



Prospects for China's Corn Yield Growth and Imports

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Abstract

Chinese corn yields are growing, but at a slower pace than U.S. yields. Chinese corn yield growth is most evident in the North China Plain region. The Northeast region is expected to account for most of China's increase in corn supply, but yield growth is weaker in that region. Extrapolating historical trends into the future suggests that China's consumption of corn will outpace growth in domestic supply. Imports from the United States and other countries are likely to fill China's corn deficit.

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Introduction

Improvement in crop yields is a critical factor determining China's ability to meet its growing demand for grains with domestic production. In particular, the focus of China's demand for grains has shifted from staple grains—rice and wheat—to corn (maize), which is used primarily as an animal feed. China's demand for corn is expanding at a robust pace, driven mainly by growth in animal feed consumption, while consumption of staple grains is growing at a more moderate rate.

China's growing demand for animal feed is an important component of analyses of future global food supply-demand balance (Keyzer et al., 2005; Wirsenius, Azar, and Berndes, 2010). During 2010-13, China imported 2 to 5 million metric tons (mmt) annually, a reversal from 2003 when the country exported 16 mmt of corn. The Organisation for Economic Co-operation and Development and the United Nations' Food and Agriculture Organization anticipated that China's rising animal-protein demand might place higher resource demands on agriculture, increasing imports of corn and other coarse grains to 13 mmt by 2022/23 (OECD-FAO, 2013). The U.S. Department of Agriculture anticipates that China's corn imports will rise to 22 mmt by 2023/24 (USDA, 2014).

With growing competition for a limited supply of land, improvements in crop yields are the key to China's growth in corn production. The World Bank (2007) observed that improvements in China's crop yields during the latter part of the 20th century were an important contributor to growth in global food output, but it is unclear whether these improvements will continue in the 21st century.

A number of studies of global crop yields have observed a general pattern of declining rates of growth in grain yields and raised concerns about whether future output growth can keep pace with demand in China and other countries (Harris and Kennedy, 1999; Hafner, 2003; Ray et al., 2012). Yield improvements may diminish over time as application of fertilizer and other inputs reach a high level or one-time gains from importing technology or institutional reforms are exhausted (Huang, Pray, and Rozelle, 2002). Recent research has emphasized ecological constraints (Harris and Kennedy, 1999) and negative effects of climate change on crop yields in China (Wang et al., 2009; Chen, et al., 2013).

This report examines historical trends in Chinese corn yields in order to assess the potential for future growth. The report discusses the history of corn production in China and factors influencing growth in yields. It analyzes long-term trends in China's corn yield using two data sources. These yields are reported in comparison with historical trends in U.S. yields as a benchmark to assess the Chinese trend. The report analyzes data for major corn-producing provinces and finds a high degree of year-to-year variation in provincial yields, with weaker yield growth in some key corn-producing provinces. The report concludes with a discussion of the prospects for future corn imports, their sensitivity to trends in yield growth, and the role of the United States in meeting China's rising demand for corn.

Background: Corn in China

Corn has played an important role in China's food system since it was introduced from the American continent in the 1500s. The introduction of corn contributed to a surge of Chinese population growth as its cultivation expanded on hillsides and other marginal land (Elvin, 2004).¹ Corn's importance was magnified when its use as an animal feed became common in the late 20th century. In the 1940s, Shen (1951) estimated that only 19 percent of China's corn was consumed as animal feed (66 percent was consumed directly as food).² Feed became the dominant use as the commercial livestock sector grew. By the 1980s and 1990s, more than two-thirds of corn was used for animal feed, and Chinese scientists and officials were raising concerns about emerging competition for grain between humans and livestock (Fu, 1991; Ren and Li, 1996). In the 21st century, China also began increasing industrial uses of corn for production of starches, alcohol, sweeteners, feed additives, and chemicals while feed use continued growing (Gale et al., 2009).

At present, approximately 60 percent of China's corn is consumed as animal feed, 30 percent is used in industrial processing, and less than 10 percent is consumed directly as human food and seed.³ China's growth in corn use is driven by rising livestock output and a transition to "modern" production systems that substitute corn for traditional energy sources such as brans, hulls, straw, vines, tubers, vegetables, table scraps, and residue from agricultural processing.

Corn's role in Chinese agriculture has increased dramatically. Area planted in corn expanded nearly sevenfold from approximately 5.5 million hectares in the 1940s⁴ to 35 million hectares in 2012 (a hectare (ha) measures 2.47 acres (ac)). Shen (1951) estimated China's corn output in the 1940s at 7.5 mmt, but in 2012 it exceeded 205 mmt. In 2012, corn surpassed rice to become the largest single crop produced in China. China has doubled its share of global corn output from about 10 percent in the early 1960s to over 20 percent now. China is the second-leading corn producer in the world after the United States. (The U.S. share of world output is about 40 percent in most years.)

Li and Wang (2009) emphasized yield improvements as a factor behind the growth in China's corn output through the 1980s. However, data for the most recent decade show that China's 70-percent increase in corn output was achieved primarily by expanding area planted (fig. 1). During 2002-12, the area planted in corn grew 42 percent, more than twice as fast as the 19-percent improvement in yields. China and the United States now plant roughly equal areas of cropland in corn, but China's corn output is still only half as large as that of the United States. A corn industry experts' group formed by the Chinese Government cited slow growth in corn yields when calling for investment in research and industry support to meet national corn production targets (Corn Industry Technology System, 2013; Fan, 2013).

The expansion of corn area itself may be partly responsible for slow growth in average yield. Much of the increase in China's corn area has occurred in marginal areas where soil quality is uneven

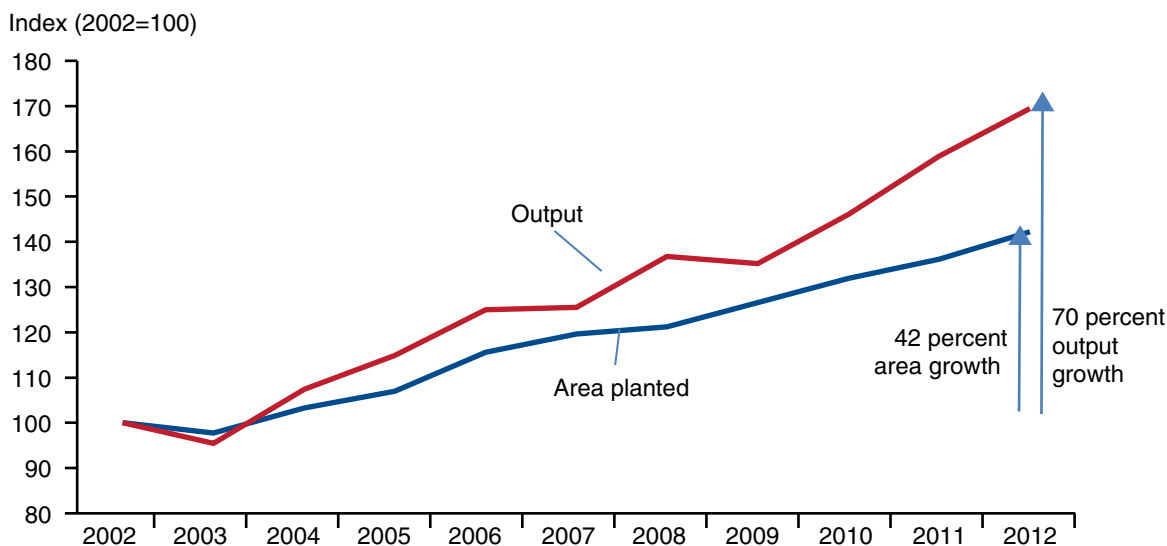
¹Elvin also reported evidence that corn cultivation on sloped land led to erosion that washed soil into waterways.

²Shen (1951) also estimated that 9 percent of corn was saved for seed and 6 percent for other uses.

³The amount of corn consumed in China must be estimated since there are no official statistics, and estimates vary. Ren and Li (1996) estimated feed use at 64 percent of corn consumed in 1978 and 73 percent in 1994. Tan (1995) estimated the proportion at 61 percent, and Tan and Xin (2001) reported an average of 70 percent. The proportions reported here were calculated from estimates reported by China's National Grain and Oils Information Center.

⁴Shen (1951) reported 2.3 million hectares in 15 "war-free" provinces and 3.2 million hectares in Manchuria.

Figure 1
Indexes of China's corn output and area planted, 2002-12



Source: USDA, Economic Research Service analysis of data from Global Trade Information Services, Inc.

and weather is variable. Adding production in areas with below-average yields slows growth in the average. Yields may become more volatile if marginal areas are more vulnerable to fluctuations in temperature and rainfall. Officials in Inner Mongolia raised concerns that yields in their region had risen only marginally because new corn area had been added by planting on the fringes of grasslands and desert regions (Wu et al., 2011). A study of corn yields and weather in Heilongjiang Province showed that corn grown on the northern and western fringe of the province is at higher risk of frost damage (Shuai Li et al., 2013).

Factors Influencing Corn Yields

Crop yields can improve by delivering more nutrients, water, and energy to plants; improving the efficiency of plants in producing starch or other desired components of seeds or kernels; and by reducing vulnerability of plants to pests, disease, wind, hail, and flooding. Improvements in crop yields at a 2- to 3-percent annual rate in China and other developing countries during the 20th century helped alleviate food security concerns. Johnson (1977) expressed confidence that investments in science and technology could accelerate growth in crop yields. A more recent World Bank (2007, chapter 2) assessment of agricultural performance cited average 2.8-percent annual improvement in developing-country crop yields from 1961 to 2004.

Improvement of corn yields is a longstanding concern in China, and farmers have adopted many new varieties and practices to raise yields. Fu (1991) identified improved varieties, dense planting, improved fertilization techniques, water-saving irrigation, and plastic sheeting as key measures for improving corn yields. Officials introduced important field-management practices in the 1980s, such as covering fields with plastic film to warm the soil and conserve moisture and planting stalks on ridges to leave channels for irrigation water between rows (Crook et al., 1994). Meng et al. (2006) cited dissemination of hybrid varieties, use of chemical fertilizers, investments in irrigation projects, and institutional reforms as factors contributing to growth in China's corn yields.

Increasing the density of plants is instrumental to increasing corn yields. Increasing the density of plants requires breeding varieties with suitable traits and spacing plants so that growth is not inhibited by competition for water, nutrients and sunlight in densely planted fields. Zhang and Li (2009) emphasized that corn density rose from 15,000 plants/ha (6,000 plants/ac) in the 1950s to 52,500 plants/ha (21,000 plants/ac) in the 1990s. They noted that Chinese experimental plots with 70,000 to 100,000 plants/ha achieved yields of 15,000 kg/ha—nearly 3 times the average Chinese yield—during 2005-08. More recently, Niu and Thukral (2012) reported an average of 60,000 plants/ha in China.⁵ USDA's National Agricultural Statistics Service reports show densities in U.S. Corn Belt States averaged 70,000-75,000 plants/ha during 2013.⁶

By the 1990s, provincial research institutes conducted most of the crop breeding in China and a steady stream of new corn varieties were being produced (Crook et al., 1994). During that decade, China began commercializing the seed industry, and a seed law opened the market to commercial operators in 2000. After China joined the World Trade Organization (WTO) in December 2001, corn seeds offered by multinational seed companies gained popularity, and their share of the corn seed market rose to 11 percent in 2012.

China's top leadership initiated a "seeds project" in 1996 to consolidate seed companies and commercialize breeding and propagation to boost grain productivity (China Ministry of Agriculture, 1996, pp. 78-80; World Bank, 1996). A recent report by China's leading corn industry experts noted that crop yield improvements have slowed since the mid-1990s as rapid gains from disseminating hybrid varieties during the 1970s and 1980s were exhausted (Corn Industry Technology System, 2013). The experts attributed slower growth in yields to failure to breed corn varieties suitable for

⁵A recent news report claimed that test plots in Xinjiang Autonomous region achieved record yields by planting 130,000 plants per hectare (Xinhua News Service, 2013).

⁶See USDA/NASS, 2014.

farmers' needs, increased incidence of plant disease and pest damage, degraded soil structure, slow development of mechanization, and neglect of irrigation facilities.

China introduced a subsidy of 10 yuan per mu (about \$10 per acre; 1 acre = 6.07 mu) for improved corn seeds in 2004. However, the subsidy did not focus on achieving high yields; discussions of the program featured varieties with high oil content or corn for silage. The subsidy was initially paid to a designated company (not directly to farmers) in each county, and it was often used to induce farmers to buy seeds from that company, not necessarily the best quality seeds (Zhang and Li, 2009, pp. 115-118). In response to these concerns, many areas began giving farmers the seed subsidy as a cash payment that is not contingent on buying particular seeds.

Increases in chemical fertilizer use contributed to increases in yields in recent decades, but fertilizer use per hectare is already high by world standards (Zhang et al., 2009; Yuxuan Li et al., 2013). Recent soil fertility surveys have revealed nutrient imbalances and acidification of soils due to excessive use of chemical fertilizers. China's Ministry of Agriculture (2013) initiated subsidies for soil fertility testing in 2005 and hopes to improve yields by recommending better fertilizer formulations.

Shen (1951) reported that corn borers were the primary pest affecting corn production in the 1940s. Five decades later, officials were still concerned about these pests and encouraged use of biological controls and special lights to control them (Crook et al., 1994). Nevertheless, these and other pests are still cited as major barriers to corn yield improvements (Corn Industry Technical System, 2013). During 2012 and 2013, infestations of "army worms" (a type of caterpillar) caused widespread damage to corn stalks.

China's corn is less reliant on irrigation than some other crops since rainfall in major growing regions is concentrated during the key summer months for corn growth (Meng et al., 1996). Nevertheless, drought commonly affects the crop in provinces of the southwest and northwest. In most years, corn yields in various localities are curbed by lodging, flooding, and hail damage from storms. Increasing resistance to drought and floods is a key part of China's strategy for improving grain production. Agricultural officials are subsidizing installation of lined canals, pipes, and drip irrigation to irrigate corn fields.

Genetically modified (GM) corn varieties potentially could alleviate drought and pest problems that constrain yields in China, but authorities there have not approved any for commercial production (see box, "Cumbersome Approval Process Prevents GM Corn-Planting"). According to Chinese news media, several GM corn varieties marketed as conventional seed were banned when Ministry of Agriculture testing found they were genetically modified.⁷ Inspection and quarantine authorities reported intercepting smuggled GM corn seed, and there were reports of unauthorized fields of GM corn and rice in five provinces during 2013.

Scientific advances do not always translate to improvements in production. Wan et al. (2006) reported that experimental field trials during 2000-04 obtained corn yields about twice the average yields obtained by farmers in those regions. Wu et al. (2011) reported that yields obtained on local experimental plots in Inner Mongolia were 33 to 50 percent higher than yields obtained by farmers in the same districts.

⁷See Jingji Guancha Bao, 2011.

Cumbersome Approval Process Prevents GM Corn-Planting

China has a lengthy approval process for production of genetically modified (GM) crops. Regulations and decrees issued by the State Council require that each GM variety be evaluated through a five-step process of laboratory tests, planting on test plots, environmental and field tests, lab animal tests and application for commercial use before it can be grown commercially in China (Lagos and Jie, 2012; *Peoples Daily*, 2014). The sequence of approvals granted by the Ministry of Agriculture, a National Biosafety Committee, and provincial officials take years to complete, and the process lacks transparency.

No GM corn or other grain varieties have been approved for commercial cultivation in China (*Peoples Daily*, 2014). A high-phytase corn variety received a safety certificate from the Ministry in 2009, but it is not likely to affect yields and commercial release has still not been approved. A Chinese plant-protection scientist advocated insect-resistant genetically-modified corn as a way to reduce losses to corn-borers which he estimated at 8-10 percent of the harvest (He, 2011). The scientist reported that China had developed the technology to transfer insect-resistant genes to corn in 1993. Several such strains of insect-resistant and herbicide-tolerant corn are at various stages of the evaluation process.

Imported GM commodities also must undergo a lengthy approval process that can take two years or longer. In 2013, China had approved 17 GM varieties of imported soybeans, cotton, corn, canola, and sugar beets for processing use in China (*Peoples Daily*, 2013). A number of GM corn varieties have been approved for import. However, corn trade was disrupted during 2013-14 when Chinese authorities rejected dozens of shipments containing a GM corn variety that was not yet approved for import by the Ministry of Agriculture.

The uneven quality of extension services and lack of training for many technicians can slow the dissemination of new techniques. Strategies to disseminate new varieties and cultivation techniques rely on demonstration plots in model villages, districts, and counties intended to display the benefits of new techniques, but the impact often falls short of expectations (see box, “Corn Production Success and Challenges in an Inner Mongolia District”). New techniques are often confined to villages and townships where leaders have mobilized local farmers to use them. Most Chinese farmers choose seeds and techniques based on advice from neighbors and dealers, and they typically buy seeds from itinerant dealers and small shops. Farmers who plant at most a few acres of corn are often unaware of advanced techniques.

The quality of corn seed and other inputs reaching farmers is highly variable. Poor propagation and manufacturing of seeds frequently leads to low germination rates or other problems with commercial seed, and name-brand seeds are often counterfeited or adulterated. Fertilizers and pesticides are often poorly formulated, use substandard ingredients, or are falsely labeled. Farmers often overuse ineffective chemical inputs to achieve desired results.

Corn Production Success and Challenges in an Inner Mongolian District

Local officials have been working to improve corn yields in Horqin Banner, a district of Inner Mongolia, but the region faces some chronic difficulties (see “Tongliao Prefecture Horqin District Corn Production Situation and Development Measures,” *Modern Agriculture Technology*, 2011, No. 6, p. 374).

Horqin Banner (a county-equivalent region) is one of 100 model corn-production counties chosen by agricultural officials to demonstrate best practices in China. About 30 percent of Horqin’s corn is used by local industrial processors and 25 percent is fed directly to livestock or processed by feed mills, but 40 percent is sold to other regions. Local authorities say precision planting, coated seeds, and soil fertility testing are used on all corn fields in the region, and corn-borer control techniques are used on 89 percent of fields. Planting on ridges, a dense-planting technique, and biological pest controls are each used on about 5 percent of corn planted in the district.

About 20 different varieties of corn are planted in the Horqin Banner region. According to the article, the most popular variety, Zhengdan 958, is becoming less productive because it is vulnerable to pests. Planting density has increased to 67,500 to 72,000 plants/ha, and some fields have density as high as 82,500-90,000 plants/ha. However, density is constrained by soil fertility in some plots. Field management is uneven.

The switch from organic to chemical fertilizer during the 1990s led to soil compaction and reduced organic matter in the soil. Chemical fertilizer used by most farmers has a high proportion of nitrogen but insufficient amounts of potassium and micronutrients. Few farmers use compound fertilizer.

Horqin officials say the effectiveness of extension services is limited by the lack of trained personnel. Most extension workers were hired in the 1990s or earlier, when education and training standards were low. Most have a middle-school education and have little access to new knowledge or training. Universities emphasize theoretical courses over applied agricultural science. University graduates seldom join the extension system.

Corn Yield Data

The United States is the world's leading corn producer, and improvement of U.S. corn yields since the mid-20th century is one of the most prominent achievements in agricultural science and technology. Trends in U.S. corn yields provide a reference for evaluating progress in Chinese yield growth as China goes through a similar period of technical progress.⁸ This study analyzes historical trends in China's corn yields to provide a basis for anticipating future growth prospects. The study presents national and provincial corn yield data produced by two Chinese Government sources. The study also presents data on historical U.S. corn yields as a benchmark for assessing trends in Chinese yields.

Chinese data include official yield estimates reported by China's National Bureau of Statistics (NBS) and yields reported by an annual China National Development and Reform Commission (NDRC) survey of crop returns and production costs. Those data sources are discussed in appendix 1. NBS is the official source of crop production statistics in China, and USDA and other organizations generally rely on the NBS data in forming their estimates of China's grain output. NDRC is an independent data source used as a reference for comparison with the NBS data.

NBS conducts annual crop surveys in partnership with provincial and local statistical bureaus, compiles the data, and issues annual estimates of planted area, yield per planted acre, and total output for each province.⁹ NBS crop estimation methods have evolved over time as sample surveys replaced administrative reporting systems, agricultural censuses in 1996 and 2006 provided benchmarks for national sampling and estimation, and more sophisticated sampling and estimation methods were adopted during the first decade of the 2000s (Ma, 2013). NBS provides only sparse explanations of its methodology. Large revisions in crop area statistics and opaque adjustments by NBS raise questions about the consistency of crop yield data over time (see box, "Revised Cropland Statistics Raise Questions About Yield Statistics").

NDRC reports yields from a national survey of farm production costs for major commodities. The NDRC survey's purpose is to guide policymakers in setting price and procurement policies, not to estimate yields or production. The NDRC yield data were probably not adjusted by statisticians to compensate for underreporting of cropland as NBS data apparently were. Thus, NDRC data may be useful as a reference to evaluate possible inconsistencies in the NBS data.

The NDRC survey reports average corn yields for 21 of China's 31 province-level regions. The NDRC instructs local offices to select a representative sample of farms, but it excludes producers in minor producing regions, farms with very small plots of corn, and those in inaccessible areas. NDRC's description of the sampling process suggests that estimates appear to be less precise than the NBS estimates (see appendix 1), but neither organization releases any standard errors or other indicators of precision.

⁸Discussions of corn yields in China frequently refer to the large gap between U.S. and Chinese yields. China Corn Technology System (2013) also noted that recent growth of Chinese yields was slower than that in the United States, Brazil, and Argentina.

⁹NBS does not report *harvested* acres.

Revised Cropland Statistics Raise Questions About Yield Statistics

Since the 1990s, Chinese authorities have increased their estimates of the country's cropland area by over 40 percent, as cultivated land and crops previously not reported to authorities were included in statistics. Statisticians apparently made adjustments to grain production estimates to account for unreported cultivation that raise questions about the consistency of China's crop yield statistics.

In the 1990s, official statistics reported a cultivated area of 95 million hectares, an estimate that was widely believed to be understated. Chinese statisticians acknowledged the understating of crop area and said they inflated crop yields 20 to 30 percent to arrive at what they thought was an accurate estimate of grain output (Crook and Colby, 1996).

The results of a 1996 land survey announced in 2000 increased cropland area to 130 million hectares (Lin and Ho, 2003). Statistical publications for 2008-13 reported a smaller total of 122 million hectares that was attributed to China's Ministry of Land Resources. There were no matching revisions in statistics on yields or area planted in grains accompanying these revisions in cropland area.

In December 2013, the Ministry of Land Resources announced an even larger cropland area totaling 135 million hectares from a Second Land Survey completed in 2008. An NBS official explained that statisticians had already incorporated the larger crop area total in their estimate of area sown to grain (Xinhua, 2013). He explained that a policy change from taxing to subsidizing grain land had induced farmers to begin reporting use of cropland previously not reported to authorities, and he said NBS statisticians had incorporated this land by making adjustments to their survey data.

The increased area planted in corn reported in NBS statistics from 2006 to 2012 could be a statistical artifact that reflects statisticians' inclusion of land that was previously unreported. This also raises the possibility that the trend in yields may be stronger than indicated by historical statistics if statisticians abandoned the practice of inflating yields as they adjusted sown area statistics.

Varying Chinese statistics on cropland area

Year	Cropland area (million hectares)	Source
1995	95	Administrative reporting of land contracted to villagers
1996	130	First land survey
2006	122	Attributed to Ministry of Land Resources in statistical publications from 2008 to 2013
2008	135	Second national land survey, announced 2013

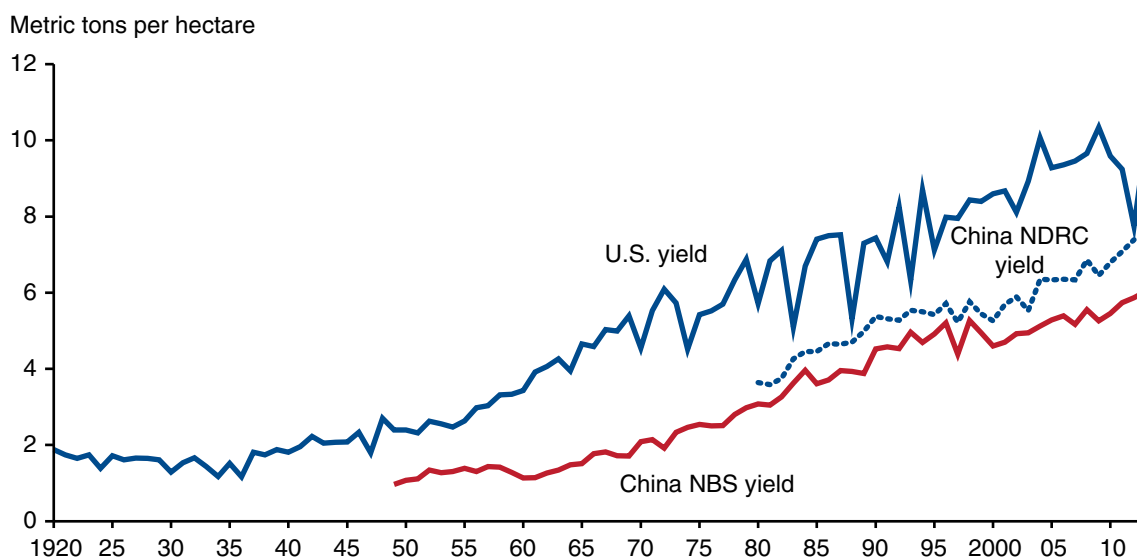
Note: U.S. intelligence analysts estimated China's cropland at 140 million hectares (MEDEA, 2000).

Trends in National Average China and U.S. Yields

Figure 2 shows the trends in U.S. and China corn yields expressed in metric tons per hectare (mt/ha). The China corn yield reported by NBS began to follow a rising trend in the early 1960s. NBS yields in the 1950s and 1960s were similar to those reported by Shen (1951) for the 1940s (1.3 to 1.5 mt/ha, or about 20-24 bushels per acre), suggesting little or no improvement over those three decades. China's corn yield reached 2 mt/ha in the early 1970s and began to rise during that decade until it reached about 5 mt/ha in the 1990s. The yield fell in the late 1990s and then rose from 4.7 mt/ha in 2001 to 5.9 mt/ha in 2012. A preliminary estimate by NBS indicated the yield surpassed 6 mt/ha (about 96 bushels per acre) for the first time in 2013.¹⁰

The NDRC corn yield exceeded the NBS yield each year, but both followed an upward trend. Year-to-year variation in the two series appears to be consistent. While Crook and Colby reported that NBS inflated yields during the 1990s, NBS yields were consistently lower than NDRC yields, a pattern that assuages concerns about inflated NBS yields. The difference between NDRC and NBS yields could partly reflect the NDRC sample's exclusion of farms with very small plots of corn and farms in minor producing regions.¹¹ Lower NBS yields could also reflect its practice of discounting yields for moisture content and waste losses.¹²

Figure 2
U.S. and China corn yields



Notes: China National Bureau of Statistics (NBS) publications omit data for most years from 1958-69. Data for these years were obtained from a China Ministry of Agriculture database.

Source: China NBS, China National Development and Reform Commission (NDRC), and USDA, National Agricultural Statistics Service.

¹⁰See China National Bureau of Statistics (2013).

¹¹NDRC officials direct local officials to choose a representative sample, but it excludes subsistence producers and probably does not include regions that are not major corn-producing areas (see appendix 1).

¹²It is also possible that NBS's practice of collecting samples 10 to 15 days prior to harvest could understate yield.

Like the NBS yield, the NDRC yield stagnated during the late 1990s, but it did not fall as sharply as the NBS yield. The NDRC yield rose from 5.7 mt/ha to 7.4 mt/ha between 2001 and 2012. Since 2001, the NDRC yield has been 20 to 24 percent higher than the NBS yield (in earlier years the difference was 10 to 20 percent in most years).

The average U.S. corn yield is also shown as a reference for evaluating progress in Chinese yield. The U.S. yield was at or below 2 mt/ha (about 32 bushels per acre) until the mid-1940s and began rising in the 1950s, a phenomenon often attributed to dissemination of hybrid corn and subsequent technological improvements. The U.S. yield continues to rise, reaching 10 mt/ha (159.3 bushels per acre) during 2004, 2009, and 2013—a more-than-fivefold increase since 1940. Since the 1980s there have been several years of low U.S. yields due to drought. The yield fell to 7.7 mt/ha during the severe drought of 2012 but was still higher than any year prior to 1992. The average yields of both Chinese data series are well below average U.S. yields in each year except 2012, when the average U.S. yield was slightly higher than the Chinese NDRC yield.

We fit trend lines to the NBS (1980-2013), NDRC (1980-2012), and U.S. (1950-2013) data (expressed in mt/ha) using ordinary least squares. We did not attempt to explain the growth in yields using inputs or other factors since data on aggregate input use for corn are not available.¹³ The data indicate that the trends in yields have been remarkably persistent over time.

China data from 1980 to the present were analyzed. The U.S. trend was estimated for data from 1950—when the rising trend first became evident—to 2013. A linear trend provided a better fit than quadratic or exponential trends for all three data series. This is consistent with other studies that found diminishing percentage rates of growth in crop yields.¹⁴

Yield_t is the average corn yield for year t, the intercept represents the yield in a base year (1950 for the U.S., 1980 for China), and the slope coefficient reflects the average annual growth in yield (mt/ha). The residual reflects weather and other randomly distributed effects on yields. The results are as follows:

$$\text{U.S. (1950-2013): } \text{Yield}_t = 2.39 + .119 (\text{Year} - 1950), R^2 = .92$$

$$\text{NBS (1980-2013): } \text{Yield}_t = 3.41 + .075 (\text{Year} - 1980), R^2 = .88$$

$$\text{NDRC (1980-2012): } \text{Yield}_t = 3.94 + .096 (\text{Year} - 1980), R^2 = .91$$

All coefficients were statistically different from zero with 95-percent confidence. The intercept reflects the U.S. trend yield in 1950 of 2,380 kg/ha. The trend coefficient suggests that the average U.S. corn yield tends to rise 119 kg/ha/year. The R^2 values indicate that the trend accounted for all but 8 to 9 percent of the variation in the average yield for the U.S. and the NDRC data, and all but 12 percent of variation in the average NBS yield. Variation around the trend reflects effects of weather, measurement error, and other factors.

¹³The yield is a partial productivity measure of output per unit of land; its growth could reflect increased use of other inputs, weather, or technology improvements. Sun-ling Wang et al. (2013) found that growth in input use contributed about half of China's growth in agricultural output.

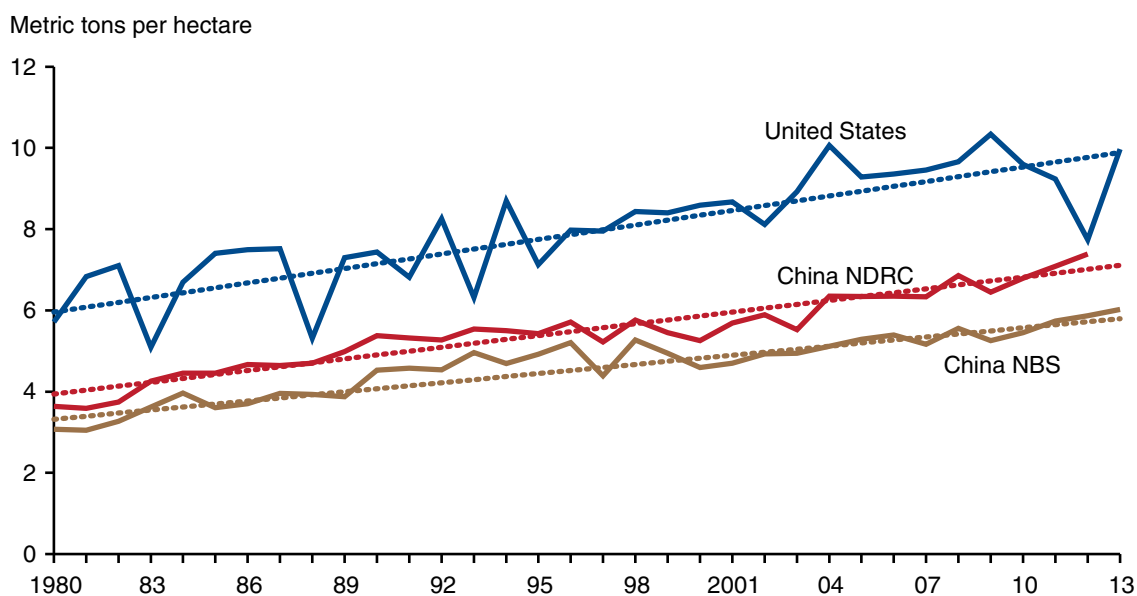
¹⁴Harris and Kennedy (1999) found that logistic functions best described the diminishing growth rate, and Hafner (2003) found yield growth was linear.

Since 1980, the variation in Chinese yields around the estimated trend lines has been less than that of the U.S. average corn yield (fig. 3). A trend model for the U.S. using data for 1980-2013 produced an R^2 of .69, much lower than obtained from the 1950-2013 data and much lower than R^2 for China models over the same period. The absence of large deviations in yield from the trend in China could be due to (1) the wide geographic spread of corn production in diverse regions, which means that adverse weather events are often restricted to a single region and are offset by good weather in other regions, (2) irrigation in some areas that mitigates drought impacts, and (3) an alleged tendency of statistical officials in China to “smooth” data over time to eliminate extreme values.¹⁵

The long-term growth in the U.S. corn yield has been faster than that of the Chinese yield. The U.S. data have a trend coefficient of 119 kg/ha/year with a standard error of 4.4.¹⁶ The NBS data have an average increase in yield of 75 kg/ha/year while the NDRC data have an average increase of 96 kg/ha/year. Each of the China trend coefficients has a standard error of 5.4 kg/ha. A 95-percent confidence interval for the NBS trend is (64, 86) kg/ha/year and the confidence interval for the NDRC coefficient is (85, 107). The U.S. trend is above the upper limit of both of these confidence intervals, suggesting that the growth in the U.S. yield exceeds the growth in Chinese yield. The faster pace of growth in U.S. yields suggests that the gap between U.S. and Chinese corn yields is growing over time.

The estimated trend from the NDRC data exceeds the trend in the NBS data. However, their confidence intervals overlap, indicating that there is not a statistically significant difference between the trends estimated from the two Chinese data sources.

Figure 3
Corn yields and trend lines, U.S. and China, 1980-2013



NRDC = National Development and Reform Commission.

Source: USDA, Economic Research Service estimates based on data from China National Bureau of Statistics (NBS) and USDA, National Agricultural Statistics Service.

¹⁵ERS researchers found that provincial yields have a much higher degree of year-to-year variation than the national average.

¹⁶The U.S. trend coefficient estimated for 1980-2013 was 112 kg/ha/year with a standard error of 13, not significantly different from the 1950-2013 trend.

The finding of a linear time trend implies that yields increase by a constant amount each year. Thus, the *percentage rate* of growth in yields is declining. The annual yield trend of 75 kg/year estimated from the NBS data above equaled 2.3 percent of the 1980 trend yield and 1.2 percent of the yield in 2012. The arithmetic average of annual changes in yield for 1980-2012 was 2.3 percent for the NBS data and 2.4 percent for the NDRC data.¹⁷ These rates are slightly less than the 2.8-percent long-term growth rate in developing country crop yields reported by World Bank (2008). The average U.S. yield growth for 1950-2012 was 2.8 percent.

Growth at a constant proportional rate implies an exponential trend model. An exponential trend model produces these results:

$$\text{U.S. (1950-2013): } \text{Yield}_t = 2.80 e^{.0214(\text{year} - 1950)}, R^2 = .89$$

$$\text{NBS (1980-2013): } \text{Yield}_t = 3.46 e^{.0170(\text{Year} - 1980)}, R^2 = .85$$

$$\text{NDRC (1980-2012): } \text{Yield}_t = 4.01 e^{.0181(\text{Year} - 1980)}, R^2 = .90$$

The trend coefficients suggest a 1.7- to 1.8-percent annual rate of growth in yield for China yields, slower than the arithmetic average of growth rates reported above. The exponential model does not fit the data as well as the linear trend model, but the difference is slight: R^2 values for the exponential model are several percentage points lower than those for the linear model. A systematic pattern of residual values for the U.S. exponential model suggests that the model is inappropriate: residuals are all positive at the beginning and end of the 1950-2013 period. In contrast, there is little difference in fitted values and residuals between the exponential and linear trend models for Chinese data during 1980-2013.

The linear trend growth is consistent with assumptions underlying the *USDA Agricultural Projections to 2023* which anticipate linear growth in future crop yields. However, the projections assume strong growth in China's corn yield of 117 kg/ha/year. This assumed growth is close to the historical trend in U.S. corn yield, but it is faster than the historical trend in China's corn yield. The report will discuss the sensitivity of projected imports to yield-growth assumptions in "Summary and Outlook."

¹⁷The mean growth rate obscures the wide variation in growth rates. During 32 years (1980-2012), the NBS yield fell in 11 years and increased by more than 5 percent in 10 years. The NDRC yield grew 4 to 5 percent during 2010-12.

Analysis of Yields by Province

Corn is grown in a variety of terrains, climates, and socioeconomic conditions in all of China's provinces (see appendix 2, "China's Corn Regions"). The largest production regions are concentrated in relatively land-abundant temperate northern provinces, which have similar temperature and precipitation to those of the U.S. Corn Belt region (fig. 4).

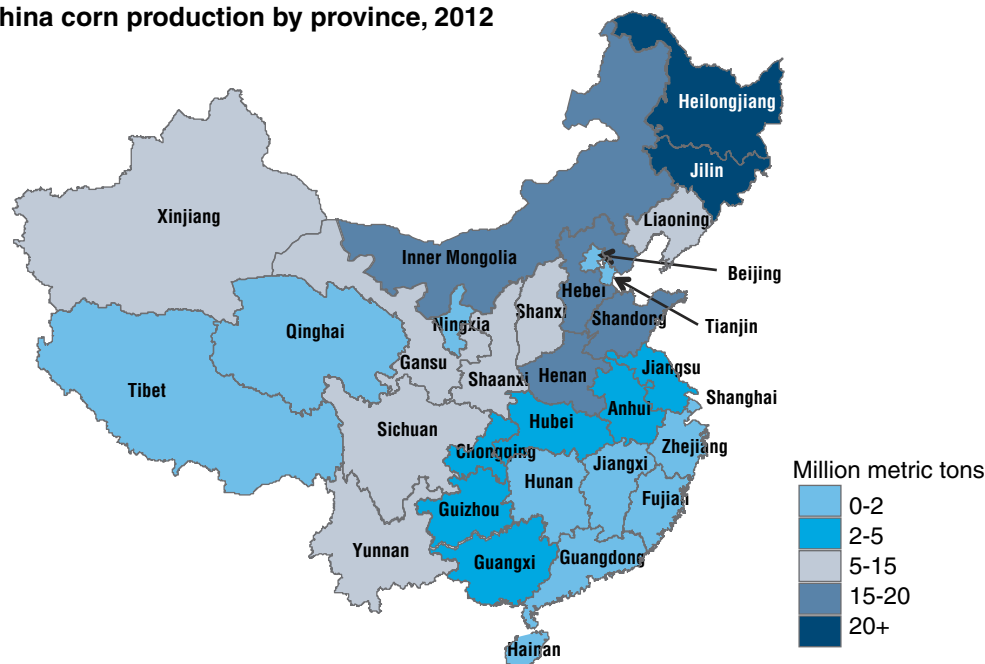
China's northern corn-producing regions have contributed most of the gains in corn output. From 2003 to 2012, 7 of China's 31 provinces accounted for 65.8 percent of the increase in corn output (table 1). These include two broad regions: northeast China (Heilongjiang, Inner Mongolia, Jilin, and Liaoning) and the North China Plain (Henan, Shandong, and Hebei). One northeast province—Heilongjiang—accounted for 22.9 percent of corn output growth. The northeast region combined accounted for 42 percent of production in 2012 and about half of the growth in output during 2003-12. The provinces accounting for most of the output growth had slightly higher per-hectare yields than other provinces.

The Chinese Government's strategic plan for grain production and marketing relies on boosting production in relatively land-abundant provinces of the northeast and North China Plain. Northern surplus grain is to be shipped to southern corn-deficit regions of China where much of the country's feed milling and livestock production is located.

Improvement in corn yields is less evident in recent data for individual provinces than it is in national aggregate data. Figure 5 shows the 1978-2012 yield history for two provinces (Heilongjiang and Henan) that together accounted for one-third of 2003-12 growth in comparison with the national average yield. Provincial yields varied more from year to year than did the national yield. Year-to-year fluctuations in yields in the two provinces are not closely correlated. These patterns bolster the conclusion that geographic diversity attenuates fluctuations in the national

Figure 4

China corn production by province, 2012



Source: Compiled by USDA, Economic Research Service from China National Bureau of Statistics data.

Table 1

Growth in China corn output, 2003-12, by province

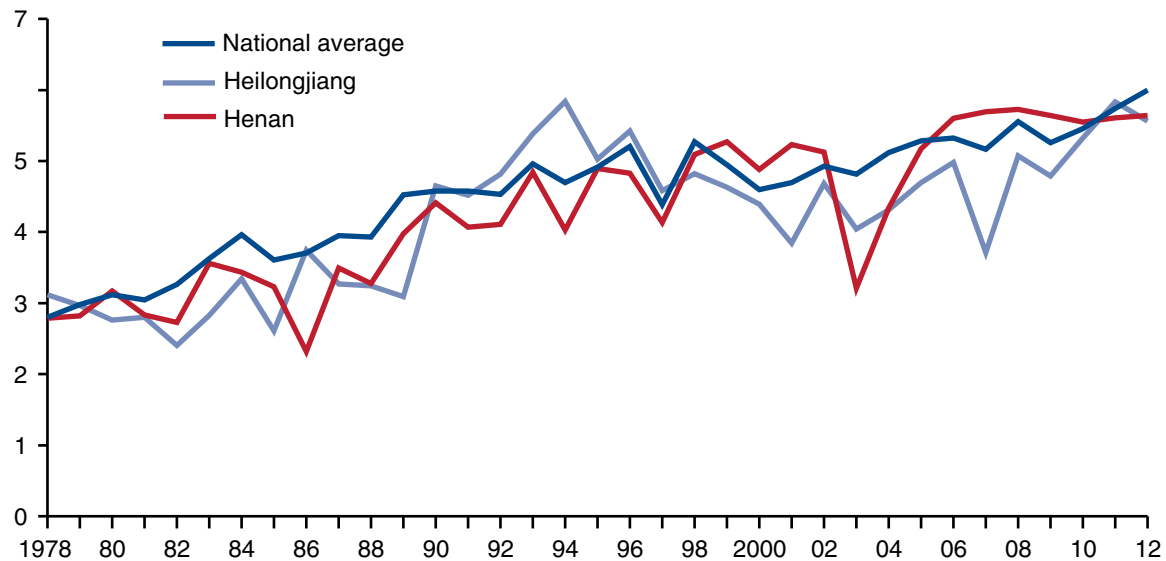
Province	Corn yield, 2012	Growth in corn output	Share of growth
	<i>Metric tons per hectare</i>	<i>Metric tons</i>	<i>Percent</i>
Heilongjiang	5.6	20.6	22.9
Henan	5.6	9.8	10.9
Inner Mongolia	6.3	9.0	10.0
Jilin	7.9	9.6	10.7
Shandong	6.6	5.8	6.5
Hebei	5.4	5.8	6.4
Liaoning	6.5	5.2	5.8
These provinces	6.2	65.8	73.2
Other provinces	5.3	24.0	26.8

Source: USDA, Economic Research Service calculations using data from China National Bureau of Statistics.

Figure 5

China corn yields: national average, Henan and Heilongjiang Provinces, 1978-2012

Metric tons per hectare



Source: USDA, Economic Research Service analysis of data compiled from China National Bureau of Statistics yearbooks.

average corn yield. Yields clearly improved during the 1980s in both Henan and Heilongjiang, but data show no clear trend in yields from 1990 to 2012. Henan's yield appears to have plateaued from 2005 to 2012.

Yields Vary Widely Within Provinces

The expansion of corn in low-yielding areas tends to suppress growth in the average yield. Heilongjiang's yield was at or below the national average every year from 1998 to 2012.

Heilongjiang's expansion of output during the first decade of the 2000s came entirely from expansion of planted area, which grew from 2 million to nearly 5.2 million hectares during 2003-12.¹⁸

Without access to complete data on yields for subprovincial geographic units, we note that yields vary widely within provinces. For example, Jing Wang et al. (2012) found that trends in yield were positive in some counties of Heilongjiang Province and negative in others.¹⁹

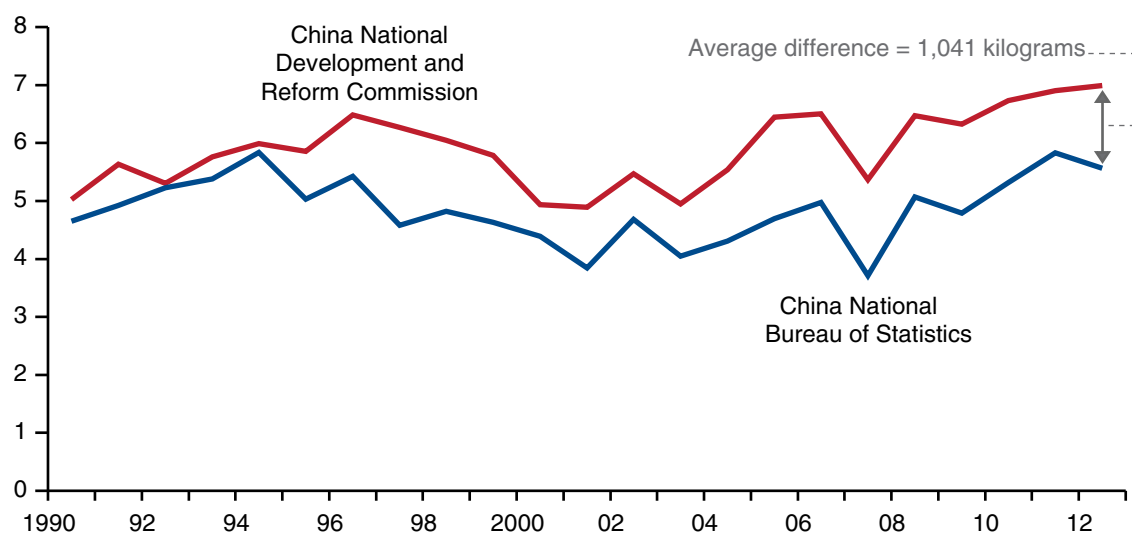
Provincial NBS and NDRC yield data were compared. NDRC yields exceeded NBS yields in every province to varying degrees. For example, the Heilongjiang NDRC yield exceeded the NBS yield by an average of 1,041 kg/ha—over 20 percent of the NBS average (fig. 6). For Henan, the yields from the two sources were very similar during the 1990s, but, after 2000, the NDRC yield was on average 15 percent higher than the NBS yield (fig. 7). Henan's NDRC yield rose from 2006 to 2012 while there was no trend in the province's NBS yield. The difference between NDRC and NBS yields was more than 20 percent in Hebei, Henan, and Inner Mongolia, and 4 to 17 percent in Shandong, Jilin, Liaoning, and Heilongjiang. It is unclear why the NDRC data report systematically higher corn yields than NBS.

Trends in corn yields vary across provinces—some have trends stronger than the national average while others show little or no trend in yield. Trend regressions for the most important corn-producing provinces were estimated using NBS and NDRC data for 1990-2012 (table 2). The NBS data showed no trend in corn yield for four northeast provinces (Heilongjiang, Inner Mongolia, Jilin, and Liaoning). The NDRC data did have a positive trend of 50 kg/ha/year for Heilongjiang and Inner Mongolia but no trend for Jilin or Liaoning. North China Plain provinces—Henan, Shandong,

Figure 6

Average corn yield from two data sources, Heilongjiang Province, 1990-2012

Metric tons per hectare



Source: China National Bureau of Statistics yearbooks and China National Development Reform Commission, *Agricultural Commodity Production Costs and Returns* yearbooks.

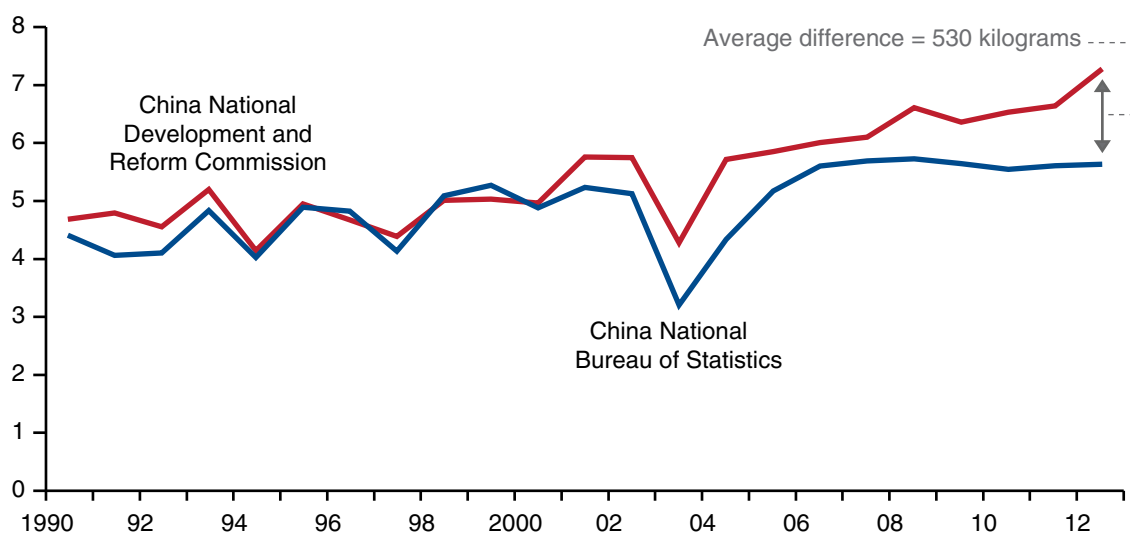
¹⁸Some of the increase in Heilongjiang's land could reflect the inclusion of previously-unreported land in statistics.

¹⁹In 2012, China's National Bureau of Statistics began conducting surveys in major grain-producing counties, because county-level statistics were believed to be unreliable (Ma, 2013).

Figure 7

Average corn yield from two data sources, Henan Province, 1990-2012

Metric tons per hectare



Source: China National Bureau of Statistics yearbooks and China National Development Reform Commission, *Agricultural Commodity Production Costs and Returns* yearbooks.

Table 2

Corn yield trend regression results, selected Chinese provinces, 1990-2012

	NBS data trend	R ²	NDRC data trend	R ²
National	.048*	.66	.085*	.79
Northeast region				
Heilongjiang	-.002	.00	.050*	.27
Inner Mongolia	.027	.14	.050*	.26
Jilin	.017	.02	.038	<.01
Liaoning	.014	.01	.004	<.01
North China Plain region				
Shandong	.080*	.62	.107*	.73
Henan	.066*	.43	.111*	.74
Hebei	.036*	.29	.093*	.69

Note: Table shows trend regression results:

$Yield_t = a + b(t - 1990) + e$, where t is the year and b is trend coefficient. Intercept estimates, a , are not shown.

Yield is expressed in metric tons (1,000 kg) per hectare.

* indicates statistically significant at .05 level.

NBS = China National Bureau of Statistics; NDRC = China National Development and Reform Commission.

Source: USDA, Economic Research Service calculations using China National Bureau of Statistics data.

Hebei—had positive trend coefficients using both data sources. The trends in NDRC data were stronger than NBS trends, ranging from 93 kg/ha/year for Hebei to 111 kg/ha/year for Henan. The North China Plain province trends measured using NBS data ranged from 36 to 80 kg/ha/year, bracketing the 48 kg/ha/year national trend during this period. The trend accounted for less than half of yield variation for all provinces except for Shandong (over 60 percent for both NBS and NDRC

data) and Hebei's NDRC data trend. There is no evidence of a 1990-2012 yield trend in either Liaoning or Jilin provinces. Both data sources indicate that yield trends in northeast provinces are relatively weak.

The northeast provinces had high yields in the 1990s that were not matched again until 2009-10. A period of low yields during 2000-03 coincided with a period of low corn prices that reduced incentives to produce corn. That was also a period when China's National Bureau of Statistics incorporated new statistical methods for crop estimates. The early-2000s dip in yields could be a statistical artifact reflecting changes in statistical methods or sampling.²⁰

The provincial yield trends varied over time. Provinces showed gains in yield during the 1980s, but yields fell in most provinces during the early 2000s and then rose again later in that decade. Estimating yield trends with northeast province data reveals significant positive yield trends using data for 1980-2012 and for 2000-2012. For example, analysis using the NBS data for 2000-2012 shows that Heilongjiang (123 kg/ha/year), Jilin (197 kg/ha/year), and Inner Mongolia (94 kg/ha/year) had statistically significant yield trends. Heilongjiang's 2000 to 2012 trend accounted for 54 percent of variation in yield during that period, and Jilin's and Inner Mongolia's trends accounted for more than 70 percent of yield variation in those provinces. Thus, there is some evidence of improvements in yields in northeast provinces in the last decade, but it is hard to discern the trends given the large amount of year-to-year variation in reported provincial yields.

Can Weather Explain Year-To-Year Variation in Provincial Yields?

The influence of weather on the high degree of year-to-year variation in yields was investigated. Studies of U.S. corn yields by Thompson (1969), Ash et al. (1987) and Westcott and Jewison (2013) showed that precipitation has a positive impact on yield, particularly when corn enters the reproductive stages of tasseling and silking approximately 60 days after planting (the timing of this stage varies by region). Using these studies for guidance, we investigated the contribution of weather to Chinese provincial yield variation by adding temperature and precipitation indicators to the yield trend models for major corn-producing provinces.

Provincial average temperature and precipitation for June, July, and August (the key corn-growing period) for major corn-producing provinces over 1990-2012 were compiled and the 1990-2012 provincial average of each variable was calculated. Each weather variable was transformed in order to calculate an index showing its value as a percentage deviation from its provincial mean.

For example, in Heilongjiang Province, the July precipitation varied widely from 44 percent below the average to 62 percent above the average, and July temperature varied from 9 percent below to 7 percent above the average during 1990-2012.

Six weather variables (precipitation for June, July, and August and temperature for each of the 3 months) were added to each province's trend regression model to investigate the potential for weather measures to help explain the year-to-year variation in yields:

$$\text{Yield}_t = \beta_0 + \beta_1(\text{Year} - 1990) + \sum_{j=1}^6 \delta_j w_{jt} + e_t$$

²⁰Statisticians may have inflated yields during the 1990s to compensate for underreporting of cropland (see box, "Revised Cropland Statistics Raise Questions About Yield Statistics")

Yield regression models were estimated for each province using yields from both NBS and NDRC. We dropped weather variables that did not add explanatory power to achieve a more succinct model. Each province had one to three significant weather variables included in its model.

Incorporating weather variables increases the proportion of variation accounted for in most provinces compared with simple trend models (table 3). R^2 values range from .27 to .84, with the highest values in North China Plain provinces. However, adding weather variables still leaves most of the large year-to-year variations in yields unexplained in northeast provinces (Heilongjiang, Inner Mongolia, Jilin, and Liaoning). Models with weather variables explain only 27 to 58 percent of variation in NBS yields, and they explain 36 to 52 percent of the variation in NDRC yields in those provinces.

Adding weather variables had little effect on the measured trend coefficients for most provinces, but NBS yield trend coefficients were no longer significant for Henan and Hebei provinces. Only Shandong had a significant trend in NBS yields when weather variables were included. The NDRC data for Heilongjiang and Inner Mongolia had statistically significant trend coefficients. Shandong had a statistically significant trend for both NBS and NDRC data when weather variables were included. Henan and Hebei NBS yield trends were not significantly different from zero when the weather variables were included in the regression models.

Table 3
Corn yield trend regressions with weather variables, selected provinces, 1990-2012

Province	NBS		NDRC		Weather effects in regressions					
					Temperature			Rainfall		
	Trend	R^2	Trend	R^2	Ju	Jl	Au	Ju	Jl	Au
Heilongjiang	-.010	.31	.041*	.52		+		+	+	
Inner Mongolia	.035	.27	.059*	.36		-				
Jilin	.020	.38	.030	.47			-		+	
Liaoning	.013	.58	.011	.52			-	+		
Shandong	.085*	.73	.115*	.84		+			+	
Henan	.033	.54	.122*	.78			-			+
Hebei	.017	.71	.083*	.83	+			+		+

Notes: NBS = yield data from China National Bureau of Statistics yearbooks.

NDRC = yield data from China National Development and Reform Commission production cost survey yearbooks.

* coefficients are significantly different from zero with 95 percent confidence.

Weather variables include June, July, and August average temperature and precipitation expressed as deviations from mean values.

Source: USDA, Economic Research Service calculations using China National Bureau of Statistics and China National Development and Reform Commission data.

Summary and Outlook

China's increasing consumption of corn is expected to outpace growth in its production, increasing China's demand for imported corn. The USDA *Agricultural Projections to 2023* anticipate that China's corn imports will rise to 22 mmt by 2023/24. This section discusses the sensitivity of this projection to assumptions about the growth in yields.

The USDA baseline projects a 41-percent increase in China's corn consumption over the 10-year projection period to 2023/24.²¹ The increase averages 8.8 mmt annually. It reflects increased meat production and a transition to modernized commercial livestock operations that substitute corn for traditional energy-supplying feedstuffs. China's industrial use of corn is expected to grow at a more modest pace. Rising demand for meat is based on continued robust income growth and an increasing urban share of population that alters consumption patterns. A slowdown in income growth, rising prices, or other factors like disease epidemics in the livestock sector could temper growth in demand for corn (see box, "China's Demand for Feed Can Fluctuate"). The baseline projections anticipate that China will meet its rising meat demand mainly from domestic production. An increase in meat imports could shift corn demand away from China to meat-exporting countries.

China's demand for imported corn depends on how much of the increase in consumption can be met by expanded domestic production. The baseline projects a 6.7-mmt annual increase in production, leaving a 22-mmt deficit in 2023/24 that will be filled by imports (fig. 8).

The projected increase in China's corn output assumes growth in both corn area and yield. It assumes corn area will grow by 3.6 million ha as more land is attracted away from soybeans and minor crops, reaching about 39 million ha by 2023/24. The projection assumes China's average corn

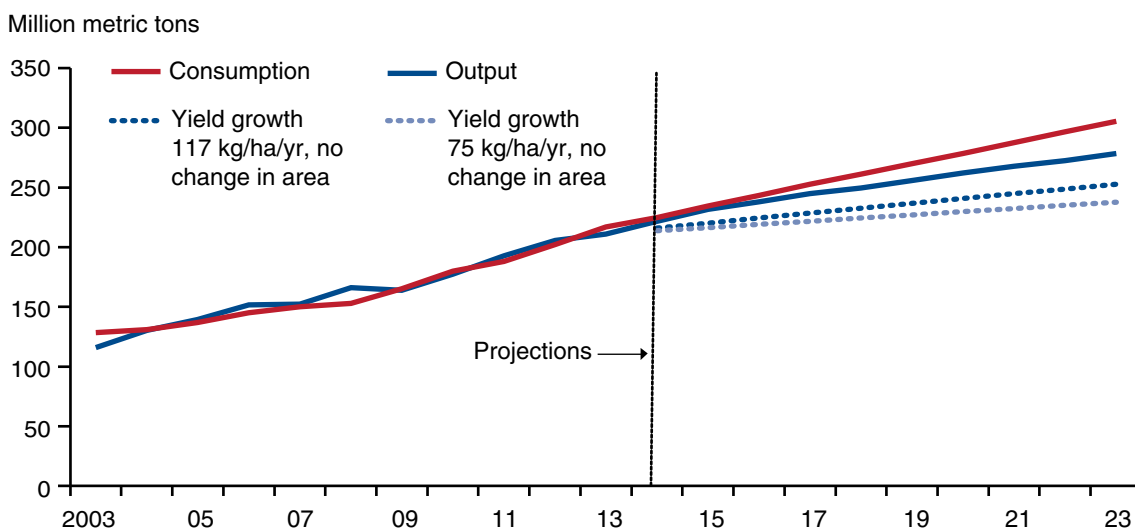
China's Demand for Feed Can Fluctuate

The baseline projections assume normal weather and stable macroeconomic conditions, but unanticipated epidemics, food safety scandals, or economic fluctuations can disrupt growth. During 2013, China experienced a number of nearly simultaneous events that affected pork and poultry markets. Government officials were ordered to cut back on banqueting and consumer spending was sluggish, two factors that crimped demand for meat. Demand for poultry was affected by a scandal over abuse of pharmaceuticals by broiler producers in late 2012 and an outbreak of H7N9 avian influenza during March-April. The hog industry experienced low prices related to excess capacity and was influenced by negative publicity over thousands of dead pigs discovered floating in Shanghai's major river.

Industry statistics reported a 1.8-percent decrease in feed production during 2013. This was a reversal of 8 to 10 percent growth in previous years. Weak demand for corn and a record harvest during 2013 resulted in a glut of Chinese corn that prompted authorities to launch an aggressive corn-stockpiling program to prevent prices from falling. China's demand for corn is expected to resume its strong growth as the effects of these incidents dissipate in future years.

²¹See USDA/ERS, "International Baseline Data," <http://www.ers.usda.gov/data-products/international-baseline-data.aspx>

Figure 8

Growth in China corn production and consumption, 2003-23

Note: Kg = kilogram; ha = hectare; yr = year. Consumption and output are USDA projections. Other output values are extrapolations based on constant growth in yield with no change in corn area.

Source: *USDA Agricultural Projections to 2023*, and USDA, Economic Research Service calculations.

yield will rise by 117 kg/ha/year over 10 years, faster than the past growth trend of 75 kg/ha/year we found in our analysis.²²

China's demand for imported corn could be sensitive to these assumptions. For example, if China has no growth in corn area and all output growth comes from yield growth of 117 kg/ha/year, the gap between consumption and output in 2023/24 could double. The larger gap would imply a much larger demand for imports. If yield growth were to follow the slower pace of 75 kg/ha/year (again with no change in area planted), the gap would be even wider. Thus, China's progress in improving yields may be an important factor influencing its potential demand for corn imports.

Provincial patterns of China's yield growth make prospects for national growth in output even more tenuous. China's strategic plans (the 12th "5-Year Plan" for 2011-15 and medium-term plan for grain production) call for expanding corn production in northeast provinces, particularly Heilongjiang, Inner Mongolia, and Jilin. These provinces have relatively abundant land resources and fewer competing land uses than other regions of China. However, their trends in corn yield are weaker than the national average. The northeast provinces also have large year-to-year variations in yield that our models were unable to explain using weather data. This suggests that the concentration of production in the northeast may contribute to greater volatility in China's national corn output. Expansion of corn area will also be limited by increasing concerns about environmental impacts of cultivating land on hillsides, grasslands, and wetlands expressed in the 2014 "No.1 document" on rural policy issued by China's central leadership.

The projected imports exceed China's annual 7.2-mmt tariff rate quota (TRQ) for corn that was set when China joined the WTO. Imports within the quota are subject to a low 1-percent tariff and over-quota imports are assessed a prohibitive 65-percent tariff. The projections presume that China would expand the quota or introduce a sliding-scale tariff mechanism (as it has done for

²²This is also faster than OECD-FAO (2013) assumed growth in coarse grain yields of 1.5 percent per annum.

cotton) to accommodate demand for imported corn that exceeds the quota. With future robust demand for corn, domestic prices for corn might rise sharply if China fails to open its market to more corn imports. Higher corn prices might draw land away from other crops to boost corn output, but high corn prices would undermine competitiveness of domestic corn-using industries. Higher corn prices would likely raise meat prices. That, in turn, would slow growth in China's corn consumption by crimping growth in meat consumption and prompting a shift from feed grain imports to meat imports.

China's growing demand for imports will increase demand for U.S. corn. The baseline analysis anticipates that U.S. corn exports will rise to 57 mmt in 2023/24. The analysis does not specify how much of the increased corn sales will go to China, but China's rising demand will surely contribute.

During 2010-12 the United States accounted for 97 percent of China's corn imports and will continue to be a key supplier as China increases its demand for corn. Other countries, including Ukraine, Argentina, and Brazil, will likely expand sales to China as well. However, those countries are also experiencing rising living standards, and their own livestock industries may absorb some of the growth in their corn output.

As China's demand for corn imports grows, the United States and other exporting countries will need to boost production to prevent world prices from rising sharply. Sustained growth in corn yields in the United States and other countries will be critical to ensuring that corn is available to meet China's rising demand.

U.S. farmers produce higher corn yields than Chinese farms with less chemical fertilizer. Thus, meeting Chinese demand with U.S. corn conserves resources. The USDA baseline anticipates that the relative efficiency of U.S. corn production will continue to rise. The average U.S. corn yield is projected to rise 126 kg/ha annually, faster than the growth in Chinese yield. With China expected to import more corn, a significant portion of the increase in U.S. production is likely to be exported to China.

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Appendix 1.

Two Data Sources for Corn Yields

This appendix describes methodology used by the China National Bureau of Statistics (NBS) and an alternative survey by the China National Development and Reform Commission (NDRC), which were used as a reference to check the accuracy of NBS yields.

National Bureau of Statistics Grain Production Estimates

Vogel (1999) and Ma (2013) described the NBS methodology for measuring grain production. Corn is one of three major grains that are the focus of these methods, but corn was not discussed specifically. NBS news releases of grain statistics include brief descriptions of methodology that are consistent with these explanations.

Since the 1980s, NBS has transitioned from an administrative reporting system to a sample-survey-based system for collecting and reporting grain statistics. Under the administrative reporting system, statistics were compiled and reported up through five levels of government until they reached NBS in Beijing. These numbers were often distorted or falsified since they were also used to administer taxes, set procurement quotas, and judge progress in fulfilling production targets.

In 1984, NBS established a network of local and provincial rural survey teams in 857 counties (about one-fourth of counties) to estimate agricultural production and monitor income of rural households. The country's first agricultural census conducted in 1996 gave NBS a benchmark to estimate national crop area and set up a national sampling system. A second census was conducted in 2006, which resulted in minor revisions in crop estimates.

NBS now estimates grain yields primarily from surveys conducted in a sample of village plots. NBS grain production estimates are based on a combination of (1) a sample survey of rural households and (2) administrative reporting by other agricultural units (companies, collectives, state farms, government units, and institutional farms).²³ NBS says households account for 90 percent of grain output. During 2001-09, NBS developed a multi-stage sampling system to estimate grain yields and area using agricultural census data. They use a hierarchical method to sample 140,000 household farming units in 846 counties.

Corn is one of the three grain commodities included in surveys of all sample households. Survey teams are composed of county and township statisticians and village officials and farmers. They estimate yields by taking measurements from sample plots 10 to 15 days before harvest. They choose five to seven representative fields from a village, and sample plots are selected from each field. A total of 130,000 fields are used to estimate grain yields. It is unclear how often sample villages and plots are adjusted.

Grain is collected from sample fields, dried, and measured. An adjustment is made for moisture content with reference to national standards. Further deductions are made for losses and waste in harvest, handling, storage, and transportation.

²³The reporting by agricultural units is similar in nature to NBS methods for collecting industrial statistics via reporting by large companies.

While NBS appears to have made significant improvements in methodology, a number of factors raise questions about the precision of estimates. The drying and discounting of corn for moisture content could introduce variability in yield estimates. Farmers use a variety of drying methods, and the moisture level of corn varies widely. Most farmers do not have their own grain-drying equipment, and it dries at varying rates during the months following harvest. In recent years, wet weather in various regions increased moisture of corn held by farmers during the months after harvest to over 30 percent, making it difficult to sell the grain.²⁴

The NBS survey system is not flexible enough to capture the rapid changes occurring in rural China. NBS has used the same sample counties since the 1980s, despite major socioeconomic changes and regional shifts in production. Vogel (1999) pointed out that the unchanged sample of counties may no longer be representative of national production. The increasing prevalence of off-farm employment and renting of land, changing seed varieties, and cultivation techniques may have affected the representativeness of the sample since the 2006 census. The large number of enumerators—most with little or no training—and diverse regions are likely to introduce variation in methods and interpretations of methods. Also troubling is significant difference between many local estimates and official provincial estimates.

Ma (2013) reported that NBS began experimenting with new survey methods that shift from household-based sampling to incorporating an area frame based on land segments chosen using satellite images and maps from a national land survey. Pilot surveys began in five provinces during 2010-11. Ma also reported that NBS began a survey of major grain-producing counties in 2012 in response to a mandate from the State Council to improve capability of monitoring and forecasting grain output by ensuring that “truthful, reliable” data are collected from counties. In late 2013, Hunan Province and several rice-growing counties reported area and production statistics from this survey.

National Development and Reform Commission Production Cost Survey

The NDRC cost of production survey is designed to monitor the costs and returns to production of various commodities. The NDRC survey has been conducted since the 1970s by asking a sample of farms to record expenditures, inputs used, output, and sales over the course of the season. Statistical reports include average production per unit of land.

Information here is based on documentation in NDRC (various years; 2005), interviews with NDRC officials, and a site visit in 2006 to learn about the survey. The survey is intended to be representative of national production, but the sample is small, and sample farms are ultimately chosen by local offices in an ad hoc manner. Provincial and county offices choose representative counties and townships in their province. County NDRC offices (which sometimes are the same as local statistical bureau offices) are instructed to choose a representative sample of farms for each commodity that consists of a minimum of three farms at three townships—a minimum of nine farms. In its 2003 publication, NDRC reported that the sample included 4,097 corn producers in 457 counties—about 9 per county.²⁵ The farms are to represent different types of operations—small, medium, and large. However, subsistence farms with no commercial sales are to be excluded. Minor corn-producing

²⁴According to news media reports, a significant but unknown portion of corn in the North China Plain remained unsold during 2011/12 due to high moisture. Similar problems occurred in the northeast during 2012/13 and in Heilongjiang Province during 2013/14.

²⁵More recent publications did not report the sample size.

counties and townships are probably excluded. Local officials are urged to keep the sample farms fixed for 5 years and change no more than 25 percent of the sample in a single year.

The sample farms keep records of expenditures, production, and sales. The output of the main commodity (shelled corn) and the area actually harvested are the components of the yield calculation. Fields where the crop is lost to disasters are excluded. The volume of corn is discounted for moisture to estimate the weight at the national standard of 14.5 percent moisture.

Each province compiles data from prefecture-level surveys which are reported to the central NDRC in Beijing. The data are compiled and averages are published in an annual statistical report (see NDRC, various years) (appendix table 1).

Appendix table 1

Average corn yields, China and United States, 1980-2013

Year	China-NBS	China-NDRC	United States
<i>Metric tons per hectare</i>			
1980	3.076	3.636	5.711
1981	3.048	3.587	6.835
1982	3.266	3.746	7.105
1983	3.623	4.260	5.090
1984	3.960	4.455	6.697
1985	3.607	4.454	7.406
1986	3.705	4.665	7.494
1987	3.953	4.646	7.519
1988	3.928	4.698	5.310
1989	3.878	4.986	7.299
1990	4.524	5.375	7.437
1991	4.579	5.318	6.816
1992	4.534	5.273	8.253
1993	4.963	5.540	6.320
1994	4.694	5.502	8.699
1995	4.917	5.424	7.124
1996	5.203	5.717	7.977
1997	4.387	5.220	7.952
1998	5.268	5.759	8.435
1999	4.945	5.448	8.398
2000	4.597	5.258	8.592
2001	4.699	5.691	8.674
2002	4.925	5.889	8.115
2003	4.945	5.528	8.925
2004	5.120	6.354	10.061
2005	5.287	6.339	9.283
2006	5.394	6.353	9.358
2007	5.167	6.336	9.458
2008	5.556	6.858	9.659
2009	5.258	6.449	10.337
2010	5.454	6.791	9.590
2011	5.740	7.084	9.239
2012	5.870	7.388	7.740
2013	6.027*	NA	9.967

Notes: *Preliminary from NBS article published November 29, 2013. NA = data not available.

NBS = China National Bureau of Statistics; NDRC = China National Development and Reform Commission.

Source: China National Bureau of Statistics; China National Development and Reform Commission; and USDA, National Agricultural Statistics Service.

Appendix 2.

Description of China's Corn Growing Regions

Corn is grown in every province of China, but climates, topography, and socioeconomic conditions vary widely. The most important regions are the northeast and North China Plain, which have temperatures and rainfall roughly comparable to those in the U.S. Corn Belt (see appendix table 2). Additional details on specific growing regions are listed below. Much of the information was obtained from Chinese Academy of Agricultural Sciences (1999) and Meng et al. (2006).

Northeast

The Northeast includes the provinces of Heilongjiang, Jilin, Liaoning, and the eastern part of Inner Mongolia Autonomous Region. This is China's main corn-producing region; its share of national corn output rose from 37 percent to 42 percent during 2003-12. It has the richest endowment of cropland in China and is less densely populated than other regions. It is typically a cooler, semi-humid climate zone with very low temperatures during the winter months. The growing season is short with typically 165 to 205 frost-free days per year. Temperature and rainfall during the growing season are comparable to those of the U.S. Corn Belt States, but rainfall in northeast China is somewhat higher in the summer months.

Appendix table 2

Temperature and precipitation in major corn-growing regions of China and United States

	Average temperature, 1990-2012				Average precipitation, 1990-2012		
	June	July	August	September	June	July	August
	<i>Degrees fahrenheit</i>				<i>Inches</i>		
China, major corn regions:							
Heilongjiang	69	73	70	58	3.54	5.61	3.92
Jilin	71	75	73	62	3.38	4.95	4.02
Liaoning	72	77	75	66	3.52	5.93	4.70
Inner Mongolia	72	76	74	63	2.83	3.91	2.92
Shandong	78	81	79	71	3.09	6.42	5.68
Henan	79	82	80	72	3.39	6.71	4.78
Hebei	79	82	79	71	2.34	5.57	4.16
Range	69-79	73-82	70-80	58-72	2.3-3.5	3.9-6.7	2.9-5.7
U.S. Corn Belt:							
Minnesota	65	69	67	58	4.49	3.89	3.39
South Dakota	66	73	71	61	3.63	2.81	2.20
Nebraska	69	75	72	63	3.76	3.11	2.77
Iowa	70	73	71	63	5.29	4.37	4.03
Indiana	71	74	73	65	4.60	4.27	3.60
Illinois	72	75	74	66	4.52	3.88	3.44
Missouri	73	78	76	68	4.65	4.13	3.42
Range	65-73	69-78	67-76	58-68	3.6-5.3	2.8-4.4	2.2-4.0

Source: USDA, Economic Research Service compilations.

North China Plain

The North China Plain is China's leading agricultural region but it is also densely populated and industrialized. It includes provinces in and around the Yellow and Huai River basins. Main corn-producing provinces in this region include Shandong, Henan, Hebei, and Shanxi Provinces, as well as the municipalities of Beijing and Tianjin. These provinces accounted for 31 percent of China's corn output in 2012. The major corn-growing parts of northern Jiangsu and Anhui Provinces are also in the Yellow and Huai River basins, but Jiangsu and Anhui are not typically included in this region. The North China Plain supports a wide variety of crops, livestock, and aquaculture, so there is strong competition for land. The relatively warmer climate (170-255 frost-free days) allows more than 60 percent of the area to be planted in winter wheat followed by corn planted in early summer. Temperatures are higher than in northeast China and the U.S. Corn Belt, and rainfall is concentrated in the summer months. The winter wheat crop is typically irrigated during the dry winter and spring months while the corn crop benefits from relatively heavy rainfall during July-August.

Southwest

China's Southwest includes Sichuan, Yunnan, Guizhou, and Guangxi Provinces and Chongqing Municipality. Close to 90 percent of the area in this region is comprised of mountains, hills, and plateaus; plains represent only 5 percent of area. Corn is widely grown, often on small plots and on hillsides with varying practices. In 2012, the Southwest accounted for 11 percent of China's corn output. Hog production is also widespread in this region. The climate in this area is warm-to-temperate, semi-moist with abundant rainfall (31 to 47 inches). Cloudy conditions reduce availability of sunlight. This region generally has a long growing period (240 to 365 frost-free days). Most of the rainfall is concentrated between April and October, favorable for the cultivation of corn, but the region has been severely affected by drought in recent years. Pest and disease pressures are relatively complex and serious in this region.

South

South China covers a vast area including the Yangtze River delta (Jiangsu, Zhejiang, Shanghai), southern coastal provinces (Fujian, Guangdong, Hainan), and major rice-growing provinces (Jiangxi, Hubei, Hunan). The climate in this region is a subtropical to tropical moist climate, with relatively high temperatures and abundant rainfall (39 to 70 inches). The growing season in this region is long, ranging from 220-365 days per year. South China accounted for 6 percent of corn output in 2012.

Northwest

The Northwest corn-growing region of China includes Xinjiang Autonomous Region, Shaanxi, Gansu, and Ningxia. Gansu is a major region for corn seed production. The Northwest accounted for 9 percent of corn output in 2012. The climate is dry with annual precipitation totaling less than 8 inches. High-yielding corn relies on melting snow or river irrigation systems. In Northwest China, there are large differences in midday and nighttime temperatures that are beneficial for yields and the quality of production.

Appendix 3.

Intensity of Fertilizer Use

Corn production relies on intensive use of chemical fertilizer. The International Fertilizer Industry Association (IFA) estimated that corn accounted for 16.1 percent of global fertilizer use in 2010, more than any other crop (Heffer, 2013). The IFA report also estimated that China's corn consumed about 24 percent less fertilizer than U.S. corn, even though the two countries planted similar acreages. This suggests that China's fertilizer use is relatively low, and higher application might boost Chinese corn yields.

We investigated use of fertilizer in China and the United States by analyzing data from national surveys of corn producers in the two countries. Comparing average fertilizer use from these surveys indicates that Chinese producers are already applying large amounts of chemical fertilizer to their corn crops. The data are available for a number of years (annually for China, intermittently since 2001 for the United States), allowing for trends to be discerned.

NDRC's production cost survey reports Chinese corn producers' chemical fertilizer use in kilograms per mu annually. The data are based on records kept by sample farmers and were converted to kilograms per hectare.

Average fertilizer application by U.S. corn producers was obtained from USDA's Agricultural Resource Management Survey (ARMS) database.²⁶ The ARMS included detailed surveys of corn producers in 1996-2001, 2005, and 2010 (indepth surveys of corn producers are not conducted every year). ARMS reports the share of acres treated with chemical fertilizers and the amount applied to those acres. Overall fertilizer use per unit of land was calculated by multiplying volume of fertilizer per treated acre by the share of acres treated. These values were calculated separately for nitrogen, phosphorus and potassium fertilizers and summed to obtain the total chemical fertilizer use per acre. Values were converted to kilograms per hectare.

Appendix figure 1 shows average chemical fertilizer use by corn producers in China and the United States from 1998 to 2011. China values are reported for each year, and U.S. values are reported for years when an indepth corn-producer survey was conducted.

There is no clear trend in intensity of fertilizer use that explains rising corn yields, except that the highest Chinese values were recorded in the most recent 2 years—2010 and 2011 (see appendix figure 1). Chinese fertilizer use was approximately 300 or more kg per hectare in most years except 2004-05 when it fell below 300 kg/ha. U.S. fertilizer use was approximately 260 kg/ha in each year. Chinese chemical fertilizer application exceeded U.S. use per hectare by 15 to 20 percent. In 2010 Chinese fertilizer use was 28 percent higher than the U.S. rate.

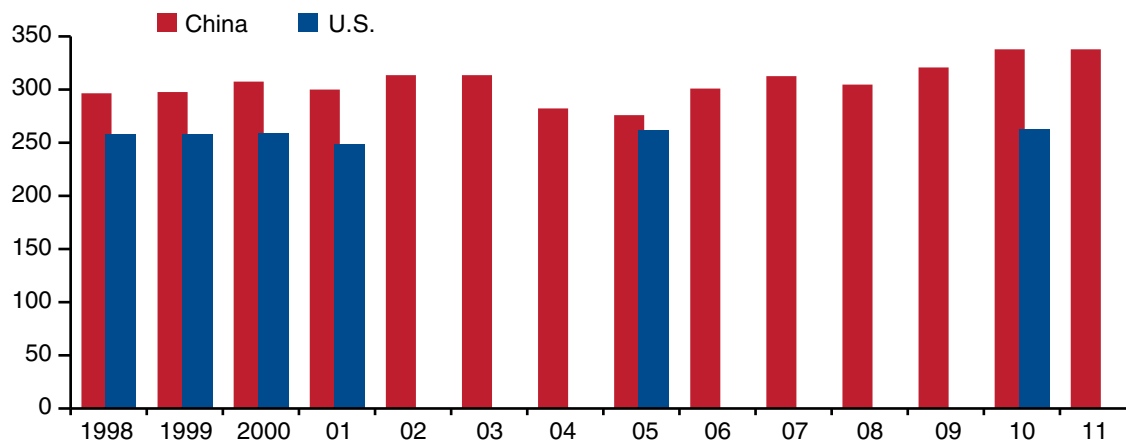
The China survey data indicate that there is no trend in fertilizer use that could explain the increase in corn yields. Moreover, fertilizer use reported by the farmers participating in the survey is already at a high level. This is consistent with China's subsidies for fertilizer—initially for fertilizer companies and through a “general input subsidy” payment to farmers initiated in 2006. Zhang and Li (2009) raised concerns about low soil fertility, but their recommendations emphasized addition of organic matter to soil, crop rotation, and more efficient use of chemical fertilizer—not higher

²⁶Data were accessed at www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices.aspx

Appendix figure 1

Average chemical fertilizer use for corn production, Chinese and U.S. farms, 1998-2011

Kilograms per hectare



Note: U.S. fertilizer use is estimated by multiplying number of acres with fertilizer applied by amount per fertilized acre.
Source: China National Development and Reform Commission and USDA, Agricultural Resource Management Survey.

applications—to improve corn output. Officials have followed these recommendations by offering new subsidies for soil tests and suppliers of organic fertilizer.