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A method for maize hybrids zoning

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Abstract: The article proposes a method for maize hybrids zoning. The theoretically expected yield for each hybrid from each location is calculated according to the following formula: $X_t = a_1 + a_2 - a_3 + (PC_{1g} \times PC_{1e})$. When the theoretical yield of a certain hybrid exceeds the actual yield at a given location, it can be grown to the advantage of that region, as well as the reverse version. An example is attached with calculated theoretical yields of 22 early (FAO 300-400) and 45 mid-early hybrids (FAO 400-500), as a part of the ecological variety testing of Maize Research Institute – Knezha at four locations (Knezha, Pavlikeni, Russe, Pazardzhik) in 2018. The year was chosen as representative for normal maize cultivation, after survey of a twenty-years' test (ESO) of the Institute's hybrids (2001-2020). The data analysis shows the following results: In FAO 300-400 group, the most suitable cultivation location is Russe with 13 hybrids (59.0% of all tested); followed by Knezha with 12 hybrids (54.5%); and Pavlikeni and Pazardzhik with 10 hybrids each (45.5%). In FAO (400-500) group the most suitable location is Pavlikeni with 27 hybrids (60.0%); Knezha and Russe with 23 hybrids each (51.1 %); and Pazardzhik – 21 hybrids (46.6%). The proposed method for hybrids zoning creates conditions for a more objective assessment of the places (locations) for priority cultivation of the varieties. The method is applicable to all field crops.

Key words: maize hybrids; theoretical yield; zoning

INTRODUCTION

The grain yield is a complex trait resulting from the combined effects of many factors, in significant place of which are the genotype, environment and the relation between them (Kang & Gorman, 1989; Troyer, 1996; Stojaković et al., 2015; Vulchinkov et al., 2021). The importance of the genotype by environment interaction is that it causes different reactions of maize hybrids productivity when they are grown in different environments / locations. With an accurate zoning, a greater expression of the genetic potential of the individual hybrid is assumed, which is of a significant economic interest for the agricultural producers (Tomov, 1997). This is of utmost importance for obtaining and maintaining high and stable yields over the years, especially in the context of world climate change (Georgieva et al., 2022; Kazandjiev et al., 2022). A global climate simulation model, used by Alexandrov & Hoogenboom (2000), suggests climatic scenarios that projected a decrease in grain yield of winter wheat and especially maize, caused by a shorter crop growing season due to the higher temperatures and a precipitation deficit. Adaptation measures to mitigate the potential impact of this climate change on maize crop production in Bulgaria suggests the possible need of alternate in sowing dates, new more adaptive hybrids selection and agricultural practices.

Gerber et al. (2024) investigated the yield gaps, defined as the difference between actual and attainable yields, providing a framework for assessing opportunities to predict agricultural productivity gaps for ten major crops (including maize) for thirty-five years' period (1975 – 2010). The authors confirm that the 'ceiling pressure' correlates with subsequent yield stagnation, signaling risks for multiple countries currently realizing gains from yield growth.

Similar study of Van Wart et al. (2013) suggests yield gap analysis, which evaluates magnitude and variability of difference between crop yield potential (Yp), the water limited yield potential (Yw) and actual (real) farm yields, which provides a tool for untapped production capacity and yield safety. The same authors summarize at least 11 schemes for agro-ecological zoning of crops, covering half a century of research, enveloping in the methodologies a large number of variables – average annual precipitation, average annual temperatures, growing degree days, harvested areas for target crops, soil types, etc., which are most often presented in a matrix or cluster form. In our method, we use the average grain yield of tested maize hybrids as an integral reflection of all environmental factors, genotypes and their interaction.

Butler & Huybers (2013) used a spatial adaptation model as a surrogate for future adaptation, and find that losses to average US maize yields from a 2 °C warming would be around 6 to 14 % in net production. A survey of Georgieva et al. (2023) shows that the temperatures and humidity (both air and soil) state in the region of Central North Bulgaria is deteriorating. The future cultivation of maize for grain must be carried out with a very precise choice of hybrids, their water requirements and local environment adaptability (Troyer, 1996).

The question of the correct zoning of agricultural crops is not new, but in context of the current understanding of ever-greater changes and externalities in the climate, and the need for optimal and sustainable use of natural resources management, it acquires the meaning of new relevance. The newly suggested method for maize crops zoning could be useful in this regard.

MATERIAL AND METHODS

Twenty-two maize hybrids from FAO (300-400) and forty-five FAO (400-500) maturity groups are tested in 2018 at 4 locations. The locations are Knezha (Maize Research Institute); Russe (Agricultural and Seed Science Institute “Obraztsov Chiflik”); Pavlikeni (Experimental Stations for Soybean and Grain Crops), under non-irrigated conditions; and Pazardzhik (Experimental Station for Irrigation Practice, vil. Ivailo) – with irrigation. The adapted agricultural technique of the Maize Research Institute is applied. The experiment has been a part from a greater twenty years’ ecological multilocational network evaluation (ECO) of the Maize Research Institute – Knezha, which testing includes hybrids from all FAO groups before the official government evaluation. 2018 is selected as the most representative year for the entire study period. The trial is set up in randomized block design (RBD) with 3 replications and 10 m^2 harvesting plots. A cluster analysis of the results with “nest “design (Ward, 1963); multifactorial ANOVA (Perkins & Jinks, 1968; Hallauer, 1988); AMMI (Zobel at al., 1988; Gauch, 2006; Gauch, 2013) and their principle components (PC) analysis are performed on the input data. The theoretically expected yield (x_t) is calculated according to a formula proposed by Vulchinkov et al. (2021). The formula is based on further developed idea of Zobel et al. (1988) and represents the theoretically expected yield, as follows:

$x_t = a_1 + a_2 - a_3 + (PC_{1g} \, x \, PC_{1e})$, where

a_1 – hybrids mean yield from all locations;

a_2 – mean yield from one particular location;

a_3 – general mean yield for the trial;

PC_{1g} – PC_1 of the hybrid (genotype)*;

PC_{1e} – PC_1 of the location (environment)*

**In the proposed formula, the added product of the two components (PC_{1g} x PC_{1e}) is of great importance for the precise calculation of the theoretically expected yield.*

A comparison of the actually obtained (real) and theoretically expected yields by hybrids and locations is made. After redistribution, the hybrids that can be grown with priority (zoned) for the respective place are determined. The computer programs SPSS25 and Microsoft Excel have been used for all calculations and data processing.

RESULTS AND DISCUSSION

Figure 1 shows the "nest "designed cluster analysis of mean yields and grain moisture at harvest of maize hybrids from all maturity groups. The data is obtained from a twenty years' period (2001-2020) multi-environment testing or ecological trials (ECO) from 66 locations (48 under non-irrigated conditions), including 2727 hybrids of the Maize Research Institute – Knezha, of which: FAO (300-400) group – 398; FAO (400-500) – 852; FAO (500-600) – 849; FAO (> 600) – 628. *Cluster A* defines the "wet" years, with relatively high yield and high grain moisture. *Cluster B* unites stress years, which can be determined with low yield and not very low grain moisture. *Cluster C* represents favorable (or normal) years – relatively high yield with relatively low grain moisture. *Cluster D* combines the successful years – high yield with low grain moisture. As can be seen from the figure, the extreme years of the period (clusters B and D) alone form about a quarter of it, with group C (that of the relatively good years) occupying about 50% of the entire study.

For this reason, and based on the agrarian report of Bulgarian Ministry of Agriculture for 2020 (https://www.mzh.government.bg/bg/politiki-i-programi/otcheti-i-dokladi/agraren-doklad/), we have chosen 2018 as the relative most representative, from the point of view of the relatively high yields of the hybrids, combined with low harvest moisture. A separate cluster analysis by FAO groups, which we don‘t publish here now, includes another 1-2 years more in cluster C for FAO 400-500 and 300-400 groups, respectively. For the 500-600 and over 600 groups, the years in cluster C are one and two less, respectively, which suggests the better adaptation of the earlier groups to stressful conditions (Vulchinkov et al., 2013).

The joint analysis of variance (ANOVA) of the data for FAO (300-400) and (400-500) groups are shown in Table 1. The results for FAO 300-400 (A*) maturity group shows that the locations; the hybrids; the replications in the locations; locations by hybrids, as well as PC_1 have significant variances. In the later maturity group (B*), the same pattern for all sources of variation is observed at a probability level of P=1 %. The environmental conditions (locations) for both FAO groups have the highest value, which is also observed in other similar studies (Ilker et al., 2009; Mitrovič et al., 2012; Stojaković et al., 2015).

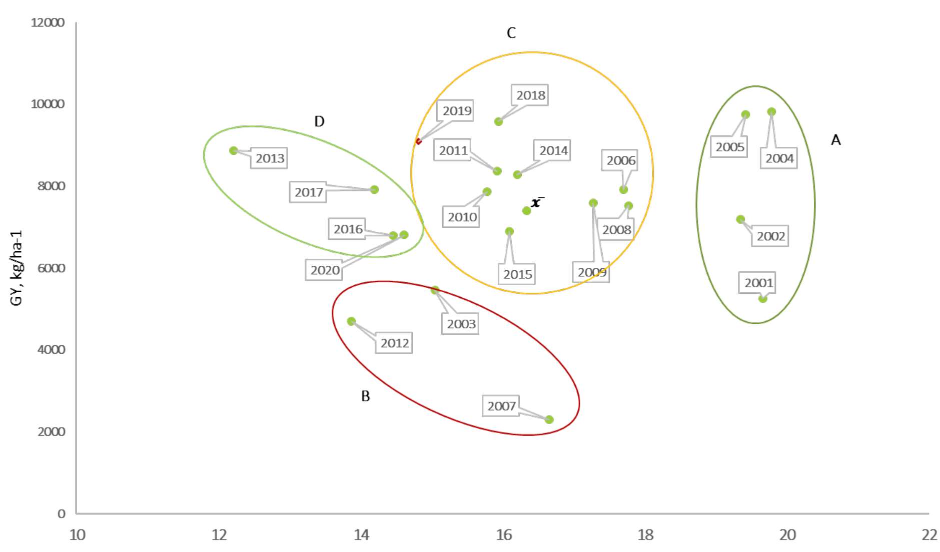

Figure 1. Cluster analysis of 20-year conditions (2001-2020) of average yields and grain moisture at harvest for maize hybrids from all FAO groups

Table 1. Joint ANOVA analysis for grain yield of 22 hybrids (FAO 300-400) (A*) and 45 hybrids (FAO 400-500) (B*) tested at 4 locations at ecological variety testing in 2018, including principal components (PC)

(A*) Source of Variation	dF	SS	MS	F	% of SS
Total	263	12388654,4			100,00
Locations	3	6838998,57	2279666,2	176,66**	66,91
Hybrids	21	1709334,6	81396,9	6,30**	16,72
Reps. In locations	8	418113,7	52264,2	4,05*	4,00
LxH	63	1254392,5	19910,9	1,54*	12,28
PC_1	(23)	765527,7	32283,8	2,58**	
PC_2	(21)	371342,8	17682,9	1,37	
Error	168	2167815,1	12903,7		
(B*) Source of Variation	**dF**	**SS**	**MS**	**F**	**% of SS**
Total	539	23876580,0			100,00
Locations	3	11783852,0	3927950,5	35,33**	49,35
Hybrids	44	3506741,8	79698,677	3,17**	14,68
Reps. In locations	8	889397,52	111174,69	8,95**	3,72
LxH	132	3321975,1	25166,478	2,03**	13,91
PC_1	46	1907185,6	41460,557	3,34**	
PC_2	44	801610,34	18218,417	1,47	
Error	352	4374613,6	12427,88		

Significance of variances at P=5% (*) and P=1% (**)

Table 2 presents the results of the testing of 22 hybrids (300-400 FAO) at 4 locations in 2018. The actual grain yields (RY) from the Knezha, Russe, Pavlikeni and Pazardzhik locations are shown, as well as the theoretical yields (TY) from these locations, calculated according to the proposed formula. Average yields (MY) for each hybrid from 4 test environments were also calculated. These average yields match the average theoretical yields from the same locations. This fact was stated in our previous study (Vulchinkov et al., 2021).

Displacements of the obtained theoretical yields at individual locations compared to the actual yields are observed, which are interesting from the point of view of the purpose of the study. For example, the first hybrid from the experiment (E1) in Knezha location has a lower theoretical yield than the actual one, which makes it unsuitable for this location, but in the other three locations - Russe, Pavlikeni and Pazardzhik – this hybrid shows higher theoretical yields and it can be grown there with priority. The second hybrid (E2) is in the opposite position – it has a higher theoretical yield only in Knezha and can be zoned only for that of the four locations.

Such comparisons can be made for every single hybrid in the trial, but the rightmost column of the table lists the number of suitable locations for each hybrid, which summarizes the comparisons made. The high-yielding hybrid from the experiment E13 with 1133.81 kg/da, which significantly exceeds the standard E15 (Kn 307), is suitable for two locations - Knezha and Pazardzhik. Hybrid E12 has the lowest yield in the experiment (830.06 kg/da), which does not significantly differ from the standards and is suitable for zoning only at one location – Knezha. No relationship was observed between yield size and the number of suitable locations for each hybrid. For example, E11, which is high-yielding hybrid, second only to E13, is suitable for only one location. In a previous study by Vulchinkov et al. (2021) this hybrid was determined to be the most stable in the

Table 2. Distribution of 22 maize hybrids (FAO 300-400), tested in 2018 at 4 locations with actual and theoretical yield.

H	MY	RY				PC1g	MTY	TY				NSL
		Kneja	Russe	Pavlikeni	Pazardjik			Kneja	Russe	Pavlikeni	Pazardjik	
E1	900,4	1053,05	1110,67	617,87	820,03	-0,07	900,4	957,56	**1118,9**	**677,16**	**848,00**	**3**
E2	913,81	888,54	1144,67	711,19	910,86	0,08	913,81	**970,91**	1132,44	690,54	861,36	**1**
E3	956,1	1057,39	1150,33	746,51	870,17	-0,10	956,1	1013,28	**1174,6**	732,87	**903,71**	**2**
E4	945,74	1075,6	1166,2	702,04	839,12	-0,02	945,74	1002,88	**1164,3**	**722,49**	**893,32**	**3**
E5	1075,35	1034,16	1418,93	851,40	996,92	0,51	1075,4	**1132,3**	1294,41	**851,97**	**1022,75**	**3**
E6	782,84	831,74	955,4	564,67	779,53	-0,17	782,84	**840,05**	**1001,2**	559,63	730,47	**2**
E7	1020,89	1004,45	1501,67	684,29	893,17	1,00	1020,9	**1077,6**	1240,44	**797,39**	**968,13**	**3**
E8	924,29	961,08	1090,27	760,29	885,53	-0,18	924,29	**981,5**	**1142,7**	701,08	871,92	**2**
E9	882,41	1017,73	1032,47	657,02	822,45	-0,29	882,41	939,67	**1100,7**	**659,23**	**830,08**	**3**
E10	954,25	1143,14	1034,73	733,99	905,13	-0,57	954,25	1011,63	**1172,2**	731,14	902,01	**1**
E11	1106,86	1167,54	1335,07	865,99	1058,84	0,03	1106,9	1163,98	1325,44	**883,60**	1054,42	**1**
E12	830,06	781,64	1063,07	621,22	854,33	0,09	830,06	**887,16**	1048,7	606,78	777,60	**1**
E13	1133,81	1115,7	1443,87	922,51	1053,18	0,38	1133,8	**1190,8**	1352,74	910,46	**1081,26**	**2**
E14	963,95	1070,7	1076,67	812,38	896,07	-0,40	963,95	**1021,3**	**1182,1**	740,80	**911,65**	**3**
E15 – St	923,86	928,14	1236,47	629,40	901,46	0,36	923,86	**980,84**	1142,77	**700,52**	871,31	**2**
E16	916,6	915,03	1211,53	661,21	878,62	0,30	916,6	**973,61**	1135,45	**693,27**	864,07	**2**
E17	897,35	1037,83	1199,07	719,83	632,68	0,30	897,35	954,36	1116,2	674,02	**844,82**	**1**
E18	982,09	1023,24	1165,07	766,25	973,8	-0,13	982,09	**1039,3**	**1200,5**	**758,87**	929,71	**3**
E19 – St	997,08	1066,53	1056,27	780,00	1085,5	-0,61	997,08	1054,47	**1215**	773,98	944,85	**1**
E20	947,6	986	1127,67	783,77	892,96	-0,13	947,6	**1004,8**	**1166**	724,38	**895,22**	**3**
E21	925,54	999,98	1127,67	681,78	892,72	-0,07	925,54	982,7	**1144**	**702,30**	873,14	**2**
E22	892,29	970,92	1033,6	687,95	876,69	-0,30	892,29	949,55	**1110,5**	669,11	839,96	**1**
$\bar{x}$	948,78	1005,92	1167,34	725,53	896,35			12	13	10	10	
	PC1e	**-0,43**	**1,00**	**-0,25**	**-0,33**			**NZH**				

LSD at 5 % = 183,64 (kg/da); H – Hybrids; MY - Mean Yield (kg/da); RY – Real Yield (kg/da); MTY - Mean Theoretical Yield (kg/da); TY - Theoretical Yield (kg/da); NSL - Number of suitable locations for each hybrid; NZH - Number of zoned hybrids by location

experiment, closest to the center of the AMMI-1 biplot. This fact partly disagrees with the thesis of Stojaković et al. (2015) about the importance of the stability of hybrids used as an element of their zoning. The Russe location has the highest average yield (1167.34 kg/da). It also has the largest number of zoned hybrids (13), indicated in the lower right corner of Table 2, followed by Knezha with 12 hybrids, and Pavlikeni and Pazardzhik with 10.

From the number of suitable locations for each hybrid growing, there is no "four out of four" case test locations suitable for any hybrid zoning. Hybrids suitable for three locations are 8 or 36.36 % of all in the experiment, and for two and one locations are 7 (31.81 %), respectively. The "*success*" rate of the locations is at most 3 out of 4 (or 75%), indicating that the greater the number of environments covered by an ecological trial, the clearer and more detailed zoning distribution can be expected. The 4 locations we used represent practically a minimum for this kind of research. In this regard, the official government testing of maize hybrids for biological and economic qualities in the Executive Agency for Variety Testing and Seed Control (EAVT&SC) at only three locations – Selanovtsi, Brashlen and Radnevo is insufficient. In the recent past (the end of the 20th century), the official testing was carried out at 23 locations, approximately half of which were under irrigated conditions, which in 75% of each case would give a real picture of the zoning. However, then "*zoning for the whole country*" decisions were made, which, especially for the late hybrids group, were not particularly objective. The Russe location, as indicated above, as the most suitable for mid-early hybrids, covers 59 % of them, followed by Knezha (54.5 %), Pavlikeni and Pazardjik with 45.5%, respectively (Figure 2).

Table 3 presents the test results of 45 mid-early hybrids (FAO 400-500) in the same year (2018) for the locations mentioned. The evaluated hybrids were twice as many compared to the earlier maturity group, but the pattern of the observed results is identical. The mean actual yield (MY) and the mean theoretical yield (MTY) of the hybrids of all locations match. The general average of the trial (948.56 kg/da) almost equivalents with that of the first test (Table 2), which indicates that the productive capabilities of the hybrids from

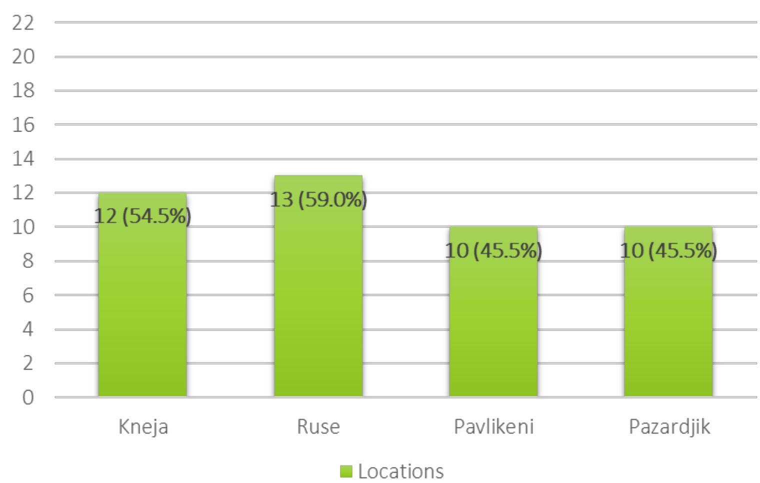

Figure 2. Number of hybrids most suitable for growing at the respective location by FAO (300-400) group

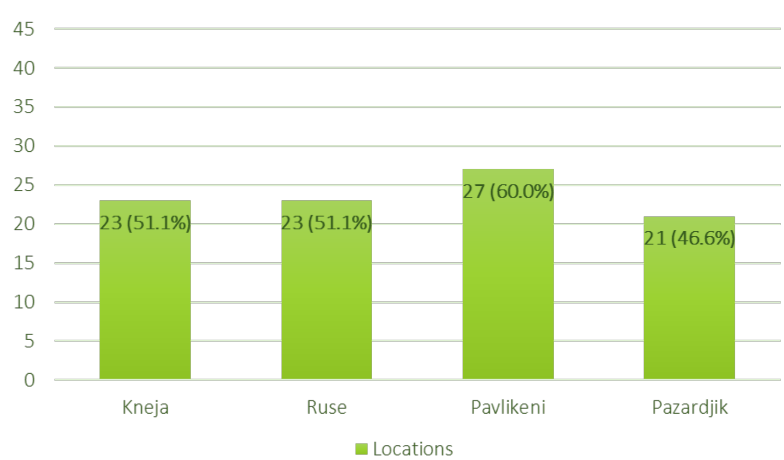

Figure 3. Number of hybrids most suitable for growing at the respective location by FAO (400-500) group

Table 3. Distribution of 45 maize hybrids (FAO 400-500), tested in 2018 at 4 locations with actual and theoretical yield

H	MY	RY				PC1g	MTY	TY				NSL
		Kneja	Russe	Pavlikeni	Pazardjik			Kneja	Russe	Pavlikeni	Pazardjik	
E23	874,38	982,7	617,3	1006,9	890,6	0,10	874,38	896,90	**652,38**	**1068,04**	880,21	2
E24	920,43	984,5	716,5	1110,4	870,3	-0,09	920,43	942,95	698,43	**1113,89**	**926,43**	2
E25	928,37	1040,0	621,9	1176,5	875,1	-0,18	928,37	950,90	**706,37**	**1121,74**	**934,47**	3
E26	932,62	985,8	746,7	1150,9	847,1	-0,18	932,62	955,15	710,62	**1125,99**	**938,72**	2
E27	840,01	858,3	741,8	995,2	764,8	-0,07	840,01	**862,53**	618,01	**1033,49**	**846,00**	3
E28	897,71	940,9	660,9	1140,3	848,8	-0,16	897,71	920,24	**675,72**	1091,11	**903,79**	2
E29	970,12	931,8	733,8	1204,3	1010,6	0,00	970,12	992,64	**748,12**	1163,67	976,05	1
E30	900,68	874,6	674,6	1143,5	910,1	-0,07	900,68	923,20	**678,68**	1094,17	906,67	1
E31	927,55	892,3	838,9	1064,5	914,4	0,06	927,55	**950,07**	705,56	**1121,16**	**933,42**	3
E32	1040,62	1061,5	714,4	1374,9	1011,7	-0,26	1040,62	**1063,15**	**818,62**	1233,91	**1046,80**	3
E33	914,17	875,3	732,4	1226,7	822,3	-0,33	914,17	**936,70**	692,17	1107,39	**920,41**	2
E34st	1226,73	1352,6	952,7	1354,7	1246,9	0,12	1226,73	**1249,24**	**1004,73**	**1420,40**	1232,54	3
E36	993,90	956,7	791,2	1146,7	1081,0	0,19	993,90	1016,41	771,90	**1187,64**	999,64	1
E37	897,65	921,1	730,4	988,8	950,3	0,23	897,65	920,16	675,65	**1091,43**	903,36	1
E38	945,04	1007,6	805,7	1102,9	863,9	-0,09	945,04	967,56	723,04	**1138,50**	**951,04**	2
E39	878,04	922,6	626,3	1228,8	734,4	-0,47	878,04	900,57	**656,04**	1071,12	**884,41**	2
E40	950,70	995,8	656,9	1065,6	1084,5	0,32	950,70	973,21	**728,70**	**1144,57**	956,32	2
E41	829,54	812,8	563,4	985,6	956,4	0,25	829,54	**852,05**	**607,54**	**1023,34**	835,22	3
E42	1008,46	982,4	669,2	1296,0	1086,3	-0,03	1008,46	**1030,98**	**786,46**	1201,99	1014,41	2
E43	875,39	787,6	597,0	1180,8	936,2	-0,08	875,39	**897,91**	**653,39**	1068,87	881,39	2
E44	915,64	864,5	791,2	987,7	1019,2	0,34	915,64	**938,15**	693,64	**1109,53**	921,24	2
E45	911,66	907,6	708,6	1043,2	987,2	0,20	911,66	**934,17**	689,66	**1105,42**	917,39	2
E46st	1226,80	1262,2	962,0	1426,1	1256,9	0,03	1226,80	**1249,32**	**1004,80**	1420,38	1232,70	2
E47	914,37	1011,3	767,6	1356,8	521,8	-1,00	914,37	936,93	692,38	1106,93	**921,26**	1
E48	1051,60	1013,2	879,3	1278,9	1034,9	-0,08	1051,60	**1074,12**	829,60	**1245,07**	**1057,60**	3
E49	996,16	979,6	815,6	1265,1	924,3	-0,23	996,16	**1018,69**	774,16	1189,48	**1002,31**	2
E50	880,54	967,2	673,7	972,8	908,5	0,18	880,54	**903,06**	658,54	**1074,28**	886,29	1
E51	816,52	770,3	669,6	878,9	947,3	0,40	816,52	**839,02**	594,52	**1010,47**	822,06	2
E52	895,02	925,7	731,7	1102,9	819,8	-0,15	895,02	917,54	673,02	1088,42	**901,09**	1
E53st	986,67	995,2	804,3	1060,3	1086,9	0,33	986,67	1009,17	764,67	**1180,55**	992,28	1
E54	963,65	901,6	833,5	1150,9	968,5	0,01	963,65	**986,17**	741,65	**1157,21**	**969,56**	3
E55	986,03	1083,4	748,2	1166,9	945,6	-0,06	986,03	1008,55	**764,03**	**1179,52**	**992,01**	3
E56	893,67	925,8	741,7	928,0	979,2	0,36	893,67	916,18	671,67	**1087,59**	899,25	3
E57	966,08	969,9	700,8	1173,3	1020,3	0,06	966,08	**988,60**	**744,08**	1159,69	971,95	2
E58	998,46	1098,3	735,4	1160,5	999,6	0,04	998,46	1020,98	**776,47**	**1192,05**	**1004,35**	3
E60	943,09	921,9	678,6	1146,7	1025,2	0,11	943,09	**965,61**	**721,09**	1136,75	948,91	1
E61	936,64	958,2	733,1	1065,6	989,7	0,17	936,64	**959,16**	714,64	**1130,37**	942,40	2
E62	866,46	818,2	650,4	1092,3	905,0	0,01	866,46	**888,98**	644,47	1060,02	872,38	1
E63	924,77	981,2	673,9	1056,0	988,0	0,18	924,77	947,28	**702,77**	**1118,51**	930,52	2
E64	937,61	959,0	684,3	1182,9	924,1	-0,11	937,61	**960,13**	**715,61**	1131,05	**943,64**	3
E65	1040,66	1247,3	668,0	1081,6	1165,7	0,41	1040,66	1063,16	**818,66**	**1234,62**	1046,19	2
E66	977,43	1017,7	709,9	1113,6	1068,5	0,22	977,43	999,94	**755,43**	**1171,20**	983,14	2
E67	1000,73	964,6	736,9	1365,3	936,1	-0,36	1000,73	**1023,26**	**778,74**	1193,92	**1007,00**	3
E68	967,83	1063,3	608,0	1286,4	913,6	-0,28	967,83	990,36	**745,83**	1161,10	**974,02**	2
E69	935,11	924,8	797,0	1108,3	910,4	-0,02	935,11	**957,63**	713,11	**1128,65**	**941,05**	3
$\bar{x}$	948,56	971,1	726,6	1142,1	954,5			23	23	27	21	
	PC1e	**-0,036**	**-0,005**	**1**	**-0,959**			**NZH**				

LSD at 5 % =179,30 kg/da;H – Hybrids; MY - Mean Yield (kg/da); RY – Real Yield (kg/da); MTY - Mean Theoretical Yield (kg/da); TY - Theoretical Yield (kg/da); NSL - Number of suitable locations for each hybrid; NZH - Number of zoned hybrids by location the two FAO groups for the conditions of 2018 are equal. The two highest-yielding hybrids in the experiment, standards E34 and E46, have practically equal theoretical (and real) yields, but their zoning is different. E34 is suitable for priority cultivation in three locations - Knezha, Russe and Pavlikeni, and in the last place it has the highest theoretical yield of the entire experience (1440.40 kg/da), while E46 has an advantage for the first two locations, because and its actual yield in Pavlikeni is higher than theoretical. The genotype with the lowest yield in the experiment (E51) is suitable for zoning in two places (Knezha and Pavlikeni). Here, also, there is no correlation between the amount of yield and the number of most suitable for cultivation locations. The calculated correlations between these two traits are $_r$=0.13 and $_r$=0.19 for the two trials respectively, which are insignificant and this confirm our thesis in both cases.

Hybrids suitable for three locations are 14 or 31,11 % of all cases, while in the first trial (Table 2) as a share they are more – 36,36 %, as stated above. Zoned hybrids are the most for two locations – 21 or 46,66 %, while for one they are the least – 10 or 22,22 % of the studied mid-early hybrids. The greater proportion of hybrids from the early group are suitable for three locations, which confirms the adaptive potential of this group, also shown in another study by Vulchinkov & Vulchinkova (2018). In terms of the maximum number of suitable locations for each hybrid, the situation is identical as in the first test - 3 out of 4 or 75 % percent of cases.

Regarding the number of zoned hybrids by location, the most suitable place in 2018 is Pavlikeni with 27 hybrids or 60 % of all genotypes, unlike Ruse in the first test. It should be noted that both locations showed the highest average yields – 1167,34 and 1142,10 kg/da, respectively (Tables 2 and 3). In both places, their first principal component (PC_{1e}) is the highest. It can be reasonably assumed that locations with higher yielding conditions could have more hybrids zoned, but this requires further study involving a much higher number of test sites, as pointed out above in the text.

As for the share of hybrids most suitable for the respective location, it remains at almost the same level (59 and 60 %, respectively) for Russe and Pavlikeni (Figures 2 and 3), regardless of different numbers of hybrids in the two trials.

CONCLUSIONS

The proposed zoning method indicates from one to three locations suitable for priority cultivation of the studied hybrids. With a larger number of test locations, the scope of their zoning increases respectively.

For FAO (300-400) group, the most suitable location (with the most hybrids with high theoretical yields) is Ruse, and for FAO (400-500) group is Pavlikeni.

The method for hybrids zoning creates conditions for a more objective assessment of the places (locations) for priority cultivation of the varieties.

The method is applicable to all field crops.

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