Evaluation of maize varieties in a changing climate: on-farm vs. experimental stations

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Abstract: Increased weather variability as predicted in current climate change scenarios is particularly challenging on sandy soils where the soil does not buffer well against shortages of water: Plant breeders increasingly attempt to find crop genotypes that can cope with these stress situations. While current variety recommendations are based on replicated small-plot trials in a specific region for which the trial is thought to be representative, genotype x environment interactions, genotype x management interactions, and increasing weather fluctuations make it increasingly difficult to predict which variety will be best in a given environment. An alternative approach is therefore to decentralize variety trials and place them on working farms. However, although on-farm trials offer potentially more relevance for direct variety selection on site, they are also likely to be subject to more noise and trial entries can often not be fully replicated. To evaluate the relative merit of on-farm trials vs. fully replicated trials conducted at experimental stations, we tested 6 maize varieties at four farms and at two stations in a region dominated by sandy soils. The variance of variety rankings over the years within each site was used as proxy to evaluate the consistency of variety information gained at each location. For dry matter yield, on-farm trials showed both the highest and the lowest consistency of variety ranking, with the consistency being intermediate at the experimental stations. For some quality parameters, namely non-fiber carbohydrate content and starch content, the majority of on-farm trials showed more consistent variety ranking over the years than the most consistent of the two replicated trials. This suggests that in terms of year-on-year reliability of maize yield and quality, on-farm trials may have the potential to complement, or even to outperform replicated variety trials. For both types of trials however, there is also scope for decreasing technical sources of variation.

Keywords: Genotype environment interactions; adaptation; on-farm research; stability

Introduction

Model-based climate scenarios predict an upward shift in the mean temperature and changes in the distribution of precipitation for the coming decades (Stocker *et al.*, 2013). In addition, it has been predicted that climate change also involves a rise of weather variability, i.e. increasing deviations from the mean (Schär *et al.*, 2004; Motha and Baier, 2005; Hansen *et al.*, 2012), although recent research has contested this view (Huntingford *et al.*, 2013). In any case, however, climate change is likely to affect the frequency of at least some types of extreme weather events, and this will have impacts on the growth of terrestrial plants (Reyer *et al.*, 2013).

Such effects may be of particular importance when the capacity of the site on which plants are grown is low. This is the case in the East German region of Brandenburg where yearly precipitation is less than 600 mm and light sandy soils prevail, showing a low buffer capacity against shortages of water. In this region, climate scenarios predict decreasing evapotranspiration in particular in the months of May to July (Gerstengarbe *et al.*, 2003). In face of increasing frequency of extreme weather events, coupled with a poor ability of the soil to buffer against water fluctuations, the ability of arable crops to produce high and stable yields under highly variable environmental conditions becomes more and more important (Döring *et al.*, 2010; Urban *et al.*, 2012). One possibility for adaptation on climate change is to cultivate varieties with a higher climatic tolerance such as temporal drought stress. In addition, it is necessary to create new variety selection strategies, which are more adapted to the local natural conditions and take the regional climatic differences into account.

Generally, variety choice can be based on fully replicated field trials conducted on experimental stations or on variety trials conducted on working farms. Experimental stations offer standardized techniques of gathering variety data and, because of replication ensure that data can be analyzed statistically. However, such trials are typically characterized by small plot sizes, which can result in substantial edge effects. By the use of machinery adapted for plot trials (e.g. for sowing and harvesting) that differ from farm scale machinery. In addition, farmers have been shown to be skeptical about the relevance of information from experimental stations, because transferability of results to local conditions on the farm remains questionable in their view (Rzewnicki, 1991). Therefore, both farmers and researchers have advocated on-farm research, to obtain more locally relevant information about variety performance in a decentralized way. While progress has been made in the past in terms of showing how to make on-farm trial more robust (Piepho *et al.*, 2011; Thöle *et al.*, 2013), constraints on the farm often mean that requirements suggested by statisticians cannot be met in practice. With these complementary benefits and drawbacks of trials conducted on-farm trials and on experimental stations, there is a need to know which type of trial provides more reliable information for on-farm variety selection. However, there is currently little quantitative evidence about the relative merit of the two different types of experimentation.

This study therefore aimed to compare on-farm trials and fully replicated trials in the region of Brandenburg to support variety choice on agricultural farms, with a focus on the four main crops grown in the region, namely maize, rye, wheat and oilseed rape. Here we report results from the maize trials, including yield and quality data. The trial series was run as part of the INKA-BB project (Innovation network adaptation to climate Brandenburg Berlin). It was organized by a farmer-researcher network established in the INKA-BB subproject "Variety Strategies to Adaptation on Climate Change".

Material and Methods

The on-farm trials and the fully replicated plot trials were conducted over three years under different local conditions in cooperation with four agricultural farms in the study region.

Field trials

The regional situation of the farms represents the range of geo-ecological conditions in Brandenburg with a gradient from north to south relating to soil, climate and weather (Table 1). The locations Groß Schönebeck and Trebbin are characterized by very light sandy soils and low yield potential (average 28 soil points). Passow and Groß-Gastrose represents locations with comparatively better soil conditions and higher yield potential (average 51 soil points). In both the replicated and the on-farm trials, row width was 75 cm. On-Farm trials were set up as unreplicated strips, and two rows were harvested from four pseudoreplicated plots from each strip. The average length of these plots in the on-farm trials was 16.4 m (min: 8.1 m; max: 33.3), resulting in an average harvested area of 4 x 16.4 m x 1.5 m = 98 m² for each variety. The field trials on the experimental stations in Berlin-Dahlem and Thyrow were set up in a randomized complete block design with three replicates in each year and a plot size of 10 m x 3 m. In these trials, the central two rows were harvested from a length of 8 m, i.e. 1 m at each end of the plot as well as the outer two maize rows were not included in the analysis in order to reduced edge effects. This resulted in a harvested area of 3 x 8 m x 1.5 m = 36 m² for each variety.

Table 1: Experimental stations and on-farm locations in Berlin and Brandenburg. 'German soil rating index' represent a German system of classifying general productivity of an arable site, with 1 and 100 being the minimum and maximum respectively (Finnern *et al.*, 1996).

Type	**Name**	**Acronym**	**Region**	**Coordinates (latitude °N, longitude °E)**	**German soil rating index**
Experimental stations	Berlin-Dahlem	DAH	Berlin	52.46629,13.29924	35
	Thyrow	THY	Teltow-Fläming	52.25418,13.23679	28
On-farm-locations	Passow	PAS	Uckermark	53.14035,14.10801	50
	Groß Schönebeck	GSB	Barnim	52.91136,13.52784	28
	Trebbin	TRE	Teltow-Fläming	52.19847,13.24494	27
	Groß Gastrose	GRG	Spree-Neiße	51.88270,14.64833	51

Figure 1: Maize rows in on-farm trial harvested with trial harvest technology.

At the beginning of the project, mobile weather stations were installed on all four farms, in order to assess the results in relation to locally prevailing weather conditions.

Varieties

Variety selection for the trials was based on the recommendations of the "State Agency for Rural Development, Agriculture and Land Reassignment Brandenburg" (LELF). In the years 2010-2012 the maize varieties Kalvin (S 220), LG 30.218 (S 220), Mazurka (S 240), Torres (S 250), Aabsolut (S 260), and Ingrid (S 260) were cultivated at all six locations. The values given in brackets indicate the silage maturity of maize. The German Federal Office of Plant Varieties specified these values based on the dry matter content at the point of harvest. The values are classified in three groups. Values of S 220 and below represent the "early" group varieties, the group "mid-early" contains varieties with values from S 230 – S 250, and in group "mid-late to late" are values larger than S260 (BSA, 2013). Thus, in each of the three maturity groups two varieties were tested in the trials. In addition to the on-farm trials the varieties were cultivated in fully replicated trials in Berlin-Dahlem and Thyrow, which are locations of the Training and Research Station of the Faculty of Agriculture and Horticulture of the Humboldt-University Berlin. On the farms, additional varieties commonly grown the region were included in the trial programme; the results of these additional varieties are not reported here.

Harvesting technology and quality analysis

In the on-farm trials the maize was harvested in the second half of September of each year, using trial harvest technology of the Training and Research Station of the Faculty of Agriculture and Horticulture of the Humboldt-University Berlin (Figure 1). In this way it was possible to quantify the maize yield of different varieties and locations more exactly than if farm machinery had been used for harvesting. For all locations the analyses of maize dry matter yield and quality of harvested plant samples were conducted in each of the three years. The analysis of the quality parameters were carried out in the Laboratory of the State Control Association Brandenburg (LKVBB) according to established laboratory standards (VDLUFA, 1976).

Statistical analysis

A common way to compare crop varieties across different locations is to use rankings of their performance within each test environment (e.g. Huehn, 1990; Vlachostergios and Roupakias, 2008). Here, our aim was to compare the two different trial set ups (replicated trials at two locations and on-farm trials at four locations) in terms of their reliability of variety data.

The rationale was to assess for each of the six locations how much the variety rankings varied over the three study years. In this case large variances of the variety rankings over the three years suggest that reliable information about which varieties performed best (or worst) at a particular location was difficult to obtain; conversely, low variance indicates high reliability of the information gathered about variety performance. Put differently, the variance of variety rankings over the years within each site was used as proxy to evaluate the consistency of variety data gained at each location. At the same time, these variances correspond to Huehn's stability parameter $S_i^{(2)}$ (Huehn, 1990).

In addition, the maize data was analyzed with a mixed model approach using site and year as random factors and variety as fixed factors to compare variety performance. Varieties were compared to 'Ingrid' as a control variety using Dunnett's test, since Ingrid showed the highest mean dry matter yield.

Results

The variety testing showed considerable site-specificity of the differences among the varieties. Therefore, no common variety recommendation could be given for the study region as represented by the set of trial sites.

Comparison of variety means: dry matter yields

Despite the underlying differences in soil quality at the six different trial sites (Table 1), dry matter yields, averaged over the three study years showed only relatively small differences between the sites (Table 2). For instance, despite the low yield potential at Thyrow (28 soil points) the mean yield achieved there was nearly the same over the three years as obtained at the location with the generally higher yield potential (Berlin-Dahlem, 35 soil points).

However, as reported elsewhere (Klepatzki et al., 2013), the yield fluctuations over the years at the locations were related to soil quality, i.e. the light sandy soils showed higher yield variability than the better sites. Dry matter yields of varieties Aabsolut and Torres were not significantly different from control variety Ingrid, whereas differences between Ingrid and the other three varieties were significant.

Table 2: Mean maize yields (dt ha^{-1} DM) of six different varieties in on-farm (GRG, GSB, PAS, TRE) and fully replicated trials (DAH and THY), means over three years (2010-2012).

Variety	DAH	THY	GRG	GSB	PAS	TRE	Mean
Aabsolut	188	190	196	165	162	181	180.2
Ingrid	187	191	197	161	172	186	182.4
Kalvin	175	175	160	162	165	184	170.3
LG 30.218	168	163	181	144	162	161	163.1
Mazurka	170	159	168	157	164	164	163.6
Torres	182	184	186	171	182	188	182.2
Mean	**179**	**177**	**181**	**160**	**168**	**177**	**173.6**

Comparison of variety means: quality

Among the quality parameters, relatively large differences between varieties were observed for crude fat (CL, 35.6% difference between maximum and minimum) and starch content (ST, 26.1%), whereas differences between varieties were small for usable crude protein (UCP, 5.3%), metabolisable energy (ME, 4.8%) and enzyme digestible organic matter (ELOS, 5.0%) (Table 3). Differences between individual varieties and the control variety Ingrid were significant for Kalvin (all parameters except RA and NEL); LG 30.218 (all parameters except CP, CL, and RNB); Mazurka (all parameters except RA and NFC); and Torres (all parameters). In contrast, differences between Aabsolut and Ingrid were non-significant for all parameters except ST.

Table 3: Comparison of quality parameters in g kg^{-1} DM (means over three years over all locations)

Variety	CL	CP	UCP	ST	RNB	CF	ME	NEL	oNDF	NFC	ELOS	RA
Aabsolut	19.5	67.4	125.1	275.8	-9.2	200.9	10.5	6.3	480.1	393.7	700.3	39.3
Ingrid	18.8	67.6	123.6	248.2	-9.0	210.7	10.4	6.2	494.3	379.6	686.1	39.7
Kalvin	21.2	74.3	128.6	296.6	-8.7	184.8	10.7	6.5	461.8	404.1	710.2	38.7
LG 30.218	20.2	69.9	127.8	313.1	-9.2	187.4	10.7	6.5	459.7	413.0	720.6	37.1
Mazurka	21.8	76.1	128.6	292.7	-8.4	190.0	10.7	6.4	472.6	389.3	703.8	40.2
Torres	25.5	71.2	130.1	302.5	-9.4	184.8	10.9	6.6	456.2	411.4	720.3	35.7
Mean	**21.2**	**71.1**	**127.3**	**288.2**	**-9.0**	**193.1**	**10.7**	**6.4**	**470.8**	**398.5**	**706.9**	**38.5**

Parameters: Crude fat (CL), crude protein (CP), usable crude protein (UCP), starch (ST), ruminal nitrogen balance (RNB), crude fiber (CF), metabolisable energy (ME), net energy content for lactation (NEL), organic neutral detergent fiber (oNDF) non-fiber carbohydrate (NFC), enzyme digestible organic matter (ELOS), raw ash (RA)

Comparison of on-farm and replicate trials

Variety rankings of dry matter yield varied both between sites and between years (Table 4). Across all locations and years varieties Aabsolut, Ingrid and Torres were consistently better than the other three varieties. In terms of reliability of the dry matter yield data gained at each location, the on-farm trials showed both the highest ($\sum S_i^{(2)}=3.7$) and the lowest ($\sum S_i^{(2)}=18.3$) consistency of variety ranking, with the consistency being intermediate at the experimental stations (Table 5).

Table 6 shows the variability of the rankings for the quality parameters in g kg^{-1} dry matter for the examined locations. As can be seen the parameter non-fiber carbohydrate (NFC) presented in all on-farm trials more consistent variety ranking over the years than the best of the replicated trials. For the other parameters there was a mixed picture, but in 10 out of 12 quality parameters at least one on-farm trial showed lower variability of the variety rankings than the best of the replicated trials. For two quality parameters, namely non-fiber carbohydrate content (NFC) and starch content (ST), the majority (i.e. 3 or 4 out of 4) of on-farm trials showed more consistent variety rankings over the years than the most consistent of the two replicated trials.

Table 4: Variety rankings of six maize varieties at six locations over three study years.

	site																	
	DAH			**THY**			**GRG**			**GSB**			**PAS**			**TRE**		
Year*	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Aabsolut	1	3	1	1	2	3	3	1	1	2	2	3	2	2	6	1	4	4
Ingrid	2	1	3	3	1	1	1	2	2	5	3	2	1	6	1	2	3	3
Kalvin	3	5	4	4	4	5	5	6	5	4	1	4	4	5	4	4	1	2
LG 30.218	6	6	5	5	6	4	4	4	3	6	6	6	5	4	5	5	5	6
Mazurka	4	4	6	6	5	6	6	5	6	3	5	5	6	3	3	6	6	5
Torres	5	2	2	2	3	2	2	3	4	1	4	1	3	1	2	3	2	1

*Years: 1=2010, 2=2011, 3=2012

Table 5: Mean ranks and Huehn´s Si(2) of the six maize varieties at the six locations: data for dry matter yield.

	Variety	**DAH**	**THY**	**GRG**	**GSB**	**PAS**	**TRE**
Mean ranks	Aabsolut	1.7	2.0	1.7	2.3	3.3	3.0
	Ingrid	2.0	1.7	1.7	3.3	2.7	2.7
	Kalvin	4.0	4.3	5.3	3.0	4.3	2.3
	LG 30.218	5.7	5.0	3.7	6.0	4.7	5.3
	Mazurka	4.7	5.7	5.7	4.3	4.0	5.7
	Torres	3.0	2.3	3.0	2.0	2.0	2.0
$S_i^{(2)}$	Aabsolut	1.3	1.0	1.3	0.3	5.3	3.0
	Ingrid	1.0	1.3	0.3	2.3	8.3	0.3
	Kalvin	1.0	0.3	0.3	3.0	0.3	2.3
	LG 30.218	0.3	1.0	0.3	0.0	0.3	0.3
	Mazurka	1.3	0.3	0.3	1.3	3.0	0.3
	Torres	3.0	0.3	1.0	3.0	1.0	1.0
	Sum	**8.0**	**4.3**	**3.7**	**10.0**	**18.3**	**7.3**

Table 6: Variability of variety rankings with regard to the quality parameters, calculated as Si(2) summed over all six varieties as in Table 5. 'Best rep' represents the replicated trial with the lowest ∑Si(2), 'Median rep' is the median value for the two replicated trials.

	Yield	**CL**	**CP**	**UCP**	**ST**	**RNB**	**CF**	**ME**	**NEL**	**oNDF**	**NFC**	**ELOS**	**RA**
Site	**(dt ha^{-1})**						**(g kg^{-1} DM)**						
DAH	8.0	6.3	6.3	9.3	13.7	6.3	10.7	11.0	12.7	14.7	21.3	14.7	11.7
THY	4.3	13.0	9.3	11.0	11.0	11.3	18.3	16.3	18.3	18.3	21.0	19.3	19.7
GRG	3.7	4.7	4.0	7.3	12.7	10.7	14.7	16.0	16.0	16.7	18.7	16.7	14.0
GSB	10.0	8.3	15.3	10.7	6.0	22.0	6.0	5.7	7.0	5.3	8.3	21.3	21.7
PAS	18.3	8.3	9.0	4.7	8.3	6.7	8.0	6.3	6.3	6.7	9.0	7.3	16.7
TRE	7.3	13.3	9.0	11.3	10.3	12.7	14.0	13.7	13.0	15.3	11.3	10.3	17.7
Median	7.7	8.3	9.0	10.0	14.0	11.0	12.3	12.3	12.8	15.0	15.0	15.7	17.2
Best rep	4.3	6.3	6.3	9.3	13.7	6.3	10.7	11.0	12.7	14.7	21.0	14.7	11.7
Median rep	6.2	9.7	7.8	10.2	14.0	8.8	14.5	13.7	15.5	16.5	21.2	17.0	15.7

Parameters: Crude fat (CL), crude protein (CP), usable crude protein (UCP), starch (ST), ruminal nitrogen balance (RNB), crude fiber (CF), metabolisable energy (ME), net energy content for lactation (NEL), organic neutral detergent fiber (oNDF) non-fiber carbohydrate (NFC), enzyme digestible organic matter (ELOS), raw ash (RA).

Further, 2 out of 4 on-farm trials showed more consistent variety rankings than the most consistent of the replicated trials for the usable crude protein (UCP), crude fiber (CF) metabolisable energy (ME), net energy content for lactation (NEL), organic neutral detergent fiber (oNDF), and enzyme digestible organic matter (ELOS). Thus, our results suggest that for a considerable number of parameters replicated plot trials at experimental stations do not necessarily outperform on-farm trials in terms of consistency of variety rankings.

Discussion

Usually, variety trials on experimental stations are characterized by relatively small plot sizes. In addition, sites of experimental stations are typically selected for homogeneous soil conditions. Thus, underlying heterogeneity of soil conditions are expected to be low in such trials. In contrast, on-farm trials, with their larger plots size, the use of pseudoreplications and potentially less careful site selection, can be expected to show comparatively large underlying soil heterogeneity within a trial. As a consequence on-farm trials would be predicted to show smaller reliability than trials conducted at experimental stations. However, the results of this study indicate that in terms of year-on-year reliability of maize yield and some quality parameters, on-farm trials may have the potential to complement, or even to outperform replicated variety trials.

One possible reason for this outcome may be that year x variety interactions may generally be stronger than interactions between variety and soil conditions within sites, so that the effects discussed above may just not relevant. Underlying mechanisms for the observed results however, remain speculative. In general, our results are preliminary in that they are based on a relatively small data set. Therefore, more research with a larger number of stations and on-farm locations, and conducted over a longer period time. In any case however, experiences obtained during the variety trialling here show that there is also scope for decreasing technical sources of variation for both types of trials.

Conclusions

In summary, we have shown that on-farm experiments can generate valuable information about variety performance and adaptation to site conditions in arable systems on comparatively marginal sites. Thus we have demonstrated that on-farm trials allow a practically relevant complementation of regional variety testing. This is of particular importance when resources for state-funded, i.e. official variety testing are being cut, so that regionally relevant and independent information on variety performance is increasingly difficult to obtain for farmers. Adaptation of agricultural production to climate change will require coordinated strategies. Our study supports the view that it is useful to build a regional network of on-farm trials when using variety selection as one component of these efforts. Such networks are likely to be instrumental for mastering the multiple challenges lying ahead.

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