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The Impact of Exotic Genetic Materials on Rice Production in China

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Abstract

The genetic contribution and economic impacts of exotic germplasm (particularly IRRI's and Japan's material) to China's rice production are studied based on the analysis of varieties' pedigree information from 16 major rice producing provinces in China during 1982-2011. The results indicated that the exotic germplasm, especially those coming from the International Rice Research Institute (IRRI) and Japan contributed greatly to China's rice production and varietal improvement efforts. IRRI is the biggest contributors to China rice production, the average contribute rate reach 16.3% in 30 years. The contribution to china rice production increase gradually during the 1980s', it reached its peak 23.59% in 1990 then declined gradually over the years that followed. The trend of Japanese varieties manifests a steady share since 1992. And their overall importance shows no sign of fading. The policy implication means that government should encourage breeders to focus more on the use and improvement of exotic germplasm.

Keywords: Exotic genetic, Rice production, China

JEL codes:O13 Agriculture; Natural Resources; Energy; Environment; Other Primary Products, Q58 Environmental Economics: Government Policy, C5 Econometric Modeling

IAAE

1. Introduction

Introduction and utilization of exotic germplasm is a sustainable solution for increasing crops' resistance to pest and stress environments, improving the grain quality and productivity of current varieties by broadening the genetic diversity (Hu, 2002; Wang, 2001； Smale, 1998 etc). The studies indicated that the direct and indirect adoption of exotic varieties and germplasm have contributed the replacement, development and popularization of fine strains of rice in China for which be identified as one of the major factors that accelerated the rapid increase in China's rice production (Lin etc., 1992). Particularly for the germplasm that coming from the International Rice Research Institute (IRRI) and Japan, beside being directly adopting by farmers in their rice production, they have provided the first generation of hybrid rice restore lines and contributed the germplasm of diseases resistance and dwarf in the new varieties improvement (Cabanilla, 2000). Even up to today, many rice varieties still take the consanguinity of IRRI or Japan's germplasm materials.

The impact of exotic germplasm on crop production has been studied by many scientists (Fan, 2003; Rubenstein, 2004; Huang, 2004; Jin, 2002, Hossain, 2001, 2002; Hu, 2000). A book on the germplasm impact assessment and evaluation of the Consultative Group on International Agricultural Research (CGIAR) was published in 2002 (Evenson, 2002). It builds the methodologies to assess the contribution of CGIAR's germplasm for which were undertaken by the CGIAR centers and their partners of national agricultural research systems (NARS). Although a number of studies assess the impacts of germplasm to monitor and document the released varieties and corresponding adoption rates and production gains for individual crop commodities (Fan et al., 2003; Cabanilla et al., 2000; Hossain et al), only a few studies assess the genetic contribution of germplasm on crop's production (Widawsky，1998； Gollin，1998， Hartell，1998， wangli，2001). Besides our studies that traced out the spacial distribution of genetic contribution of exotic germplasm on maize production in China (Li et al., 2005), we have not found the same rigorous analysis on the genetic contribution for other crops in China from that period onward.

This paper aims to examine the spacial distribution of genetic contribution of exotic germplasm and its impacts on rice production. We will separate the exotic germplasm as IRRI's materials, Japan's materials and other countries'. The paper is organized as follows. A description of the method and data sources in this paper is given in section 2. Section 3 deals with the impact of exotic germplasm (especially IRRI materials and Japan materials) on rice production in China. The regression result and decomposition analysis of the contribution of exotic material to Chinese rice production is reported in Section 4. The last section sums up the overall findings and gives a few concluding remarks, which is followed by conclusions and policy recommendations.

2. Index of genetic contribution on rice production

A index based on the pedigree analysis was used to estimate the genetic contribution of germplasmson China's rice production. By tracing of the parents, and parents grand back to the ultimate ancestors, the pedigree analysis (Hargrove, 1978, 1979, 1985; Gollin and Evenson, 1991; Evenson and Gollin, 1997; Hu et al., 2001; Janaiah et al., 2002， li， 2005) described the detail origin of varieties from different ancestors and composition of their genealogies.

To estimate the index of genetic contribution, we calculated the coefficients of parentage (COP) between all adopted varieties and their parents from different sources by analyzing their pedigree first. We assume that each parent contributed the equal genetic materials for each hybrid process. For example, to any pair of hybrids X and Y,

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

Where rxy stands for the COP between parents Xs and Y (Kempthorne, 1957), rxa and rxb are the COP between strain X and the parents of strain Y. For a strain named Z, this COP is equal to:

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

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

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

Where HMZYGz is defined as the genetic homogeneity coefficient of varieties Z .while rcd stands for the COP between the parents of strain Z. Fz is then used in equation (2) to calculate the COP of strain Z with itself. HMZYGz, Fz, and rzz would all have a value of one if strain Z was developed from an individual that had been self for an infinite number of generations after the initial hybridization of strains C and D.

The formula for calculating HMZYGz is as follows:

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

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

Then we separate all the parents' germplasms to domestic, IRRI, Japan and other countries to estimate the index of the exotic source genetic contribution. It was assigned to the original parents that the parents that come from the other countries while we calculated the COP between all adopted varieties and their parents. The COPs of every rice variety grown by farmers in their production are the genetic composition we estimated.

By weighting every variety's sown area in rice production, the area weighted COPs (WCOPs) can be estimated. The value of each WCOP is the genetic contribution of one parent to one variety. By aggregating each genetic contribution of parent originating from the same source to one variety in every region and year, we can obtain each parent line's genetic contribution to the special production region in the special year.

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

where Uhkt stands for the contribution of the h parent line to all planted hybrids in region k in year t. pjkt represents the acreage share of planted hybrid j of total acreage in region k in year t. rhj 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 Ugkt represents the genetic contribution of the n parent lines from region g to all hybrids planted in regain k in year t.

To study the impacts of exotic genetic germplasm on rice production in China, we elected 16 rice-growing provinces to estimate the index of the exotic source genetic contribution. These 16 provinces covered 95% of total rice area and 96% of total rice production in China: Hebei, Heilongjiang, Jilin, Liaoning (North and Northeast region), Anhui, Jiangsu, Zhejiang (East region), Hubei, Hunan, Jiangxi (Central), Guangdong, Guangxi, Fujian, (South), Sichuan, Guizhou, Yunnan (Southwest). The data consisted of 3,356 adopted varieties in an area of more than 100,000 mu or 6,667 hectare in at least one province in one season (popular variety). These varieties were traced to 7750 parents that originate or developed from China, IRRI, Japan and other countries. Data on varietal sown area of 1982 to 2011 were from Ministry of Agriculture of China. Information on the pedigrees of varieties was obtained from the formal and informal published materials or interviewing the breeders or relevant breeding institutions.

3. Genetic contribution and impacts of exotic germplasms on China's rice production

3.1. Rice varieties release and the contribution of exotic varieties

As the origins of rice biodiversity centers (Jiang，2004), China owe abundant rice local varieties (Lin et al., 1992). As the hometown of rice, China farmers and scientists developed the largest number of rice varieties in the worlds (Lin et al., 1992) for which did not only adopted by China's farmers, it also contributed to green revolution (Cabanilla, 2000). Particularly since the foundation of the People's Republic of China in 1949, the process speedup and for which included the first semi-dwarf rice variety "Ai Jiao Nan Te" in the world (Lin et al., 1992).

There were 3356 popular varieties grown by China's farmers in rice production during 1982-2011 (table 1). The number of rice varieties farmers adopted has increased more than 5 times during the past 30 years for which it is from 534 in 1982-1986, 840 in 1997-2001, 1663 in 2007- 2011. Among the varieties, only very few varieties are introduced from other counties. However, the introduced varieties were grown more years than the domestic developed varieties by China's farmers. Although more than 92% farmers adopted domestic developed varieties in their rice production every year, the number of varieties containing foreign material (2002) is about 56.3% of the total popular varieties.

Exotic germplasm contributed China's rice varieties development (table 1). Among all the popular rice varieties China's farmers adopted during 1982-2011, 1066 varieties take the consanguinity of the varieties IRRI developed, 556 varieties take the consanguinity of the varieties Japan developed, and 122 take the consanguinity of the varieties other countries developed. Only 1077 popular varieties are the pure descendant of China's local germplasm. It should indicate that besides it was used extensively in the morphologic traits development such as semi-dwarf, short duration and others, IRRI's germplasm have been directly used in most of the first generation of hybrid restorer lines in China's hybrid rice varieties development.

3.2 The genetic contribution of exotic germplasm on China's rice production

To examine the exotic germplasm contribution to China's rice varieties improvement and the impacts on China's rice production, we calculated the genetic contribution of germplasm from IRRI, Japan and other countries. The results showed that there average genetic contribution to China's rice production reaches 10.3% during 1982-2011. IRRI have contributed biggest genetic germplasm for which it takes about 16.3% of total genetic materials for China's rice varieties. Japan contributed 11.2% genetic materials and other countries contributed 3.35% materials (figure 1).

Nationwide, IRRI is the biggest genetic contributors to China rice production during 1982-2011 (figure 1). The contribution to china rice production increase gradually during the 1980s', it reached the peak 23.59% in 1990 then declined gradually over the years that followed and in 2011 it still reaches 8.83%. The change of IRRI's genetic contribution describes the story of hybrid rice variety development in China. The scientists developed the first generation of three line hybrid rice in 1970s and then was diffused and adopted by more and more farmers in 1980s. As the first generation of restore line or its parent, IRRI germplasm' contribution increased with the three line hybrid varieties diffusion. This process has been maintained until in the middle of 1990s. While the two lines hybrid line has been developed and diffused, the varieties included fewer IRRI genetic materials have taken three line hybrid varieties adopted by more farmers. It makes the fast decline of the contribution during 1995 to 2001 and gently decline after that time when the two line hybrid varieties are adequately adopted by the farmers who can grow the varieties in their region.

The proportion varied over years and across provinces. Figure 2 shows that IRRI genetic contribution focused mainly on the provinces where indica rice was mostly grown. The central, south, and southwest regions got the most contribution from IRRI. The north, northwest, and northeast regions, which mainly planted japonica rice, got the least from IRRI. Most varieties or genetic materials developed in IRRI used indica-based materials. Also, provinces with bigger areas sown to hybrid rice had more IRRI genetic contribution since most hybrid rice varieties have parental materials from IRRI.

In 1982, IRRI germplasm contributed the most to rice production in Hunan and Hubei provinces, followed by Anhui, Jiangxi, Zhejiang, Jiangsu and Sichuan. In 1988, IRRI's genetic resource contribution to Chinese rice production increased rapidly and so did the number of provinces that use IRRI materials. At that time, all of the south, central, and southwest regions used IRRI germplasm. The rice production in Hunan, Jiangxi, and Zhejiang provinces got the greatest boost from IRRI varieties. The contribution of IRRI materials peaked in 1994 and the distribution moved from the center to the southwest. Hunan Province was still the biggest gainer from IRRI. The IRRI germplasm contribution are still higher in most south, central and southwest provinces where plant indica rice. From 2006 to 2011, the genetic contribution had declined for the whole country.

One of the reasons for the decline in IRRI's genetic contribution is that the area planted to japonica varieties increased in the beginning of the 1990s in Jiangsu and Zhejiang provinces in the central region. Another reason is that the restorer lines for hybrid rice varieties have been improved, which directly used IRRI varieties before the 1990s. The improved restorer lines were composed of genetic components from local germplasm and other countries'. Japan's rice varieties had been extensive adopted by China's farmers in the region that grow Japonica rice before 1980s (Lin et al., 1992). As one of the major resources of disease resistant and high grain quality, Japan's rice germplasm have been used by China's scientists as the parents in their new variety development program up to today. Although the genetic contribution has a little decline in early 1980s, it still reaches about 10%.The trend has changed since the late 1990 (figure 1). The contribution has increased from 1999 to 2004. It reached 15% and then decreased and in 2011, it still reaches 11.2%. The trend also shows the process of Japonica rice variety development in China. Before the middle of 1990s, higher yield potential was the top priority breeding objectives (Fan et al.2003， Hu et al., 2000). The germplasm with high diseases resistance have been used as one of the major genetic resources for that maintained the little changes of the genetic contribution. While the priority of breeding objectives has changed from higher yield potential to both yield potential and high grain quality, more Japan's high grain quality germplasm were used by China's scientists for that made the contribution increased during 1999 to 2004. While China's scientist found more local higher grain quality germplasm and used them in their new rice variety improvement program after the late 1990s, the genetic contribution of Japan declined. Japan's breeding materials played a significant role in China's breeding program, especially in the northern part. The Japanese genetic contribution was mainly distributed in provinces which grow japonica rice (Fig.3). These were in the north, northeast, and northwest regions. Other areas with indica rice mainly planted got little from Japan. Because of similarity in agricultural environment between north China and Japan, the adopted varieties developed in Japan or the parental lines and landraces originated from Japan all have the good traits of high quality, high yield, and that high disease and pest resistance.

In 1982, Japan's materials contributed the most to rice production in Liaoning. With nearly all adopted varieties in these provinces developed from Japan, the contribution of Japan reached 100%. Jinlin and Hebei provinces got the most contribution from Japanese varieties, and nearly 80% of germplasm contribution of varieties adopted in these two provinces came from Japan. That in Heilongjiang and Jiangsu provinces reached about 60 -70%.In 1988, the use of Japan's varieties or materials remained stable in the northeast region. But Japan's genetic contribution to Chinese rice production declined in 1994. There area two reasons for this. One is that national research agencies have become strong enough that they did not only introduce varieties from Japan directly, they also used Japan's material more as parents or landraces than as adopted varieties. The other is that provincial and district agricultural research institutes selected more materials from the locality and they used more and more native landraces in varietal improvement.

From 2000 to 2011, the declining trend of contribution to the northeast continued, but Sichuan, Yunnan Guangdong and Guangxi increased in use of Japanese materials. From 1982 to 2002, the genetic contribution remained stable in the whole country. Improvement of japonica rice varieties occurred later than improvement of indica varieties. In the beginning of the 1980s, most of the adopted varieties in the japonica-growing planting regions were introduced from Japan. The actual japonica varietal improvement program started in the mid-1980s. Many improved varieties developed in China gradually became the popular varieties in these regions, including some japonica hybrid varieties.

3.3 Impact of exotic germplasm

3.3.1Model

Production function is used to assess the impact of exotic germplasm on China's rice production. A rice yield model is estimated. Besides the genetic contribution, technology progress, inputs, institution, and other control variables are included in the models. The model is as follow:

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

Where t is a matrix of technology variables including time series variable measured the contribution of technology progress during 1982-2011. GC is the genetic contribution variables of exotic germplasm. It includes IRRI, Japan and other countries contributions. R is a matrix of institution variables for which includes rural household responsibility system (HRS) reform, the commercialization government agricultural extension system reform (D88, see Hu et al., 2009; 2004) in the end of 1988 and public services government agricultural extension system reform started in the middle of 2000s (D04, see Hu et al., 2011), and seed industry reform started for which the China's government decreed and enforcement the seed law in 2000 (Seed reform). X is a matrix of input variables including fertilizer, labor, pesticide, machine and irrigation. E is environmental variables including the area proportion of drought and flood disaster hit area and regional dummies (compared with Hebei province).

3.3.2 Data and model estimation

Rice yields for 16 provinces come from the China Agricultural Statistical Yearbook (NBSC 1982-2011).Input data came from the Agricultural Commodity Cost and Revenue Statistics Compilation (NDRC 1982-2011). Among them, fertilizer input is calculated through dividing urea price by fertilizer expend price index in corresponding province and year. Pesticide input is from dividing Oxidized Rogor price by pesticide expend price index in corresponding province and year. Machine input (kw/ ha) and irrigation input are from the agricultural production cost survey data and calculated by dividing machine and irrigation expenditure by machine price index and country retail price index in corresponding province and year. The price indices for major agricultural inputs and drought and flood area come from the China Statistical Yearbook (NBSC 1982-2011). To get a robust result, while estimating the mode, line and log models are estimated respectively.

3.3.3 Estimated results

Estimated results for both linear and log-linear models generally perform well and robust (table 2). The adjusted R-squares reaches 0.83 and most of the signs of the coefficients of control variables are as expected and most of the t-ratios reach significant level. For example, the coefficient of fertilizer and machine variables are positive and reach significant level. The coefficients of labor and other input variables are not significant, it indicate that the marginal products of labor and other inputs are still nearly zero in China. The negative and significant coefficient of pesticides variable indicates that the higher the pesticides input, the heavier plant diseases and insect pests occur. The coefficients of the two disaster variables are negative and reach significant level. It shows that the drought and flood significantly reduced rice yields.

It should indicate that the coefficient of seed industry reform variable is positive and significant (table 2). It shows that the decree and enforcement of seed law has promoted the rice yield increases. The coefficient of time series variable is significant, it indicates that technology progress has accelerated China’s rice yields increases. The positive and significant coefficient of HRS variable again demonstrated the effects of the reform of rural household responsibility system reform (Huang et al., 1997).The significant coefficient of

D88 and D04 variables promulgated that the conducted commercialization government agricultural extension system reform and public services government agricultural extension system reform did promote the rice yields. Although some studies query the effects of commercialization government agricultural extension system reform started in the end of 1980s for which permits that the agricultural extension station marketing agricultural inputs (Huang et al., 2001; Hu et al., 2004), this study certified that the reform has a positive impacts on rice yields. The new finding is the effect of new round reform of the public services government agricultural extension system reform that started in the middle of 2000s. The reform has promoted the rice yields increase.

The impact of exotic genetic material will promulgate the story of the China's rice scientists using IRRI, Japan, and other countries germplasm in their rice variety improvement programs. For both linear and log-linear models, there are good performances for the variables of genetic contribution of IRRI, Japan and other countries germplasm. All the variables coefficients are significant (table 2, row 1, 2, and 3). The variables coefficients of IRRI and Japan materials are positive and other countries' is negative. It shows that compared to domestic germplasm, IRRI and Japan's materials would contribute rice variety yield potential increases, and other countries, would not contribute rice variety yield potential increase, but contribute the adverse effects of yield potential. It certifies that the use of IRRI and Japan's germplasm by China's rice scientists are to improve the morphologic characteristics relating to the yields potentials, such as the height and duration and of other countries germplasm, is to improve other morphologic characteristics, such as the disease resistance.

The coefficients of IRRI and Japan germplasm of the log-linear are 0.149 and 0.130 respectively (table 2, row 1 and 2, column 2). It means that compared to using domestic germplasm, if the genetic contribution of IRRI germplasm increases by 1%, result on gains of rice yield potential would increase by 14.9%. And if the genetic contribution of Japan germplasm increases by 1%, result on gains of rice yield potential would increase by 13.0%.It indicates that IRRI and Japan's germplasm would still be the major genetic resources that the scientists use in their new variety improvement programs. The use of germplasm would effectively improve rice new variety yield potentials.

It is notable that the significant negative coefficient of other countries germplasm is -0.590 (table 2, row 3, column 2). It means that the impact of germplasm from other countries to rice yield potential is lower than domestics, and the genetic contribution of germplasm from other countries increases by 1%, rice yield potential would reduce by 8%. It indicates that although the other countries germplasm are used by China's scientists in some provinces such as guangxi， guizhou and jiangxi, it usually is used to improve the low yield potential varieties jinyou974,Honglianzao. These germplasm would be used in these regions if the yield potential is still not high enough.

4. Conclusion

As the origins of rice biodiversity centers, China farmers and scientists developed the largest number of rice varieties in the worlds, it includes the first semi-dwarf rice variety "Ai Jiao Nan Te" in the world. There were 3356 popular varieties grown by China's farmers in their rice production in the major rice provinces during 1982-2011. The number of rice varieties farmers adopted has increased more than 5 times during the past 30 years. Among the varieties, only 11% of the varieties are introduced from other counties.

Exotic germplasm contributed China's rice varieties development. Among all the popular rice varieties China's farmers adopted during 1982-2011, more than two thirds of them take the consanguinity of exotic germplasm. The introduced germplasm were used extensively in the morphologic characteristics improvement such as semi-dwarf, short duration, diseases resistances, high grain quality etc. IRRI's germplasm has contributed the first generation of restore line of hybrid rice varieties development and most of three lines hybrid rice varieties development.

To examine the exotic germplasm contribution to China's rice varieties improvement and the impacts on China's rice production, we calculated the genetic contribution of germplasm from IRRI, Japan and other countries. The results showed that there average genetic contribution to China's rice production reaches 10.3% during 1982-2011. IRRI have contributed biggest genetic germplasm for which it takes about 16.3% of total genetic materials for China's rice varieties. Japan contributed 11.2% genetic materials and other countries contributed 3.35% materials (figure 1).

IRRI and Japan have contributed most of genetic materials in China’s varieties development programs besides the domestics in the past 30 years. Among the average genetic contribution of 10.3 %, IRRI contributed 16.3% and Japan contributed 11.2%, and other contribute only contributed 3.35%. The biggest contribution for IRRI is in 1990s, and then declined. In 2011 it still is only 8.83%. Although Japan’s genetic contribution on China’s rice production declined since the late of 1980s, but it rises a little again after 1990s. The changes of genetic contribution of IRRI are partly determined by the hybrid varieties development from two lines to three lines.

Comparing to the domestics germplasm, IRRI and Japan’s materials would contribute rice variety yield potential increases. The results indicate that IRRI and Japan’s germplasm would still be the major genetic resources that China’s scientists should use in their new variety improvement programs. The use of germplasm would effectively improve rice new variety yield potentials.

Tables and Figures

Table 1 The number of released varieties in China adopted by farmers by origin and time period,1982-2011

Year	Total	Using Chinese resources	Introduced Foreign varieties				varieties containing foreign material			
			subtotal	IR	Japan	Other	subtotal	IR	Japan	Other
1982-1986	534	138	26	5	13	8	370	114	110	146
1987-1991	524	123	18	1	12	5	383	171	114	98
1992-1996	631	143	18	2	12	4	470	274	113	83
1997-2001	840	221	10		9	1	609	366	142	101
2002-2006	1139	287	4		3	1	848	523	221	104
2007-2011	1636	654	4		3	1	850	501	234	115
Total	3228	1186	40	5	25	10	2002	106	556	380

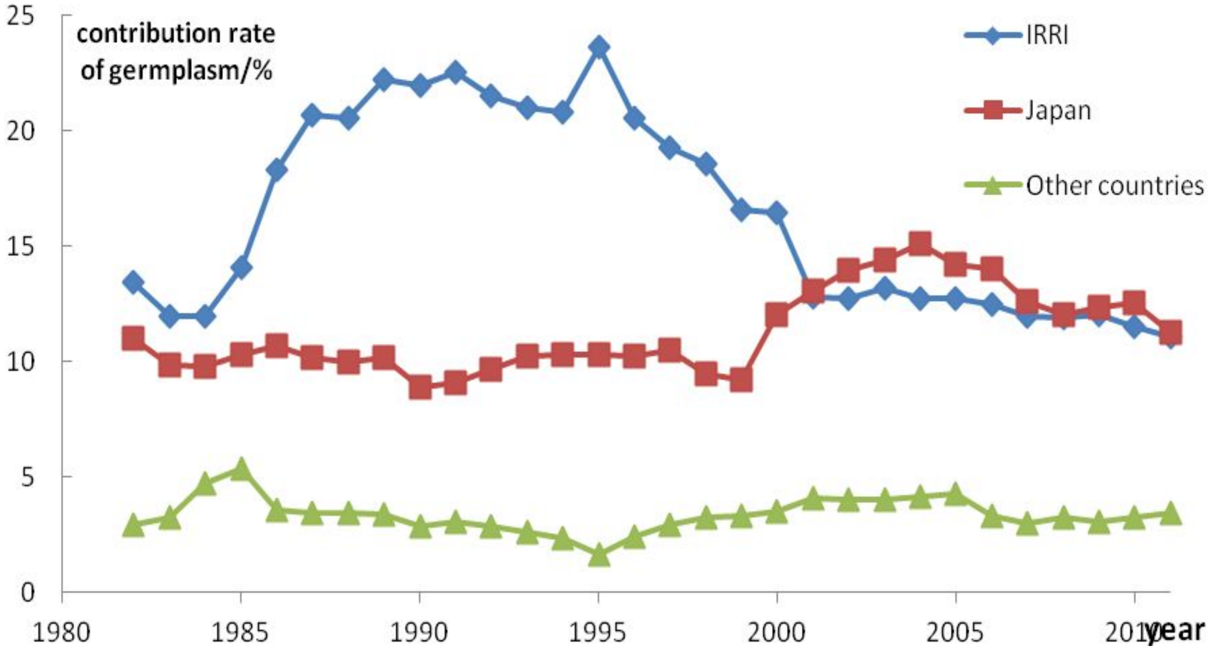
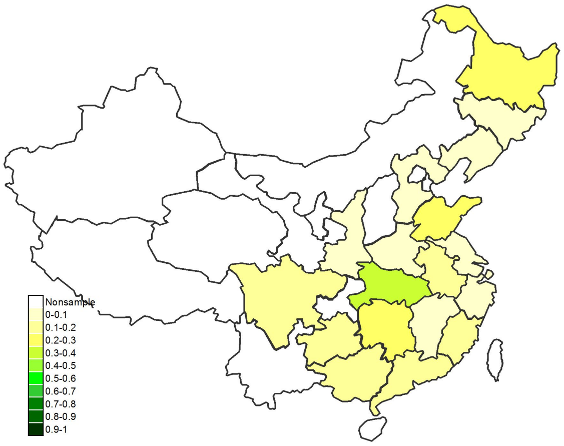
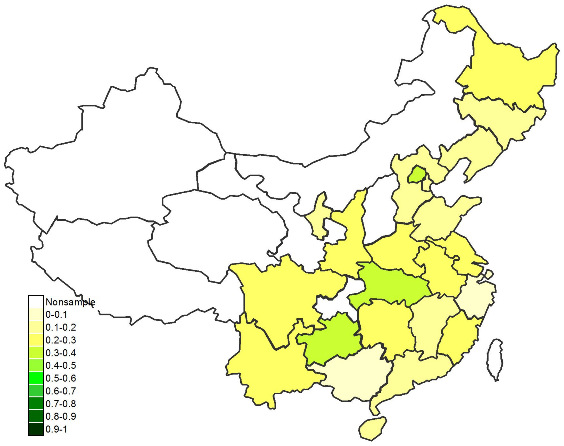


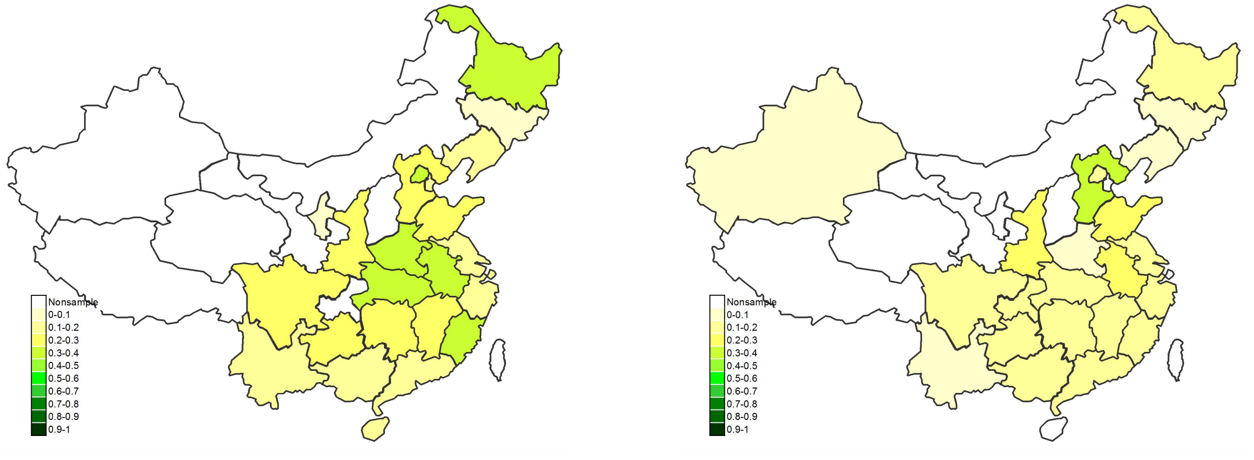
Figure1. Genetic contributions of exotics materials to rice production in China,1982-2011



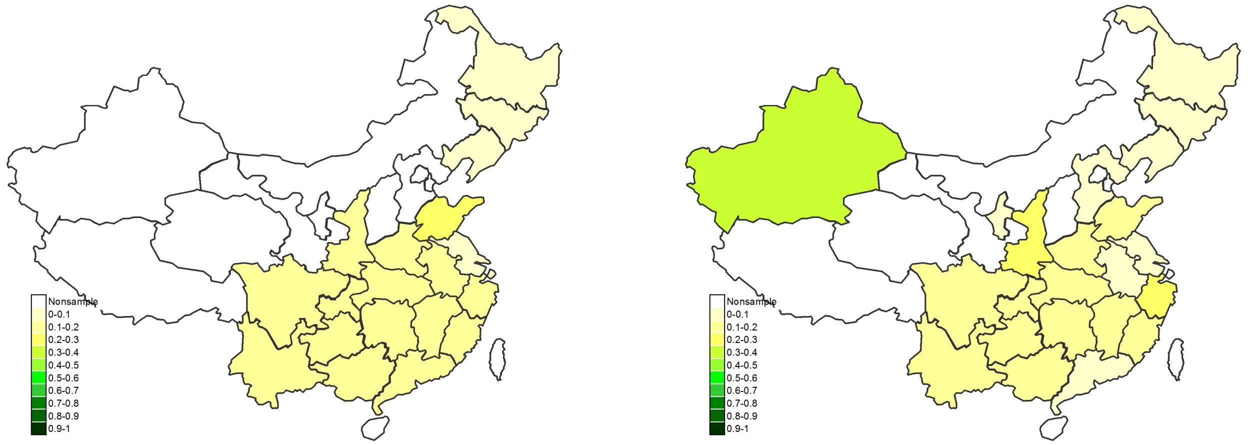
1982



1988

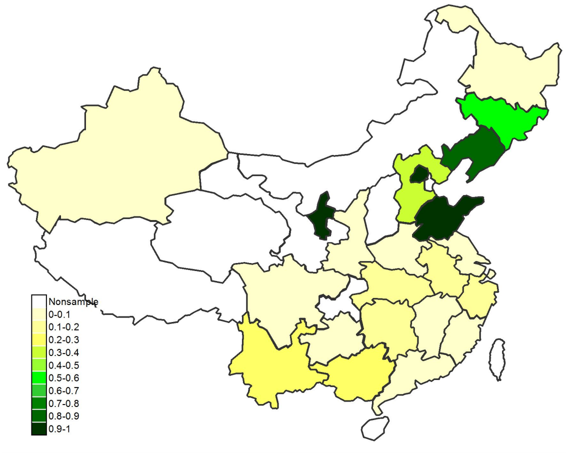


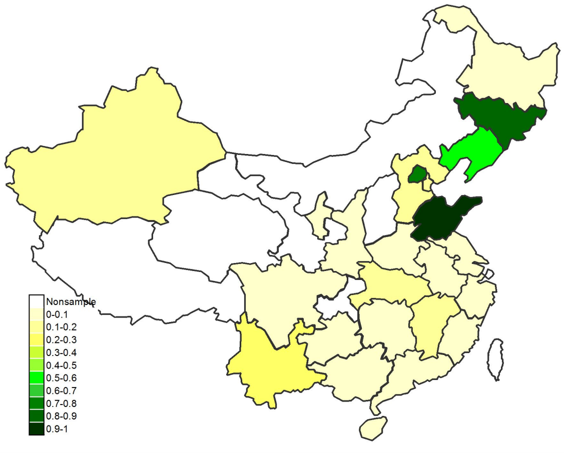
1994 **2000**



2006 **2011**

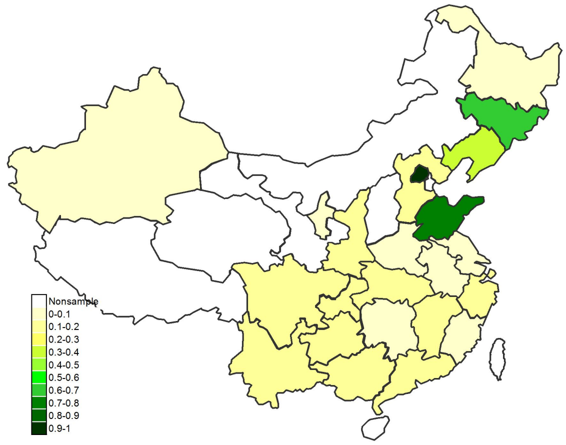
Fig.2 Changes in contribution of IRRI germplasm to rice production in china

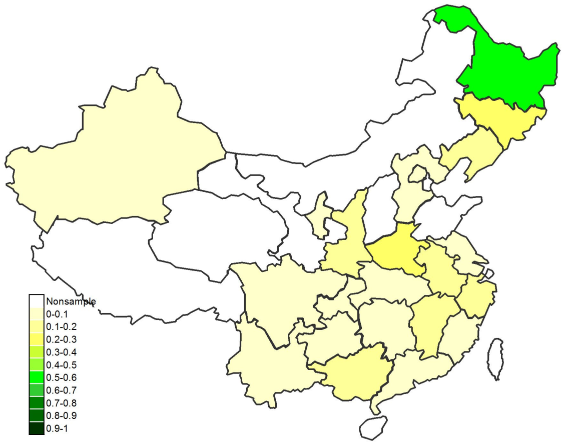




1982

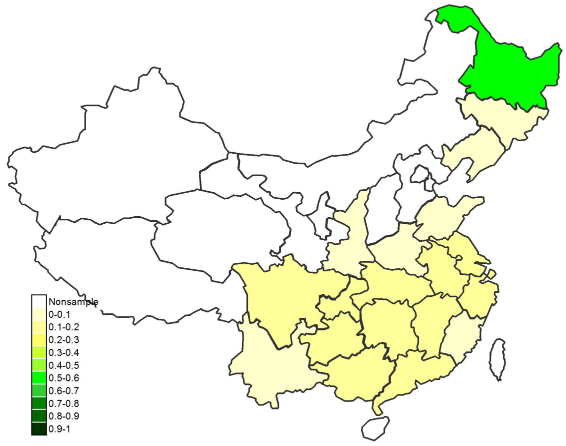
1988

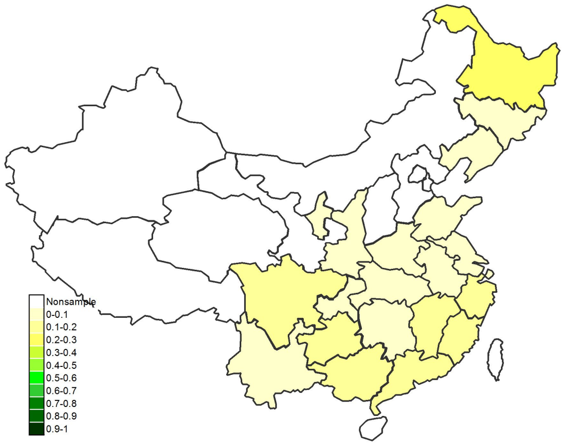




1994

2000





2006 2011

Fig.3 Changes in contribution of Japan germplasm to rice production in china

Table2. Estimation results of contribution of exotic germplasm to rice yield in China,1982-2011

variable	log-linear model	linear model
R&D		
Time series	0.00693***	0.0285**
	(0.00242)	(0.0139)
Exotic germplasm		
IRRI germplasm	0.149**	0.718*
	(0.0712)	(0.427)
Japan germplasm	0.130***	0.590***
	(0.0388)	(0.227)
Foreign germplasm from other countries	-0.590**	-3.353*
	(0.297)	(1.759)
Input		
Labor	-0.0193	0.000139
	(0.0244)	(0.000449)
Fertilize	0.138***	0.000372***
	(0.0308)	(0.000139)
Machine	0.00176	0.000258**
	(0.00297)	(0.000108)
Pesticide	-0.080***	-0.0001**
	(0.02)	(0.00)
Irrigation	-0.016	-0.001
	(0.01)	(0.00)
Other input	-0.034	0.001
	(0.02)	（0.00）
Environment		
Area percentage hit by drought	-0.252***	-1.376***
	(0.0589)	(0.354)
Area percentage hit by flood	-0.417***	-2.417***
	(0.0729)	(0.434)
Institutional innovation dummy		
HRS	0.342***	2.048***
	(0.129)	(0.778)
D88	0.0317*	0.286**
	(0.0187)	(0.111)

D00	0.0706**	0.553***
	(0.0292)	(0.181)
D04	0.0561	0.498*
	(0.0424)	(0.255)
Constant	1.027***	4.431***
	(0.279)	(0.793)
Observations	454	454
R-squared	0.830	0.829

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

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