4	26	**PRZECŁAW**	62.5	73.7	53.7	63.3
6	**DUKLA**	67.7	57.3	48.7	57.9	27	**RADOSTOWO**	79.8	83.5	72.1	78.4
7	*FALĘCIN*	71.3	63.5	56.0	63.6	28	**RARWINO**		66.2	64.0	65.1
8	**GŁODOWO**	52.0	63.1	60.4	58.5	29	**RUSKA WIEŚ**	68.0	46.3	54.9	56.4
9	**GŁUBCZYCE**	81.4		45.8	63.6	30	**RYCHLIKI**	68.0	60.0	53.6	60.5
10	**JELENIA GÓRA**	68.2	63.0	60.9	64.0	31	**SEROCZYN**	49.7	50.5	56.8	52.3
11	**KARŻNICZKA**	58.3	55.0	57.1	56.8	32	**SŁUPIA**		73.5	56.9	65.2
12	**KAWĘCZYN**	65.4	65.8	49.3	60.2	33	**SŁUPIA WIELKA**		56.2	66.7	61.4
13	**KOCHCICE**	43.2	52.1	63.4	52.9	34	**ŚREM**	52.7		67.3	60.0
14	**KOŚCIELEC**	37.9	46.6	36.8	40.4	35	**TARNÓW**	70.0	65.5	59.4	65.0
15	**KOŚCIELNA WIEŚ**	66.0	44.1	62.1	57.4	36	**TOMASZÓW BOL.**	50.6	47.7	59.2	52.5
16	**KROŚCINA MAŁA**		38.4	70.2	54.3	37	**UHNIN**	60.9	37.3	47.9	48.7
17	**LUBINICKO**	53.3	48.9		51.1	38	**WĘGRZCE**	77.3	70.9	42.3	63.5
18	**NOWY LUBLINIEC**	58.2	26.5	55.2	46.7	39	**WRÓCIKOWO**	76.5	56.1	52.8	61.8
19	**LUĆMIERZ**	60.6	44.2	63.7	56.2	40	**WYCZECHY**	48.5	52.2	67.6	56.1
20	**ŁOPUSZNA**	74.9	60.0	59.0	64.6	41	**ZYBISZÓW**	54.2	29.3	65.9	49.8
21	**MARIANOWO**	80.1	58.8	57.1	65.3						

By bold print still existing variety testing experimental stations are designated while by italics the stations that disappeared.

There were 22 varieties tested in the year 1993, 20 in the year 1994 and 24 in the year 1995, respectively. But only 15 varieties were present in all three years (see Table 3) and there were 31 locations in which these varieties participated in trials. The orthogonal subset of trial data (average yield adjusted according to experimental design) is presented in Table 3).

The method described by Lin (1982) and by Lin and Butler (1988) and applied by Pilarczyk and Fraś (2007, 2010) for set of winter wheat trials was used here.

In the method, the mean square for interaction of all varieties with the set of n locations MS(1,2,…,n) is decomposed into two components. The first component is related to the interaction of considered varieties with the subset of n–1 locations, it means with one location excluded, let say location n. The second component SR(n) is the sum of mean squares for interaction of all varieties with all possible pairs of locations containing location n. Such decomposition enables to identify the minimum subset of locations that guarantee the stable assessment of interaction of varieties with locations. All details of the method can be found in a papers by Lin (1982), Lin and Butler (1987), see also Pilarczyk and Fraś (2007, 2010). The method was applied for results of each year from 1993 to 1995 independently and for mean (over years) values in orthogonal subset of data presented in Table 3.

Both the results for particular years and averaged over three years are presented graphically.

Table 2. List of spring barley varieties tested in a period 1993–1995 and their mean yields

No	Variety	1993	1994	1995	Mean	No	Variety	1993	1994	1995	Mean
1	ARS	57.7	51.9	51.6	53.7	17	NAGRAD	60.0	54.7	55.5	56.7
2	BARONESSE			56.7	56.7	18	POA 1790	59.8			59.8
3	BIELIK	58.8			58.8	19	POA 1893		53.7	57.9	55.8
4	BIES		54.9	58.4	56.6	20	RABEL		55.9	57.8	56.8
5	BKH 1590	60.4			60.4	21	RAH 1193			57.2	57.2
6	BKH 2292	59.6	54.3	55.7	56.5	22	RAH 691	55.8			55.8
7	BKH 2594			56.9	56.9	23	RAH 892	61.1	54.7	57.3	57.7
8	BOSS	62.4	54.1	55.7	57.4	24	RAMBO	59.0	53.9	57.5	56.8
9	BRYL			58.2	58.2	25	RATAJ	63.3	54.6	59.5	59.1
10	DEMA	60.4	54.9	56.7	57.3	26	REFREN			58.7	58.7
11	EDGAR	60.3	53.4	53.1	55.6	27	RIMA ABED	59.7	51.2		55.4
12	HOCKEY	61.7			61.7	28	RODION		55.9	58.6	57.3
13	KLIMEK	59.3	52.3	54.2	55.3	29	RODOS	59.7	54.4	57.4	57.2
14	LOT	61.8	55.0	55.7	57.5	30	START	63.8	56.1	58.3	59.4
15	MAGDA	60.2	54.1	58.1	57.5	31	USB 591	57.5			57.5
16	NAD 1592	61.0	54.1	57.0	57.4						

Table 3. Variety mean yields in locations in which experiments were performed in every year from 1993 to 1995

No	Location / Variety	BOBROWNIKI	CICIBÓR	CZESŁAWICE	DUKLA	FALĘCIN	GŁODOWO	JELENIA GÓRA	KARZNICZKA	KAWĘCZYN	KOCHCICE	KOŚCIELEC	KOŚCIELNA WIEŚ	NOWY LUBLINIEC	LUĆMIERZ	ŁOPUSZNA	MARIANOWO
1	ARS	49.29	41.88	56.66	54.47	59.51	56.89	60.35	57.44	57.03	49.64	37.11	51.17	45.31	52.31	59.89	62.09
2	BKH 2292	53.77	42.44	60.32	56.31	64.42	58.16	62.77	56.60	60.98	52.60	41.75	57.17	47.48	58.56	60.88	64.04
3	BOSS	52.67	41.85	60.50	53.64	61.50	60.88	65.61	61.51	63.54	55.35	40.34	60.45	50.95	58.15	63.67	66.90
4	DEMA	54.61	46.01	63.45	62.05	62.12	58.16	64.77	58.21	58.62	52.75	38.91	55.22	48.40	56.25	59.57	65.68
5	EDGAR	53.62	36.70	61.36	57.01	64.41	57.10	65.27	52.25	57.52	48.21	38.93	56.70	45.47	55.32	63.32	62.82
6	KLIMEK	51.74	33.23	55.99	62.27	66.90	59.98	66.58	48.32	50.81	50.49	36.84	51.33	37.56	53.98	64.12	67.06
7	LOT	52.17	43.03	64.74	58.69	63.18	59.72	64.45	56.43	58.82	53.94	40.80	57.71	45.97	55.42	62.81	68.12
8	MAGDA	58.36	40.73	59.61	57.49	66.40	57.95	63.82	58.82	63.09	52.42	41.93	61.36	50.42	57.12	61.43	64.59
9	NAD1592	56.45	43.95	63.96	55.87	65.29	58.84	64.10	54.91	59.84	53.34	43.88	58.85	46.69	55.97	62.99	64.28
10	NAGRAD	50.72	45.07	60.81	59.08	59.56	57.87	63.20	56.53	61.86	52.09	40.97	56.98	45.64	54.45	63.54	64.17
11	RAH 892	56.17	42.77	65.49	56.99	63.02	58.04	65.58	57.20	59.98	54.32	40.44	57.57	47.56	56.74	66.93	64.88
12	RAMBO	52.26	44.72	58.26	61.93	62.79	56.54	63.48	55.68	61.12	51.71	40.32	58.28	50.98	55.33	64.39	63.81
13	RATAJ	54.62	44.53	62.82	57.15	67.50	60.17	65.75	60.79	61.00	54.68	44.99	60.01	48.06	59.20	70.65	66.77
14	RODOS	53.18	42.71	59.17	63.59	63.33	58.34	64.67	53.34	60.80	50.59	38.69	58.95	46.69	58.24	67.28	65.83
15	START	54.48	44.11	63.76	58.30	65.49	61.29	65.54	57.42	63.78	56.64	41.67	60.38	46.91	60.52	70.29	67.44
Mean		53.61	42.25	61.13	58.32	63.70	58.66	64.40	56.36	59.92	52.58	40.50	57.47	46.94	56.50	64.12	65.23

Table 3 (continued). Mean yields in locations in which experiments were performed in every year from 1993 to 1995

No	Location / Variety	MASŁOWICE	POKÓJ	PRUSIM	PRZECŁAW	RADOSTOWO	RUSKA WIEŚ	RYCHLIKI	SEROCZYN	TARNÓW	TOMASZÓW BOL.	UHNIN	WĘGRZCE	WRÓCIKOWO	WYCZECHY	ZYBISZÓW	Mean
1	ARS	52.66	35.05	49.63	60.56	77.92	55.24	59.05	48.73	60.17	47.65	45.71	59.48	59.65	51.41	45.31	53.53
2	BKH 2292	54.96	34.28	55.78	62.70	77.59	54.07	58.25	54.66	66.41	57.46	48.19	63.29	59.25	50.99	48.38	56.28
3	BOSS	56.19	36.81	54.42	61.63	74.02	56.66	60.20	50.46	64.54	55.14	48.81	62.54	60.12	56.49	49.24	56.93
4	DEMA	56.89	37.47	50.76	67.15	85.66	55.20	58.62	52.55	64.61	50.65	51.23	64.52	61.97	53.56	51.22	56.99
5	EDGAR	52.69	32.54	53.31	63.19	75.00	54.63	57.74	47.95	66.51	48.91	45.83	64.86	63.43	56.15	47.13	55.03
6	KLIMEK	53.23	35.42	56.25	61.66	81.69	59.42	61.55	50.29	59.04	42.60	41.70	64.77	68.51	56.10	44.51	54.64
7	LOT	56.42	34.35	52.53	61.13	83.02	58.45	62.62	54.57	61.63	52.67	50.27	64.57	65.68	54.85	51.03	57.09
8	MAGDA	56.82	33.98	55.96	64.02	75.63	50.77	57.97	49.00	68.68	56.59	49.34	65.18	57.14	53.92	51.28	56.83
9	NAD 1592	54.73	34.78	52.91	64.54	76.77	55.36	64.93	50.34	65.59	52.68	46.60	62.95	61.32	61.63	49.27	56.89
10	NAGRAD	55.11	31.61	48.76	63.47	81.89	56.58	58.92	53.66	67.14	51.06	48.24	63.78	63.76	56.82	49.96	56.24
11	RAH 892	55.08	37.66	54.32	63.60	79.05	56.90	63.07	53.54	67.08	52.03	48.88	62.88	60.27	56.79	48.56	57.21
12	RAMBO	56.42	39.14	53.78	64.43	74.80	55.00	61.32	49.34	64.87	51.11	49.36	62.72	60.18	55.39	50.44	56.45
13	RATAJ	55.95	34.44	54.22	66.41	81.11	60.56	60.28	54.00	69.44	56.55	50.70	64.52	61.96	59.62	51.93	58.72
14	RODOS	56.99	31.12	52.61	67.21	76.55	59.98	58.98	49.64	67.47	52.20	46.70	62.52	64.00	52.62	51.73	56.64
15	START	58.01	36.13	57.13	65.28	79.31	59.95	62.49	57.13	65.50	57.98	51.37	64.86	65.49	56.67	51.56	58.93
Mean		55.48	34.99	53.49	63.80	78.67	56.58	60.40	51.72	65.25	52.35	48.20	63.56	62.18	55.54	49.44	-

4. Results

The highest average (over all tested varieties) yield reached 83.5 dt/ha at location Radostowo in the year 1994, the lowest 25.7 dt/ha was at location Pokój also in the year 1994, see Table 1. So it is easy to notice that locations differ considerably. It means that soil and climatic condition were very different among locations. Also tested varieties (genotypes) differed meaningfully as the highest average (over locations) yield 63.8 dt/ha was observed for variety Start in the year 1993 while the lowest average yield, 51.2 dt/ha, for variety Rima Abed in the year 1994, see Table 2. In every year there was significant (at α=0.01 level) genotype–environment interaction. Mean squares for that interaction were 14.17, 10.60 and 10.32 respectively in the years 1993, 1994 and 1995. For averaged over years data (data in Table 3) the value 16.02 was obtained.

Separately for each year, using variety adjusted mean values received from analysis of variance of single trials, the analysis of variance of one–year series was performed and mean square for genotype by environment interaction was calculated. Next, one by one – at each step – one location was excluded from the set of analyzed data. Always the location with the smallest contribution to the genotype by environment interaction was eliminated. The process was ended when the last two locations remained with the highest mean square for interaction among all pairs of locations. In results of the whole process, the increasing sequence of mean squares for interaction was received for decreasing numbers of locations involved. The mean squares for interaction for numbers of locations larger than two were next expressed in percentages of the mean square of interaction obtained for two locations with the highest interaction. And finally the results were presented graphically (Fig. 1) jointly with the analogous results for orthogonal subset of locations and varieties over the whole three years period, data from Table 3.

It can be observed that from the number of locations about 15, the curves presenting the relationship between numbers of locations and mean squares for interaction are relatively flat. It means that additional gain (is sense of decreasing the interaction) resulting from enlarging the size of series (using more locations) is relatively small. Mean squares for genotype–environment interaction for series consisting of 15 locations chosen in above described methods were respectively 23.15, 17.41 and 17.33 in the years 1993, 1994 and 1995. For averaged over years data the value 24.60 was obtained.

In order to assess the usefulness of particular experimental stations for estimation of genotype–environment interaction, the numbers of cases were counted that each location belonged to the minimal subset of 15 locations that guarantee receiving stable estimate of mean square for interaction. The results are presented in Table 4. There are four locations (Dukla, Radostowo, Ruska Wieś and Tomaszów Bol.) that are present in the minimal set of 15 locations every year and also in over years analysis (see the values 3 in four column of Table 4 supported by sign "+"). There are also four locations (Cicibór Duży, Karżniczka, Łopuszna and Wrócikowo) that occurred twice in the minimal set of 15 locations in three yearly analyses and in over–year analysis. So these are also recommended to have spring barley trials on their fields. On the other hand there are nine locations (Głodowo, Jelenia Góra, Kochcice, Kościelna Wieś, Lućmierz, Marianowo, Masłowice, Uhnin and Zybiszów) in which trials were conducted in all three analyzed years, but those do not occur in minimal set of 15 locations neither in yearly analyses nor in the over year one. So these locations are less suitable for estimation of the genotype–environment interaction in experimentation on barley varieties.

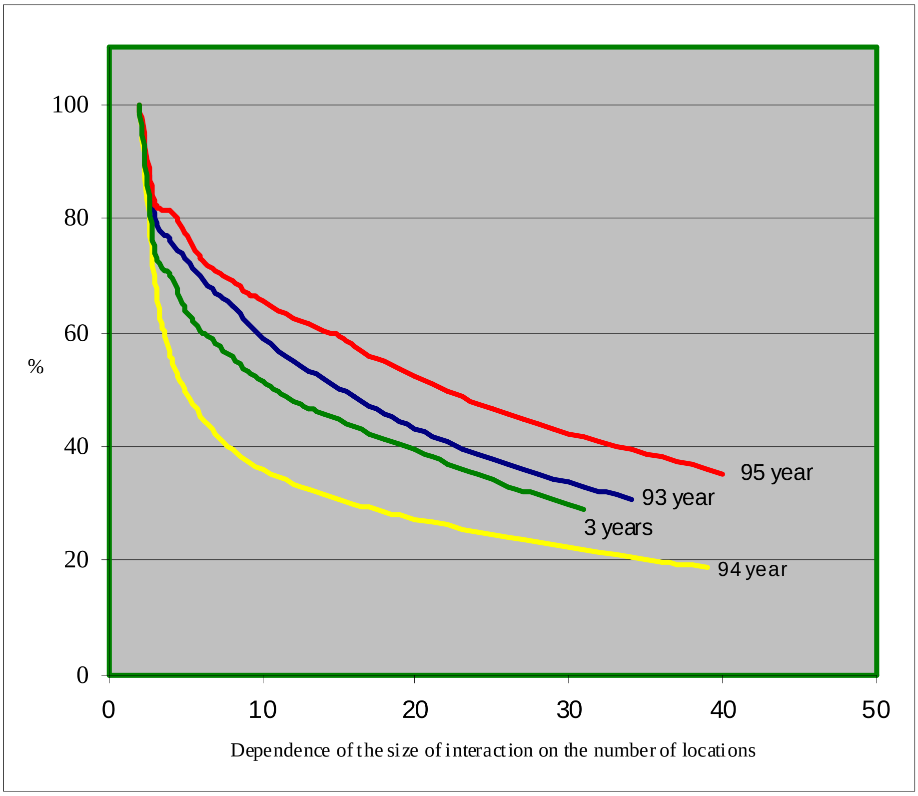

Fig. 1. Relative values of maximum mean squares for interaction for subsets of locations of different sizes, expressed in percentages of the mean square for interaction for pair of locations with maximum interaction

5. Discussion

It has been shown that different experimental stations (locations) differently contribute to the genotype–environment interaction. Identification of environments represented by locations that have dominant influence on the interaction is very important as this information can be effectively used in planning new series of variety trials. Currently, as there is economical pressure on reduction of the size of series of trials, it is crucial to conduct trials in such localities that “generate” interaction similar to the interaction provided by larger set of locations (with some of them having small contribution).

There is another side of the problem not discussed here. Not only “contribution” of location is important but also representativeness for the region in which location is placed. Sometimes better solution is to conduct trial in location with slightly smaller contribution to the genotype–environment interaction but with much better representativeness. This aspect of the problem is not discussed here, but it was discussed in a paper by Lin and Butler (1988) where the method of identification of location with similar contribution to the interaction is presented. In this paper the results of relatively “old” series of trials were analyzed. It is justified by the fact that it is the last so extensive set of data available as in the following years the numbers of trials (for all species) were seriously reduced.

Table 4. List of locations (experimental stations) and their participation in genotype by location interaction

No	Location	Years n			n_i	Years n_i		
1	BEZEK		1994	1995	1			1995
2	BOBROWNIKI	1993	1994	1995	2	1993	1994	
3	BUKÓWKA		1994	1995				
4	CICIBÓR DUŻY	1993	1994	1995	2+	1993		1995
5	CZESŁAWICE	1993	1994	1995	2		1994	1995
6	DUKLA	1993	1994	1995	3+	1993	1994	1995
7	FALĘCIN	1993	1994	1995	1+			1995
8	GŁODOWO	1993	1994	1995				
9	GŁUBCZYCE	1993		1995	1	1993		
10	JELENIA GÓRA	1993	1994	1995				
11	KARŻNICZKA	1993	1994	1995	2+		1994	1995
12	KAWĘCZYN	1993	1994	1995	1+	1993		
13	KOCHCICE	1993	1994	1995				
14	KOŚCIELEC	1993	1994	1995	1		1994	
15	KOŚCIELNA WIEŚ	1993	1994	1995				
16	KROŚCINA		1994	1995				
17	LUBINICKO	1993	1994					
18	LUĆMIERZ	1993	1994	1995				
19	ŁOPUSZNA	1993	1994	1995	2+	1993	1994	

No	Location	Years n			n_i	Years n_i		
20	MARIANOWO	1993	1994	1995				
21	MASŁOWICE	1993	1994	1995				
22	NAROCZYCE		1994	1995	1			1995
23	NOWY LUBLINIEC	1993	1994	1995	2+	1993		1995
24	POKÓJ	1993	1994	1995	1+	1993		
25	PRUSIM	1993	1994	1995	1+			1995
26	PRZECŁAW	1993	1994	1995	1		1994	
27	RADOSTOWO	1993	1994	1995	3+	1993	1994	1995
28	RARWINO		1994	1995				
29	RUSKA WIEŚ	1993	1994	1995	3+	1993	1994	1995
30	RYCHLIKI	1993	1994	1995	1		1994	
31	SEROCZYN	1993	1994	1995	2	1993	1994	
32	SŁUPIA		1994	1995	2		1994	1995
33	SŁUPIA WIELKA		1994	1995	2		1994	1995
34	ŚREM WÓJTOSTWO	1993		1995				
35	TARNÓW	1993	1994	1995	1+	1993		
36	TOMASZÓW BOL.	1993	1994	1995	3+	1993	1994	1995
37	UHNIN	1993	1994	1995				
38	WĘGRZCE	1993	1994	1995	1		1994	
39	WRÓCIKOWO	1993	1994	1995	2+	1993		1995
40	WYCZECHY	1993	1994	1995	1+	1993		
41	ZYBISZÓW	1993	1994	1995				

Years n number of cases that experiment was performed in particular location.
n_i denotes the number of cases that i–th location occurred in a minimal (within year) set of 15 location with the highest genotype by location interaction, while “+” means such occurring in three year series of trials
Years n_i – list of years in which location occurred in the minimal set of 15 locations with the highest interaction

At least partly performed analyses confirm conclusions from a paper by Pilarczyk and Fraś (2010) that properly chosen set of about 15 locations can satisfactorily describe the genotype–environment interaction.

It is interesting to observe that some localities (Radostowo, Ruska Wieś, Wrócikowo) that occur here in the minimal subset of 15 places with the highest interaction, occurred also in such subsets when series of trials on winter wheat was analyzed, see Table 4 in a paper by Pilarczyk and Fraś (2010). All these stations are characterized by relatively good soils and by placement in north–east part of Poland with the most severe climatic conditions.

Slightly different approach to identify locations with similar contribution to the genotype–environment interaction was applied by Pilarczyk (1983) in analysis of series of potato trials. He applied cluster analysis aimed at forming groups of locations with similar interactional effects of analyzed varieties.

6. Conclusion

Performed analysis of three year series of spring barley trials allows to conclude that, the minimal set of locations for satisfactory assessment of genotype–environment interaction should consist of at least 15 experimental stations chosen according to their contribution to that interaction. Locations with higher contribution are preferable. Locations that do not contribute to the genotype–environment interaction neither in yearly analyses nor in over–year analysis can be discarded from the list of places to conduct trials with no serious harm to the assessment of interaction.

Acknowledgement

The paper was partially supported by Ministry of Science and Higher Education Grant N N310 447838.

References

Lin C.S. (1982). Grouping genotypes by a cluster method directly related to genotype–environment mean square. *Theor. Appl. Genet*. 62, 277–280.

Lin C.S., Butler G. (1988). A data–based approach for selecting locations for regional trials. *Can. J. Plant Sci.* 68, 651–659.

Pilarczyk W. (1983). Wykorzystanie analizy skupień do podziału stacji doświadczalnych na grupy o małej interakcji odmianowo–środowiskowej. *Colloquium Biometryczne* 13, 133–147.

Pilarczyk W., Fraś A. (2007). Próba określenia reprezentatywnego zbioru miejscowości w serii doświadczeń odmianowych z pszenicą. *Biuletyn IHAR* 246, 3–10.

Pilarczyk W., Fraś A. (2010). Próba określenia reprezentatywnego zbioru miejscowości w serii doświadczeń odmianowych z pszenicą. Cz.II. Wyniki czteroletnie. *Biuletyn IHAR* 254, 3–12.