Lehr- und Forschungszentrum für Landwirtschaft
Raumberg-Gumpenstein, Irdning, Austria

60. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs 2009, 1 – 3
ISBN: 978-3-902559-37-1

Importance of appropriate selection environments for breeding maize adapted to organic farming systems

Monika M. Messmer[1], Henriette Burger[2], Walter Schmidt[2] and Hartwig H. Geiger[3]

Abstract

Organic farming systems, characterized by special attention to soil fertility, recycling techniques and low external inputs, gained increased significance in recent years. As a consequence, there is a growing demand for varieties adapted to organic and/or low input farming. The objectives of the present study were to (i) compare the testcross performance of segregating maize (*Zea mays*) populations under established organic (OF) and conventional farming (CF) systems, (ii) determine quantitative genetic parameters decisive for the selection response under OF vs CF conditions, and (iii) draw conclusions for breeding new varieties optimally adapted to OF. Testcross performance of four different material groups of preselected lines (90 lines per group) derived from early European breeding material was assessed under OF and CF in three different geographic regions in Germany in 2008. Grain yields under OF were 3 to 18% lower than under CF in the individual experiments depending on the test region and, to a lesser extent, on the genetic material. On average, grain dry matter yield under OF was 1077 g m^{-2} compared to 1186 g m^{-2} under CF. Phenotypic correlations between OF and CF were small or moderate for grain yield in each of the four material groups (0.22 to 0.45), while strong and highly significant correlations were found for dry matter content (0.89 to 0.94). Genotypes with top grain yields under OF often did not show this superiority under CF and vice versa. Despite considerable heterogeneity of the OF test sites, the heritability for grain yield was in the same order of magnitude under OF and CF. It is concluded that test sites managed by OF are indispensable for making maximum progress in developing maize varieties for these conditions.

Keywords

Genotype by farming system interaction, indirect selection, organic farming, testcross performance, *Zea mays*

Introduction

Organic farming (OF) systems, characterized by special attention to soil fertility, recycling techniques and low external inputs, gained increased significance in recent years. As a consequence, there is a growing demand for varieties adapted to organic and/or low input farming. In several studies modern varieties as well as landraces have been tested for their suitability for organic farming, whereas special breeding programs aiming at genotypes optimized for this farming system are scarce. Comparing the testcross performance of unselected recombinant inbred lines derived from the widely used US hybrid B73×Mo17 under conventional (CF) and organic farming systems, LORENZANA and BERNARDO (2008) concluded that high yielding maize hybrids for OF can be developed by screening under CF. In contrast, BURGER et al. (2008) found moderate phenotypic correlation between OF and CF in unselected breeding material indicating strong genotype by farming system interactions. Apparently, specific yield associated characteristics are necessary to reach maximum performance under OF and CF, respectively. Such traits include early vigour, competitiveness to weeds, and high nitrogen use efficiency under OF on the one hand, and resistance to green snapping and early root lodging under CF on the other. Thus, selection under OF conditions might be needed to fully exploit the genetic potential of maize for this management system. This is in line with previous studies demonstrating that breeding maize for improved nitrogen use efficiency was more efficient under low nitrogen levels compared to indirect selection under high nitrogen conditions (PRESTERL et al. 2003). But organic farming conditions are very difficult to characterize since they strongly depend on factors like crop rotation, soil fertility, organic fertilizer input, weed, pest and disease pressure, making it challenging to choose a representative selection environment. The objectives of the present study were to (i) compare the testcross performance of segregating maize populations under established organic and conventional farming (CF) systems, (ii) determine quantitative genetic parameters decisive for the selection response under OF vs CF conditions, and (iii) draw conclusions for breeding new varieties optimally adapted to OF systems.

Materials and Methods

Testcross performance of four different material groups of preselected lines (90 lines per group) derived from early European breeding material of KWS SAAT AG was assessed under OF and CF in three different geographic regions in Germany in 2008. Material groups ‘151’ and ‘152’ comprised flint lines crossed with a dent tester (Tdent),

[1] Research Institute for Organic Agriculture (FiBL), CH-5070 FRICK
[2] KWS SAAT AG, D-37555 EINBECK
[3] University of Hohenheim (350), D-70593 STUTTGART
[*] Ansprechpartner: Monika M. MESSMER, monika.messmer@fibl.org

while material groups '153' and '154' comprised dent lines crossed with a flint tester (Tflint). The lines were derived from various F1 crosses of elite breeding material by in vivo haploid induction as described by RÖBER et al. (2005) and preselected for their line per se performance for vigour, flowering date, pollen production, lodging resistance, fertility, kernel quality, and general field appearance. Each material group was tested together with a set of 10 standard hybrids in a lattice design (10×10) with two replications at three locations, i.e. Einbeck (EIN) in Lower Saxony, Stuttgart-Hohenheim (HOH) in Baden-Württemberg, and Kaufering (KAUF) in Bavaria. At each location one experiment per material group (with 200 entries) was set up under CF and another experiment under OF with a distance of 2 to 13 km between the test sites, resulting in totally 24 single trials. For each entry, grain yield at harvest, dry matter content (DMC) and dry matter grain yield (DMY) was determined as well as lodging at harvest time.

Results

Grain yields under OF were 3 to 18% lower than under CF in the individual experiments depending on the test region and, to a lesser extent, on the genetic material (*Table 1*). In general, grain yield and dry matter content at harvest was lower under OF than under CF, resulting in an average DMY of 1077 g m^{-2} under OF compared to 1186 g m^{-2} under CF. The phenotypic variation for DMY among the 90 testcross lines was great in all material groups and farming systems, with a difference from 750 up to 1050 g m^{-2} between highest and lowest yielding genotypes. Phenotypic correlations between OF and CF were small or moderate for DMY within the four material groups (0.31 to 0.43), while strong and highly significant correlations were found for DMC (0.89 to 0.93). Phenotypic correlations between the different locations within farming systems ranged from 0.28 to 0.67 for DMY under CF and from 0.14 to 0.58 for DMY under OF, reflecting the greater environmental diversity expected in OF. ANOVA across locations revealed high heritability coefficients for DMC and moderate to high values for DMY.

In order to exemplify the effectiveness of selection under CF and OF for OF we selected in each material group the highest yielding 9 lines based on the entry mean DMY across the two locations EIN and KAUF under CF and OF, respectively, and compared their performance with that obtained at the third location (HOH) under OF (*Table 2*). In addition, we estimated the phenotypic correlation between the average DMY in Einbeck and Kaufering under CF and OF, respectively, with the testcross performance in Hohenheim under OF for all 90 lines. Results demonstrate that OF-adapted genotypes can be more reliably selected under OF than under CF.

Discussion

WOLFE et al. (2008) distinguished between three origins of varieties suitable for organic agriculture: (1) varieties derived from breeding programmes for conventional agriculture (BFCA) showing acceptable performance under organic conditions; (2) varieties derived from specific breeding programmes for organic agriculture (BFOA) but for economic reasons, only advanced generations are tested under OF; and (3) varieties derived from 'organic plant breeding' (OPB), which means that all breeding steps are executed under OF using selection and propagation techniques that comply with OF principles. While indirect selection under CF is quite effective for traits with high heritability, like

Table 1: **Mean testcross performance of the four material groups (averaged across 90 lines excluding standards) tested at three locations (EIN, HOH, KAUF) for dry matter grain yield (DMY) and dry matter content (DMC), percentage of performance under OF in relation to CF (OF-CF) as well as phenotypic correlation between CF and OF (r_{phen}) for these traits**

Material group/ Location	DMY CF g m^{-2}	DMY OF g m^{-2}	DMC CF %	DMC OF %	DMY OF/CF %	DMC OF/CF %	DMY r_{phen} (CF-OF)	DMC r_{phen} (CF-OF)
151 Flint lines × Tdent								
EIN	1209	1148	71.9	68.4	94.9	95.0	0.14	0.80
HOH	1351	1266	70.8	68.2	93.7	96.4	0.31	0.90
KAUF	1005	933	68.3	66.1	92.9	96.7	0.37	0.88
mean	1188	1116	70.4	67.6	93.9	96.0	0.36	0.92
152 Flint lines × Tdent								
EIN	1253	1155	72.3	68.0	92.2	94.0	0.31	0.82
HOH	1282	1147	71.0	67.4	89.5	95.0	-0.04	0.77
KAUF	1020	883	67.7	65.5	86.6	96.7	0.45	0.85
mean	1185	1062	70.3	67.0	89.6	95.2	0.39	0.89
153 Dent lines × Tflint								
EIN	1169	1133	71.6	68.0	97.0	94.9	0.14	0.84
HOH	1295	1180	70.1	67.5	91.1	96.3	0.30	0.86
KAUF	1047	860	68.3	67.2	82.1	98.4	0.51	0.89
mean	1170	1057	70.0	67.6	90.4	96.5	0.43	0.93
154 Dent lines × Tflint								
EIN	1209	1140	72.2	68.7	94.3	95.2	0.36	0.76
HOH	1349	1213	71.0	68.2	89.9	96.0	0.18	0.87
KAUF	1042	867	69.4	67.8	83.2	97.7	0.23	0.90
mean	1200	1073	70.9	68.2	89.5	96.3	0.31	0.91
Across groups	1186	1077	70.4	67.6	90.8	96.0	0.36	0.89

Table 2: **Phenotypic correlation (r_{phen}) for testcross grain yield (DMY) between Hohenheim under OF (HOHOF) and the average DMY at the other two locations under CF and OF, respectively, as well as the DMY realized in HOHOF for the highest yielding 9 genotypes across EIN and KAUF locations under the different farming systems**

Material group	r_{phen} HOH_{OF} – $(EIN+KAUF)_{CF}$	r_{phen} HOH_{OF} – $(EIN+KAUF)_{OF}$	Average DMY at HOH_{OF} of best 9 genotypes selected at EIN+KAUF CF (g m^{-2})	OF (g m^{-2})
151	0.26	0.39	1313	1331
152	0.16	0.33	1186	1194
153	0.29	0.59	1195	1265
154	0.29	0.52	1307	1305

earliness, plant height, and thousand kernel mass, this is not always the case for more complex traits characterized by high genotype by environment interaction. For breeding success, it is essential that the selected genotypes show superiority in the target environment, i.e. under organic farming. Especially for complex traits, like grain yield, it is therefore important to determine the ratio of expected indirect versus direct selection gain in order to optimize the breeding strategy. This ratio depends on the heritability coefficients determined under OF and CF and genotypic correlations between the two farming systems.

In contrast to the study of LORENZANA and BERNARDO (2008) comparing the testcross grain yield of 117 unselected inbred lines derived from one US single cross hybrid under CF and OF, our data which are based on four different material groups representing a wide range of the early maturing European germplasm clearly demonstrated the advantage of direct selection under OF for improved grain yield. In view of the fact, that in all three studies the average DMY was very high (>1000 g m^{-2}) for both farming systems with a yield reduction of only 6 to 15% under OF compared to CF, maize production under OF in practice might frequently be exposed to less favourable growing conditions such as limited nitrogen supply and/or release from organic fertilizer, weed interference, and seedling diseases, causing yield reduction of up to 55% (TOLLENAAR et al. 1997). Therefore, genotype by farming system interactions might be even more pronounced under those conditions and selecting in OF environments appears indispensible for making maximum progress in developing maize varieties for these conditions.

References

BURGER H, SCHLOEN M, SCHMIDT W, GEIGER HH, 2008: Quantitative genetic studies on breeding maize for adaptation to organic farming. Euphytica 163, 501-510.

LORENZANA RE, BERNARDO R, 2008: Genetic correlation between corn performance in organic and conventional production systems. Crop Sci 48, 903-910.

PRESTERL T, SEITZ G, LANDBECK M, THIEMT EM, SCHMIDT W, GEIGER HH, 2003: Improving nitrogen-use efficiency in European maize: Estimation of quantitative genetic parameters. Crop Sci 43, 1259-1265.

RÖBER FK, GORDILLO GA, GEIGER HH, 2005: *In vivo* haploid induction in maize - performance of new inducers and significance of doubled haploid lines in hybrid breeding. Maydica 50, 275-283.

TOLLENAAR M, AGUILERA A, NISSANKA SP, 1997: Grain yield is reduced more by weed interference in an old than in a new maize hybrid. Agron J 89: 239-246.

WOLFE MS, BARESEL JP, DESCLAUX D, GOLDRINGER I, HOAD S, KOVACS G, LÖSCHENBERGER F, MIEDANER T, OSTERGARD H, LAMMERTS VAN BUEREN ET, 2008: Developments in breeding cereals for organic agriculture. Euphytica 163, 323-346.