JARQ 50 (1), 63 – 71 (2016) http://www.jircas.affrc.go.jp

Decomposition of the Factors Determining Changes in China's Maize Yields

Eiichi KUSANO[1]*, Hsiaoping CHIEN[2], Yongfu CHEN[3] and Osamu KOYAMA[1]

[1] Research Strategy Office, Japan International Research Center for Agricultural Sciences (Tsukuba, Ibaraki 305-8686, Japan)
[2] Social Sciences Division, Japan International Research Center for Agricultural Sciences (Tsukuba, Ibaraki 305-8686, Japan)
[3] College of Economics and Management, China Agricultural University (Beijing 100094, China)

Abstract

China's maize productivity and fertilizer consumption both have significant impact on global markets, and must be clarified through macro-level studies of Chinese maize yields. As such, this study used a crop response model to estimate the effects of fertilizer nutrients, seed input per unit area, and climate factors on maize yield. The results suggest that phosphorus and potassium inputs significantly affect maize yield, especially in major maize-producing areas. This study also confirmed the relationship between lower seed input per unit area and a higher yield.

Discipline: Agricultural economics/Crop production
Additional key words: crop response model, decomposition analysis

Introduction

According to the Food and Agriculture Organization (FAO), China is the world's second-largest producer and consumer of maize, and as of 2011, the second-largest exporter of nitrogen and phosphorus, and the third-largest importer of potassium. China's maize productivity and fertilizer consumption thus have significant impact on global markets. For example, in order to conserve natural resources, the Chinese government sharply increased export tax rates for chemical fertilizers and raw materials in 2008 (WTO 2010). Macro-level research on Chinese maize production will thus help to improve domestic agricultural systems, formulate policies on fertilizer use, and offer insight on the future of global markets.

Chinese maize production doubled during the period from 2000 to 2012, with an 18% average annual increase in yield (Fig. 1). Chemical fertilizer input levels per unit of maize area also increased 6% annually over the same period, likely playing a key role in higher yields. On the other hand, seed input per unit area has been declining since the 1980s in many regions of China due to the expansion of precision seeding, which entails using fewer seeds per hole (Cao 1998, Na et al. 2013, Shang et al. 2009). Although there have been widespread concerns regarding maize yields in China, it remains unclear how such structural changes have affected maize production at the macro level.

In particular, the effects of individual inputs have not been sufficiently analyzed in previous macro-level studies. For example, such process models as CERES-Maize and Hybrid-Maize have often been used to estimate potential yield, but these models mainly consider meteorological factors (Chen et al. 2012, Liu et al. 2012, Xiong et al. 2007). Meanwhile, time-series analysis generally assumes that anthropogenic factors can be explained by exogenous deterministic or stochastic trends (Furuya & Koyama 2005, Lobell 2007, Tao et al. 2008).

The macro-level effects of inputs and climate factors on yield are often measured via production functions (Chen et al. 2013, Holst et al. 2013, Ma et al. 2012). Such production functions (derived from a profit-maximization problem) generally encompass labor, land area, fertilizer, and agricultural technology as explanatory variables. For example, Ma et al. (2012) used household data from Hebei Province (covering the period from 2003 to 2010) to show that precipitation in June has a more significant and positive impact on maize yield than other factors, such as the amounts of seed and fertilizer used. However, many production function analyses omit essential factors, such

*Corresponding author: e-mail kusano11@affrc.go.jp
Recieved 19 September 2014; accepted 2 June 2015.

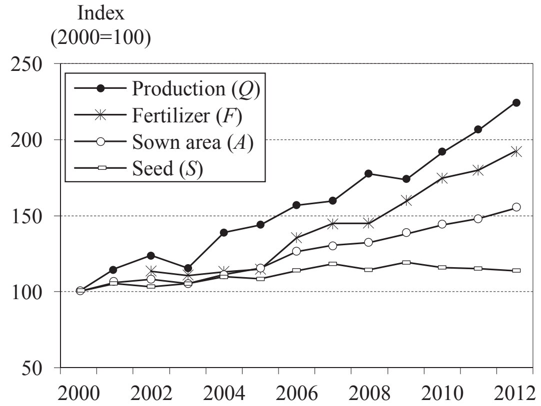

Fig. 1. Maize production and input use for maize in China (2000 to 2012)

Values are calculated using data from 18 provincial-level regions (see text). Fertilizer refers to the weight of chemical fertilizer products used for maize production.

Source: Sown area: NBSC. Production, fertilizer, and seed: Estimated by production, fertilizer, and seed use per unit area (NDRC 2001-2013) multiplied by sown area (NBSC).

as individual nutrients and seed quantities, or aggregate those factors into other items. As a result, there is a disconnect between analyzing the effects of agricultural inputs and discussing their consumption at the macro level.

The present study thus focuses on maize yields in China by examining the effects of individual fertilizer nutrients, seed input per unit area, and climatic conditions on maize productivity. First, macro-level data for nitrogen, phosphorus, and potassium inputs in maize production are calculated using both numeric data and information in policy documents. Then, temperature, precipitation, and sunshine hours during a specific period when these factors are thought to affect maize productivity are estimated based on daily climate data and annual seeding days. The effects of these factors on maize productivity are then estimated through regression analysis. Finally, these effects are expressed in terms of how much each factor contributes to changes in maize yield.

Methods

1. Decomposition of the rate of change

Fig. 2 shows the relationships between maize yield and its determinants as assumed in this study. The annual rate of change was calculated using a semi-log regression across time in each region. For example, the annual rate of change in yield (Y) in region i can be described by

$$\ln Y_{i,t} = \alpha_0 + \alpha_1 \cdot t + \varepsilon_{i,t}$$
$$i = 1,2,\ldots,22, \quad t = 2004, 2005, \ldots, 2012$$

where, ε is an error term. Subscript i denotes the region and t the year. The annual rate of change (α_1) equals $d\ln Y_i$. The annual rate of change (%) of a given item is decomposed into changes in other items, referred to here as contributions and expressed in percentage points. The decomposed relationships a, b, c, and d in Fig. 2 can be described by Eqs. (1), (2), and (3), respectively:

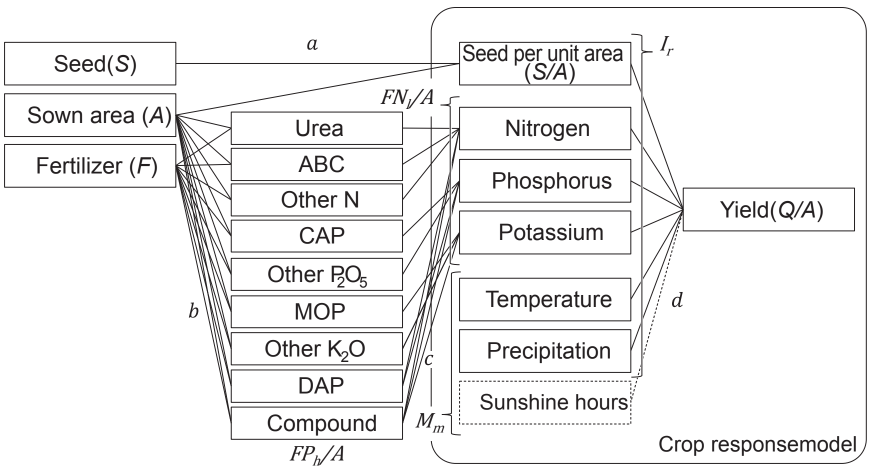

Fig. 2. Conceptual diagram for yield decomposition

ABC: ammonium bicarbonate; Other N: other nitrogen fertilizers; CAP: calcium superphosphate; Other P_2O_5: other phosphorous fertilizers; MOP: potassium chloride; Other K_2O: other potassium fertilizers; DAP: diammonium phosphate; and Compound: compound fertilizer. Relationships a, b, and c are expressed in Eqs. (1), (2), and (3), respectively. Relationship d is estimated through the crop response model. "Sunshine hours" are specified with a dotted border as this factor was eventually dropped from the model.

$$d\ln(S_i/A_i) = d\ln S_i - d\ln A_i \quad (1)$$

$$d\ln(FP_{h,i}/A_i) = d\ln n_{h,i} + d\ln F_i - d\ln A_i \quad (2)$$

$$d\ln(FN_{l,i}/A_i) = \sum_{h\subset l} d\ln(FP_{h\subset l,i}/A_i)\frac{n_{h\subset l,i}FP_{h\subset l,i}}{FN_{l,i}} \quad (3)$$

$$h = 1,\ldots,9, \quad l = 1,2,3, \quad i = 1,2,\ldots,22$$

where, S denotes the quantity of seeds used, A the sown area, F the total quantity of fertilizer used, FP the quantity of major fertilizer products, n_h the ratio of such products to total fertilizer input, $n_{h\subset l}$ the ratio of nutrients in each product, which is constant over time, and FN the quantity of fertilizer nutrients used. Subscript h (h = 1,…,9) refers to the products examined: urea, ammonium bicarbonate (ABC), other nitrogen fertilizers (Other N), calcium superphosphate (CAP), other phosphorous fertilizers (Other P_2O_5), potassium chloride (MOP), other potassium fertilizers (Other K_2O), diammonium phosphate (DAP), and compound fertilizers (Compound). Subscript l denotes the nutrients: nitrogen, phosphorus, and potassium for l = 1, 2, 3.

2. Estimation of macro-level data for factors impacting maize production

Input quantity data for such nutrients as nitrogen, phosphorus, and potassium in each region (FN) could not be directly obtained. Thus, the data was calculated using the quantities of major fertilizer products used for maize production in each region (FP; NDRC 2005-2013) and their nutrient contents ($nhcl$; DEPG 2006) (Tables 1 and 2). The ratio of nutrients to the total amount of compound fertilizer was assumed to be that recommended by the government for the "basal and additional fertilizer application method" (GOMA 2013).

Climate data (including temperature, precipitation, and sunshine hours in specific periods) were aggregated as needed for the model. To determine the period in which climate data would be aggregated, we first estimated the seeding days of year (DOY) for each provincial-level region based on information from a crop calendar (Meng et al. 2006), and a map of sowing and maturity days (Zhai et al. 2012). Second, the silking periods were estimated based on the growing degree days (GDD) accumulated after the seeding DOY (Dixon et al. 1994, Kaufman & Snell 1997). GDD estimates were obtained using Method 2 in McMaster & Wilhelm (1997), along with the daily maximum, minimum, and base air temperatures. A base air temperature of 10°C has been used in many field experiments on maize in China, with the results indicating that the accumulated number of GDD for silking falls within the range of 600 to 1000 for most sites (Chen et al. 2012, Wang et al. 2013). Thus, we estimated the silking periods as being in the 600-1000 GDD range. Observations from 119 meteorological stations available across the area that produces 99% of China's maize (USDA) were averaged for each region. Climate data was also collected for Tianjin, even though it is not within a major maize-producing area.

Table 1. Studied regions and regional classifications for compound fertilizer

	Province	Fertil. Region	Region		Province	Fertil. Region	Region
1	Beijing	II - 1	NC-Sm	12	Henan	II - 1	NC-Sm
2	Tianjin	II - 1	NC-Sm	13	Hubei	IV - 2	SW
3	Hebei	II - 1	NC-Sm	14	Guangxi	IV - 2	SW
4	Shanxi	III - 1	N-Sp	15	Chongqing	IV - 1	SW
5	Inner Mongolia	III - 2	N-Sp	16	Sichuan	IV - 1	SW
6	Liaoning	I - 4	N-Sp	17	Guizhou	IV - 2	SW
7	Jilin	I - 2	N-Sp	18	Yunnan	IV - 3	SW
8	Heilongjiang	I - 1	N-Sp	19	Shaanxi	III - 1	N-Sp
9	Jiangsu	II - 2	NC-Sm	20	Gansu	III - 1	N-Sp
10	Anhui	II - 2	NC-Sm	21	Ningxia	III - 2	N-Sp
11	Shandong	II - 1	NC-Sm	22	Xinjiang	III - 3	N-Sp

Fertil. Region: Regional classification code used to calculate the nutrient components of compound fertilizer. Region: Regional classification code used in estimates of the crop response model (N-Sp: North Spring Maize region, NC-Sm: North China Summer Maize region, and SW: Southwest region). Both Fertil. Region and Region are selected using the classification in GOMA (2013).

Table 2. Nutrient contents in the studied fertilizer products (%)

	Nitrogen	Phosphorus	Potassium
Urea	46	0	0
ABC	17	0	0
Other N	20	0	0
CAP	0	17	0
Other P_2O_5	0	20	0
MOP	0	0	55
Other K_2O	0	0	20
DAP	17	47	0
Compound			
Fertil. Region			
I - 1	14	18	13
I - 2	15	18	12
I - 3	13	20	12
I - 4	17	17	12
II - 1	18	12	15
II - 2	18	15	12
III - 1	15	20	10
III - 2	13	22	10
III - 3	17	23	6
IV - 1	17	16	12
IV - 2	20	15	10
IV - 3	19	15	11

Source: DPEG, Mixed fertilizer component: GOMA (2013).

3. Crop response model

The current study used a crop response model to estimate the relationships between maize yield and its determinants, which are often based on data from field experiments (Ackello-Ogutu et al. 1985, Frank et al. 1990, Lanzer & Paris 1981). Unlike in field experiments, however, we must assume the availability of nutrients for each crop, as provided from chemical fertilizer. If fertilizer is applied evenly across the relevant area, area expansion will lead to less dense fertilization, potentially decreasing the availability of nutrients for each crop. In this case, using the crop response model, yield *Y* can be represented as

$$Y = g\left(\frac{FN_l}{A}, M_m, \frac{S}{A}, O\right) \qquad l = 1,2,3,\ m = 4,5,6 \qquad (4)$$

where, *FN/A* refers to the nutrients per unit area, *M* to climate factors, and *S/A* to seed input per unit area. *O* represents site-specific conditions related to maize production, such as the variety of seed, soil properties, and cropping method. Subscript *m* denotes the average temperature, total precipitation, and total sunshine hours for $m = 4, 5, 6$. It is assumed that neither climate nor site-specific factors are affected by area (*A*).

For the estimation, we use the basic linear unobserved effects panel data model (Wooldridge 2010). The empirical literature has discussed in depth the best functional form to use for a crop response model (e.g., quadratic, Von Liebig, Mitscherlich-Baule) toward reaching the goal of accurately pinpointing the optimal input levels for nutrients and/or water (Ackello-Ogutu et al. 1985, Frank et al. 1990, Lanzer & Paris 1981). However, the number of explanatory variables included in such forms is quite limited and thus insufficient for the purposes of this study. Therefore, comparatively simple functional forms (i.e., linear, semi-log, double-log, inverse, log-inverse forms) were considered as candidates for specifying Eq. (4). We then conducted exploratory estimations to select the most appropriate form. Consequently, the following linear forms were selected based on statistical test results and the significance of coefficients:

$$Y_{i,t} = \beta_0 + \sum_l \beta_l \frac{FN_{l,i,t}}{A_{i,t}} + \sum_m \beta_m M_{m,i,t} + \beta_S \frac{S_{i,t}}{A_{i,t}} + \upsilon_i + \epsilon_{i,t} \quad (5)$$

$$l = 1,2,3,\ m = 4,5,6,\ i = 1,2,\dots,22,$$
$$t = 2004, 2005, \dots, 2012$$

where, υ refers to individual effects capturing site-specific conditions and ϵ is an idiosyncratic error term satisfying the standard assumptions (Wooldridge 2010). The individual effects term was used to separate effects β_l, β_m, and β_s from the region-specific characteristics represented as *O* in Eq. (4). The null hypothesis that these individual effects jointly have zero significant impact was tested using an F test. Furthermore, the null hypothesis of no correlation between explanatory variables and individual effects was tested using the Hausman test (Hausman 1978). White's standard errors were calculated in cases where autocorrelation and heteroscedasticity were suspect according to the Wald and Breusch-Pagan (BP) tests, respectively. EViews Version 7.2 was used to conduct the tests and estimate the parameters.

To estimate the relationship denoted by *d* in Fig. 2, the input elasticity—percentage change in yield ($Y_{i,t}$) associated with a 1% change in an explanatory variable—was calculated for each region and year by using the following formula:

$$\eta_{r,i,t} = \frac{\partial \ln Y_{i,t}}{\partial \ln I_{r,i,t}} = \frac{\partial Y_{i,t}}{\partial I_{r\,i,t}} \frac{I_{r,i,t}}{Y_{i,t}} = \beta_r \frac{I_{r,i,t}}{Y_{i,t}} \qquad (6)$$

$$r \supset l, m, S,\ r = 1,\dots,7,\ \ i = 1,2,\dots,22,$$
$$t = 2004, 2005, \dots, 2012$$

where, *I* refers to the explanatory variables, excluding the constant in Eq. (5). To calculate the average elasticity from 2004 to 2012, time-averaged *I*, *Q*, and *S* were used. The contribution of input *I* to an annual change in yield $Y_{i,t}$ was estimated based on the annual rate of change of *I* multiplied by the elasticity values ($= d\ln I_{r,i} \cdot \eta_{r,i}$). The contribution of "Others" was obtained from the actual rate of change minus the components' total joint contribution.

Data

This study uses panel data (i.e., pooled cross-sectional time-series data) from 22 major maize-producing provincial-level regions in China from 2004 to 2012 (Table 1). To estimate the parameters and elasticities of the crop response model, panel data covering 22 regions—nine regions in the North Spring Maize zone, seven regions in the North China Summer Maize zone, and six regions in the Southwest zone—are used (Table 1). Classification of "Fertil. Region" is aggregated by region in Table 1 to ensure a sufficiently large sample size for analysis. The change in maize yields and the contributions of its component factors are calculated using time-series data, averaging across 18 regions. Four regions (Beijing, Tianjin, Guangxi, and Ningxia) were excluded due to insufficient data. Similar calculations were also made for each region separately, including the four excluded regions.

Data on maize yields (*Q/A*) and input quantity, including fertilizer products (*FP*), was collected from official publications (NDRC 2005-2013). Data on the sown area in each region was obtained from the National Bureau of Statistics of China (NBSC). Data on production and input quantities by region was calculated by multiplying the area by the amount of inputs used per unit area. Daily maximum, minimum, and average air temperatures, precipitation amounts, and sunshine hours from a total of 120 meteorological stations were obtained from the China Meteorological Administration National Meteorological Information Center (NMIC).

Results and discussion

1. Macro-level input data

Fig. 3 shows the input quantities of nutrients from chemical fertilizer used for maize production, where all three nutrients clearly show increasing trends. The input quantity of nitrogen is notably higher than those of the other nutrients. Table 3 lists the estimated DOYs for aggregating the climate data, which are consistent with the

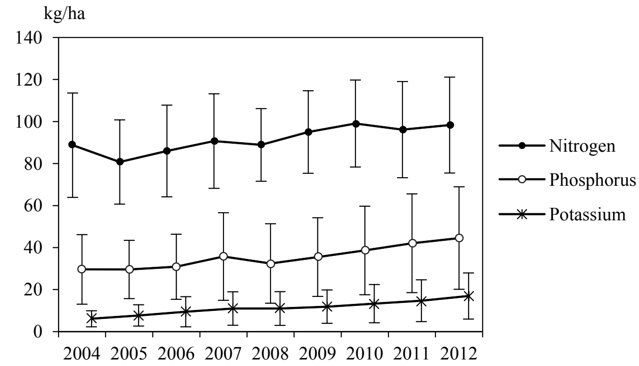

Fig. 3. Average chemical fertilizer utilization for maize in terms of nutrients (2004 to 2012)
Values are estimated using data from 18 provincial-level regions (see text). The vertical lines indicate standard deviations ± means.

Table 3. Estimated days of the year for aggregating daily climate data

Province		Seed-ing	Silking Bgn.	Silking End.	Province		Seed-ing	Silking Bgn.	Silking End.
1	Beijing	155	194	218	12	Henan	155	193	216
2	Tianjin	155	194	217	13	Hubei	175	209	231
3	Hebei	155	197	222	14	Guangxi	185	218	240
4	Shanxi	95	165	192	15	Chongqing	145	187	210
5	Inner Mongolia	115	191	224	16	Sichuan	145	188	213
6	Liaoning	115	179	207	17	Guizhou	195	238	270
7	Jilin	115	187	215	18	Yunnan	195	243	277
8	Heilongjiang	125	195	225	19	Shaanxi	105	167	195
9	Jiangsu	175	210	232	20	Gansu	115	189	223
10	Anhui	175	210	232	21	Ningxia	115	177	207
11	Shandong	155	195	219	22	Xinjiang	115	172	200

Seeding: Beginning day for seeding, Bgn.: first day for silking, End.: final day for silking.

Table 4. Descriptive statisticsa

			Mean	S.D.	Max.	Min.	Obs.
Input and output quantity							
Production of maize	Q	1000 t	9527.220	7637.348	36278.400	617.925	186
Seed	S	1000 t	55.576	44.206	161.467	3.999	186
Chemical fertilizer	F	1000 t	446.193	331.241	1445.063	27.781	186
Sown area	A	1000 ha	1420.784	1095.881	5190.600	93.540	186
Yield	Q/A	kg/ha	6655.585	1199.847	10307.550	3448.200	186
Chemical fertilizer							
-Nitrogen	F_1/A	kg/ha	93.617	21.778	143.678	54.737	186
-Phosphorus	F_2/A	kg/ha	36.280	20.491	104.159	5.994	186
-Potassium	F_3/A	kg/ha	11.187	8.727	36.756	0.010	186
Average temperature	M_4	°C	24.701	2.577	29.958	19.158	186
Total precipitation	M_5	mm	116.785	59.971	422.102	3.957	186
Total sunshine hours	M_6	hours	177.897	62.933	323.550	49.900	186
Seed per unit area	S/A	kg/ha	38.117	8.543	69.000	22.050	186

Data for 22 major maize-producing regions (2004 to 2012) (See Table 1.)

number of silking days shown in the agricultural atlas (CCSA 1989) and information from field experiments (Chen et al. 2012, Liu et al. 2013, Zhang et al. 2013). Table 4 lists the descriptive statistics for the 22 major maize-producing regions from 2004 to 2012, along with estimated nutrients and climate data.

2. Results of the crop response model

Table 5 lists the estimation results for the crop response model in Eq. (5). The fixed-effects model, which assumes correlations between explanatory variables and individual effects, was used to estimate the parameters in Eq. (5), as supported by results of the Hausman test (Wooldridge 2010). The t-statistics for the regional coefficients (excluding the Southwest) were calculated using White diagonal standard errors, as heteroscedasticity and autocorrelation were suspect based on the Wald and BP tests. The number of sunshine hours was dropped from the model estimation because it made the parameters unstable due to a high negative correlation with precipitation.

For the region overall, the results show significant coefficients on the fertilizer and seed per unit area variables, while those on the climatic conditions are largely insignificant. Previous studies using data covering a longer time period (Furuya & Koyama 2005) or more detailed household-level data (Chen et al. 2013, Ma et al. 2012) report significant effects of temperature and/or precipitation on maize yield. Hence, the insignificant coefficients found here could be simply caused by a smaller dataset. The significant positive coefficients on the fertilizer indicators are consistent with previous macro-level research (Holst et al. 2013). The negative coefficient on the seed per unit area variable reflects lower levels of loss in seed inputs. Such an interpretation is supported by information suggesting that precision seeding is spreading in China (Cao 1998, Na et al. 2013, Shang et al. 2009). It is also possible that lower seed or plant density due to using fewer seeds affects yield (Duncan 1984, Li et al. 2013,

Table 5. Estimation results for the crop response model

	Entire region			North Spring Maize region			N. China Summer Maize region			Southwest region		
	Coefficient	t-stat.	p-value	Coefficient	t-stat.	p-value	Coefficient	t-stat.	p-value	Coefficient	t-stat.	p-value
Constant	5828.671 **	3.509	0.001	7096.619 **	2.682	0.009	7017.093 *	2.251	0.030	6367.144 *	2.118	0.041
Fertilizer per area												
–Nitrogen	9.249 *	2.366	0.019	-9.097	-1.025	0.309	11.588 †	1.411	0.166	13.108 *	2.213	0.033
–Phosphorus	14.390 *	2.381	0.019	30.169 **	3.448	0.001	-6.330	-0.637	0.528	-19.527	-0.566	0.575
–Potassium	14.358 †	1.429	0.155	-5.589	-0.247	0.805	41.621 **	2.760	0.009	14.226	0.536	0.595
Seed per unit area	-35.212 **	-2.832	0.005	-36.761 *	-2.536	0.014	-35.288	-1.229	0.226	-17.737	-0.700	0.488
Temperature	20.481	0.376	0.708	32.302	0.358	0.721	-19.023	-0.233	0.817	-49.253	-0.464	0.645
Precipitation	0.981	0.908	0.365	5.352 *	2.166	0.034	-1.431	-0.575	0.568	0.499	0.401	0.691
Observations		186			81			53			52	
Number of regions		22			9			7			6	
Adjusted R^2		0.828			0.832			0.549			0.372	
		Test stat.	p-value		Test stat.	p-value		Test stat.	p-value		Test stat.	p-value
F test for all $u_i = 0$		10.672	0.000		18.257	0.000		3.170	0.012		2.480	0.048
Hausman test		34.041	0.000		22.185	0.001		19.020	0.004		---	---
Wald test for autocorrelation		4.011	0.045		24.530	0.000		5.493	0.019		0.636	0.425
BP test for heteroskedasticity		46.688	0.058		25.321	0.189		30.608	0.032		18.262	0.373

$^{**}p < .01$, $^{*}p < .05$, $^{\dagger}p < .2$. There are nine periods (2004 to 2012). "N. China" represents North China. "Test stat" is the F statistic for the F test and the χ^2 statistic for all other tests. The null hypothesis of no serial correlation was tested using the Wald test (Wooldridge 2010). A fixed-effects approach was selected for both models based on the results of the F and Hausman tests. The Hausman test was not conducted for the Southwest region due to limited data. Values of *t* statistics and *p* values in all other regions were calculated using White diagonal standard errors. Fixed-effects coefficients not directly related to this paper's discussion are omitted.

Table 6. Factor elasticities for seed productivity

	Entire region				North Spring Maize region				N. China Summer Maize region				Southwest region			
	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min
Fertilizer per area																
-Nitrogen	0.133	0.034	0.242	0.073					0.168	0.036	0.303	0.117	0.214	0.061	0.337	0.116
-Phosphorus	0.075	0.032	0.164	0.015	0.211	0.056	0.343	0.103								
-Potassium	0.025	0.019	0.096	0.000					0.097	0.052	0.206	0.000				
Seed per unit area	-0.204	0.043	-0.093	-0.354	-0.216	0.048	-0.097	-0.346								
Precipitation	0.018	0.011	0.071	0.001	2.873	1.792	7.217	0.102								
Observations	186				81				53				52			
Number of regions	22				9				7				6			

Average elasticities by region (2004 to 2012). "N. China" represents North China. Coefficients with significance levels higher than 20% in Table 5 are omitted. Elasticities of precipitation for the entire region are shown for reference.

Yu et al. 2013), but no such effect could be verified due to unavailable data on density. Table 5 also shows that the significant coefficients vary across regions.

Table 6 lists descriptive statistics for the elasticities in each provincial-level region, estimated from Eq. (6) and the coefficients in Table 5, excluding insignificant values. The elasticities summarized in Table 6 were used to estimate the contribution.

3. Decomposition of effects on yield

Fig. 4 shows the annual average rate of change (in %) and the contributions of the yield components (in percentage points) for the 2004-2012 period. The figure shows that the average annual change in yield (1.8%) can mainly be attributed to a 3.4% decrease in seed input per unit area, and 2.0%, 6.6%, and 11.6% increases in nitrogen, phosphorus, and potassium inputs, respectively. Given the definitions expressed in Eqs. (1), (2), and (3), and in the contribution of input *I*, the total contribution of each item on the right side of Fig. 4 equals the annual rate of change of that item.

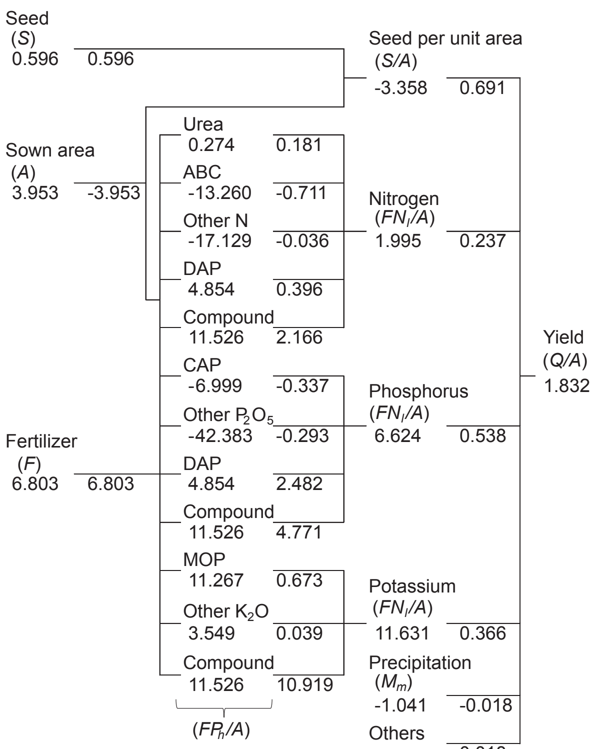

Fig. 4. The decomposed annual average rate of change in maize yields (2004 to 2012)

The number below each item is the average annual rate of change (%). The numbers below the lines are the contributions of the left-side items to the right-side items (in percentage points). Values are calculated for the sum across 18 provincial-level regions (see text) using coefficients for the entire region from Table 5.

The most substantial contributors among the nutrients are phosphorus (0.5 percentage point) and potassium (0.4 percentage point). Mapping the contributions of each factor shows that the effects of phosphorus and potassium are larger than those of other factors in the major maize-producing areas, the North China Plain, and the northeast region (Fig. 5). This result, consistent with recent field experiments (Niu et al. 2011, Tan et al. 2012, Wu et al. 2013), underscores the importance of these nutrients for enhancing production. Increases in phosphorus and potassium levels are attributable to 6.6% and 11.6% increases, respectively, in quantities applied per unit area (Fig. 4). Such high rates of change are mainly brought about by the large contribution of compound fertilizer (4.8 and 10.9 percentage points, respectively), which accounts for a major proportion of the phosphorus and potassium nutrients applied. This result implies that policies supporting deliberate fertilization based on soil analysis (CCCPC & SC 2004, GOMA 2013) can contribute to maize production by increasing the use of phosphorous and potassium inputs in the major maize-producing areas.

The contribution of nitrogen per unit of area—for which the yield elasticity is higher than those of phosphorus and potassium—is low (at 0.2 percentage point). This is the result of stagnation in nitrogen input quantities; moreover, the low rate of increase in the use of urea (0.3%), the main source of nitrogen, and the sharp decrease in the use of ABC (–13.3%) are likely to be mainly responsible for the low contribution. The contribution of compound fertilizer to the increase in nitrogen is comparatively small, as only a limited portion of the nitrogen nutrient volume can be attributed to compound fertilizer use.

The contribution of seed input per unit area to productivity is comparatively large at 0.7 percentage point (Fig. 4). The decrease in seed input per unit area (–3.4%) is apparently related to the rapid increase in seed prices experienced at the time (Kusano et al. 2015). This suggests that mutual relationships exist between seed price rises, lower levels of seed input per unit area, and higher yields. One possible interpretation of such relationships is that using higher-quality seeds (despite the higher prices) decreases seed loss and increases maize production per unit area. Thus, production was enhanced through technological progress made in seed quality or seeding methods, and thus not only by changes in input quantity.

Conclusion

This study used a crop response model to investigate the effects of fertilizer nutrients, seed input, and

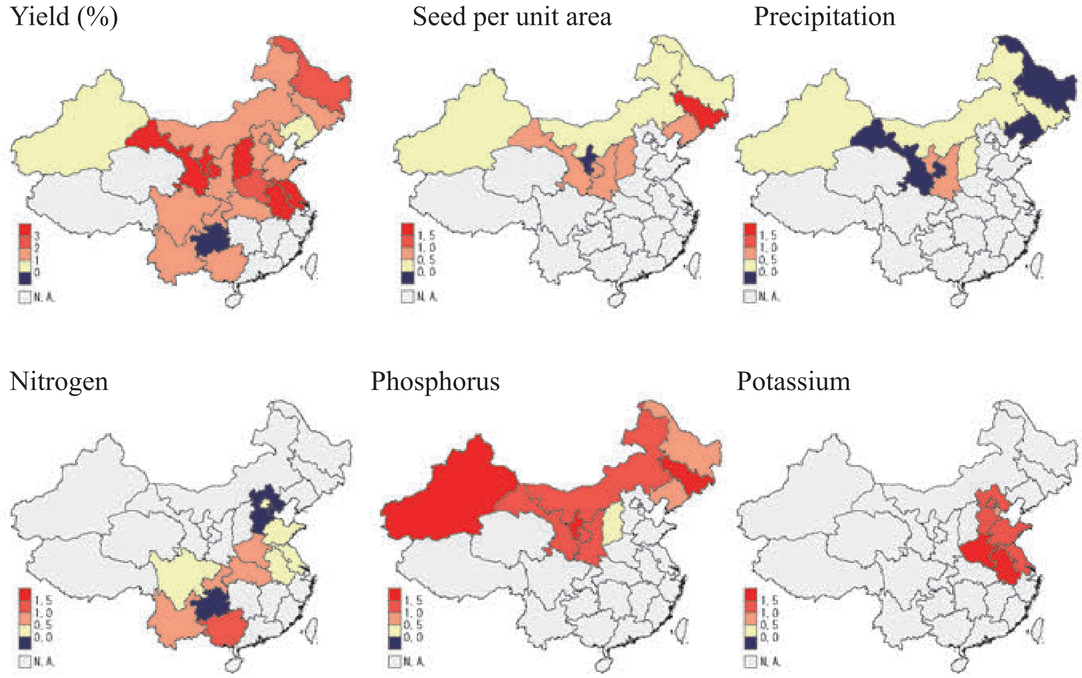

Fig. 5. Decomposed annual average rate of change in maize yields by region (2004 to 2012)
Values are calculated for each provincial-level region using the coefficients of the North Spring Maize region, North China Summer Maize region, and Southwest region from Table 5. Coefficients with significance levels above 20% in Table 5 are omitted. Values are in percentage points unless otherwise noted.

climate factors on maize yields in China. First, the effects of nitrogen, phosphorus, and potassium were measured individually. Phosphorus and potassium inputs per unit area could improve productivity, especially in major maize-producing areas where the use of phosphorus and potassium was comparatively limited in the past, though with rapid increases in the amount of compound fertilizer now being used. Second, the relationship between lower levels of seed input per unit area and a higher yield was confirmed by analyzing macro-level data.

Considering the significant effects of the nutrients in chemical fertilizers on maize yield, it seems likely that the global fertilizer market will continue to be affected by the growing demand for maize and its production in China. The results of this study support the effectiveness of fertilization plans determined based on soil analysis, and of technological progress made in seeding, such as precision seeding. Many macro-level studies forecasting crop yields assume that cultivation methods and anthropogenic factors are exogenous. The appropriateness of this assumption should be scrutinized, as these trends can be influenced by policies and market conditions.

While insightful, this study was subject to several limitations. Although it was assumed that the proportion of fertilizer products (n_h) was set exogenously, it would be possible to provide more concrete policy recommendations if this value was associated with the respective product's price. Analyses of nutrients supplied from organic matter and of carryover nutrients in the soil of multiple-cropping areas would also contribute to a more practical and comprehensive assessment. For now, however, this paper has helped to shed light on key recent trends in Chinese maize production.

Acknowledgements

This study used data collected by the Agro-Meteorology Division of the National Institute for Agro-Environment Sciences in Japan, as obtained from the National Meteorological Information Center of China.

References

Ackello-Ogutu, C. et al. (1985) Testing a Von Liebig crop response function against polynomial specifications. *Am. J. Agr. Econ.*, **67** (4), 873-880.

Cao, Y. (1998) Utilization and investigation of precision seeding for maize. *Yumi kexue* (*Journal of Maize Science*), **6** (2), 60-64 [In Chinese].

CCSA (The Compiling Committee of State Atlas) (1989) *The national agricultural atlas of China*. Beijing: China Cartographic Publishing House [In Chinese].

CCCPC & SC (Central Committee of the Communist Party of China & the State Council) (2004) The first policy document for 2005. http://www.gov.cn/test/2006-02/22/content_207406.htm/ [In Chinese].

Chen, G. et al. (2012) Factors affecting summer maize yield under climate change in Shandong Province in the Huanghuaihai Region of China. *Int. J. Biometeorol*., **56**, 621-629.

Chen, Y. et al. (2013) Agricultural policy, climate factors and grain output: Evidence from household survey data in rural China. *J. Integr. Agr*., **12**, 169-183.

DEPG (Department of environmental protection of Guangdong province) (2006) Reference of the conversion from chemical fertilizer to net quantity of nutrient. http://www.gdep.gov.cn/swrfz/sybh/sydgh/201008/t20100806_79882.html/ [In Chinese].

Dixon, B. L. et al. (1994) Estimating corn yield response models to predict impacts of climate change. *J. Agr. Resour. Econ*., **19** (1), 58-68.

Duncan, W. G. (1984) A theory to explain the relationship between corn population and grain yield. *Crop Sci*., **24**, 1141-1145.

FAO, FAOSTAT. http://faostat.fao.org/

Frank, M. D. et al. (1990) A comparison of alternative crop response models. *Am. J. Agr. Econ*., **72** (3), 597-603.

Furuya, J. & Koyama, O. (2005) Impacts of climatic change on world agricultural product markets: Estimation of macro yield functions. *JARQ*, **39** (2), 121-134.

GOMA (General Office of the Ministry of Agriculture) (2013) *Circular of the General Office of the Ministry of Agriculture on printing and distributing the recommendations for soil nutrient analysis-based fertilizer application for wheat, rice and maize for 2013*. **119**, 46-56 [In Chinese].

Hausman, J. A. (1978) Specification tests in econometrics. *Econometrica*, **46** (6), 1251-1271.

Holst, R. et al. (2013) Climate change, risk and grain yields in China. *J. Integr. Agr*., **12** (7), 1279-1291.

Kaufmann, R. K. & Snell, S. E. (1997) A biophysical model of corn yield: Integrating climatic and social determinants. *Am. J. Agr. Econ*., **79**, 178-190.

Kusano, E. et al. (2015) Effect of factor demand prices on maize yield in China. *Kaihatsugaku kenkyu* (*Journal of Agricultural Development Studies*), **26** (1), 34-43.

Lanzer, E. A. & Paris, Q. (1981) A new analytical framework for the fertilization problem. *Am. J. Agr. Econ*., **63** (1), 93-103.

Li, Z. et al. (2013) Aboveground dry matter and grain yield of summer maize under different varieties and densities in North China Plain. *Maydica*, **58** (2), 189-194.

Liu, H. et al. (2012) Optimizing parameters of CSM-CERES-Maize Model to improve simulation performance of maize growth and nitrogen uptake in Northeast China. *J. Integr. Agr*., **11** (11), 1898-1913.

Liu, Y. et al. (2013) Phonological responses of maize to changes in environment when grown at different latitude in China. *Field Crop Res*., **144**, 192-199.

Lobell, D. B. (2007) Changes in diurnal temperature range and national cereal yields. *Agr. Forest Meteorol*., **145** (3-4), 229-238.

Ma, J. et al. (2012) Climatic factors, intermediate inputs and growth in maize yield: Multilevel model analysis of farmers in Hebei province. *Zhongguo nongcun jingji* (*Chinese Rural Economy*), **11**, 11-20 [In Chinese].

McMaster, G. S. & Wilhelm, W. W. (1997) Growing degree-days: One equation, two interpretations. *Agr. Forest Meteorol*., **87**, 291-300.

Meng, E. C. H. et al. (2006) *Maize in China: Production systems, constraints and research priorities*. CIMMYT.

Na, M. et al. (2013) Current situations and strategies for development of precision seeding for maize. *Zhongguo zhongye* (*China Seed Industry*), **6**, 14-15 [In Chinese].

NBSC (National Bureau of Statistics of China). http://www.stats.gov.cn/ [In Chinese].

NDRC (National Development & Reform Commission) (2001-2013) National Agricultural Products Cost and benefit Data Collection. Beijing: China Statistics Press [In Chinese].

Niu, J. et al. (2011) Potassium fertilization on maize under different production practices in the North China Plain. *Agron. J.***,** **103** (3), 822-829.

NMIC (China Meteorological Administration National Meteorological Information Center), China Meteorological Data Sharing Service System. http://www.cams.cma.gov.cn/ [In Chinese]

Shang, H. et al. (2009) Utilization and outlook for precision seeding of maize. *Zhongguo zhongye* (*China Seed Industry*), **1**, 19-20 [In Chinese].

Tan, D. et al. (2012) Potassium assessment of grain producing soils in North China. *Agr. Ecosyst. Environ*., **148**, 65-71.

Tao, F. et al. (2008) Climate-crop yield relationships at provincial scales in China and the impacts of recent climate trends. *Climate Res*., **38**, 83-94.

USDA (U.S. Department of Agriculture), Major World Crop Areas and Climate Profiles. http://www.usda.gov/oce/weather/pubs/Other/MWCACP/easia.htm/

Wang, L. et al. (2013) Impact of sowing date on the spring maize in the east of Gansu at global warming environment. *Yumi kexue* (*Journal of Maize Sciences*), **21** (5), 94-99 [In Chinese].

Wooldridge, J. M. (2010) *Econometric analysis of cross section and panel data (2nd ed.)*. Boston: MIT Press.

WTO (2010) Restructuring and further trade liberalization are keys to sustaining growth. *Trade Policy Review*, WT/TPR/S/230. http://www.wto.org/english/tratop_e/tpr_e/tp330_e.htm

Wu, L. et al. (2013) Current potassium-management status and grain-yield response of Chinese maize to potassium application. *J. Plant Nutr. Soil Sci*., **176**, 441-449.

Xiong, E. et al. (2007) Modelling China's potential maize production at regional scale under climate change. *Clim. Chang*., **85**, 433-451.

Yu, J. et al. (2013) Effect of matter production and yield formation on sowing date and density in maize. *Yumi kexue* (*Journal of Maize Sciences*), **21** (5), 76-80 [In Chinese].

Zhai, Z. et al. (2012) Change of maize growth period and its impact factor in China. *Zhongguo nongye kexue* (*Sci. Agric. Sinica*), **45** (22), 4587-4603 [In Chinese].

Zhang, C. et al. (2013) Study of crop coefficient and the ratio of soil evaporation to evapotranspiration in an irrigated maize field in an arid area of Yellow River Basin in China. *Meteorol. Atmos. Phys*., **121**, 207-214.