11 Agriculture: Output, Inputs, and Technology

For centuries, food availability was the gravest challenge facing China. After 1949, the return of peace, redistribution of land and repair of infrastructure banished the specter of famine for almost a decade, but after the failure of the GLF, China was again confronted with the basic question of whether or not Chinese agriculture would be able to feed China's growing population. Today that question has been definitively answered: In the last forty years, China's agriculture has displayed the resilience and increased productivity necessary to feed China, while also releasing hundreds of millions of workers to work in the cities. Grain is by far the most important product of Chinese agriculture: by this aggregate measure, production in 1956-57 (after recovery from war and revolution) was near 200 million metric tons, and today has tripled to over 600 million tons (in 2013-14), while China's population has just more than doubled. For the first time in history, food sufficiency in China is not in question. Meanwhile, an extraordinary increase in the quality and variety of the Chinese diet is plainly evident.

How did Chinese agriculture achieve this sustained growth? One simple fact that will emerge from this chapter is that the Chinese countryside has undergone a technical revolution, beginning in the 1970s. Before 1970 the technology of agricultural production was prescientific, in that it relied on traditional techniques (albeit refined through centuries of experimentation) without significant application of modern inputs. During the 1970s, new technologies and modern inputs began to flow to the Chinese countryside in significant quantities for the first time. Since that time, the technological transformation of Chinese agriculture has only accelerated, and output began to rely on massive application of modern inputs. Technological change has enabled Chinese agriculture to adapt to dramatically changing factor endowments while increasing total factor productivity at a rapid and sustained pace. Changing incentive structures caused Chinese farmers to transfer labor out of agriculture in the early 1980s when reforms were introduced (as the previous chapter showed); after this initial surge, sustained technological change facilitated an even greater transfer of labor out of agriculture (as this chapter shows).

Indeed, China's extraordinary growth would not have been possible without this successful transformation of agriculture.

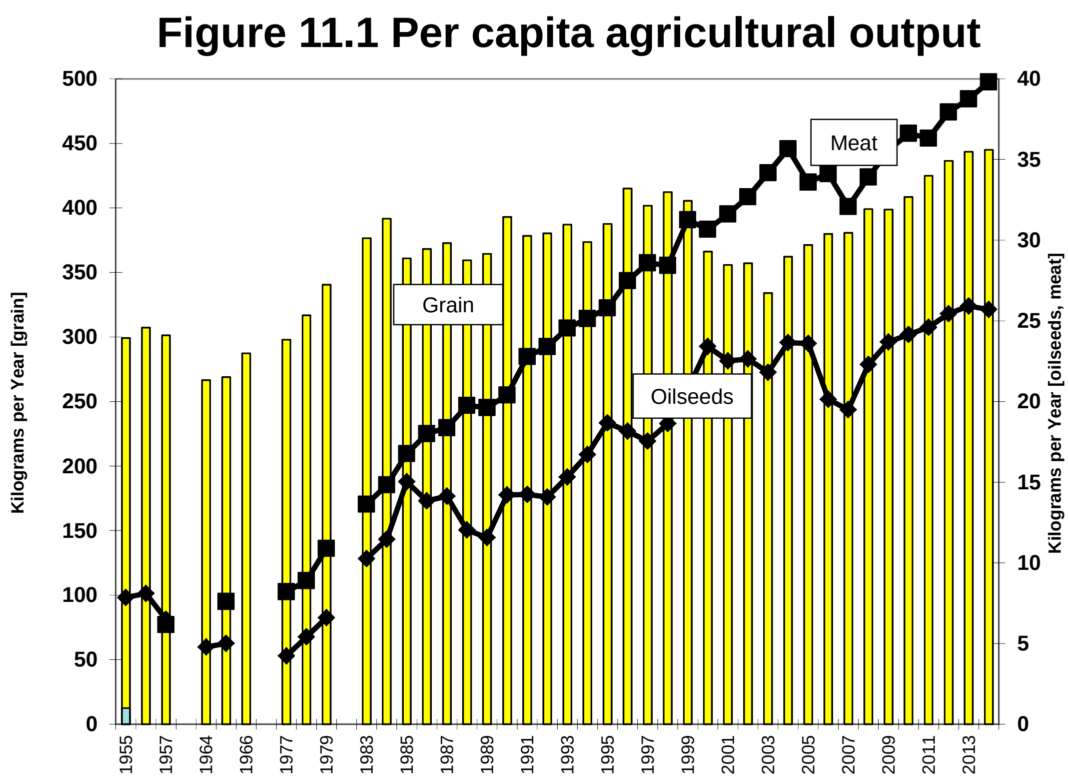
On the demand side, as incomes have risen in China, demands for improved diet have dramatically reshaped markets for food. Traditionally almost totally dependent on grain, China's consumers are today demanding a diverse diet, which puts greater and different demands on the agricultural system. The shift to higher meat consumption, in particular, causes major structural shifts in the agricultural system.

The major successes in Chinese agriculture have been achieved at the cost of an extraordinary application of modern inputs and policy support. Both these "inputs" have a high cost. Large application of pesticides and nitrogen fertilizers have significant negative impacts on China's water, already a scarce resource. The "chemicalization" of China's agriculture may not ultimately be sustainable in the long term. Policy support is also costly, especially because it is tied to an ongoing grain "self-sufficiency" policy that limits gains from international trade. For these reasons, the future of Chinese agriculture is unlikely to be one of continuing quantitative expansion. Rather, output will probably stabilize, while further structural change and adjustments in the division of labor will drive additional quality improvement.

11.1 OVERVIEW OF POST–1949 AGRICULTURE

Beginning in the 1970s a Chinese green revolution began to transform agriculture. Surprisingly, the key elements of the green revolution—improved seeds, fertilizer, and irrigation— were the same three elements on which the traditional system was based (Chapter 2). However, the green revolution elements were produced through the systematic application of scientific research and the use of industrial methods to produce improved inputs.

After 1949, the newly formed agricultural collectives, discussed in the previous chapter, were used to organize improved application of traditional agricultural inputs, particularly through rapid expansion of the area under irrigation and in the increase in the number of days farmers put into land improvement. Per capita grain production recovered—despite some disruption due to collectivization--and it was running about 300 kilograms by the 1955–1957 period (Figure 11.1). This was (barely) enough to feed the population, given the highly equitable food distribution that China had at the time. But this level was not to be sustained. The folly of the GLF pushed production per head to below subsistence levels and led to the famine described in previous chapters (not shown in Figure 11.1 due to absence of data). By the mid-1960s, recovery from the immediate GLF crisis was complete, but per capita output was still well below the 1955-57 level. Given the still very low levels of consumption of fats in the form of oilseeds and meat, this implies that millions were still on the margins of subsistence.



Over the next twenty years, China imported grain and began a long, slow, steady increase in grain production. By the late 1970s, total output had increased by 50% to 300 million tons, but China's population had also increased 50%, leaving per capita output almost unchanged from the 1950s. After rural reforms began, per capita output initially soared toward 400 kilograms in 1984. At this level, there is more than enough grain for direct human consumption, and higher per capita output is only sustained through the diversion of substantial amounts of grain to animal feed. Indeed, only well into the 21st century, as meat production steadily climbed, did total grain production sustain output over 400 kilograms per capita.

What lay behind the steady increase in production from the 1970s onward? Beginning in the 1960s, Chinese scientists began to produce green revolution technologies that were able to push agricultural production up to qualitatively higher levels. Green revolution technologies were pioneered in the West, but Chinese scientists, working independently, created parallel achievements and, in one or two areas, made independent breakthroughs that surpassed what was done in the West. A particularly striking fact is that the green revolution, while based on modern science and technology, is based on the same triad of modernized varieties, large-scale fertilizer application, and precise water control on which Chinese traditional agriculture was also founded.

During the later 1960s and 1970s, China's agriculture grew from the process of intensification of land use, that is, concentrating on increasing yields from a given amount of land. Gradually, modern science was used to accelerate the application of nutrients to the soil. New patterns of grain cropping evolved, including triple cropping and intercropping of different varieties, to facilitate this intensification. While producing an adequate increase in grain output, the agricultural policies adopted through the 1970s neglected potential gains from diversification and commercialization. Indeed, the increased output of grain was achieved in part through the Grain First agricultural policy (Chapter 10) that stressed grain to the exclusion of many other crops. This policy succeeded in maintaining growth in per capita grain output, but it resulted in harmful reductions in per capita output of a number of important non-grain crops. For example, as Figure 11.1 shows, production of oilseeds per capita was significantly lower in the 1970s than in the 1950s. Average availability was less than a tablespoon of vegetable oil per day, and oil was strictly rationed. Considering that Chinese cuisine is dependent on vegetable oil for deep-frying and stir-frying, and that a tablespoon of oil is hardly adequate for a single dish, one can see that Chinese households were limited to a monotonous and austere diet, even when there were adequate calories. Beginning in 1979 policy shifted drastically and output surged. Even more striking than the increase in grain is the remarkable increase in non-grain products, such as oilseeds and meat. Peasants were given much greater control over their own economic activity, and this resulted in very large one-time-only gains as peasants responded to better incentives, to work harder but also to meet market demands more effectively. This produced a better geographical output mix, in which products were better suited to the varieties demanded and the location of production was better suited to natural conditions.

11.2 TECHNOLOGY CHOICE AND TECHNICAL INNOVATION IN AGRICULTURE

Agriculture in China, as anywhere else, adapts to the availability of production factors, such as land and labor. Farmer use of inputs and their relative proportions in the agricultural production process are determined by relative resource scarcity and hence the relative input prices. Figure 11.2 shows the standard way that economists analyze the choice of technology in agricultural production (or any kind of production, for that matter). The horizontal axis shows the quantity of land, and the vertical axis shows the quantity of labor used in the production process. The curved line is an isoquant: At any point on the isoquant, a given output, x, can be produced with the use

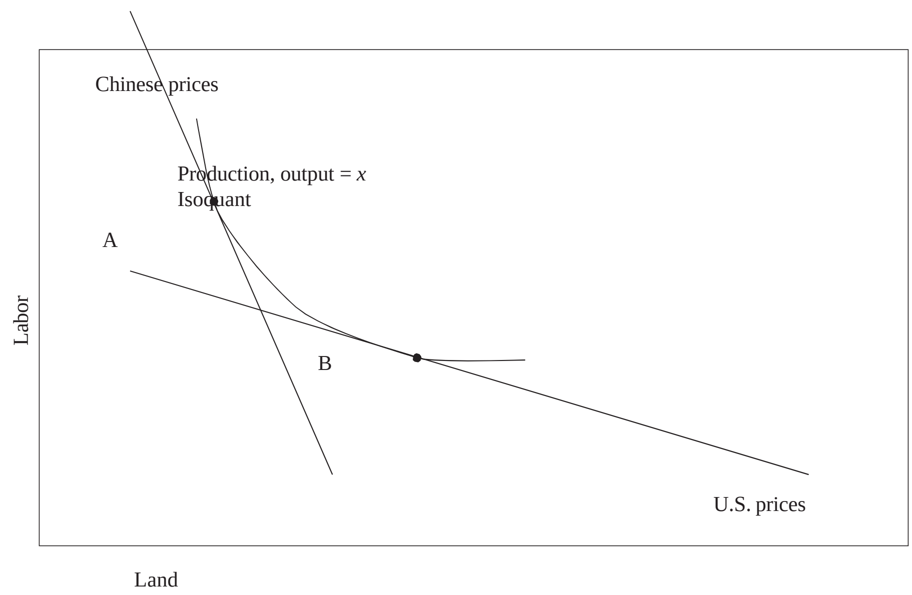


Figure 11.2

Choice of technology

of the quantities of land and labor corresponding to that point on the graph. Different points on the isoquant display varying factor (input) proportions: the isoquant shows the range of input combinations that are technologically capable of producing output x. In a land-abundant, labor-scarce economy like the United States, the shallow straight line expresses U.S. relative prices: one worker's wage equals the rental value of a large area of land. Any point on this line shows an equal cost outlay for production in the United States. Minimizing cost, a U.S. farmer will produce output x at point B. In China's labor- abundant, land-scarce economy, the much steeper straight line displays Chinese relative prices: a small plot of land has a rental value equal to one worker's wage, and any point on the steep line is an equal cost outlay for production in China. Minimizing cost, a Chinese farmer will produce output x at point A. A Chinese farmer will use a labor-intensive production process, applying large amounts of labor to a small amount of land, relative to, for example, a U.S. farmer. This much is a straightforward application of relative prices and cost minimization.

This simple analysis can be extended to the more challenging area of technological change. The "induced-innovation" hypothesis states that technical change is also derived from the demands of cost-minimizing agents to save on relatively scarce resources and to use relatively plentiful ones. Chinese farmers will especially value new technologies that allow them to economize on land—that is, to use the existing land resources more intensively. They will thus seek out and adopt new technologies that allow them to apply more of (relatively cheap) labor to their land. Hayami and Ruttan (1985) originally demonstrated this process for the cases of agricultural development in the United States and Japan over the period from 1880 to 1980. The growth paths of the two countries differ greatly. In the United States, with plentiful land and relatively scarce labor, power machinery was developed to substitute for relatively scarce labor. In Japan, with plentiful labor and relatively scarce land, a package of high-yielding seeds, fertilizer, and water control was developed to substitute for relatively scarce land. While the paths of development were different, the rates of growth and levels of output were commensurate. The different paths implied by this East Asian experience and North American experience are shown in Figure 11.3 (note that the axes are different from Figure 11.2). China, like Japan, followed a process of technical advance in agriculture in which the fundamental achievement was the improvement in yields per unit of land. We might label the two paths "tractorization" and "chemicalization" respectively.

China followed the East Asian pattern. From the 1950s through the 1980s, China moved primarily "up" (North), as output per unit of land increased, while output per agricultural laborer increased relatively little. After the 1980s, following the East Asian pattern, China turned "right" (East) as output per worker began to increase much more rapidly. Output per unit of land continued to increase, but less dramatically compared to output per worker. This was a clear response to the increased opportunity cost of labor, as farm households transferred workers to more lucrative non-agricultural work.

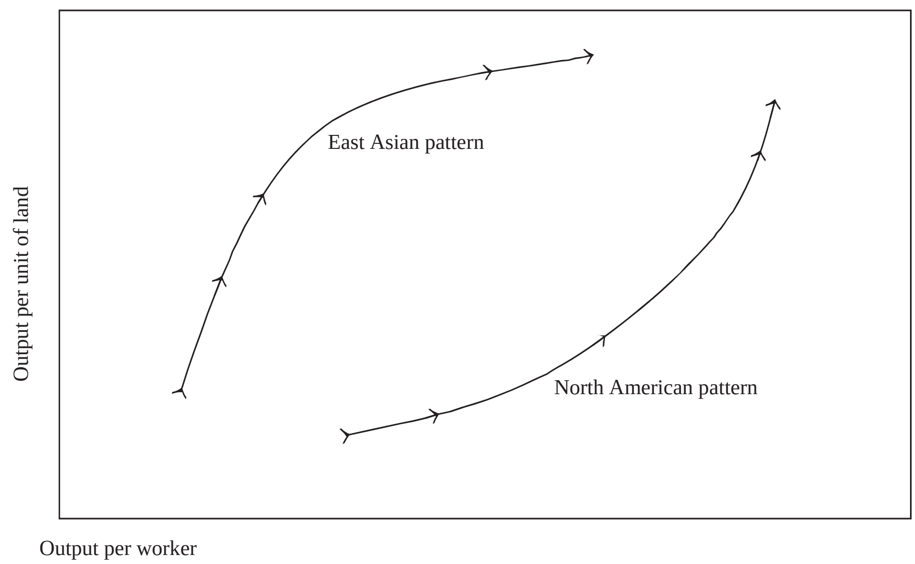


Figure 11.3

Induced-innovation paths

To be sure, agricultural production is distinctive precisely because of the way it must always be adapted to concrete conditions. Regional differences in the amount and seasonal distribution of sunlight, water and heat must always be taken into consideration by farmers, and also influences induced-innovation paths. China is traditionally divided into rice- and wheat-growing regions, and then into a larger number of sub-regions. The dividing line between the rice and wheat is about 33° north latitude, between the Yangtze and Huai rivers (see Figure 1.2).

The rice region has abundant water and a longer growing season, and it has long had significant irrigation networks. The green revolution was easily adapted to these conditions, and we use this region as a concrete example of technological change. Expanding the land available for cropping is not much of an option in China, since nearly all land that is economical to cultivate is under cultivation. Since such an extensive form of development is not possible, intensification of land use is necessary. This has often required land improvement, which may entail land leveling such as terracing, where small flat plots are carved into hilly or mountainous topography. Sowing cultivated land more than once each year, or multi-cropping, grew significantly after the 1950s, with substantial regional variation. In Zhejiang Province the multi-cropping index was above two, indicating that, on average, farmland in that province was sown more than twice in a given year. Multiple cropping includes rotation, intercropping, and relay cropping. Crop rotation is the sequential planting of crops one after another. It entails sowing, cultivating, and harvesting one crop followed by another crop. Rotation patterns are diverse and can be quite complicated, ranging up to intensive three- to seven-year patterns of crop succession. When compared to monoculture (growing the same crop repeatedly in succession), such great diversity in the crops grown has positive effects on soil fertility and disease prevention, in addition to increased output in the short run. Intercropping is the cultivation of two crops at the same time in the same field in alternating rows. There may be physical advantages to such a practice, such as one tall crop requiring direct sunlight shading a shorter, more shade-tolerant crop. Growing conditions for one are improved while conditions for the other remain unchanged. Relay cropping is intermediate between rotation and inter-cropping. One crop is planted, and before it is harvested another is planted in the same field. This technique gives the second crop a head start on growth with no appreciable effects on the first crop. These techniques increase output per unit of land, but at the cost of a tremendous concentrated application of labor. During the busy season, when one crop was being transplanted while another was harvested, every able body in the village might be working in the fields.

Later, farmers in these relatively rich and highly commercialized areas were the first to have abundant off-farm employment opportunities. The opportunity cost of farm labor increased dramatically. Multi-cropping declined substantially, but increased application of chemical fertilizer and pesticides kept per-area yields high and rising. Particularly in a relatively rich province such as Zhejiang, output per worker increased dramatically. Technological change facilitated this shift.

11.3 THE GREEN REVOLUTION

"Green revolution" technology updates and improves the traditional input package of seeds, fertilizer, and water. It allows great intensification of agricultural production. High-quality water control and delivery, manufactured agricultural chemicals, especially fertilizers, and water- and fertilizer- responsive varieties of seeds are the components of the system. China has invested much money, human capital, and time in developing appropriate systems of high-yielding modern varieties adapted to specific local conditions. A crucial feature of the green revolution technologies is that they form a complementary package of techniques: the productivity of each specific technology is significantly enhanced by the presence of the other technologies. There is thus a triad of green revolution techniques that must be implemented together in order to achieve maximum efficiency. A simple way to display this complementarity is to look at the output response of different crop varieties to fertilizer application. Figure 11.4 shows that traditional crop varieties increase yields, up to a point, with application of chemical fertilizers. Green revolution crops—so-called high-yield varieties, or HYVs—are superior not so much because they produce more in the absence of fertilizer, but rather because HYVs make it possible to continue to apply fertilizer and continue to get a significant positive output response with much larger total fertilizer application.

11.3.1 Irrigation

The first part of the green revolution triad to be developed in China was quality irrigation and drainage throughout the country. Starting in the early 1950s, irrigation projects were built and technical capacity increased. Figure 11.5 shows the development of irrigated area. Construction of irrigation projects was carried out by labor from the collective farms, mobilized during the winter slack season. Irrigated area grew rapidly, as shown in Figure 11.5, through the collective period until the late 1970s. During the 1980s irrigated area stagnated, and even declined slightly. This pause was related to the decline

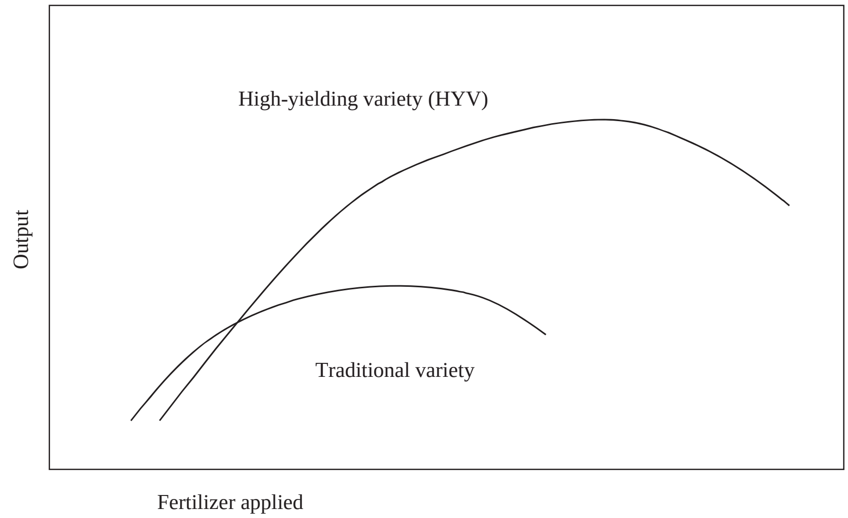
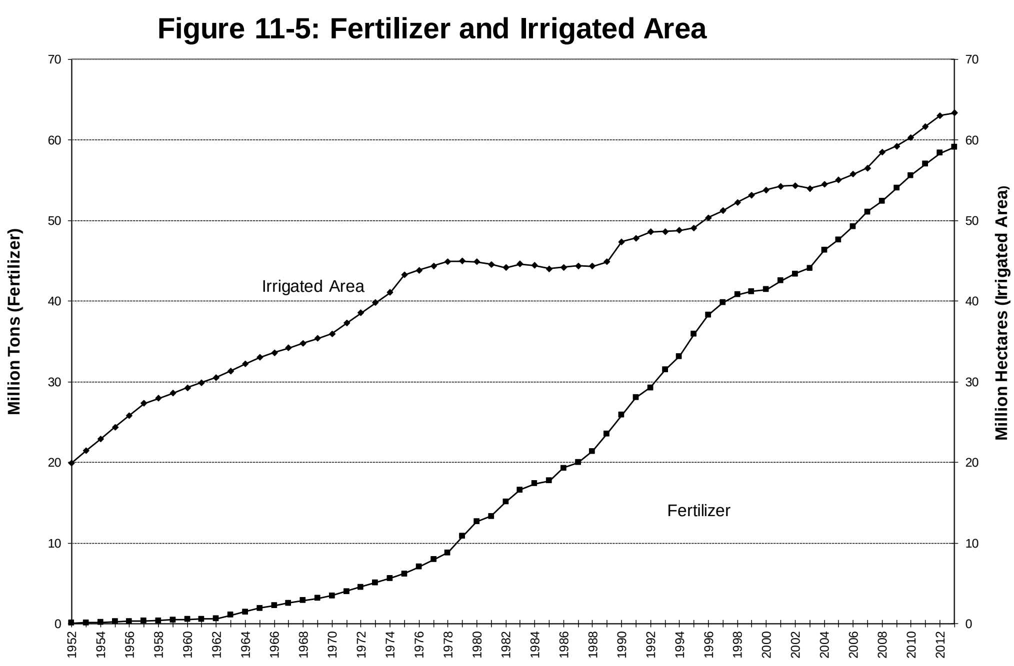


Figure 11.4

The green revolution: fertilizer responsiveness

Figure 11.5

Fertilizer and irrigated area



in public-good provision that marked the dissolution of the collectives. It was not until new organizational forms were worked out for irrigation districts in the 1990s that growth of irrigated area resumed. By 2013, total irrigated area had grown 40% from the mid-1990s.

Power machinery has been introduced to improve the efficiency of water control. In the 1950s water was lifted by human power or animal traction. Today two-thirds of the irrigated area is serviced by machine pumping, facilitating the more precise water control necessary to support production of HYVs. Tens of millions of electric and diesel pumps now drive China's irrigation systems. This had an enormous impact in allowing the Green Revolution to be extended to China's wheat region, and especially the North China Plain. As Chapter 1 recounted, the whole Yellow River area is chronically short of water, with much competition between urban, industrial, and agricultural water users. Lack of water has been a key constraint to expanding production in this area with rich soil and abundant sun. Nevertheless, irrigation networks were rare until very recently, so farmers were dependent on seasonal rainfall. The innovations of the green revolution could not be applied to the wheat region until substantial infrastructure construction and technology adaptation had taken place. Moreover, many areas of the North China Plain have a high saline (salty) water supply; as a result, salt builds up on otherwise productive land when surface water evaporates (salinization). Many aquifers underlie the North China Plain, but this rich water resource was unavailable to Chinese farmers until they had pumps. During the 1970s a submersible pump was developed that could bring up fresh water from 30 meters below the surface, and since then literally millions of pumps have been installed, permitting intense exploitation of aquifers and rapid expansion of wheat production. Today, however, overexploitation of aquifers is leading to a water crisis and may eventually lead to the curtailment of wheat production on the North China Plain (Chapter 20).

11.3.2 Fertilizer and Agricultural Chemicals

The second leg of the green revolution tripod is agricultural chemicals, including chemical fertilizer and pesticides. In the traditional agricultural input system used in China, large amounts of organic fertilizer, up to six tons per hectare, were used. Organic fertilizer provides sufficient nutrients for traditional varieties, but it is very labor intensive to use, is unpleasant to handle, and does not give the boost in yield that modern HYVs require. Initially meant to augment the labor-intensive organic fertilizers, chemical fertilizer production at first developed slowly (see Figure 11.5). In the 1960s and the early 1970s small-scale local factories produced nitrogen fertilizers of low quality. In 1973–1974 the central government made a huge commitment to the development of a modern domestic nitrogen fertilizer industry by importing 13 large synthetic ammonia and urea factories, which eventually served as the foundation for a large domestic fertilizer industry. As Figure 11.5 shows, fertilizer supply really took off between 1978 and 1996, during which time supplies quadrupled from an already substantial base. During the mid–1970s there was certainly latent, unsatisfied demand for fertilizer, and the reforms that followed gave farmers new stronger incentives. Fertilizer has been a key part of the emerging modern triad.

Domestic capacity alone has been insufficient to meet the demand, so China has imported fertilizer for the past 40 years (about 20% of total supply in recent years), preferring to import fertilizer, augmenting domestic food output, rather than importing food. After the turn of the century, inputs of traditional organic fertilizer have begun to fall off rapidly (Liu, Huang and Zikhali 2014). This is unfortunate since organic fertilizer, for all its drawbacks, contributes to maintaining long-term soil fertility and structure. Moreover, the end of the traditional system of recycling human wastes simply means that another pollutant must be disposed of properly.

11.3.3 Seeds

The third leg of the green revolution tripod is improved seeds. Improvement and molding of the genetic characteristics of germplasm requires investment in research capacity. The outcomes of that investment are demonstrated in the higher yields of improved crops made more responsive to high fertilizer applications and timely irrigation. Research capacity in agriculture has been developed strongly but unevenly since 1949 (Pardey, Roseboom, and Anderson 1991, 226–234). Even before 1949 the Republic of China, during the Nanjing decade, launched an initial research and development effort. During the 1950s the People's Republic founded a multilevel research system with the Chinese Academy of Agricultural Sciences (CAAS) at the apex. Along with provincial-level academies and an agricultural extension service in every county, China built a seed production and distribution system that is today the largest in the world. The disruption of the GLF and Cultural Revolution caused great problems for agricultural researchers. But even in the middle of the Cultural Revolution, there was some progress, as agricultural technology, research, and extension organizations were created at the county, commune, and brigade levels (see Table 10.1). The focus was put on adaptation of cultivars to local conditions and dissemination of new varieties. Little attention was paid to basic agricultural science, but practical and adaptive work advanced. After 1979 research institutes were reconstituted, and basic research was begun again. Provincial-level and lower-level institutes focus research more on local conditions, and the overall system is unusually decentralized compared to other countries.

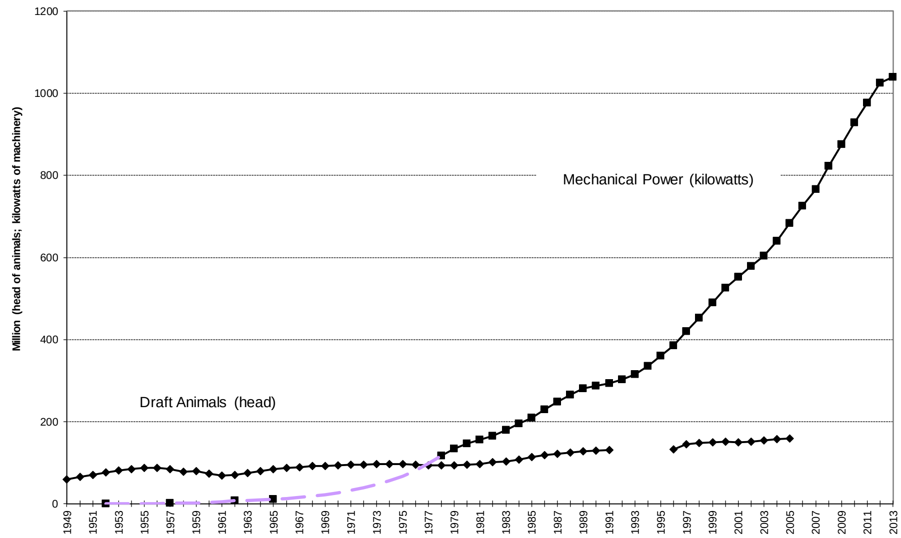
This national agricultural research system produces and disseminates the technologies that make the green revolution possible. The most important among the outputs is improved seeds for HYVs. Plant-breeding programs include components of conventional plant breeding like selection and hybridization as well as a gradual move into advanced genetic engineering techniques. During the 1950s the stock of plant material was augmented by seeds imported from abroad, including wheat, cotton, and maize and new material from domestic sources. Chinese scientists developed the first true high-yielding dwarf variety of rice in 1964. This was two years before the International Rice Research Institute in the Philippines released its own revolu- tionary high-yielding dwarf, IR-8, an event that is frequently taken as the beginning of the global green revolution. Dwarf varieties were a critical break- through in the green revolution. Dwarf varieties can absorb enormous amounts of nutrients from fertilizer, since they channel more of the plant's energy into the grain and less to the (short and stubby) stalk. This develop- ment solved the problem of lodging—plants toppling over because of weak, spindly stalks—that had bedeviled early research efforts. Following their own breakthroughs, Chinese scientists established contact with the international agricultural research system during the 1960s that led to the exchange of germplasm with the collections at the various international crop institutes. These helped Chinese scientists advance during the travails of the Cultural Revolution.

Another successful experience was the introduction and extension of hybrid varieties of various crops. Hybrid maize was introduced in 1961, and by 1990 about 90% of sown area was sown with the hybrid variety. Hybrid rice was introduced in 1976, and by 1990 it was sown to more than 40% of rice-sown area. Hybrid varieties produce an increased yield, but their output cannot be used as seed for the next generation of crop. China was able to disseminate hybrid varieties largely because the agricultural extension service was quite reliable in supplying new generations of seed to farmers. Here is an example of institutional infrastructure created during the socialist period—indeed, strengthened during the Cultural Revolution—that contributed to rapid tech- nological change and robust output growth later during the market reforms. The green revolution technologies are complements: However, in China, it was not until the 1980s that all three legs of the tripod were available to stand on. There were, therefore, latent technological gains that could only be realized when all three elements were present simultaneously. In fact, the completion of this technological revolution took place at almost exactly the same time as the institutional revolution led by rural reforms. Some observers argue that technological change was the most important cause of increased agricultural productivity improvement in the early 1980s. They stress the complementarity of fertilizer, the last leg of the green revolution triad to arrive (Stone 1990), and the adoption of improved seed varieties, especially hybrid rice (Huang and Rozelle 1996). This view contrasts with the mainstream interpretation, which holds that the incentive properties of rural reforms deserve most of the credit for productivity increase (McMillan, Whalley, and Zhu 1989; Lin 1992). In either case, we should recognize the crucial role of both incentives and technological change, and also how recent the technological revolution in China's countryside has been.

The development of improved seed varieties is likely to continue to be rapid. China is making a major research and development effort in biotechnology, especially in genetic modification. Moreover, Chinese genetically modified organisms (GMOs) have moved rapidly into the field and produced some substantial successes. Perhaps the most dramatic is the development of genetically modified Bt Cotton, which has an inserted gene that makes the plant less susceptible to insect pests. Cotton is an extremely important crop that receives an especially heavy dose of pesticides. Insect pests have developed resistance to many pesticides, with the result that Chinese cotton farmers in the late 1990s were applying a toxic cocktail of several kinds of pesticides (even including illegal DDT) to their fields. Bt Cotton was developed by the CAAS in the mid–1990s and released in 1997. It enables an almost two- thirds reduction in the amount of pesticides applied to cotton. Bt Cotton has revitalized the North China cotton crop, which had been reeling during the early 1990s (Pray et al. 2002; Huang et al. 2003). China's broad effort in biotechnology that will likely see important applications in other crops, none more important than rice. Chinese researchers are especially strong in building insect and disease resistance into crops. In the case of rice, though, we will also see strains with added vitamins and protein emerging from the pipeline soon. A new wave of technological change will reshape Chinese agriculture.

11.4 MOTIVE POWER IN THE COUNTRYSIDE

Figure 11.6 Rural Motive Power



In the traditional cultivation system animal traction and human muscle were the sources of power. Figure 11.6 shows the evolution of motive power in the countryside. Until the early 1970s mechanical power was relatively insignificant. Human labor was augmented primarily by beasts of burden, with draft animals pulling the plow and doing the heavy hauling. Draft animals—oxen, horses, mules, and camels—were attractive in the 1950s because animals not only provided power cultivation, but also provided organic fertilizers, could be used for transportation, and provided some food security. The recovery of the rural economy in the first half of the 1950s is reflected in the substantial increase in the number of draft animals. However, the peak year was 1955, and after collectivization the number of draft animals first stagnated and then, after the GLF, plunged. Clearly, peasant households were not enthusiastic about seeing the collectives take control of their household animals. There was not a catastrophic collapse in the number of draft animals, as there had been in the Soviet Union, but the 21% decline in total draft animals between the 1955 peak and the 1961 trough dealt a heavy blow to farm productivity. The stock of draft animals recovered through the early 1970s, only to stagnate again in the period just before rural reforms kicked in at the end of the 1970s.

Mechanical power began to be significant in the countryside in the 1970s. (Note that in Figure 11.6 the scales for draft animals and mechanical power are roughly comparable. A kilowatt of mechanical power capacity is equiva- lent to 0.736 horsepower. Thus the relative position of the two lines roughly reflects the aggregate importance of animal and mechanical power in the countryside: Total machine power surpassed animal power only in the late 1970s.) Labor-augmenting technology, particularly mechanization, is a traditional feature of the “Big Push” industrialization strategy that China initially borrowed from the Soviet Union. As our preceding discussion of induced innovation indicated, it was not likely to be appropriate in China, given Chinese factor endowments. Despite this obvious mismatch, Chinese agricultural planners under socialism invested large sums of capital in developing agricultural machines such as large tractors that were poorly suited to China’s conditions. Farmers resisted adopting them, of course, using big tractors as miniature trucks to haul bricks and fertilizer around the countryside. However, some farm machinery, such as the small electric pumps discussed earlier, made crucial contributions to the modern input package, permitting a rapid extension of irrigation through drilling of wells and expansion of irrigation networks over complex terrain.

Machine power in agriculture developed slowly, first in irrigation and then in cultivation. After reforms peasant households shifted away from large tractors toward trucks (for hauling) and small tractors for tilling. The number of small-scale tractors grew dramatically. Starting at 1.4 million in 1978, the number grew to 17 million in 2008, before stabilizing (SYC 2014, 371). These small tractors are maneuverable, affordable, and more suited to the scale of production in Chinese agriculture. Only as land began to consolidate into larger firms did large tractors become more popular, the numbers reacing 5 million in 2013. The Chinese countryside has been recently transformed by the widespread application of mechanical power to the rural economy.

11.5 OUTPUT AND YIELDS: THE CHALLENGE OF INTENSIFICATION

By the end of the 1990s, then, Chinese agriculture had successfully united modern science-based inputs with a steady intensification of the agricultural production process. Moreover, this was achieved with a substantial reduction in agricultural labor inputs. Cao and Birchenall (2013) argue that when labor inputs are properly measured, total factor productivity in Chinese agriculture has grown at the rate of 6.5% annually between 1991 and 2009, a truly remarkable record.

Total grain yields have tripled in the 50 years since 1952. Grain still makes up about two-thirds of the sown area. Rice is the most important crop for human consumption, but output of corn (maize) surpassed that of rice in 2012 for the first time in history, because of its importance as animal feed. The most important nonfood crop by far is cotton, which accounts for 3%–4% of sown area.

Table 11.1 shows that by the end of the twentieth century China had achieved yields in rice and wheat that were well above world averages and, in the case of wheat, above U.S. yields. These results were achieved by employing almost four times as many workers per hectare as the world average, and 150 times as many workers per hectare in the United States. A high proportion of total land is irrigated, but Chinese farmers use few tractors. Most striking is the fact that Chinese fertilizer consumption per hectare is almost three times world averages and more than twice that of the United States. Figures for pesticides, if conveniently available, would certainly show that China applies more than world or U.S. averages.

Table 11.1

Comparison of yields and inputs per hectare of cropland, 1997

	Unit	China	World	United States
Production per hectare Rice, paddy	Tons	6.2	3.9	7.0
Wheat	Tons	3.7	2.7	2.8
Corn	Tons	4.6	4.3	8.6
Soybeans	Tons	1.7	2.2	2.6
Fertilizer consumption per hectare	Kilog	271	94	111
Farm workers per 100 hectares	Num	310	82	2
Land irrigated	Perce	40	18	13
Tractors per 1,000 hectares	Num ber	6	18	27

11.6 DIVERSIFICATION AND STRUCTURAL CHANGE

The development of Chinese agriculture is now being driven by the imperative of dietary improvement. The traditional Chinese diet was dominated by grain consumption. As late as 1981, 94% of the calories in the average Chinese diet came from plant products (87% from grain). Even more surprising, 90% of *protein* came from plant products (83% from grain) and only 10% from all animal products. Recently demand pressures have been concentrated on food products with high-income elasticities in the middle-income range relevant to today's China: these include meat, fresh fruit and vegetables, poultry, and eggs. A dietary transition shifts consumption from carbohydrates to higher levels of protein, fat, and sugar. This transition happens in virtually all countries as they move to middle- and upper-income status. Not coincidentally, problems with obesity begin to become serious at the time of this transition, and this is the case in China as well.

Dietary improvement places new demands on the agricultural system. It does not necessarily reduce the pressure on grain production, because, ironically, increased consumption of meat usually requires still higher levels of grain production. The reason is that meat production is a relatively inefficient way of conveying calories to the human consumer. Animals convert vegetable calories into a more highly valued food, but through a relatively "expensive" conversion process. In general, China's grain production has continued to increase, but different varieties of grain have been grown, and most of the increment is being converted into meat. Maize production has surpassed rice for this reason. A new animal-feed industry is developing that mixes grain with oilseed meal (especially from soybeans) and vitamin and protein supplements. New systems of feedlots, slaughterhouses, and marketing networks also develop alongside new feeding systems. A more sophisticated transport and storage system has developed as well: A crucial link is cold-chain facilities for warehousing and transporting high-value frozen and perishable foods, which is undergoing rapid development (Twilley 2014). Today, almost all Chinese urban households, and even most rural households, have refrigerators. They spend an increasing share of their food money at supermarkets, and buy more prepared food, including frozen food. This creates new food processing industries, while also putting new demands on the traditional agricultural sector.

Alongside these developments, China's traditional household-based "bottom-heavy" economy continues to show remarkable vitality and staying power. Every Chinese city has numerous farmers' markets where diverse fresh produce and meat—none of it remotely frozen or refrigerated—is abundantly available. By far the largest source of animal protein in China is pig farming, and China raises more than half of the world's pigs. But remarkably, most of those pigs are still raised by traditional household producers, raising several pigs in the barnyard. These producers can compete because they feed their pigs largely on farmyard by-products and waste, as well as green roughage, including leaves and stalks, tubers, and pumpkins. Improved feed grain only supplements the feed requirements of these farms. This remarkably efficient small-scale economy runs by recycling everything the farmstead produces (Iowa State 1998).

11.7 GLOBALIZATION AND FOOD SELF-SUFFICIENCY

China's entry into the WTO was expected to have a major impact on agricultural development, because membership in the WTO imposes limits on how much China can protect its agriculture. In that sense, globalization put limits on China's policy options in the rural sector. Yet what is most striking is that in the last decade China has not emerged as a large net food importer. Instead, it has steadily altered policy in the direction of supporting agriculture. Beginning in 2004 a new round of subsidies and tax reductions promised to put the national government in the position of providing net support for agriculture for the first time since 1949 (See Chapter 10). Remarkably, these pro-agriculture policies were drawn up with the challenge of WTO membership in mind, and specifically crafted to be compliant with WTO regulations. For example, subsidies to grain farmers are given based on their acreage (acceptable subsidy) rather than based on their output (forbidden subsidy). In spite of these careful provisions, China is quite close to the aggregate limit on all kinds of agricultural subsidies it accepted as part of its WTO accession protocol.

In fact, the Chinese government continues to carry out a grain self-sufficiency policy. The one important modification of this policy is that in recent years, it has been narrowed to specifically apply to food grains, i.e., to grain directly consumed by humans as a dietary staple. This interpretation has allowed China to emerge as the world's largest importer of soybeans, which are used primarily in animal feed. As Table 11.2 shows, China still maintains self-sufficiency above 98% in each of the three key food grains, rice, corn, and wheat, but 85% of soybeans are imported. This is notwithstanding the fact that most corn is actually used as animal feed; but in the case of corn China has expanded production rapidly is probably close to producing at competitive world prices.

Table 11.2 Grain Production, Imports and Exports

China's grain production and trade figures for 2014 (kilotons)						
	Production	Imports	Exports	Net imports	Total supply	Self-sufficiency
Rice	177,958	3,920	510	3,410	181,386	**98.1%**
Corn	218,489	3,100	8	3,902	221,581	**98.6%**
Wheat	112,522	1,900	15	185	114,407	**98.4%**
3 Key Grains	508,969	8,920	533	8,387	517,356	**98.4%**
Soybeans	13,850	75,000	180	74,820	88,670	**15.6%**
3KG + Soy	522,819	83,920	713	83,207	606,026	**86.3%**
Source: National Bureau of Statistics & Customs Administration; original table by Yu Xiaohua for Caixin.com						

Self-sufficiency policies for grain imply that domestic grain prices are substantially above world prices. More positive government policies have been met with a strong output response from Chinese agriculture. Domestic grain output has grown rapidly and total net grain imports have been modest. Considering its limited land endowment, China imports surprisingly little food directly. Instead, China imports an enormous amount of agricultural raw materials that feed its manufacturing sector (paper pulp, cotton, rubber and lumber) as well as feed products for animals (soybeans in particular). Moreover, fertilizer imports are large. When the balance of trade is expanded in this way, China depends on the world market for a very substantial quantity of land-replacing commodities.

China has rapidly expanded its exports of labor-intensive agricultural products. Aquatic products are by far the largest export ($18 billion in 2012), followed by vegetables, flowers, and tea. Clearly, international trade is highly advantageous to the Chinese economy as it makes use of the differential between its own factor endowments and those of developed countries, even within the agricultural sector. Were China to enter international grain markets to the extent that, say, Japan and Taiwan have, considerable adjustment would be necessary, and probably some dramatic price increases. However, farmers in most of the world—and certainly in the US—would welcome such a shift in policy. People used to worry that China's need for food might put a heavy, even insupportable, burden on world grain markets (Brown 1995). This worry has receded significantly in the past several years. However, the question remains open: to what extent will China's policies adapt further to the opportunities of globalization, in particular through accepting greater dependence on world markets for grain? Deep integration in the world economy in that sense would open up new sources of productivity growth and benefit for economies around the world.

11.8 CONCLUSION: TOWARD SUSTAINABLE AGRICULTURE

Chinese agriculture has achieved remarkable success in the past forty years, enabling the dramatic growth and transformation of the Chinese economy as a whole. At the same time, it is legitimate to raise questions about the sustainability of China's current agricultural practice. China has paid a substantial price for the performance it has elicited from its agricultural sector.

In the first place, environmental sustainability is by no means guaranteed. It is not clear that intensification of agriculture in China can be pursued much further than it already has been. The Chinese and nearby coastal environment is overburdened by the excessive amounts of nutrients from chemical fertilizer in the water. Agricultural chemicals have left residues of heavy metals that are known to be harmful to human health, although the scale of the problem is not entirely clear. Toxic pesticides are hurting bird and animal life. The depletion of aquifers in the North China plain was mentioned earlier. Groundwater and surface water sources are both showing signs of severe over-exploitation. Groundwater levels in some places in Hebei Province are falling more than 1 meter per year (Lohmar et al 2003).

Second, China's food grain self-sufficiency policy imposes significant costs on the Chinese economy. The direct financial cost of subsidies is probably bearable; more problematic is the network of tariffs and non-tariff barriers with hidden costs that diverts demand in different directions. Support for farmers was highly positive during the period of maximum structural transformation and maximum inequality between urban and rural. However, as China's economy grows richer and more sophisticated, and as the share of the labor force in agriculture continues to shrink, there will come a time when it is economically more effective to dial down the pro-production impact of current policies. Indeed, policy-makers currently envisage a transition to slower growth of grain output, such that 2020 output is roughly equal to 2014 output (a relatively good year in terms of weather). A transition to a more sustainable agriculture with slower growing grain output would not preclude continued growth in higher value products and continued increases in rural incomes.

Finally, China's agricultural labor force is changing rapidly. It is shrinking and, perhaps more importantly, aging. The median age of a farm worker (as measured by the 2nd Agriculture Census in 2006) was 42 years, and increasing rapidly. The possibilities and challenges of China's agriculture are both changing rapidly. What is certain is that agriculture has the capacity to adapt and continue to grow, contributing to China's rich and sophisticated food culture.

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Suggestions for Further Reading

Nyberg and Rozelle (1999) and USDA (2002) are both good overviews of the rural economy, touching on virtually the entire range of issues. Lin (1992) is a classic article that is an eminently clear and effective argument based on estimation of the agricultural production function.

Sources for Data and Figures

Figure 11.1: SYC 1991, 357; 1996, 378; 2005, 462–69. Meat production is carcass weight, total pro- duction of pork, mutton, and beef. Official meat production data are adjusted downward in accord with the procedures in Ma, Huang, and Rozelle (2004).

Figure 11.3: Derived from Hayami and Ruttan (1985).

Figure 11.5: *SYC* (1991, 323, 331, 356; 2005, 451).

Figure 11.6: *SYC* (1991, 323, 331, 356; 2005, 449, 467).

Table 11.1: Gale (2002, 8).

Table 11.2: Lockett (2015).

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