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The Impact of US and CGIAR Germplasm on Maize Production in China

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Abstract

Wide adoption of a few kinds of homogeneous germplasm would reduce crop genetic diversity, increase crop vulnerability to stresses, and reduce the stability of crop production. The introduction and utilization of foreign germplasm is a sustainable solution for broadening the genetic diversity and promoting periodical replacement of varieties. The genetic contribution and economic impact of foreign germplasm, particularly those of US and CGIAR (Consultative Group on International Agricultural Research, referred to as the CG system) materials, on China's maize production are evaluated on the basis of an analysis of variety pedigree information from 20 major maize-producing provinces in China from 1982 to 1997. The results indicated that the contribution of US and CG germplasm to Chinese maize production continues to increase, particularly CG germplasm, which has shown a rapid increasing trend since the 1990s. If the genetic contribution of US germplasm is increased by 1%, maize yield will gain by 0.2% (0.01 t ha^{-1}). If contribution of CG germplasm, which has greater production potential, is increased by 1%, maize yield will gain by 0.025 t ha^{-1}. A policy should be implicated by the government in this direction to encourage breeders to focus more on the use and improvement of CG germplasm. The US germplasm has been utilized extensively in China so that it can offer germplasm resources for maize breeding efforts.

Key words: germplasm, genetic diversity, maize, US, CG

INTRODUCTION

The wide adoption of uniform and homogeneous hybrids or improved varieties will reduce genetic diversity in crop production and increase the crop's vulnerability to biotic and abiotic stresses. It is also highly probable that it will increase the risk of pathogen mutation, which may lead to severe disease epidemics. This was experienced in the US in the 1970s, with the outbreak of northern blight (*E. turcicum*), literally wiping out the hybrids that used cytoplasmic male sterile germplasm in their pedigree. This could reduce the stability of crop production in spite of improved crop productivity (Hu *et al.* 2002b; Hu 1998; Wang *et al.* 2001; Smale *et al.* 1998). Hence, broadening the genetic diversity and promoting periodical replacement of varieties through introduction and utilization of foreign germplasm is a sustainable solution to increasing the crop's resistance to/or tolerance for biotic and abiotic stresses, improving yield potential, and reducing the vulnerability of farmers to unforeseen yield losses.

Foreign germplasm, especially provided by the Consultative Group on International Agricultural Research

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(CGIAR, referred to as the CG system) centers, has made great contributions at the global level to food production. A number of scientists have conducted studies on the impact of CG germplasm (Fan *et al.* 2003; Rubenstein and Smale 2004; Huang *et al.* 2004; Jin *et al.* 2002; Hu *et al.* 2000; Evenson and Gollin 1997; Pardey *et al.* 1996; Stone and Rozelle 1995; Chang and Li 1991). Although most of these studies focused on the impacts of CG's materials, the methodologies, particularly those used for foreign germplasm, are quite different. Only a few studies concentrated on the contribution of CG materials to regions in China and on assessing crop yield potential in terms of space and time.

In this article, we try to focus on the contribution of foreign genetic resources to maize production on a space-time scale in China through analysis of varieties' relatives and the genetic basis using data from 20 major maize-producing provinces in the country. First, we will discuss the data sources and the indices of genetic contribution. Then the genetic contribution of the US germplasm, CG system germplasm, and germplasm from other countries to maize production in China will be analyzed. Regression results will then be presented and explained, followed by conclusions and policy recommendations.

RESEARCH METHODOLOGY AND DATA SOURCES

Genetic contribution of foreign germplasm

To study the genetic contribution of foreign germplasm to maize production in China, we calculated the coefficients of parentage (COP) between all hybrids and their parents from different sources by analyzing their pedigree. Then the area weighted COPs (WCOPs) were calculated between all planted hybrids and their parents according to the percentage of area planted with these hybrids. The value of each WCOP is the genetic contribution of the parent to the relative hybrid. By accumulating each genetic contribution of the parent that was derived from one source region to one hybrid, we estimated the source region's genetic contribution to the hybrid. By totaling each source region's contribution to all hybrids growing in one region, we obtained the genetic contribution of the source region to the region.

The coefficient of parentage For any pair of hybrids X and Y, the equation is

$$r_{xy} = \frac{1}{2}(r_{xa} + r_{xb}) \qquad (1)$$

Where r_{xy} stands for the COP between X and Y (Kempthorne 1957), r_{xa} and r_{xb} are the COP between strain X and the parents of strain Y. For a strain named Z, this COP is equal to

$$r_{zz} = \frac{1}{2}(1 + F_z) \qquad (2)$$

Where F_z is the inbreeding coefficient of strain Z, defined as the probability that the two alleles at a locus in Z are identical by descent. F_z is equal to the COP between the parents of Z. If the parents of strain Z are not known, then F_z is assumed to equal some value between 0 (e.g., Z is heterozygous) and 1 (e.g., Z is completely homozygous). As crops are different from animals, in the sense that almost all crop varieties are purified, F_z is set at unity. If the parents of varieties Z are already known, then,

$$F_z = (1 - HMZYG_z) \cdot r_{cd} + HMZYG_z \qquad (3)$$

Where $HMZYG_z$ is defined as the genetic homogeneity coefficient of variety Z, while r_{cd} represents the COP between the parents of strain Z. F_z is then used in equation (2) to calculate the COP of strain Z with itself. $HMZYG_z$, F_z, and r_{zz} would all have a value of 1 if strain Z was developed from an individual that had been selfed for an infinite number of generations after the initial hybridization of strains C and D.

The formula for calculating $HMZYG_z$ is as follows,

$$HMZYG_z = (1 - \frac{1}{2^n}) \qquad (4)$$

Where n is the number of generations of self-fertilization.

Genetic contribution of foreign germplasm We can obtain the genetic contribution of each parent line to every cultivated hybrid through weighted area from the COP. Then,

$$U_{hkt} = \sum_{j=1}^{m} p_{jkt} r_{hj} \quad h=1, \ldots, n; j=1, \ldots, m \qquad (5)$$

Where U_{hkt} stands for the contribution of the h parent line to all planted hybrids in region k in year t. p_{jkt} represents the acreage share of planted hybrid j of total acreage in region k in year t. r_{hj} represents the COP between parent line h and planted hybrid j or, in other words, the genetic contribution of parent line h to hybrid j. n represents the number of parent lines. m is the number of hybrids planted in the production in region k in year t.

$$U_{gkt} = \sum_{h=1}^{n} U_{hkt} \qquad h=1, \ldots, n \tag{6}$$

Where U_{gkt} represents the genetic contribution of the n parent lines from region g to all hybrids planted in region k in year t.

Data sources

The data on acreage of adopted hybrids was obtained from the Ministry of Agriculture (MOA) of China. The data on area planted to maize hybrids from 20 maize-producing provinces during the 1982-1997 period were collected from the MOA. The 20 provinces covered were Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Beijing, Tianjin, Shandong, Henan, Jiangsu, Anhui, Hubei, Shanxi, Shaanxi, Gansu, Xinjiang, Yunnan, Guizhou, Guangxi, and Sichuan (including Chongqing City). All hybrids covered in this study were those grown in an acreage of more than 6670 ha (0.1 million mu) annually. A total of 699 adopted hybrids were studied from these 20 provinces between 1982 and 1997. To calculate the COP of hybrids adopted in production and the genetic contribution of foreign germplasm, pedigree information of all adopted hybrids was analyzed. Information with regard to1 416 parent lines (or varieties) was collected from these 699 adopted hybrids. The 20 provinces, together, covered more than 90% of the domestic maize area. Production in the area was more than 95% of the total.

Information on hybrid pedigrees was obtained from published materials and from varietal introduction documents available with the provincial governments. By interviewing the breeders in relevant breeding institutions, we collected additional information. Those publications included: *The List of Genetic Resources of Maize in China (1988-1996)* (Institute of Variety Resources Research, CAAS 1988-1996), *Records on Maize Variety of China, Maize Elite Germplasm in China* (Institute of Variety Resources Research, CAAS 1988) and *Records on Crops in Jilin Province* (Jilin Academy of Agricultural Sciences 1998).

GENETIC CONTRIBUTION OF FOREIGN GERMPLASM TO MAIZE PRODUCTION IN CHINA

Foreign germplasm has made a significant contribution to maize production in China. Temperate corn-belt germplasm from the USA has played a special role in the improvement of maize varieties. Furthermore, the contribution of US germplasm in the constitution of domestic maize production continues to increase. Figs. 1-3 show the genetic contribution from the USA, the CG system, and other countries to Chinese maize

Table 1 Contribution of germplasm from different countries to maize production in China[1)] (%)

Year	American germplasm	CG germplasm	Other countries' germplasm	Chinese germplasm
1982	45.0	1.1	3.6	50.2
1983	48.0	0.8	2.1	49.1
1984	50.0	1.0	1.9	47.1
1985	50.1	1.2	2.8	45.9
1986	51.8	0.5	1.6	46.1
1987	53.4	0.5	2.5	43.6
1988	56.8	0.9	1.1	41.2
1989	57.9	1.3	0.4	40.4
1990	55.2	1.6	1.3	41.9
1991	52.8	1.7	0.8	44.7
1992	60.5	1.1	1.1	37.3
1993	56.1	1.2	0.8	41.9
1994	53.4	1.7	1.5	43.4
1995	56.2	1.6	0.5	41.7
1996	57.0	2.3	0.8	39.8
1997	54.6	1.7	0.9	42.8

[1)] The numbers are the simple averages of the contribution of different countries' germplasm to maize production in 20 provinces in China.

production. Since 1984, the average contribution of US germplasm to maize production in 20 maize-growing provinces has been up to 50%, which has exceeded that of local varieties (Table 1). CIMMYT germplasm has shown a rapid increase, especially since the 1990s, although its contribution did not exceed 3%. This was felt mostly in the southern provinces where tropical and subtropical germplasm were adapted. A systematic method of introgressing foreign maize germplasm from CIMMYT has been implemented since 1990. A slow and progressive system of introgressing introduced materials from the south and working its way up to the temperate zones has been implemented. We believe this approach will bear fruit in the coming years. In the area of quality protein maize, CIMMYT germplasm has served as the unique foreign source for Chinese breeders. Compared with US and CIMMYT maize germplasm contributions, genetic contributions from other countries were not only low but also showed a declining trend. It dropped to 1% since the early 1990s.

Utilization of US maize germplasm

Fig.1 shows space-time changes in genetic contribution of US germplasm to maize production in China. In 1982, the highest contribution was to Shanxi Province, which was up to 80%; the second to Gansu and Jilin, where the contribution rate was about 60%; then to Liaoning, Shandong, Jiangsu, Shaanxi, and Sichuan. There was relatively less contribution to the other provinces. The reason for the American germplasm playing an important role in maize production in Shanxi was that Zhongdan 2 and Danyu 6 planted over large areas, had some American germplasm ancestry. The parents of Zhongdan 2, a disease-resistant hybrid developed by Prof. Li Jingxiong of the Chinese Academy of Agricultural Sciences, were Mo17 from the USA and Zi 330, which contained US germplasm. The cultivated area of Zhongdan 2 accounted for 73% of the total area, more than 667 000 ha annually in Shanxi. The parents of Danyu 6, the second hybrid in terms of the sown area, also contained Zi 330. The US germplasm was predominant because of the popularity of these two varieties in Shanxi Province.

The use of US corn-belt germplasm in China grew with the increased adoption of Zhongdan 2 by farmers. Recycling lines such as Zi 330 and Ye 107 developed on the basis of US corn-belt materials, and inbred lines such as Ji 63, E 28, Yuanwu 02, 07, Ernan 24, Weifeng 322, and Lv9Kuan, developed from crosses between

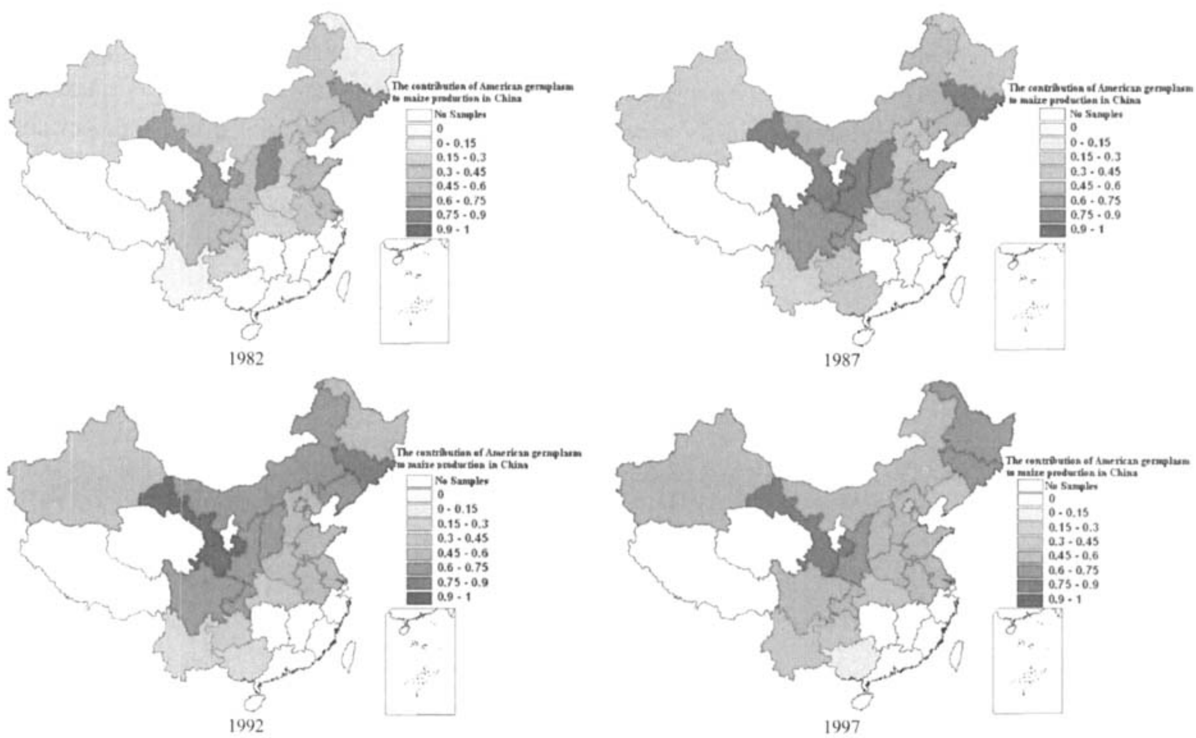

Fig. 1 Changes in contribution of American germplasm to maize production in China.

American materials and germplasm, became the core parents of commercial hybrids from the middle of the 1980s to the early 1990s. Since then, genetic contribution of American germplasm to maize production has increased significantly, especially from the northwest to northern Huanghuai and the northeast. It is noted that inbred lines with upright canopy or erect leaves (series of Yedan and Yandan hybrids) which have adapted to high-density planting were introduced in the 1980s, mostly containing US germplasm.

The contribution of American germplasm to maize production in Heilongjiang Province continued to increase steadily, from 12% in 1982 to 38% in 1987, then to 59% in 1992, up to 64% in 1997, although compared to the early 1990s, it had decreased in most maize-growing area. The main reason was that maize varieties adopted in Heilongjiang had shifted considerably. The sown area of hybrids Shongsan 1 and Longzhao 1, which contained American germplasm, accounted for 10% of the total maize acreage in the province that year. Since then, the area of commercial hybrids containing American germplasm has continued to expand. 18 out of 28 predominant hybrids whose areas were more than 667 000 ha annually, contained American germplasm, and the area planted with such hybrids accounted for 78% of total maize area in Heilongjiang in 1997. The area under Sidan 19, whose parents were Mo17 and A 619 (developed using American materials), accounted for 20% of the maize area in the province. At the same time, all the parents of Benyu 9 and Longdan 13, which were the second and the third in terms of cultivated area, were obtained from American germplasm or recycled lines from American hybrids. The genetic contribution of American germplasm to Heilongjiang Province increased considerably because of these hybrids.

Genetic contribution of CG germplasm

The maize germplasm of CG system, especially that of CIMMYT was obtained mainly from their headquarters in Mexico, which is considered to be the origin and center of diversity for maize. Additional tropical and mid-altitude materials were obtained from CIMMYT's regional centers in Thailand and Africa. These germplasm provided excellent sources of resistance to diseases and insects, lodging resistance, and drought tolerance. But tropical germplasm showed strong pho-

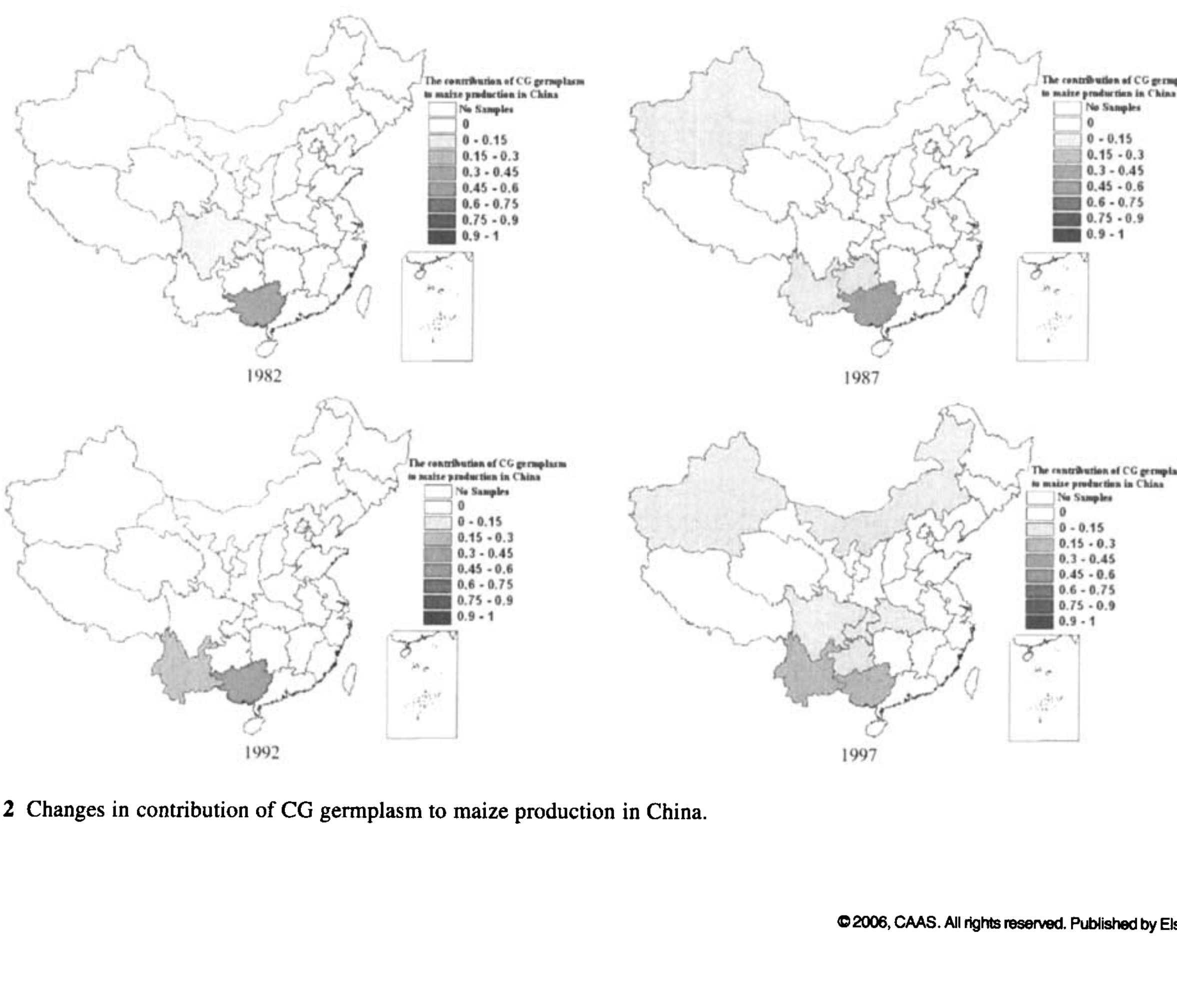

Fig. 2 Changes in contribution of CG germplasm to maize production in China.

toperiod sensitivity under long daylength conditions, so they were difficult to use directly in temperate zones. Space-time changes in the distribution of genetic contribution of CG germplasm (Fig.2) showed how Chinese maize breeders have introduced, improved, and introgressed CIMMYT germplasm into their program. The influence of CG germplasm on maize production in China extended continually from south to north (Fig. 2). In 1982, CG germplasm were being utilized only in Guangxi and Sichuan provinces, but, in 1997, seven provinces (Guangxi, Yunnan, Sichuan, Hubei, Guizhou, Xinjiang, and Inner Mongolia) started using CG materials. Materials possessing elite genes of CG germplasm have been used gradually, as breeders continued to improve them. For example, one of the hybrids utilizing CIMMYT germplasm, Nongda 108 was the first in recent years to be planted in large areas in the country. Its female parent, Huang C, which contained half of the CIMMYT germplasm and its male parent X178, were derived from an American hybrid containing a part of tropical germplasm. But Nongda 108 has not been included in the current studies because the data had not been available by then.

The genetic contribution of CG germplasm to maize production in Guangxi Province was significant. It spread from Guangxi to the other provinces. It showed that the southwest region could introduce maize germplasm directly from the same ecosystem. In fact, Mobai (Tuxpeno), Mohuang (Pob28) and their derived varieties, which were the main adopted varieties in Guangxi in the 1970s-1980s, were introduced from CIMMYT. These varieties remain as core germplasm and play an important role in marginal areas.

Genetic contribution of germplasm from other countries

The genetic contribution of germplasm from other countries to maize production in China showed a decreasing trend, although the contribution was extensive (Fig.3). In 1982, contribution from other countries to Xinjiang and Heilongjiang was higher, accounting for 15 and 14% respectively, but they were down to 5.8 and 1.8% in 1987. The same trend was observed in Jiangsu, Shandong, and Guangxi. It is important to point out that the contribution of germplasm from other countries to Gansu was 0 in 1982, but it jumped to 12% in 1987, and this province became the largest to use for-

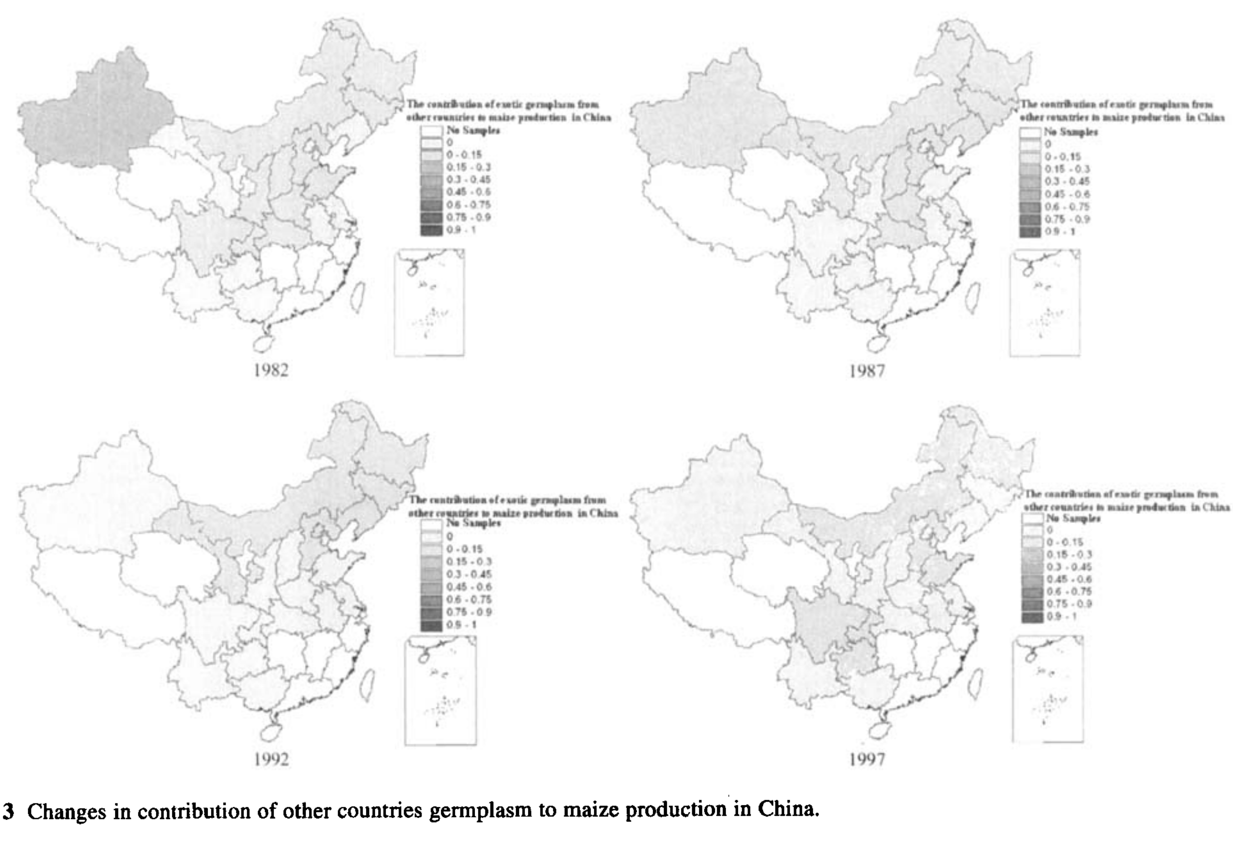

Fig. 3 Changes in contribution of other countries germplasm to maize production in China.

eign germplasm that year. This fluctuation in genetic contribution of germplasm from other countries was related to the fact that germplasm used in the provinces came from different regions and countries.

IMPACT ANALYSIS OF THE CONTRIBUTION OF FOREIGN GERMPLASM TO MAIZE PRODUCTION

Model

Production functions are used to assess the contribution of foreign germplasm to maize yield gains in different regions of China. Besides the genetic contribution, technology progress, inputs, institutions, and environmental variables were also considered as explainer variables. The model used was

$$\text{Yield} = F(t, GC, X, P, E) \quad (7)$$

Where t is a matrix of technology variables including time-series variable, which measures the contribution of technology progress during 1982-1997; GC is the genetic contribution variable of foreign germplasm (Genetic contribution of foreign germplasm from the US, CG system, and other countries compared with domestic germplasm will be included to assess the impact of the genetic contribution of germplasm to maize yield gain); X is a matrix of unit area input variables, including fertilizer, labor, pesticide, machine, and irrigation; P is a matrix of constitutional variables for which we use 1982 and 1983 (two-year dummy variables) to examine the impact of the rural household responsibility system (HRS) reforms in China in the early 1980s; E is the environmental factor, including the area proportion of drought and flood disaster-hit area, and it also represents regional dummies (as compared with Hebei Province).

Input data was obtained from surveys of agricultural production cost in the provinces as released by the State Pricing Bureau. Fertilizer input is calculated by dividing urea price by fertilizer price index in the corresponding province and year. Pesticide input is computed by dividing oxidized rogor price by pesticide price index in the corresponding province and year. Machine input (kw ha^{-1}) and irrigation input are from the agricultural production cost survey data and are calculated by dividing machine and irrigation expenditure by machine price index and country retail price index in the corresponding province and year. Data on drought and flood area were from *China Statistics Yearbook*.

Estimation results

Table 2 shows the estimation results of the production function (equation 7) with linear and log-linear models, respectively. Statistically, the results were generally significant. The R^2 in the two models are both 0.8, most of the coefficients were as expected, and most of the t-tests are significant. All coefficients expressed stable estimates.

In both linear and log-linear models, there were good performances for the genetic contribution of US germplasm. Both coefficients were positive (Table 2, row 2). There was a distinct positive relationship between American germplasm and maize yield compared

Table 2 Estimation results of contribution of foreign germplasm to maize yield in China, 1982-1997

Variable	Linear model	Log-linear model
R & D		
Time series	-0.039	-0.002
	(3.16)***	(-0.64)
Contribution of foreign germplasm		
American germplasm	0.010	0.002
	(3.01)***	(2.64)***
CG germplasm	0.025	0.002
	(2.66)***	(1.01)
Foreign germplasm from other countries	-0.025	-0.003
	(-2.15)**	(-1.50)
Input		
Fertilizer/log (fertilizer)	0.001	0.235
	(2.24)**	(6.76)***
Labor/log (labor)	0.002	0.040
	(2.03)**	(0.71)
Pesticide/log (pesticide)	-0.007	0.022
	(-0.25)	(2.37)**
Machine/log (machine)	12.745	0.016
	(5.02)***	(1.45)
Irrigation	-2.391	-0.267
	(-0.77)	(-0.47)
Environment		
Area percentage hit by drought	-0.011	-0.002
	(-4.94)***	(-3.69)***
Area percentage hit by flood	-0.001	-0.0001
	(-0.11)	(-0.16)
HRS dummy		
D82	-0.495	-0.163
	(-3.09)***	(-4.51)***
D83	-0.135	-0.052
	(-0.90)	(-1.55)
Constant	3.614	0.091
	(12.70)***	(0.27)
Sample size	312	291
R^2	0.80	0.80

Figures in brackets are test statistics of corresponding coefficients.
*, **, *** stand for significance at 0.1, 0.05, and 0.01, respectively.

to domestic germplasm. If the contribution of American germplasm were increased by 1%, maize yield would gain by 0.2% or 0.01 t ha^{-1}.

The coefficient of genetic contribution of CG germplasm in the linear model was also significantly positive as was the contribution of US germplasm (Table 2, row 3, column 1). Compared to domestic and US germplasm, CG germplasm had a higher potential to enhance maize yield. An increase in contribution of CG germplasm by 1% would result in a gain in the maize yield by 0.025 t ha^{-1}.

The coefficient of genetic contribution of germplasm from other countries was significantly negative (Table 2, row 4, column 1). It indicated that the impact of germplasm from other countries on maize yield was lower than that of the domestic germplasm. If the contribution of germplasm from other countries were increased by 1%, maize yield would be reduced by 0.25 t ha^{-1}. The main reason is the considerable fluctuation in the contribution of the germplasm from other countries to different provinces during the years.

The time-series variable appeared to be significantly positive in the linear model (Table 2, row 1, column 1). It indicated that technological progress contributed significantly to maize yield gain in China since 1982. The average yield increased by 0.039 t ha^{-1} annually.

As expected, Table 2 shows that, in the two models, D82 (one of two-year dummy variables) variable was negative and significant. This indicated that the rural household responsibility system reform had significantly enhanced maize yield, which increased on an average by 0.5 t ha^{-1}. By 1983, the rural household responsibility system reform had been carried out in most counties in China. It made the coefficients of the 1983 dummy variable insignificant.

The coefficients of the drought disaster variable were highly significant at the 0.01 level and expressed negative values (Table 2, row 11) in spite of the insignificant coefficient of the flood disaster variable (Table 2, row 10). The results indicated that drought is one of the most important constraints to maize yield increase in China.

In addition, the coefficients of fertilizer, labor, pesticide, and machine inputs shared a very significant positive relationship with maize yield, which was consistent with the production function theory (Hu *et al.* 2002a, b; Wang *et al.* 2001; Widawsky *et al.* 1998).

CONCLUSIONS AND POLICY IMPLICATION

Extensive utilization of US and CG germplasm

The extensive utilization of US and CG germplasm remarkably improved maize yield potential in China. It is evident that there is a significant positive relationship between the genetic contributions of US and CG germplasms and maize yield gains in China. Compared with domestic germplasm, the average yield gain will be 0.01 and 0.025 t ha^{-1}, respectively, if genetic contributions of US and CG germplasm increase by 1%. It indicates that germplasm in the CG system, especially CIMMYT germplasm, should be improved and utilized more, with American germplasm being utilized extensively in China.

Research and development of CG germplasm

The genetic contribution of US and CG germplasms to maize production in China increased continually during 1982-1997, in which that of American germplasm had been more than 50% since 1984. It shows that the genetic contribution of CG germplasm to maize production in China has greater potential in the future because of its increasingly steady application. Its coefficient of genetic contribution is higher than that of the US germplasm, although the data are not yet complete in the current research. The government should support and encourage breeders to focus more on the improvement and development of CG germplasm to widen the genetic pool for maize breeding.

Improvement of CG germplasm

The adoption of US and CG germplasm in different regions is closely related to their ecological adaptability, usually achieved through the improvement, development, and utilization of these foreign germplasms. Directly introduced CIMMYT germplasm is only adapted for use in the southwest, but the adoption of foreign germplasms will be extended from the south to the north rapidly after further improvement by Chinese breeders.

Increasing investment on germplasm research

Maize seed technologies have already been commercialized, and government should focus on relevant public issues such as R&D mechanism, market environment, and trade management system to ensure that hybrid technologies can go hand in hand with the marketing mechanism. The government should provide funds to support research on germplasm introduction and improve development, in order to support sustainable technological development.

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