Genetic contribution to maize yield gain among different locations in China

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Abstract

Maize (*Zea mays* L) yields have increased as the result of new hybrids and improved agronomic practices. Climatic factors markedly influenced maize growth and grain yield. The objectives of this study were to i) analyze changes in maize yield with genotype and agronomic-management improvement in different locations, and ii) assess the contributions of genotype, agronomic management, and genotype × agronomic management to maize yield gain between locations. Maize yield respectively increased 8.81 t ha^{-1} in Changji, 7.14 t ha^{-1} in Gongzhuling, and 7.98 t ha^{-1} in Xinxiang, from the 1950s to 2010s. In the three different growing sites, the contributions to yield gain were estimated 41.72 - 62.74% for genotype, 23.1 - 34.74% for agronomic improvement, and 10.6 - 29.89% for the combined effects of genotype × agronomic management. The contribution of genotype to yield gain was highest in Xinxiang at > 60%. The relative yield gain ratios of the three locations were Xinxiang > Gongzhuling > Changji considering genotype and cultivation improvement since the 1950s. The high contribution of genotype and relative yield gain ratio in Xinxiang may have resulted from Xinxiang having the lowest basic yield in the 1950s, and new hybrids having enhanced adaptability in the area. It suggested that breeding for improved adaptation to different environments is required in order to continue increasing maize yield in China.

Keywords: maize (*Zea mays* L), yield gain, contribution, location, genotypic adaptation

Introduction

China is one of the largest maize producers in the world, with a sowing area of approximately 33.54 million ha and a total production of 192.78 million t in 2011 (NBSC, 2012). Total yield increases have been mainly attributed to an increase in yield per unit area. Maize grain yield in China has increased considerably. For example, yields of 961 kg ha^{-1} in 1950 rose to 5,166 kg ha^{-1} in 2007, with an average annual growth rate for that period of 85.8 kg ha^{-1} (Li and Wang, 2008). The development of new hybrids and improvements in agronomic practices had been vital for maize yield gains (Charles, 1999; Long et al, 2006; Li and Wang, 2009, 2010). Chinese maize varieties have undergone five major stages, from the use of landraces, to between-variety hybrids, top-cross hybrids, double-cross hybrids, and finally single-cross hybrids. Plant populations increased from approximately 30,000 plants ha^{-1} in the 1950s to 70,000 plants ha^{-1} in the 2000s (Dong et al, 2006; Li and Wang, 2010), while nitrogen application for maize production increased from 45 kg N ha^{-1} in 1958 to 162 kg N ha^{-1} in 2005 (Wang et al, 2008).

A similar trend in yields has been reported in US maize production, which increased from 3,900 kg ha^{-1} in 1961 to 8,200 kg ha^{-1} in 2002 (Duvick, 2005). During the past 50 years, plant density in the corn belt of the central US increased at an average rate of about 1,000 plant ha^{-1} year^{-1}. In addition to the development of new hybrids, the application of commercial N fertilizer to US maize crops increased from an average application of approximately 58 kg N ha^{-1} in 1964 to a stable level of approximately 145 - 150 kg N ha^{-1} as of 1985 (Duvick, 2005; Daberkow and Huang, 2007).

Genetic improvements have made substantial contributions to maize yield in the US (Duvick, 1992; Duvick et al, 2004) and other countries including Argentina (Eyherabide and Damilano, 2001), Brazil (Cunha Fernandes and Franzon, 1997), Canada (Tollenaar, 1989), and France (Barrière and Argillier, 1998). Some Chinese scholars have published influential studies on genetic contributions to yield gain in maize (Zhang et al, 1998; Li, 2009; Ci et al, 2011; Wang et al, 2011), and strong interactions have been found between genetics and agronomic practices when comparing the yields of maize hybrids from different years grown at different plant densities (Duvick, 1997).

 RECEIVED 11/10/2014

Moreover, environmental conditions, especially climatic factors such as temperature, sunshine hours, solar radiation and precipitation, markedly influence maize growth, phenological response, biomass accumulation, and distribution (Andrade et al, 1993; Andrade and Ferreiro, 1996; Otegui et al, 1996; Birch et al, 1998; Tollenaar, 1999; Stone et al, 1999; Yang et al, 2004; Liu et al, 2010). Among these factors, temperature and sunshine are the two most important environmental variables influencing the rate of maize development and matter accumulation, which both affect maize yield (Duncan, 1975; Birch et al, 1998; Tollenaar, 1999; Liu et al, 2010, 2013).

Maize production is a comprehensive process involving interactions among varieties, agriculture and management practices, and the environment. The objective of this research was to determine the effects of genotype, agricultural management, and environment on maize grain yield per unit, and to compare the contributions of genotype and agronomic management to maize yields in Changji (northwest area, spring corn, irrigation), Gongzhuling (northeast area, spring corn, rain fed), and Xinxiang (Yellow and Huai rivers area, summer corn, irrigation) in China, since the 1950s.

Materials and Methods

Experimental design

The data used in this study were generated from field studies that were performed at Changji (44°02'N, 87°18'E, medium loam, desert soil) in Xinjiang Province in 2011 - 2012, Gongzhuling (43°30'N, 124°50'E, clay loam, black soil) in Jilin Province between 2011 and 2012, and Xinxiang (35°18'N, 113°56'E, medium loam, alluvial soil) in Henan Province in 2012. Table 1 shows some climate factors of three sites.

This study included nine maize hybrids and two open-pollinated corns (OPCs) that have been grown in China at a range of plant population densities (37,500, 52,500, 67,500, and 82,500 plants ha^{-1}) with four nitrogen applications (0, 150, 225, and 300 kg ha^{-1}) in Changji and Gongzhuling, and with three nitrogen applications (0, 150, and 300 kg ha^{-1}) in Xinxiang, which were included in the experiments (Table 2). Maize hybrids included Jidan101 (JD101), Zhongdan2 (ZD2), Sidan8 (SD8), Danyu13 (DY13), Jidan180 (JD180), Yedan13 (YD13), Zhengdan958 (ZD958), Xianyu335 (XY335), Nonghua101 (NH101); two OPCs were Baihe (BH) and Yinglizi (YLZ). The experiments were arranged in a split-split plot design with nitrogen treatments as the main plots, planting densities as subplots, and maize varieties as the sub-subplots. Individual plots measured about $24m^2$, and comprised six rows, 6 m in length and 0.65 m between rows with three replications each. Experiment conducted in Changji and Xinxiang was fully irrigated. Plant dates and other managements were similar to those adopted by local farmers. The individual varieties that were selected were known to be well adapted to the prevailing agro-ecological conditions. Seeds of proprietary parental lines were available, which allowed the creation of new F1 hybrid seeds.

Yield estimation

At physiological maturity, all plants in the central four rows of each plot, excluding the plants on the end of each row, were used to calculate lodging and numbers of barren plants, and were hand-harvested to measure the yield. Twenty ears were selected from each plot for measurements of kernel number per ear and kernel weight. The yield and kernel weight were measured at a moisture content of 14% (Shi et al, 2006).

Statistical analysis

Experiments at the three locations during two growing seasons were analyzed. Analysis of variance (ANOVA) was conducted for yield over nitrogen, density and variety using GLM. The following equation is based on the model for split-split design:

$$y = \mu + \rho + \alpha_k + (\varepsilon 1)_{jk} + \beta_l + (\alpha\beta)_{kl} + (\varepsilon 2)_{jkl} + \gamma_m + (\alpha\gamma)_{km} + (\beta\gamma)_{lm} + (\alpha\beta\gamma)_{klm} + (\varepsilon 3)_{jklm}$$

in which y is the yield of the genotypes; ρ is the tested blocks; α is the designed nitrogen; β is the designed densities; γ is the tested varieties; ε1-ε3 are respectively the main plot error, subplot error and sub-subplot error; j = 1, 2, 3; k = 1, 2, 3, 4; l = 1, 2, 3, 4; m = 1, 2, 3…11. Interaction between plant density and nitrogen factor were regarded as agronomic management.

The ANOVA for yield between growing locations and growing years was conducted respectively using Proc ANOVA for one way classification. To simplify the presentation and analysis of yield data, the three replicates within each combination of year, variety, nitrogen and density were averaged. Instead of treating the two years of the experiment as separate factors, they were combined for analysis in Changji and

Table 1 - The basic climate factors of maize growing period in the experimental regions.

Maize growing area	Mean growing period (day)	Annual frost-free days (day)	GDD (≥10°C)	Mean temperature (°C)	Diurnal variance of air temperature (°C)	Sunshine hours (hour)	Annual solar radiation (MJ m^{-2})	Precipitation of growing period (mm)
Changji , Xinjiang	128-164	170	1601-1702	19.9-20.4	16.1-16.3	1475-1526	5400	97-119
Gongzhuling, Jilin	133-160	155	1636-1625	20.1-20.3	9.9-10.4	940-1125	4600	333-482
Xinxiang, Henan	93-110	243	1867-1946	25.1-25.9	8.6-9.4	617-767	4400	273-353

Table 2 - Maize varieties used in the present study and their release dates.

Genotype	Pedigree	Year of release/use	Breeder
Baihe[§]	OPC	1950s	Gongzhuling farm of Jilin Province, Gongzhuling, China
Yinglizi[§]	OPC	1950s	Introduced to Liaoning Province
Jidan101	Ji63 × M14	1967	Maize Institute of Jilin AAS[#], Gongzhuling, China
Zhongdan2	Mo17 × Zi330	1972	Chinese AAS, Beijing, China
Sidan8	Xi14 × Mo17	1980	Siping AAS of Jilin Province, Siping, China
Danyu13	Mo17 × E28	1981	Dandong AAS of Liaoning Province, Dandong, China
Jidan180	J853 × Mo17	1986	Maize Institute of Jilin AAS, Gongzhuling, China
Yedan13	Ye478 × Dan340	1998	Laizhou AAS of Shandong Province, Laizhou, China
Zhengdan958	Zheng58 × Chang7-2	2000	Luohe AAS of Henan Province, Luohe, China
Xianyu335	PH6WC × PH4CV	2004	The Tieling Pioneer limited company, Tieling, China
Nonghua101	NH60×S121	2010	Beijing jin se nong hua seed S&T co, Ltd

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[§]Baihe and Yinglizi were popularly used in maize production in 1950s.

Gongzhuling.

Regression analysis on the year of release of the varieties was used to examine patterns in yield, and all data analyses were conducted using statistical software SAS 9.1 (SAS Institute, 2009).

Results

Maize yield trends in three areas

ANOVA indicated highly significant difference for yield among variety, nitrogen application and plant density in five environments (P < 0.001). Moreover, the interactions (N×D, V×N, V×D, N×D×V) were also

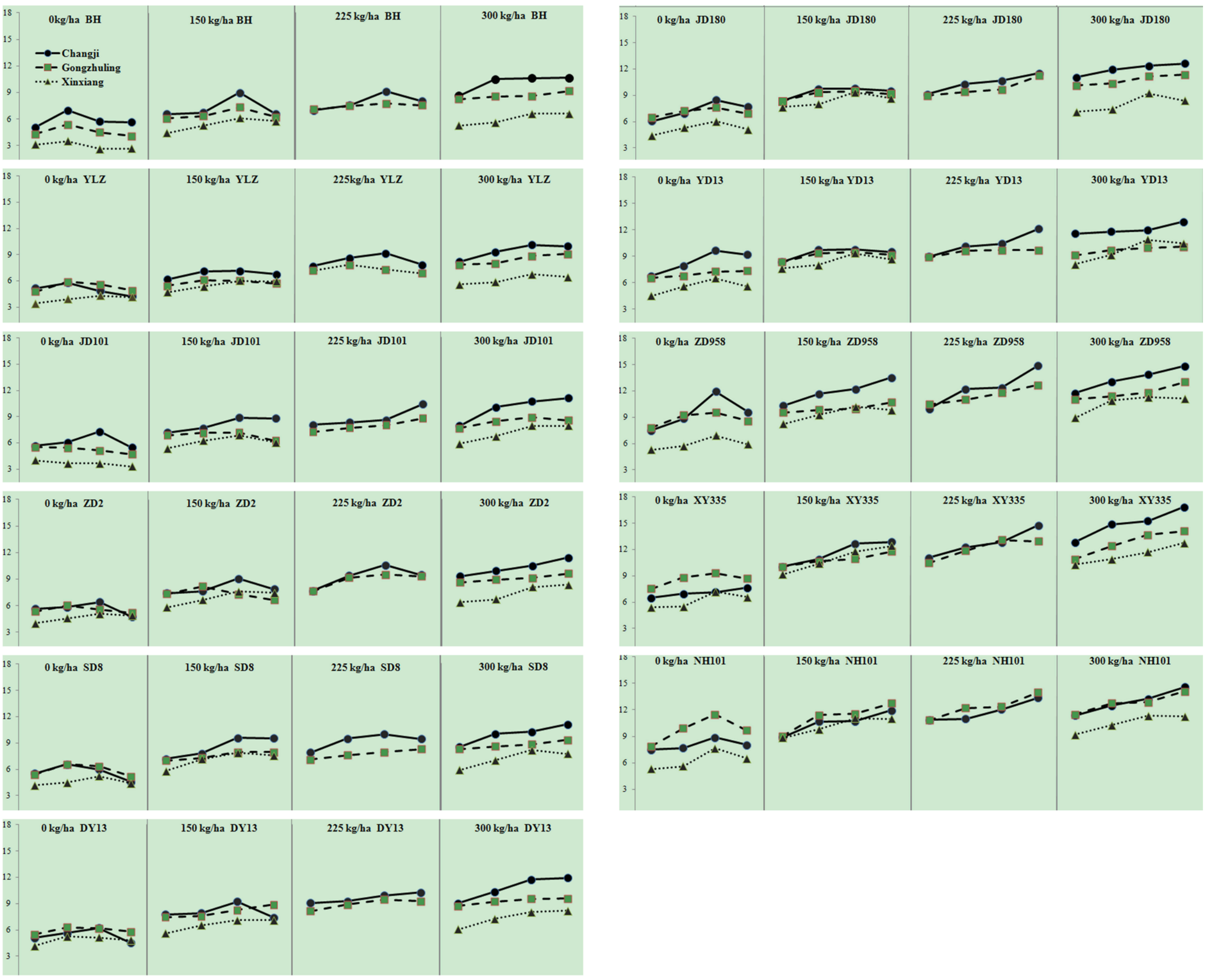

Figure 1 - The mean yield of maize varieties released from the 1950s to the 2010s, under different cultivation and growing areas. Maize varieties included BH, YLZ, JD101, ZD2, SD8, DY13, JD180, YD13, ZD958, XY335, NH101; nitrogen application were 0, 150,225,300 kg N ha^{-1}; plant densities were 37 500, 52 500, 67 500, 82 500 plants ha^{-1}; growing areas were Changji, Gongzhuling and Xinxiang.

Table 3 - Analysis of variance result for yield between nitrogen application, plant density and genotypes in three areas in 2011 and 2012. Interaction between nitrogen application and density was regarded as agronomic-management (Agro).

	2011	Changji	2011	Gongzhuling	2012	Changji	2012	Gongzhuling	2012	Xinxiang
Source	df	Mean Square	df	Mean Square	df	Mean Square	df	Mean Square	df	Mean Square
block	2	11.26	2	11.09	2	11.98	2	10.76	2	113.2
nitrogen (N)	3	421.1	3	238.6	3	645.8	3	351.2	2	534.5
Error$	6	0.054	6	0.038	6	0.089	6	0.047	4	0.687
density (D)	3	43.74	3	15.40	3	49.39	3	15.2	3	78.32
N×D (Agro)	9	13.86	9	3.74	9	6.58	9	10.6	6	7.01
Error§	24	0.014	24	0.011	24	0.013	24	0.009	18	0.52
variety (V)	10	115.5	10	144.9	10	104.0	10	129.1	10	85.15
V × N	30	5.39	30	1.86	30	6.62	30	2.27	20	9.55
V × D	30	4.34	30	3.86	30	3.52	30	3.88	30	2.18
V × Agro	90	3.65	90	0.69	90	4.098	90	1.38	60	1.96
Error‡	240	0.002	240	0.002	240	0.002	240	0.002	240	0.023

Error$, Error§, Error‡ were main plot error, subplot error, sub-subplot error, respectively.

significant for grain yield ($P < 0.001$) (Table 3). Maize grain yield was significantly different between the growing locations ($P < 0.001$). Significant differences in the yield between years were found in Changji but were not found in Gongzhuling (Table 4).

Although grain yield between years differed in quantity, they had the same change law for each combination of variety, nitrogen and density; therefore data are represented as annual averages in Changji and Gongzhuling.

The yields of individual maize varieties increased significantly with increasing year of release. For example in Changji, the relatively old maize variety BH had a lowest mean yield (calculated for two years) of 5.08 t ha^{-1} and highest yield of 10.5 t ha^{-1}. In contrast, the lowest yield of a modern maize variety, XY335, was 6.48 t ha^{-1} and the highest yield was 16.84 t ha^{-1} (Figure 1). The modern maize varieties had higher yield potential than the older varieties tested at the optimum cultivation condition, despite varying environments. Yield changes in Gongzhuling and Xinxiang displayed similar trends to those in Changji.

Each maize variety's yield was improved with application of nitrogen fertilizer and the highest yield was obtained at the maximum nitrogen application (300 kg ha^{-1}). Yields of BH were 6.99 t ha^{-1} with 0 kg N ha^{-1} and 10.34 t ha^{-1} at 300 kg N ha^{-1} when planted at 52,500 plants ha^{-1} in Changji (Figure 1). Yield changes showed similar trends in all three locations.

The yields of individual varieties did not all increase when the plant population was enlarged. The optimum plant density of each variety could be increased with increased nitrogen application. Old and new varieties obtained their highest yields at higher densities in all three locations when receiving 300 kg ha^{-1} of N fertilizer. Under 150 kg ha^{-1} nitrogen applications, heirloom genotypes such as BH and YLZ gained high yields under a planting density of 52,500 plants ha^{-1}; whereas the newer hybrids such as XY335 and NH101 obtained its highest yield under a planting density of 82,500 plants ha^{-1} in Gongzhuling (Figure 1). These same trends in yield were also seen in Changji and Xinxiang.

Growing conditions varied markedly among locations (Table 1). Maize yield was higher in Changji than in Gongzhuling and Xinxiang based on the average yield of all experiments. At the highest nitrogen application, the mean yields of the four densities and 11 varieties per density were 11.39 t ha^{-1} in Changji, 10.06 t ha^{-1} in Gongzhuling, and 8.36 t ha^{-1} in Xinxiang. Moreover, the optimum plant density for the newer hybrids grown in Changji and Gongzhuling was 82,500 plants ha^{-1}, and the corresponding density to achieve the highest yield for newer hybrids was 67,500 plants ha^{-1} in Xinxiang for all varieties except XY335 (Figure 1).

Estimated contribution to yield gain

Figure 2 shows the estimated contribution to absolute yield gain of genotype, agronomic management, and the interaction between them. As shown in Figure 2, GH (AB) and GF are the yield of early varieties released in the 1950s planted at the basic cultivation level (nitrogen N = 150 kg ha^{-1}, density D =

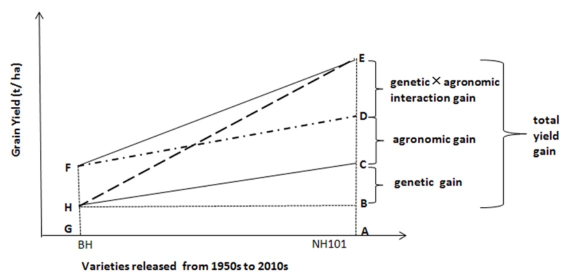

Figure 2 - Evaluation methods of maize yield gain, the contribution and relative yield gain ratio of genotype, agronomic-management, and the interaction of between the two. AB (GF) and AC represent respectively the yield of the 1950s varieties and the 2010s varieties at the basic cultivation level (nitrogen N= 150 kg ha-1, density D= 37,500 plants ha-1); GF and AE represent respectively the yield of the 1950s varieties and the 2010s varieties at the high-yield cultivation level (that achieved the highest yield); CH and EF represent respectively the yield of maize varieties released from the 1950s to the 2010s, planted at the basic cultivation level and the high-yield cultivation level; EH represents the process of yield increase. CD (EF) is the yield gains of early varieties after production level was improved. BE is the total yield gains. BC is the yield gains of genotype. CD (EF) is the yield gains of the agronomic-management. DE is the yield gains due to the genotype × agronomic-management interaction

Table 4 - Analysis of variance result for yield between locations and years.

Source	df	Mean Square	F
location	2	689.9	112.2***
year (Changji)	1	56.7	8.3**
year (Gongzhuling)	1	2.75	0.54ns
$Error_1$	2505	6.15	
$Error_2$	1054	6.84	
$Error_3$	1054	5.05	

***, **, ns showed significant at the 0.001, 0.01 probability levels and no significant, respectively. $Error_1$, the error of the ANOVA for yield between locations. $Error_2$, the error of the ANOVA for yield between years in Changji. $Error_3$, the error of the ANOVA for yield between years in Gongzhuling.

37,500 plants ha^{-1}) and the high-yield cultivation level (that achieved the highest yield). AC and AE represent the newest hybrids yield, respectively planted at above two cultivation levels.

In China in the 1950s, maize was always planted at a low density and little fertilizer was used other than manure application. Therefore, the 1950s cultivation is assumed to be 'basic cultivation'. 'high-yield cultivation' is the most recent cultivation of the 2010s that embodies the full potential of genetic and agronomic yield-increasing technologies. CH and EF were plotted in a linear regression on the year of introduction for the 11 genotypes at the 1950s cultivation level and the 2010s cultivation level (Figure 2).

Improvements in yield occurred with new hybrids, increased nitrogen application, and denser plantings, in different locations. The linear regression for varieties yield versus year of release shows significant relationships under the same cultivation at each location. As calculated by analysis of the linear regression (Niu et al, 2013), under the 1950s cultivation levels, the mean yields of 11 varieties on year of released were respectively 6.59 (GH or AB), 6.95, 7.32, 7.69, 8.06, 8.43, 8.80, 9.16, 9.53, 9.90, 10.26 (AC) t ha^{-1}; Under the 2010s cultivation levels, they were respectively 9.65 (GH), 10.22, 10.80, 11.37, 11.95, 12.53, 13.10, 13.67, 14.25, 14.83, 15.40 (AE) t ha^{-1} in Changji. The total yields gain (BE = AE - AB) was 8.81 t ha^{-1}, the yield gain included genetic improvement (BC = AC - AB) of 3.68 t ha^{-1}, agronomic-management improvement (CD = GF - GH) of 3.06 t ha^{-1}, genotype × agronomic-management interaction (DE = BE - BC - CD) of 2.07 t ha^{-1}. The experiment in Changji, the contributions by percentage of different types of improvements were as follows: genetic improvement, 41.72%; agronomic-management improvement, 34.74%; and genotype × agronomic-management interaction improvement, 23.53% (Table 5). Relative yield gain ratio was calculated by dividing yield of the 2010s (AE) by yield of the 1950s (GH or AB), which also included gain ratio of genotype (BC/AB), agronomic-management (CD/AB) and the interaction of the two (DE/AB). They were 1.33, 0.56, 0.46, and 0.31 times, respectively (Table 5).

According to the same method, the results of Gongzhuling and Xinxiang were seen in Table 5. Formulas used to calculate the contributions of various factors to the yield and relative yield gain ratio are also shown in Table 5. The increase in grain yield from the 1950s to the 2010s was in the order of Changji > Xinxiang > Gongzhuling, average 133 kg ha^{-1} $decade^{-1}$. The contribution of genotype improvement to yield increase in Xinxiang was more than 60%. Agronomic management contributed 34.74% to yield increases in Changji, more than its contribution in Gongzhuling or Xinxiang. The contribution of genotype and agronomic management interactions to yield gain in Gongzhuling was the most in three locations, about 29.89% (Table 5).

Further analysis of yield gain based on the basic yield in the 1950s revealed relative yield gain ratios of 1.33, 1.13, and 1.92 times in Changji, Gongzhuling, Xinxiang, respectively. Trends in relative genetic and agronomic yield gain ratios were in the order of Xinxiang > Changji > Gongzhuling. In Xinxiang, grain yield in maize increased by 1.21 times due to new hybrid breeds, and increased by 0.51 times from increased plant density and nitrogen fertilizer (Table 5).

Discussion

The maize growing areas in China are distributed in a north-south direction, therefore productivity levels differ among regions, especially climate conditions (Li and Wang, 2009). Dai et al (2011), in field experiments in different climates, found that lower grain yields in Xunxian and Changping than yield of Nong'an were due to relatively insufficient sunshine hours and small temperature differences between day and night, which increased the invalid breathing consumption at night. Sunshine hours and temperature are key determinants of potential productivity for crops grown under well-watered conditions with adequate nutrients in the absence of limitations caused by weeds, pests or diseases. In our study, trends in grain yield increases were positive over time for all environments, but they differed in quantity. Mean grain yield were in the order of Changji > Gongzhuling > Xinxiang, which may imply that climate conditions in Changji are superior for maize production compared to those in Gongzhuling, and in Gongzhuling bested in Xinxiang (Figure 1, Table 1).

Duvick et al (2004, 2005) compared 42 hybrids and four OPCs tested in 13 locations in US corn belt from 1996 to 2000, and reported that the most recently developed hybrid showed the greatest response to higher yield environments. Ci et al (2011) reported the opposite result, finding that maize yield gain from the 1970s to the 2000s was greater in low yield locations than in high yield locations. In our study, grain yield increase were in the order of Changji > Xinxiang > Gongzhuling, and were different from previous researches. The reasons for such unexpected variability are not known, but experimental

Table 5 - Absolute and relative maize yield gain from the 1950s-2010s and the contribution of genotype, agronomic-management, and the interaction of between the two to total yield increase at three locations.

Index	Source	Formula	Changji	Gongzhuling	Xinxiang
Absolute yield gain (t ha^{-1})					
	Genotype	BC	3.68	3.36	5.01
	Agronomic-management	CD	3.06	1.65	2.13
	Gene × Agro	DE	2.07	2.13	0.85
	Total	BE	8.81	7.14	7.98
Contribution to yield gain (%)					
	Genotype	BC/BE*100%	41.72	47.01	62.74
	Agronomic-management	CD/BE*100%	34.74	23.10	26.66
	Gene × Agro	DE/BE*100%	23.53	29.89	10.60
Relative yield gain ratio					
	Genotype	BC/AB	0.56	0.53	1.21
	Agronomic-management	CD/AB	0.46	0.26	0.51
	Gene × Agro	DE/AB	0.31	0.34	0.20
	Total	BE/AB	1.33	1.13	1.92

results indicate that such variability likely depends on interactions between genotypes and environmental conditions (Duvick, 2005).

Maize grain yield has increased over the past six decades due to the improvement of genotype and agricultural management regardless of environments. Estimations of genetic gain are a basic step in developing more effective breeding programs and more productive crop husbandry. Russell (1991) reported that genetic contributions to total yield gain varied from 29 to 94% in the corn belt of US. Further analysis revealed that the contribution of genetics to yield increase was about 51% from 1930 - 2001 for maize production in the US corn-belt state of Iowa (Duvick et al, 2004). Cunha Fernandes and Franzon (1997) estimated that hybrid maize breeding has been responsible for 57% of total yield in Brazil. Ci et al (2011) analyzed the average gain in Chinese maize yield at 94.7 kg ha^{-1} year^{-1} in Beijing over a 40-year period (1970 - 2000), 53% of which was due to genetic gain. Duvick (2005) summarized that genetic factors contributed 50 - 60% of the total on-farm yield gain based on earlier estimates.

Cardwell (1982) reported maize yield increases from the 1930s to 1980s in Minnesota were due to 47% of nitrogen application gain and 21% of plant density gain. Studies had shown changes in corn cultivations, such as increased fertilizer nitrogen, higher plant densities and better weed control, have resulted in 38 - 43% and 70 - 80% of total reported yield increases in developed and developing countries, respectively, over the past 20 years (Edmeades and Tollenaar, 1990).

However, maize yield improvement may be the result of an improved genetic and agronomic management interaction, rather than the result of either genetic and/or agronomic improvement per se (Tollenaar and Lee, 2002). Our team provided a method for analyzing the contributions of genetic and agronomic factors, and the interactions between genotype and agronomic management factors, to maize yield gains (Niu et al, 2013). In this study, the contributions of genotype to yield gain were the most of three factors, estimated as approximately 41.72 - 62.74% in three locations.

The broad variability in genetic contribution reported by many scientists may be the result of different planning and executing the experiments, maize production environments (Russell, 1991; Tollenaar, 1989). In our experiment, the advantage of variety contributed 62.74% of the total yield gain in Xinxiang, and the relative yield gain ratio was the pattern of Xinxiang > Changji > Gongzhuling (Table 5). This might be due to different climate factors (e.g. light, temperature, water) that caused differences even when the maize varieties and agricultural management were the same.

Maize adapted to regions with different ecological resources by changing its morpho-physiological components. There are evidences from different agricultural regions that increasing temperature during the growing stage of maize leads to a change in length of this stage (Cooper and Law, 1978; De Jong et al, 2001; Liu et al, 2010). On the other hand, a photoperiod extension during the photoperiod-sensitive phase in maize increased the length of vegetative stage and increased the number of leaves (Birch et al, 1998; Tollenaar, 1999). Several workers indicated that the heat units required for the completion of a given growth phase of maize are not constant but may vary depending on climate factors (Major et al, 1983; Liu et al, 2013). So the adaptation of maize to environment maybe decide on the expression of varieties for plant grain yield (Munaro et al, 2011; Tsimba et al, 2013; Liu et al, 2013).

In our study, the yield of the 2010s hybrids was about 2 times of the 1950s varieties yield and genetic gain in yield (BC) was 5.01 t ha^{-1} at the basic cultivation levels (nitrogen N = 150 kg ha^{-1}, density D = 37,500 plants ha^{-1}) disregarding plant density and nitrogen in Xinxiang. Increased yield could be due to increased tolerance to stress and increased efficiency in grain production (Duvick, 1997). So under growing conditions in Xinxiang, genetic gains in yield were most likely due to increase efficiency of grain production at the basic cultivation levels. High genetic contributions in Xinxiang may be the result of new hybrids having enhanced adaptability in the area.

Our results indicate that increased maize yields result from the adaptation of genotypes to continual increases in their environments (e.g., plant density, nitrogen application, climate factors, soil). To continue increasing maize yield in China, breeding for improved adaptation to different environments is required.

Acknowledgements

This present study was supported by the Major Project of Chinese National Programs for Fundamental Research and Development (NO.2009CB118605). The authors would like to thank www.textcheck.com for their language help.

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