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Evolution and Diffusion of Agricultural Technology in China

Bruce Stone

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

1776 Massachusetts Avenue, N.W.
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CHAPTER 3

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Bruce Stone
Project Director for Chinese Research, International Food Policy Research Institute, Washington, D.C.

The diffusion of technological innovation in agriculture involves transfers across national boundaries, among regions within countries, and among subgroups and population strata. For the process to reach all farmers and potential beneficiaries of farming technology, diffusion along each of these paths is necessary. Focusing on the People's Republic of China, this paper examines progress in diffusing the most critical elements of staple foodcrop technology.

Innovation affecting agriculture is not limited to agricultural techniques but also includes improvements in organization to facilitate their use, extending the range of beneficiaries, and ensuring the sustainability and stability of the entire process. The paper reviews fundamental changes during the 1980s in China's economic organization and the interactive effects on technological change in the staple foodcrop sector. New agricultural technology involves an array of innovations, and discussion, therefore, has to focus on critical subcategories. The definition of what is critical depends upon national objectives, factor proportions, and the stage of development within a particular country. For China, identification is rendered more complex by its size and geographic diversity.

The first section of the paper places the elements of innovation in a theoretical framework. The second section focuses on China's progress

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overall in diffusing the most fundamental technical components for the first stage of agricultural transformation and food consumption development. The third section tracks during the last decade the diffusion process for these components within China's 29 provinces and major municipal areas, and then within China's poorest and most remote counties.

The fourth section reviews economic system reform in China and its implications for the diffusion process. The fifth section identifies several areas of applied scientific research related to agriculture, state-of-the-art farmer practices for which China is a principal source of innovation, and discusses the primary mechanisms of diffusion. The final section summarizes the main arguments.

Two Stages of Food Consumption Development and Technological Transformation of Agriculture

The key elements of an agriculturally based strategy of economic development were identified between the mid-1950s and the mid-1970s.[1] Among the elements associated with agricultural development in developing countries in Asia, only three have been indispensable to rapid and prolonged growth in yields at the initial stage: improved water control; abundant supplies of fertilizer; and high-yielding seed varieties responsive to these inputs.[2] The introduction of one or more of these normally provides some growth in average yields, yet much greater returns accrue when all three are applied appropriately. These are the fundamental ingredients of the "Green Revolution," which have provided rapid growth in cereal yields throughout most of Asia and elsewhere in the developing world.

The principal criteria for judging technical change at the initial stage of modern agricultural development in a large but land-scarce peasant economy include yield growth of principal staple foodcrops, and various indicators relating to the three fundamental inputs. The latter includes growth in irrigated area, multiple cropping, capacity of irrigation and drainage machinery in use, fertilizer use, and area sown with high-yielding and early-maturing staple crop varieties.

Should yield growth greatly exceed the growth in these input indicators, it might be concluded that factors other than technical change were at work. Should yield growth fall short of what might be expected from the pace of technical progress, the quality of the inputs, the efficiency or allocative coordination of their use, the strength of the back-up systems, and other factors may be examined to explain the deficiency. Finally, the adequacy of the pace of technical progress and yields in terms of China's development strategy may be evaluated by examining the growth of

production per capita nationally, and for greater detail, the growth in rural-to-urban marketing per urban resident, and in production per agricultural laborer.

It may be argued that China during the last decade or so has entered a second stage of agricultural development, which may be defined in a number of ways. One may focus, for example, on the levels of per capita supply of basic staple crops. In Asian agricultural economies, when aggregate staple crop production per capita reaches around 300 kilograms per capita per year, emphasis on improvements in quality and diversity of diet increasingly displaces concentration on elevating calorie intake by the most readily available means.[3]

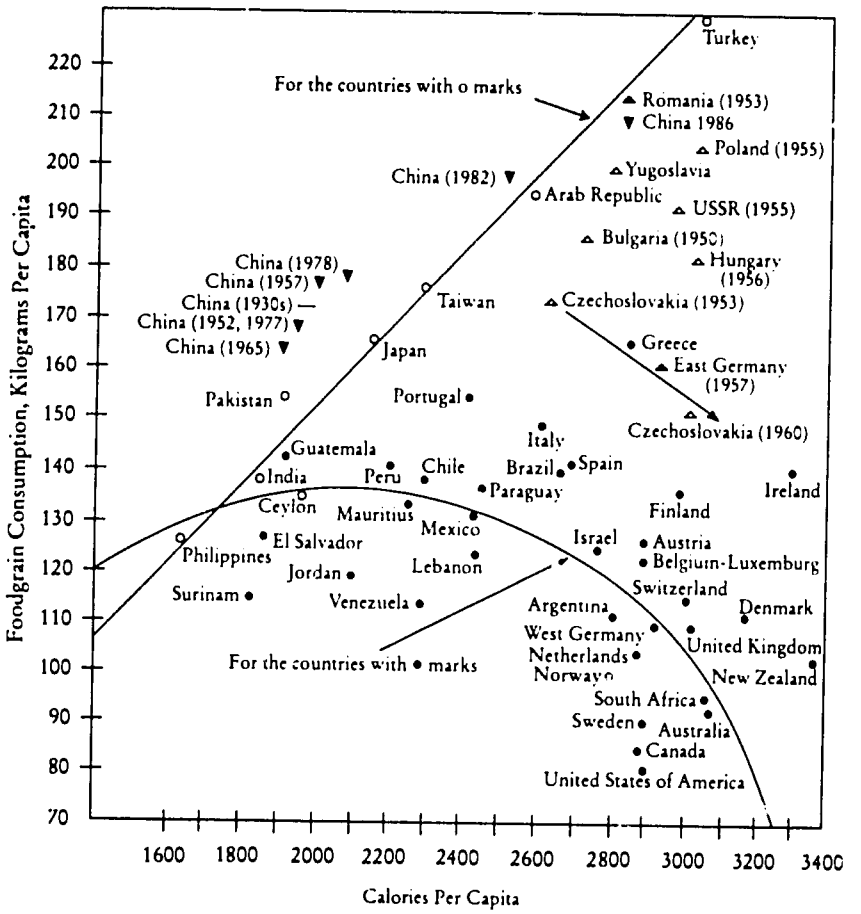
Agricultural requirements of the second stage of food consumption development in a poor land-scarce economy include: rapidly rising yields of a wide variety of nonstaple crops and a rapid increase in the production of livestock products. Although direct consumption of staple foodcrops will not increase as fast as income in the second stage, and will eventually decline, the need for continued rapid growth in staple crop yields is greater than ever. Several conditions characterize this stage: 1) supplying calories via livestock products requires much greater quantities of feedgrains than the foodgrains displaced; 2) adequate supplies are required to cover population growth and increases in consumption levels among the poor, which depends on continued rapid growth in aggregate production; 3) a larger proportion of farmland will have to be allocated to nonstaple crops; and 4) acceleration in nonfarm employment associated with the second stage normally will be accompanied by a reduction in cultivated area and/or multiple cropping, particularly on lands near cities and towns; in a peasant economy, this involves high-quality land. As Figure 3-1 indicates, Asian countries, in particular socialist countries, tend to increase direct staple crop consumption even after high-average levels have been reached.

Figure 3-2 summarizes the two stages of food consumption and technical transformation. It indicates there has to be increasing emphasis on other criteria, particularly when the second stage of food consumption development coincides with a second stage of technical transformation. Entry into the latter may be defined as the point at which increases in efficiency and quality of the three critical inputs become more important, more feasible, or more cost effective than continued growth in their gross supply.[4]

This is the context in which technological progress for Chinese agriculture in the 1980s and 1990s must be viewed. This paper, however, concentrates on the first-stage indicators that are so important in the effort to increase the consumption of basic staple crops to adequate levels: namely, water control; high-yielding seed varieties; and chemical fertilizer. Despite high-average per capita grain consumption levels, and the entry of the more advanced areas of the country into the second stage of food

Figure 3-1.

International Cross-Section Relationship between per Capita Grain Consumption per Year, and per Capita Calorie Intake per Day of All Food



Notes: The figures for per capita foodgrain consumption are calculated as the sum of the weights of processed foodgrains consumed directly by humans, and one-fourth the weight of root and tuber crops. To conform with other international data, the entries for China omit soybean consumption and have reevaluated root and tuber crops from one-fifth to one-fourth natural weight. Consumption per capita of foodgrains in Chinese data includes rice and millet at "trade grain" weight (partially processed paddy and millet weight). Rice has been converted to processed weights according to FAO convention at the time the international data were published (67.5 percent paddy weight). The 1982 calorie figure is calculated from the most authoritative data base yet generated in China, by the country's premier nutrition research organization, although estimation procedures have not been reviewed in detail for possible biases. The international data are for 1965 unless otherwise specified.

Sources: Bruce Stone, "China's 1985 Foodgrain Production Target: Issues and Prospects," in *Food Production in the People's Republic of China*, Anthony M. Tang and Bruce Stone, Research Report no.15 (Washington, D.C.: IFPRI, 1980), 93. For China, the 1982 and 1986 figures have been added and the 1952–78 figures have been recalculated on the basis of population and consumption per capita figures in ZGTJNJ 1987, 89 and 711, adjusted population data in ZGTJZY 1988, 14, and crop production data in ZGTJNJ 1987, 170. It was assumed that 50 percent of soybean production (average of cited and previous year) were included in SSB foodgrain consumption per capita figure, on the basis of Alan Piazza, *Trends in Foodgrain and Nutrient Availability in China 1950–81*, World Bank Staff Working Paper no. 607 (Washington, D.C.: The World Bank, 1983). Seventy percent of root and tuber crops in 1978 are assumed included in the SSB direct foodgrain consumption figure and 80 percent for previous years, for the purpose of recalculating foodgrain equivalents; these were adjusted to 50 percent for sweet potatoes and 60 percent for white potatoes in 1982 and 1986 on the basis of Charles Gitomer and Bruce Stone, "Sweet Potato and White Potato Development in China," a paper prepared for the International Potato Center, IFPRI, Washington, D.C., November 1, 1988. The 1982 average calorie consumption figure (2485 kcal) is based on nutritional material collected with the 1982 census and calculated by the Chinese Academy of Preventive Medicine, provided to author by Dr. Chen Chunming, President, May 1986 and confirmed June 9, 1988, Beijing. Calories not accounted for among the SSB data categories are assumed to derive from liquor, dairy products, fruits, vegetables, and other miscellaneous categories. Estimates for other years for these categories are indexed against the 1982 residual figure.

consumption development, the first-stage indicators remain relevant to less advantaged Chinese localities. This is due to the barriers in factor and product markets even more inhibiting in China than in most developing countries.[5] Thus the first question the paper addresses is the extent to which Chinese farmers throughout the country are participating in the fundamental processes of the "Green Revolution."

Progress in Water Control, Use of Fertilizer, and High-Yielding Varieties

China's performance with first-stage requirements for rapid agricultural transformation has been discussed in detail elsewhere[6] and requires no more than a brief summary here.

Water Control Development

Irrigated area increased rapidly during the 1950s and 1960s, partly based on recovery of operating systems built in the 1930s, and partly on new initiatives, both locally financed small-scale construction and nationally and

Figure 3 – 2.

Objectives, Critical Components, and Requirements for the First and Second Stages of Agricultural Technical Transformation and Food Consumption Development in Land-Scarce Peasant Economies

Stage	Principal Objectives	Critical Technical Components	Principal Success Indicators	Institutional Needs
First Stage of Technical and Food Consumption Development	↑Staple crop yields ↑Staple crop production per capita	– Water Control – Staple crop HYVs – Fertilizer use – Early maturing varieties[1] – Cultural practices	↑Staple crop yields ↑Staple production per capita ↑Irrigated area ↑Flood control area ↑Capacity of irrigation and drainage equipment ↑High- and stable-yield area ↑Multiple cropping index ↑Fertilizer application ↑Area under HYVs	– Water engineering contruction organization – Local water distribution authorities – Fertilizer distribution network – Seed production, distribution, and extension system – Agricultural research system – System for input purchase financing – Staple crop purchasing system – Some transport, power, educational, and statistical system infrastructure
Second Stage of Technical Transformation and Food Consumption Development	– Same as first state; and ↑Yields and production per capita of non-staples ↑Production per capita and efficiency in livestock sector	– Same as first state; and – Stress-tolerant staple crop varieties – Nonstaple crop HYVs – Higher quality varieties – Weed control	– Same as first stage; and ↑Nonstaple crop yields ↓Feedgrain/meat, milk, egg output conversion ratios ↑Completion of ancillary facilities on irrigation projects ↑Within-project distribution of water ↑On-farm water management ↑Balance of fertilizer nutrients ↓Nitrogen losses	– Same as first stage; and – Farmer water management organization – Soil testing and fertilizer trial network – Meteorology network – Sophisticated statistical system – Agricultural education system – Animal breeding and weight station network – Machine parts supply and repair network

	↓Labor per unit of staple crop production	– Pest and disease control for crops and livestock – Improved livestock breeds – Better livestock management – Animal nutrition – Mechanization	↑Geographic distribution of fertilizers ↑On-farm analysis of nutrient needs ↑Farm chemical use ↑Biological control of pests and diseases ↑Seed breeding for local environments ↑Experimental yields of new HYVs ↑Mechanization ↑Fuel use for farm tasks ↓Labor application to farming	– Fuel supply network – Others
Market-Related Technical Change Associated with Second Stage	– Prevent local or temporary demand constraints from lowering supply growth and pace of technical change – Allocative efficiency for inputs to food production process	– Transport infrastructure – Communications infrastructure – Rural power – General education – Rural motor vehicle stocks – Fuel supply network – Rural credit – Fertilizer stock management and facilities – Farm product stock management and facilities – Others		

Note: [1] China's considerable breeding concentration on early-maturing varieties is not duplicated elsewhere, but is a typical extension of land- and capital-scarce, labor-abundant factor proportions. (↑) denotes increase; (↓) denotes decrease.

Source: Bruce Stone, "Developments in Agricultural Technology," *The China Quarterly*, Special Issue on Food and Agriculture in China During the Post-Mao Period, no. 116 (December 1988): 768–770

Basic Indicators of Water Control Development, 1952–88, in Million Hectares (mill. ha), Kilowatts (kw), and Kilowatt Hours (kwh)

Years	Effectively Irrigated Area[a]			High & Stable Yield Area[b]	Multiple Cropping Index[c]	Number of Tubewells		Small Hydropower Stations in Rural Areas		Electricity Consumed in Rural Areas[d]	Motors for Agricultural Drainage and Irrigation	
	Total	Power-Irrigated Area Total	Power-Irrigated Area Share			Total	Out-fitted	Nos.	Generating Capacity			
	(mill. ha)		(percent)	(mill. ha)		(1000 units)		(units)	(1000 kw)	(100 mill. kwh)	(1000 units)	(100 mill. watts)
1952	19.959	0.317	1.6	–	130.9[e]	–	–	98	8	0.5	–	0.9
1957	27.339	1.202	4.4	–	140.6	–	–	544	20	1.4	40	4.1
1962	30.545	6.065	19.9	–	136.3	–	–	7,436	252	16.1	367	45.2
1965	33.055	8.093	24.5	–	138.3	100	–	–	–	37.1	558	66.7
1970	36.000	14.992	41.6	25-30	141.9	–	–	29,202	709	95.7	1,471	134.2
1971	36.441	16.601	45.6	–	144.7	590	–	40,040	817	104.5	1,640	146.0
1972	38.005	17.517	46.9	–	147.0	800	–	47,227	902	132.8	2,078	181.3
1973	39.223	19.782	50.4	33	148.2	1200	–	52,765	1,060	139.9	2,880	254.6
1974	41.269	21.664	52.5	34	148.8	1600	–	61,378	1,277	156.1	3,422	300.6
1975	43.284	22.889	52.9	34	150.0	1700	–	68,164	1,445	183.1	3,891	357.9
1976	44.981	24.228	53.9	–	150.6	1800	–	74,125	1,610	204.8	4,262	398.4
1977	44.999	24.349	54.1	–	150.5	–	–	79,047	1,868	221.9	4,695	441.6
1978	44.965	24.895	55.4	22[f]	151.0	2300	–	82,387	2,284	253.1	5,026	482.3
1979	45.003	25.321	56.3	[f]	149.2	–	2100	83,224	2,763	282.7	5,384	523.8
1980	44.888	25.315	56.4	[f]	147.4	2599	2089	80,319	3,041	320.8	5,630	549.0
1981	44.574	25.231	56.6	–	146.6	–	2081	74,017	3,360	369.9	5,672	551.5
1982	44.177	25.145	56.9	–	146.8	2621	2095	66,256	3,520	396.9	5,803	564.1
1983	44.644	25.265	56.6	32.771	146.4	2621	2410	62,328	3,463	435.2	6,077	577.3
1984	44.453	25.062	56.4	33.038	147.4	2675	2400	60,062	3,615	464.0	6,150	577.7
1985	44.036	24.629	55.9	32.871	148.3	2628	2370	55,754	3,802	508.9	6,163	575.5
1986	44.226	25.032	56.6	33.155	149.9	2674	2364	54,136	3,879	586.7	6,507	604.4

1987	44.403	24.825	55.9	–	151.2	2623	2371	51,978	3,941	658.8	6,839	625.8
1988	44.376	26.083	58.8	33.571	151.3	2732	–	51,558	4,611	712.0	7,508	656.8

Notes [a] *Youxiao guangai* defined as "level land which has water sources and complete sets of irrigation facilities to lift and move adequate water for irrigation purposes under normal conditions" (ZGTJNJ 1981, 521–22). Power-irrigated area includes area serviced by electric and fuel-injection facilities. Share of irrigated area with power facilities within total irrigated area are provided in the third column.

[b] "Fields with stable and high yields despite drought or excess surface water" (*han lao baoshou gaochan wenchen tian*) are normally expected to have adequate facilities to withstand a once-in-ten-year drought or flood without crop damage. In some places, the requirements are more stringent. In Guangdong, 100-day drought resistance capability is required. Fields so designated are also supposed to surpass National Agricultural Development Program targets ranging from 3 to 6 tons/ha for major foodgrains, depending on the region.

[c] (Sown area / cultivated area) × 100. Cultivated area and the MCI have not appeared in major publicly distributed State Statistical Bureau compendia during most of the 1980s. During the early 1980s, the Bureau was reported to be considering upward revision of the 1986–87 cultivated area figure from less than 100 mha to "2 billion mu" (133.3 mha) or to "14 percent of total land area" (134.4 mha), based on revised analysis of satellite imagery which had provided an original estimate of around 150 million hectares. While methodological problems remain with satellite-based estimates, the idea that official cultivated area figures are substantial underestimates is widely shared in technical circles. Detailed aerial surveys of two counties in Jilin and Beijing, for example, showed cultivated area underestimated in official data by 7.6 percent and 25.8 percent, respectively. *Guangming ribao* has quoted Wang Xianjin, director of the State Land Administration Bureau, as giving 120 mha and 126.6 mha as cultivated area figures for 1987–88. The larger would be more or less consistent with the satellite-based estimate for 1980–81 and subsequent retirements. The official data, nevertheless, are occasionally published in Chinese books and articles, including the 1988 and 1989 Statistical Yearbooks. The MCIs are calculated from these questionable data and the somewhat more reliable sown area figures published by the SSB.

[d] Includes electricity provided by state power grid as well as by rural power stations, excluding electricity consumed by state-owned units located in rural areas.

[e] 133.5 as recalculated to correct for underreporting of cultivated area (Thomas B. Wiens, "Agricultural Statistics in the People's Republic of China," in *Quantitative Measures of China's Economic Output*, ed. Alexander Eckstein [Ann Arbor: University of Michigan Press, 1980]).

[f] The implied decline relative to the mid-1970s may reflect a tightening of standards or improved statistical precision rather than an actual deterioration in facilities. It is significant that there was severe drought on the North China Plain in 1977 and 1978, which may have revealed the inadequacy of facilities throughout the region. In 1979 HSYA was described as approximately that of 1978, and in 1980 as "half China's irrigated area of 700 million mu" (literally 23.3 million ha) and "less than one-fourth of the total cultivated land" (< 24.8 mha).

Source: Bruce Stone, "Developments in Agricultural Technology," *The China Quarterly*, Special Issue on Food and Agriculture in China During the Post-Mao Period, no. 116 (December 1988): 772–73. Transcription errors appearing in the original publication have been corrected and data for 1988 and (for tubewells) for 1987 have been added on the basis of Zhongguo guojia tongjiju [State Statistical Bureau of China], *Zhongguo tongji nianjian 1989* [Statistical Yearbook of China 1989] (Beijing: Zhongguo guojia tongjiju, 1989), 174, 175, 184, and 192 (hereafter ZGTJNJ 1989) and ZGTJNJ 1988 (English edition), 188 and 206.

provincially financed larger-scale surface structures. Following setbacks in the early 1960s resulting from poor design and construction of a portion of the late 1950s' projects, irrigation development resumed with further reservoir construction and a major focus on tubewells.

These efforts facilitated the multiple cropping increases of the 1950s (see Table 3-1) centered in rice growing areas, and those of the 1970s, which provided for the rapid expansion of overwintering wheat on the North China Plain. Flood control and drainage efforts were similarly significant. These initiatives contributed to the establishment and expansion of high and stable yields guaranteed against drought and waterlogging.

During the 1980s, however, growth in effectively irrigated area stagnated, as did the proportion with pumping facilities. The multiple cropping index declined, recovering only between 1986 and 1989. High- and stable-yield area seems to have dropped sharply in the late 1970s, regaining but not surpassing the 1972–74 levels by the late 1980s.

A major part of the decline in high- and stable-yield area, and the lesser decline in irrigated area and multiple cropping, seems to involve corrections for exaggerated statistical claims of the 1970s. Another part represents rational adjustment correcting for economically irrational growth in the cropping index.[7] Yet there is no question that Chinese agriculture in the 1980s lost the important assistance of rapid growth in these indicators. An important question to be addressed in section III is that of the implications of this stagnation for technical change in poorer regions and localities.

Diffusion of HYV Seed

Characteristic of the 1950s were ambitious and well-oriented programs that imported desirable varieties from abroad and that selected attractive local cultivars for rapid dissemination on a provincial basis, while at the same time establishing a national network for breeding, testing, producing, and disseminating high-yielding varieties (HYVs). Some of the tasks were executed in a haphazard and overhasty fashion, and analytic and basic research had a weak theoretical base, which may have combined to produce or accelerate disasters. But the 1950s represented for China a large, if unsteady, first step in rapid varietal transformation.

During the 1960s and 1970s, excesses in management practices were considerably reduced, though not eliminated. The scientific community suffered from isolation and, to some extent, harassment, but China's own varietal breeding community became a formidable scientific force. The breeding of new varieties with superior traits was very strong, and the speed with which new varieties were tested and adapted to local environments was especially rapid. The system grew to be highly sophisticated for wheat and rice in China's major growing regions.

Table 3-2.

Area Sown with Hybrid Rice, Maize, Sorghum, and Semi-Dwarf Wheat and Rice, 1955–90

	Area Under True Hybrids			Area Under All Dwarf and Semi-dwarf Varieties		
	Maize	Sorghum	Rice	Rice	Wheat (< 100cm)	Wheat (< 105cm)
	(percent of total area planted with crop)					
1955-59	[a]			[a]		[a]
1961	(20-40)			[a]		
1962	(0-20)[b]					
1964			[c]	[c]		
1965				14	[d]	
1966	~ 40[b]					
1968				[f]	[e]	
1971		20		[f]		
1973	40		[f]		[g]	
1974				80		
1976			0.4			
1977		40	6.2	80		[h]
1978	60		12.6			
1979	65	55	14.9			
1980	69	57	13.9[i]			
1981	72	60	15.4	[f]		
1982	75	60	17.0			
1983			20.3			
1984			26.7		~ 56	(67-75)
1985			26.4	95		
1986		90	28.3			
1987			~ 34.0[j]			
1988	~ 90[k]					
1989	(86-91)[k]		(40-41)[j]			
1990	(89-94)[k] (plan)		(46-47)[j]			

~ = estimated value
cm = height in centimeters at maturity

Notes: [a] Experimental breeding work on semi-dwarf rice began in the early 1950s, but the first cross between dwarf and high-yielding varieties was accomplished in 1956. Semi-dwarf indica varieties were grown as an early crop in South China in the late 1950s; the first short stature japonica varieties (Nongken #58) were introduced in North China in 1957. The first semi-dwarfs were developed in China by cross breeding in 1959 (Guang Changai) and released in 1961. Experimental breeding work on semi-dwarf wheat varieties was initiated during the late 1950s. Chinese work on hybrid maize began in 1923 and double-cross hybrids were first released in Sichuan 1943–45. Work resumed throughout the

1950s in several institutions from which double-cross hybrids were released in 1958.

[b] Double-cross hybrids were decimated by corn blight in 1961 and 1966; total maize area declined by around 20 percent in 1962, presumably primarily in disease-affected hybrid areas; double-cross extension dropped after 1966; single-cross hybrids initially extended in 1966.

[c] Work on hybrid rice and broad-scale dissemination of semi-dwarf rice varieties initiated. Short stature (non-hybrid) indica varieties released in South China in 1963

[d] First Chinese-bred (100 cm) variety of eventual commercial importance (Beijing #10).

[e] Dwarf wheats imported for the Chinese breeding program from Pakistan and elsewhere in 1968, 1969, and the early 1970s; the first Chinese-bred variety under 90 cm of eventual commercial importance (Fan #6) was bred.

[f] Cyctoplasmic male sterile, maintainer, and restorer lines necessary for producing hybrid seed developed 1970–73. IRRI's IR#8 was first planted in China 1968 and eventually used as restorer line for hybrid rice breeding; 3,335 varieties and advanced lines provided to China by International Rice Research Institute between 1971 and 1981.

[g] Large quantities of dwarf wheat seed imported from Mexico for direct planting 1972–74; maximum sown area reached 800,000 hectares, then declined sharply due to environmental stresses not problematic in Mexico; subsequent emphasis turned to Chinese-Chinese or Chinese-foreign crosses except in a few western regions.

[h] Chinese crosses with imported Mexican varieties and other Chinese-bred semi-dwarfs were sown throughout main winter wheat producing areas, and on 2 million hectares (~40 percent of national spring wheat area) in the northeast spring wheat region

[i] Hybrid area was cut back in principal growing area (lower Yangzi Valley) due to susceptibility to yellow dwarf virus and discovery that in some localities increased hybrid yields did not compensate for losses on alternate crops as the maturation period for hybrid was normally longer than the crop it replaced. Rapid growth resumed in subsequent years with aggressive extension of new subtropical hybrids in South China (especially Guangdong and Sichuan). Some japonica hybrids were already extended in 1979–80: 43,000 hectares, with Liyou #57. These were not always successful and the total area under all japonica hybrids declined to 33,300 hectares in 1981. But more suitable varieties were developed and by 1986, 261,000 hectares were planted with japonica hybrids.

[j] Another large expansion of hybrid area in 1987; total reached "one-third" of China's rice area. Area increased 95 percent over the previous five years to almost 11 million hectares. Hybrid area grown as early rice grew substantially as new varieties proved superior to non-hybrids up to 30°N, compared with previous hybrids limited to 23°N. Better single-season hybrids for highland areas (especially Xianyou #63, up to 1,500 m) also extended, especially in the South, accounting for more large increases in hybrid area in Yunnan, Guizhou, and mountainous areas of other southern provinces. Planned hybrid area for 1990 is 15 million hectares, 1.9 million more than 1989.

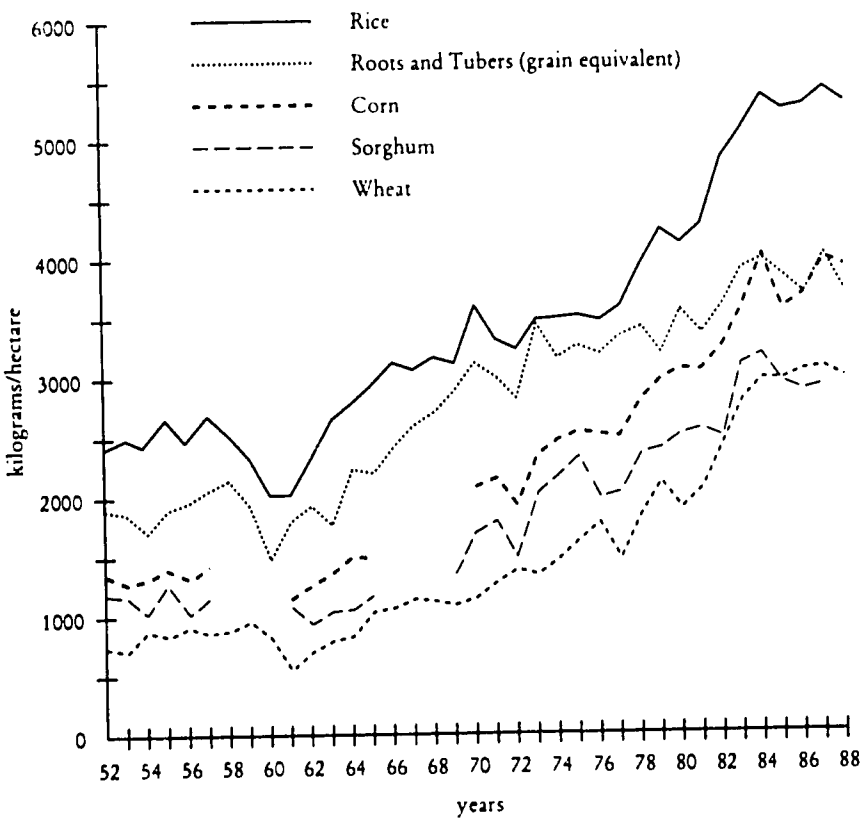
[k] According to Chinese maize scientists attending the Colloquium on Agricultural Reform and Development, October 18–19, 1989, around 80 percent of maize area is covered with HYVs bred via the single-cross hybridization process popularized in the late 1960s, 5 percent with HYVs bred via the double-cross process used primarily in the late 1950s and most of the 1960s; and 5 percent with HYVs bred via a newer triple-cross hybridization process. Eighteen million hectares of hybrids are planned for 1990, reportedly 600,000 hectares more than 1989.

Sources: For complete references, see Bruce Stone, "Developments in Agricultural Technology," *The China Quarterly*, Special Issue on Food and Agriculture in China During the Post-Mao Period, no. 116 (December 1988): 792–94, as updated and amended with data appearing in Zhongguo nongxuyuyebu jihuaju [Chinese Ministry of Agriculture, Animal Husbandry and Fisheries, Planning Dept.], *Nongye jingji ziliao, 1949–1983* [Economic

Materials on Agriculture, 1949–1983] (Beijing: Ministry of Agriculture), 285 (hereafter NYJJZL); Li Meisen and Zhao Lijian, "National Conference on Hybrid Rice Development," *Agricultural Yearbook of China 1988*, 95–96; comments provided by Chinese maize scientists at the Colloquium on Agricultural Reform and Development in China, held in conjunction with the Annual Meetings of the American Society of Agronomists, Las Vegas, October 18–19, 1989; Wang Dongtai, "State Aims to Commit New Funds to Farming," *The China Daily*, December 26, 1989, 1; "Increased Harvests a Goal for This Year," *The China Daily*, January 22, 1990, 4. The 1989 and 1990 proportional ranges are based on 13.1 million hectares and 15 million hectares for rice and 17.4 million and 18 million hectares for corn cited in *The China Daily* articles, highest and lowest actual sown area figures recorded for these crops during the 1986–88 period based on ZGTJNJ 1989, 192.

Figure 3-3.

Rice, Wheat, Corn, Sorghum, and Root and Tuber Yields in China, 1952–88, Growth in Yields, Kilograms per Hectare (Kg/ha)



Notes: Root and tuber fresh weight yields are divided by four to approximate cereal equivalents for the dominant crop (sweet potato). Currently published Chinese yield and

production data are recorded at one-fifth fresh weight and must be multiplied by 1.25 to approximate cereal equivalents. Although detailed data are not yet available, yields for most foodgrains increased in 1989, as total production surpassed the previous (1984) peak on substantially reduced area.

Sources: Root and tuber crop yields for 1984–88, all rice and wheat yields, and corn yields except those for 1961–62, are calculated from production and area data in ZGTJNJ 1984, 138, 141; and ZGTJNJ 1989, 192 and 198. Root and tuber crop yields are based on official series adjusted for statistical consistency and published in Bruce Stone, "An Analysis of Chinese Data on Root and Tuber Crop Production," *The China Quarterly* (September 1984): 596–97 (Series B). Sorghum yields except for those for 1961–62 are calculated from Zhongguo Tongjiju Nongye Tongjisi [State Statistical Bureau of China, Agricultural Statistics Department], eds., *Zhongguo nongye di guanghui chengjiu, 1949–84* [Glorious Achievements of Chinese Agriculture, 1949–84] (Beijing: Zhongguo tongji chubanshe, 1985) (hereafter ZGNYGHCJ), 42–47; He Kang, et al., eds., *Zhongguo nongye nianjin 1985*[Agricultural Yearbook of China, 1985] (Beijing: Nongye chubanshe [Agricultural Publishing House], 1986), 148 (hereafter ZGNYNJ 1985); ZGNYNJ 1986, 183; and ZGNYNJ 1987, 216–17. Corn and sorghum yields for 1961–62 are from NYJJZL, 147–48.

Chinese-bred varieties of rice, wheat, sweet potato, and to a considerable extent corn and sorghum, became comparable to the best varieties in the world in terms of yield, early maturity, and some stress factors, while lagging in resistance to other sources of stress and in taste characteristics. Average sweet potato yields surpassed those of all major world producers. Successful varieties of cassava and white potato were bred, selected, or imported prior to the late 1960s. Much of the rapid area expansion for white potatoes was based on these imported varieties or crosses among them, while area expansion for cassava was based on varieties selected for dissemination in the 1950s and early 1960s, but imported earlier. Unlike sweet potato, for which major varietal improvements continued into the 1970s, yields for cassava and white potato remain about average for Asia, although the very highest yields are comparable to the highest yields elsewhere.

Table 3–2 shows how rapid the dissemination of HYV cereals has been throughout the 1960s and 1970s and even including the 1980s. Figure 3–3 shows that yield progress for these crops has also been rapid. The contribution of yield-increasing technical change to foodgrain production growth is even greater than the impression provided by Figure 3–3, since area sown with staples has been increasingly allocated to these crops for which especially productive varieties are available. Chinese data indicate that the crops represented in Figure 3–3 provided 79.2 percent of national foodgrain production in 1952, 94.0 percent in 1978, and 92.4 percent in 1988.[8]

But the Green Revolution cannot be characterized as a single period of replacement of traditional cultivars with HYVs. Instead, in successful countries like China, it is systematized in a process of sequential adoption of a steady stream of increasingly more desirable varieties. Table 3–3 illustrates this process for wheat. By 1984, varieties having a height at

Table 3-3.

Area Sown with Semi-Dwarf Wheat Varieties, 1980–84, in Hectares

	Fall-Sown	Spring-Sown	Total
		(million hectares)	
<90 cm			
1980	2.863[a]	0.093[b]	2.956[ab]
1981	3.111[a]	0.141[c]	3.252[ac]
1982	4.739[b]	0.387[b]	5.126[b]
<100 cm			
1983	8.364[b]	0.556[b]	8.920[b]
1984	9.362[b]	0.666[b]	10.028[b]
			(16.5) [d]
<105 cm			
1977		~2.0[e]	
1984			(20–22)[d]

~ = estimated value
cm = height in centimeters at maturity

Note: Data upon which these compilations are based are incomplete, generally including only the more important semi-dwarf varieties sown over relatively large areas. The specific reference marks indicate figures that are based on compilations of data for semi-dwarf varieties including only those:

[a] With sown area exceeding 66.7 thousand hectares.

[b] With sown area exceeding 6.67 thousand hectares.

[c] With sown area exceeding 13.33 thousand hectares.

[d] With sown area exceeding 6.67 thousand hectares to which estimates have been added for remaining semi-dwarf plantings for 1984 or 1985, assuming 29 million hectares of coverage. Officially, wheat area was 29.577 million hectares in 1984 and 29.61 million hectares in 1985.

[e] Two million hectares of semi-dwarfs (<105 cm) were sown in northeast spring wheat zones by 1977. Semi-dwarfs were commonly planted in main fall-sown wheat zones by that date.

Source: Bruce Stone, "Chinese Wheat Production and Technological Change," in International Center for Maize and Wheat Improvement (CIMMYT), *The Wheat Revolution Revisited: Recent Trends and Future Challenges*, a special issue of *World Wheat Facts and Trends* (Texcoco, Mexico: CIMMYT, 1989). For another presentation based on most of the same data, see also Dana G. Dalrymple, *Development and Spread of High-Yielding Wheat Varieties in Developing Countries* (Washington, D.C.: Bureau for Science and Technology, Agency for International Development, 1986).

maturity of under 105 cm had reached between two-thirds and three-quarters of China's wheat area. But varieties under 100 cm, with even greater yield potential, increased their area by 12.4 percent in 1984 to reach 57 percent of total plantings, while even shorter-stature varieties were increasing at a yet faster pace from a lower-base level. Another example of replacement of HYVs by even higher-yielding varieties is the increasing importance of hybrid rice.

Development of Fertilizer Use

Table 3-4 shows that fertilizer use has grown rapidly throughout the People's Republic period, and especially during the last decade (see Figure 3-4), when annual increments to use exceeded 1.2 million tons of nutrients.

China's relatively rapid growth in fertilizer use implies better handling of the four fundamental processes involved in sustained progress with fertilizer adoption: 1) influencing the agronomic potential for fertilizer use (primarily via development of water control and of agricultural research and extension systems); 2) converting the potential into farmers' effective demand for fertilizers (via market development or public-sector expedients to circumvent limitations imposed by poor market development); 3) determining the growth of aggregate supply (including planning for and execution of imports, capital construction investments to develop domestic production, and policy to fully utilize that capacity); and 4) developing the

Table 3-4.

Trend Growth in Manufactured Fertilizer Use, 1952-88

	Trend Growth Increments (1000 metric tons of nutrients/year)	Growth Rate Relative to Period Average (percent)
1952-57	59.7	29.0
1957-70	235.5	15.7
1970-78	555.8	10.4
1978-88	1,207.7	7.7

Sources:

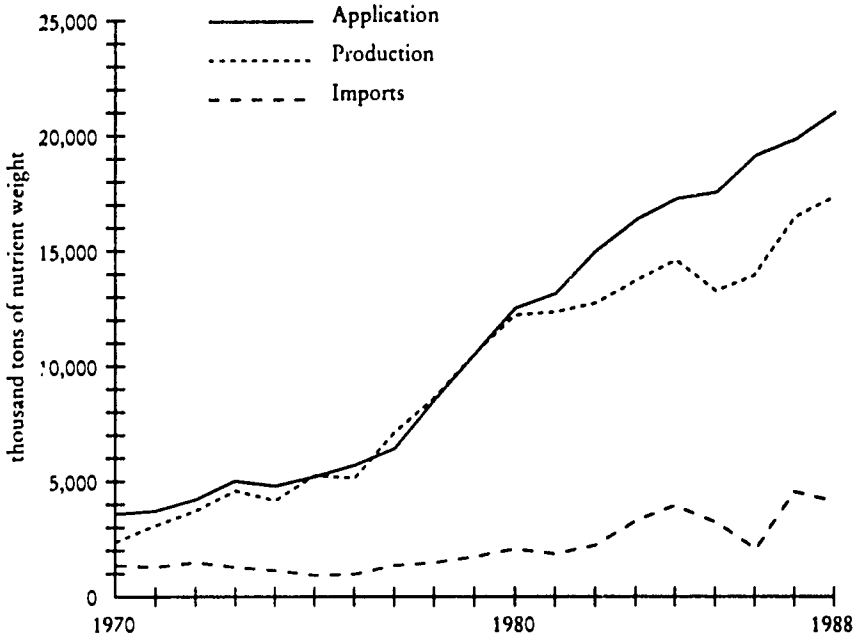
1953-56: Zhongguo nongye kexueyuan turang feiliao yangjiusuo [Chinese Academy of Agricultural Science, Soil & Fertilizer Regionalization Plan] (Beijing: Zhongguo nongye keji chubanshe [Agricultural Science & Technology Publishing House of China], 1986), 6 and 7.

1978-88: ZGTJNJ 1989, 183.

All Others: Ibid. and/or NYJJZL 1949-83, 292.

Figure 3-4.

China's Production, Application, and Imports of Manufactured Fertilizers, 1970–88



Sources:

Applications:
1970–78: NYJJZL 1949–83, 292.
1978–88: ZGTJNJ 1989, 183.

Imports:
1970–84: Converted from standard weight to nutrient weight estimated by multiplying by constant factor of 0.21. ZGTJNJ 1984, 410; ZGTJNJ 1985, 516.

1985–87: Converted from product weight found in ZGTJNJ 1987, 601; ZGTJZY 1988, 87; and ZGTJNJ 1989, 643, to nutrient weight estimates by multiplying by 0.43.

Production: ZGTJNJ 1989, 300.

fertilizer distribution system and determining the allocation of fertilizers among farmers.[9]

Yet even Chinese growth could have proceeded more rapidly. Of the four processes, aggregate supply of fertilizers seems to have been the most chronically constraining. Had more foreign exchange been allocated for fertilizer imports, had domestic capacity construction proceeded more quickly, and, particularly, had the decision to invest in large-scale efficient plants for producing high-quality fertilizers been undertaken earlier, the

other three processes would have been sufficiently robust to have allowed for faster growth in fertilizer use and farm production.[10]

Aggregate fertilizer use has continued to grow rapidly during the last decade. Later we will examine whether this is primarily due to further intensification in advanced areas, or whether poorer regions and counties are also receiving greater access to fertilizer supplies. In recent years, processes other than the development of aggregate supplies have begun to impose constraints on fertilizer development.

The Diffusion Process for the Basic Components in the 1980s

The diffusion process within China is first reviewed by monitoring progress within each of the country's 26 provinces and autonomous regions, together with the three major province-level municipalities—Beijing, Shanghai, and Tianjin.[11]

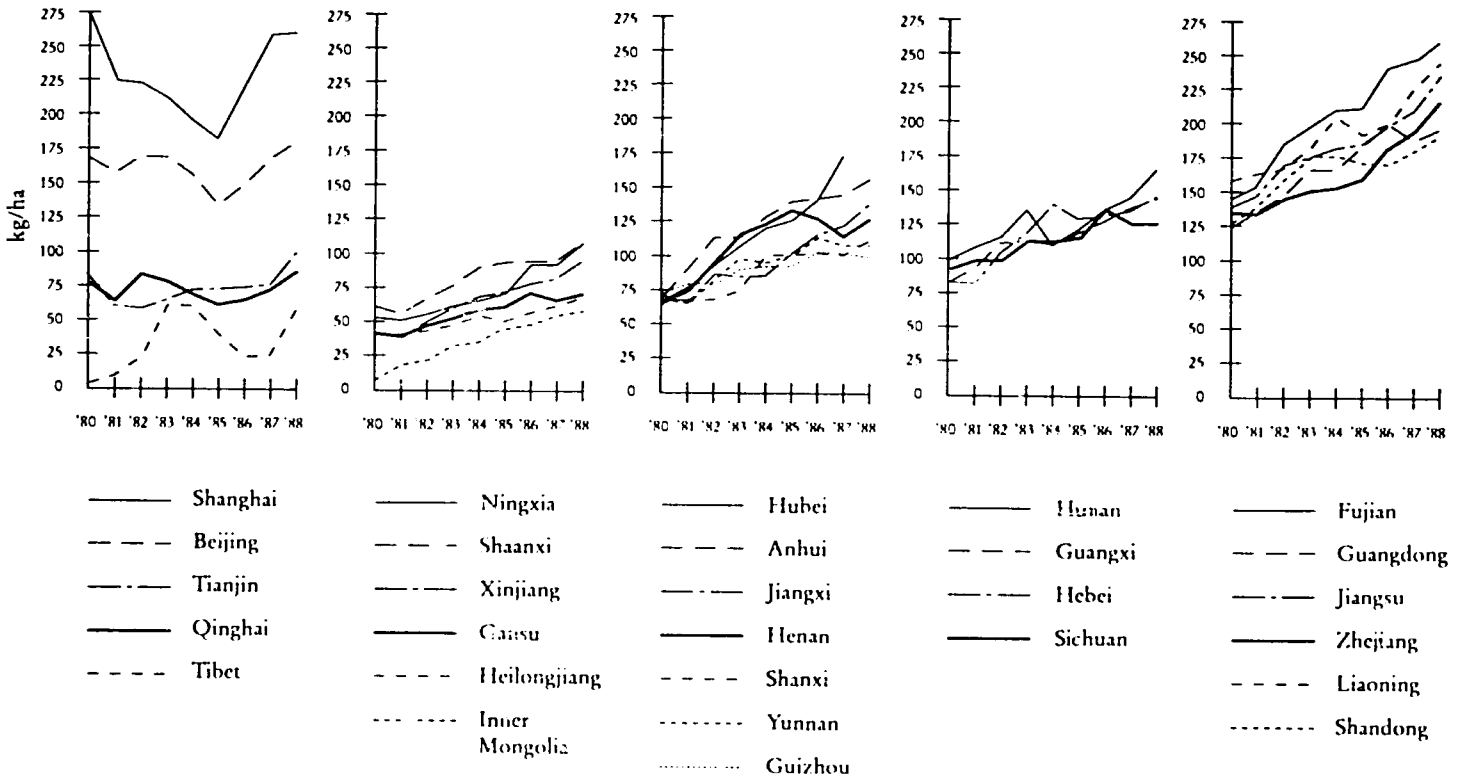
Diffusion of Fertilizer Use in the Provinces

When the People's Republic of China was formally established in 1949, the average application of manufactured fertilizers was less than one kilogram per hectare, and farmers throughout the country relied almost entirely on green manure crops and the application of other organic manures to maintain soil health and supplement soil nutrients for better crop growth. Figure 3-5 shows that major differences had developed by 1980 in the intensity of fertilizer use among China's provinces: per hectare application within Beijing and Shanghai (on the left) and the populous coastal provinces (on the right) far exceeded average levels throughout the remainder of the country, with application especially lagging in Tibet and the far northern and northwestern provinces (two left panels).

Growth in fertilizer application during the 1980s, nevertheless, has been rapid and relatively steady within most jurisdictions. The five exceptions (left panel) include the three major municipalities where labor's rapidly rising opportunity cost has engendered a continuous state of frenzied economic growth, usually in directions away from agriculture; and Qinghai and Tibet—cold, mountainous, sparsely populated herding regions with relatively little agriculture and a variety of special problems. The decline in these minor agricultural regions since 1983 may relate closely to liberalization of pasture-based livestock development, other market liberalizations, and demographic movements.

Figure 3-5.

Provincial Fertilizer Application per Sown Hectare, 1980–88



Sources: Bruce Stone, "Developments in Agricultural Technology," *The China Quarterly*, Special Issue on Food and Agriculture in China During the Post-Mao Period, no. 116 (December 1988): 806. Data for 1988 have been added, based on ZGTJNJ 1989, 182 and 192.

Development of Irrigation

While effectively irrigated area increased in most Chinese provinces during the 1970s, only one-third of them showed an unequivocal upward linear trend between 1980 and 1988, including three showing decline during the latter half of the period. Four others actually finished the period with more area irrigated than in 1980 (see Figure 3-6). In six provinces, the negative trend amounted to as much as one percent per annum.[12]

Over half the gross reduction in irrigated area took place in three provinces: Anhui, Guangdong, and Sichuan, totalling 152 percent of the net national decline. If Hubei, Henan, Shandong, and Guangxi are added, these values become 87 percent and 250 percent. So the aggregate problem is somewhat concentrated. Yet an analysis of these reductions suggests that an important portion reflects correction for statistical error. Of the seven provinces accounting for most of the decline, data for Guangdong and Guangxi clearly incorporate large statistical errors. A large share of the decline in Shandong, Henan, and, to a lesser extent, Anhui, reflects water sources that had been inadequate for a long time and the retirement of tubewells too densely placed, both of which point to corrections for overestimation in previous years. The same may be said for several of the other provinces and cities recording smaller net declines, including Beijing, Tianjin, Shanxi, and Inner Mongolia, and to a lesser extent, Zhejiang, Gansu, and Shaanxi.

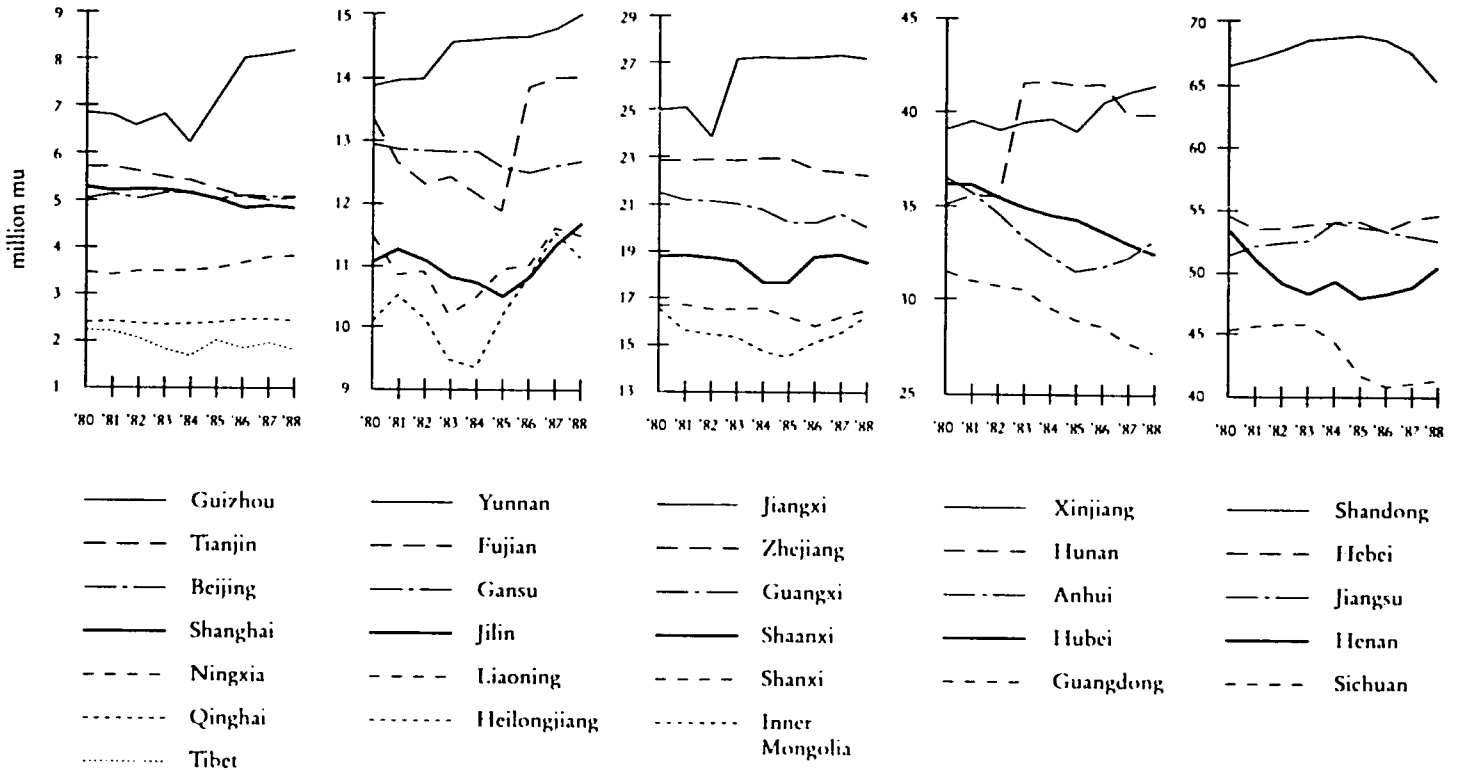
Yet if the reductions are not as serious or widespread as they originally appeared, it is nevertheless irrefutable that Chinese agricultural growth lost the important assistance of very rapid increases in aggregate irrigated area during the 1980s. Those that experienced net increases in irrigated area at an average rate exceeding one percent per annum include relatively wealthy provinces (Jiangsu, Hebei, Fujian, and Hunan), those benefitting from an increase in national funding (Xinjiang, Ningxia, and Heilongjiang), and provinces that have been too poor historically to exhaust the supply of relatively attractive potential irrigation projects (the last three and Jiangxi, Yunnan, and Guizhou).

Diffusion of HYVs

The proportion of area sown with the major Green Revolution crops and covered with high-yielding varieties is so great (see Table 3-2) that there can be little question that the regional diffusion of HYVs is relatively complete. Of course, important interregional differences in the *level* of seed technology remain. This shows up in a number of ways. For the higher valued crops like wheat and rice, varietal turnover may occur as often as every two to three years in the most sophisticated growing regions of the Yangtze Valley, Pearl River Delta, and the Huang-Huai-Hai Plain of North China; four to five years in the productive Chengdu Plain of Sichuan; and six to

Figure 3-6.

Irrigated Area by Province, 1980–88



Note: 15 mu = 1 hectare.

Sources: AGNYNJ 1981, 66–67; ZGNYNJ 1982; ZGTJNJ 1983, 198; ZGTJNJ 1984, 176; ZGTJNJ 1985, 282; ZGTJNJ 1986, 157; ZGTJNJ 1987, 147; ZGNYNJ 1988, 377; ZGTJNJ 1989 (English edition), 184

seven years in primary growing areas of Heilongjiang in the northeast. Less market-oriented areas of the northwest, west, and southwest are still growing improved varieties introduced twenty to thirty-five years ago, and a small number of counties are growing primarily traditional varieties because the regional breeding system has not yet been able to improve on them.[13]

Another way interregional differences show up is in the extent of coverage of single varieties. In the highest technology areas for rice and wheat listed above, local adaptation and breeding are so sophisticated and environment-specific that no one variety has simultaneously covered several million hectares since the 1960s. In the west and in mountainous regions throughout China, the local breeding and adaptation network is

Table 3 – 5.

Distribution of China's Rice Area by Type, Planting Season, and Province, 1980 and 1986

	Total Area		Indica Area				Japonica Area	
	Total Provincial Rice as Percentage of National Rice		Early and Late Rice as Percentage of Total Prov. Rice	Single and Mid-Season Rice as Percentage of Total Prov. Rice	Indica Hybrid Rice as Percentage of Total (Indica) Rice		Japonica Hybrid as Percentage of Total Prov. (Northern) Rice	
	1980	1986	1986	1986	1980[a]	1986	1980	1986
				(percent)				
Indica Rice Producers								
Shanghai	0.9	0.9	47.7	50.3	(6.7-8.2)	0	n.p.	n.p.
Jiangsu	7.9	7.5	6.0	94.0	(24.5-29.9)	30.6	n.p.	n.p.
Zhejiang	7.4	7.3	91.7	8.3	(17.4-21.2)	24.1	n.p.	n.p.
Anhui	6.6	6.8	57.7	42.3	(7.3-8.9)	24.4	n.p.	n.p.
Fujian	5.0	4.6	79.3	20.7	(32.5-39.6)	38.6	n.p.	n.p.
Jiangxi	10.0	10.1	92.1	7.0	(22.6-27.6)	26.7	n.p.	n.p.
Hubei	8.0	7.9	61.3	38.7	(6.1-7.4)	26.2	n.p.	n.p.
Hunan	13.1	13.4	88.5	11.5	(18.9-23.1)	36.6	n.p	n.p.
Guangdong	12.3	11.2	98.4	1.6	(3.9-4.8)	19.4	n.p.	n.p.
Guangxi	8.2	7.8	92.8	7.2	(5.2-6.3)	19.8	n.p.	n.p.
Sichuan	9.1	9.6	3.5	96.5	(22.5-27.4)	57.8	n.p.	n.p.
Guizhou	2.3	2.3	0.1	99.9	(10.6-12.9)	14.6	n.p.	n.p.
Yunnan	3.0	3.3	6.4	93.6	(2.0-2.4)	10.3	n.p.	n.p.
Sub-total (Indica)	94.0	92.5	64.7	35.3	(14.8-18.0)	29.7	n.p.	n.p.

Japonica Rice Producers								
Beijing	~0.2	~0.1	n.p.	n.p.	n.p.	n.p.	0	0
Tianjin	~0.2	~0.1	n.p.	n.p.	n.p.	n.p.	0	0
Hebei	0.4	0.4	n.p.	n.p.	n.p.	n.p.	(8.4-10.3)	0
Shanxi	<0.1	<0.1	n.p.	n.p.	n.p.	n.p.	0	0
Nei Menggu	<0.1	~0.1	n.p.	n.p.	n.p.	n.p.	0	0
Liaoning	1.1	1.2	n.p.	n.p.	n.p.	n.p.	(8.5-10.4)	6.6
Jilin	0.7	1.1	n.p.	n.p.	n.p.	n.p.	(4.8-5.9)	0
Heilong-jiang	0.6	1.2	n.p.	n.p.	n.p.	n.p.	(2.0-2.4)	0
Shandong	0.5	0.3	n.p.	n.p.	n.p.	n.p.	(7.1-8.7)	0
Henan	1.2	1.3	n.p.	n.p.	n.p.	n.p.	(5.3-6.5)	32.0
Xizang	<0.1	<0.1	n.p.	n.p.	n.p.	n.p.	0	
Shaanxi	0.5	0.5	n.p.	n.p.	n.p.	n.p.	(16.6-20.3)	55.5
Gansu	<0.1	<0.1	n.p.	n.p.	n.p.	n.p.	0	0
Qinghai	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
Ningxia	0.1	0.2	n.p.	n.p.	n.p.	n.p.	0	19.5
Xinjiang	0.3	0.2	n.p.	n.p.	n.p.	n.p.	0	0
Sub-total (Japonica)	6.0	7.5	n.p.	n.p.	n.p.	n.p.	(6.1-7.4)	10.0
China[b]	100.0	100.0	59.9	32.6	(13.9-16.9)	27.5	(0.4)	0.8

Notes: Northern rice areas plant primarily japonica varieties; others plant primarily indica varieties. The appearance of rigid boundaries differentiating these plantings coinciding with provincial boundaries reflects convenience in statistical presentation rather than an exact representation of reality. Japonica varieties are also grown in East Central China and in high altitude areas of the South for example.

"n.p." denotes that there is little or no cultivation of the type of rice or growing season in the indicated province according to available statistical data.

[a] Several figures have been published for national hybrid rice area in 1980 ranging from 72 million mu to 88 million mu (4.800-5.866 million ha.). Sources for the 72.1 million mu figure seem to be the most authoritative, but the only provincial data so far released add up to 88 million mu, although they appear with a figure for total paddy area of 542.43 million mu as opposed to 506.33 million mu (ZGNYNJ 1981, 23) or 508.18 million mu (ZGTJNJ 1984, 138 and elsewhere). The higher figures in the included ranges use the original hybrid rice area data divided by data for total area from ZGNYNJ 1981. The lower figures deflate those percentages by 0.82 (= 72.1/88.0).

[b] Data in this row provide percentages of indicated column categories in total rice area for the specified year.

Sources: 1980: Hybrid area in 1980 by province was provided to S. Virmani of the International Rice Research Institute (IRRI) and published in Robert E. Huke, *Rice Area by Type of Culture: South, Southeast, and East Asia* (Los Baños, Philippines: IRRI, 1982), 32. Other calculations are based on ZGNYNJ 1981, 23-24.

1986: Proportion of rice area under hybrids by province are unpublished data from Ministry of Agriculture, Animal Husbandry and Fishery. All other calculations are based on data published in ZGNYNJ 1987, 213-14.

For comparison of data from these sources with detailed data for Yunnan, see Table 3-7.

less dense and less capable; provincial academies of agricultural sciences are more dominant; and a single breakthrough, usually based on a variety developed elsewhere, will be extended successfully over vast areas. Furthermore, microclimatic variation in the west and in the mountainous areas is likely to be considerably greater than within China's principal growing regions.

The interregional pattern of adoption, as shown in Table 3-5 for hybrid rice, a high-technology Chinese innovation, is a complicated one. Interprovincial differences in the proportion of rice areas covered with hybrids in 1980 are largely explained by climate. Only indica hybrids for temperate climates had at that point been developed, which were superior to the non-hybrid dwarf HYVs in the region. Japonica hybrids provided less yield improvement over the Korean- and Japanese-based varieties with which they competed, and the poorer taste characteristics of early hybrids were more problematic for adoption in japonica areas, since a greater proportion of japonica production is for export or for higher-income urban consumption. For the same reasons, the adoption rate in Shanghai was relatively low, despite the city's sophisticated agricultural research program. As for the far south, successful semitropical and tropical indica hybrids had not yet been developed.

By 1986, successful semitropical indica varieties were being rapidly extended in Guangdong and Guangxi and in the warmer areas of Yunnan and Sichuan. Meanwhile, less cold-sensitive indica hybrids were being extended in medium-elevation areas of Hubei and Hunan, low-elevation areas of Anhui, Henan, and Shaanxi a little farther north, and higher-elevation areas of the southern provinces. Superior temperate hybrids were also beginning to replace the earlier successful varieties and expand their area. With continued rapid growth in cereal yields through the mid-1980s, the poorer-tasting hybrids were largely dropped in Shanghai and in the japonica areas. Ningxia, where rice is scarce and consumers are less discriminating, is a principal exception.

Diffusion of Fertilizer Use in Poor Areas

The data appearing in Table 3-6 have to be used with caution (see table notes), yet they provide some confirmation that growth in fertilizer use in the poorest one-third of China's counties and municipal areas, taken as a group, has progressed rapidly during the 1980s. Progress is still not as fast for the bottom one-third as for the national average, however, indicating that the gap in fertilizer use intensity between poor and wealthier counties is still widening. Moreover, a significant number of the very poorest counties, although awarded special quotas of subsidized supplies during the last decade, have not since that time received increased allocations at either subsidized or market prices, and consequently are suffering from severe fertilizer supply constraints on staple crop yields.

Table 3-6.

Comparison of Officially Designated Poor Counties (663) with All Counties in China: Various Categories of Agricultural Performance and Input Use, 1980–87, in Kilograms (kg), Hectares (ha), and Kilowatt Hours (kwh)

	1980	1985	1987
Fertilizer Use (kg of fertilizer nutrients per sown ha)			
NG	56.4	84.5	92.3
PPG	66.3	85.4	98.0
NAV	89.0	123.6	137.8
Rural Use of Electricity (kwh/sown ha)			
NG	105.2	158.0	187.8
PPG	108.8	162.9	214.1
NAV	220.3	354.3	454.5
Rural Use of Electricity (kwh/rural resident)			
NG	17.3	24.6	28.5
PPG	19.2	28.1	35.4
NAV	39.6	61.0	76.9
Cultivated Area with Effective Irrigation (percent)			
NG	16.9	11.8	16.1
PPG	25.0	16.0	21.8
NAV	45.3	45.5	46.3
Average Foodgrain Yields (kg/sown ha)			
NG	2,129	2,583	2,566
PPG	2,192	2,880	2,893
NAV	2,732	3,483	3,637
Foodgrain Production Per Capita (kg/rural resident)			
NG	296	315	310
PPG	321	376	373
NAV	392	454	472
Agricultural Output Value Per Rural Resident (in constant 1980 Yuan)			
NG		248	250
PPG		294	300
NAV		349	372

NG = 300 poor counties supported by the national government
PPG = 363 poor counties supported by the provincial and prefectural governments
NAV = National average of all 1,986 counties and 378 municipal areas (1987)

Notes: A number of strong reservations must be considered in drawing conclusions from this comparison. First, officially designated "poor" counties include large groups of counties that are not especially poor in the Chinese context, and exclude some groups which are quite poor. Second, the 663 poor counties constitute almost one-third of China's total poor population and one-fifth of China's total population—therefore comprising an appreciable portion of the national averages included, the comparison thus considerably underestimates the differences between "poor" and "other" counties.

Third, benchmark year comparisons are always problematic. An especially poor weather year was 1980, while 1987 weather was good. Weather was relatively poor in 1985, and there was considerable and costly confusion in markets for farm goods, fertilizer, and credit, coupled with public financial retrenchment. Thus the 1980–85–87 temporal comparison overstates positive trends for all groups.

In terms of intergroup comparisons, stronger-than-average performance by poor counties in several categories may reflect greater vulnerability during periods of poor weather, financial retrenchment, and input shortages (1080 and 1985) to a greater extent than constitutes evidence of any phenomenon of poor counties "catching up" with the average, which might be inferred from a superficial glance at the data. Finally, sown area and especially cultivated area are considerably underestimated in China. The proportional underestimation is certainly greater in poor areas.

"Foodgrains" consist of rice, wheat, corn, sorghum, millet, and other minor cereals, all evaluated at unhulled weight, sweet potatoes and white potatoes evaluated at one-fifth fresh weight, and soybeans and other bean crops.

"Effective irrigation" denotes level agricultural land which has water sources and complete sets of irrigation facilities to lift and move adequate water for irrigation purposes under normal conditions. The national increase in the proportion irrigated reflects retirement of cultivated area rather than net growth in irrigated area among official data. The degree of overestimation of official data in this category, however, has declined somewhat during the 1980s.

Sources: Guojia tongjiju nongcun shehui jingji tongjisi [State Statistical Bureau, Division of Rural Social and Economic Statistics], eds., *Zhongguo fenxian nongcun jingji tongji gaiyao* [Statistical Abstract of China's Rural Economy by County] (Beijing: Zhongguo tongji chubanshe [Statistical Publishing House of China], 1988), 639–42.

He Kang et al., eds., *Zhongguo nongye nianjian 1981* [Agricultural Yearbook of China, 1981] (Beijing: Nongye chubanshe [Agricultural Publishing House], 1982), 10, 21, 64, 65.

He Kang et al., eds., *China Agricultural Yearbook 1986* (Beijing: Agricultural Publishing House, 1987), 137, 156, 160, 267, 270.

He Kang et al., eds., *China Agricultural Yearbook 1988* (Beijing: Agricultural Publishing House, 1989), 200, 208, 214, 342, 345.

Bruce Stone, "Developments in Agricultural Technology," *The China Quarterly*, Special Issue on Food and Agriculture in the Post-Mao Period, no. 116 (December 1988): 767–822, especially 771–90.

State Statistical Bureau of the People's Republic of China, *China Statistical Yearbook 1988* (Hong Kong: International Center for Advancement of Science and Technology and China Statistical Information and Consultancy Service Center, 1988), 1.

Development of Irrigation in Poor Areas

While the irrigated area data listed in Table 3–6 are subject to the reservations discussed above, they suggest that poor counties bore the brunt of irrigated area losses during the 1980s. Reasons for this imbalance are discussed in Section IV.

Diffusion of HYVs in Poor Areas

There are a number of relevant dimensions to the diffusion process for improved staple crop technologies among poorer people: 1) the diffusion of improved and advanced technologies for the primary cereal crops into poorer prefectures and counties; 2) the access of the poorest farmers within poor counties to these technologies; and 3) technological progress and diffusion with other staple crops grown predominantly by poorer people.

Again, the HYV percentages within total area planted with these major staple crops are so high (see Table 3-2) that considerable diffusion into poorer prefectures and counties must have transpired. But what about the more advanced technologies such as hybrid rice? The two provinces with the largest numbers of very poor rice-dependent counties are Yunnan and Guizhou. These provinces displayed the lowest proportions of paddy area under hybrid rice among indica producers in 1986. This is not only because they are poor and their breeding systems are less developed. The geographic complexity of these provinces and their dependence upon developments for both semitropical and cold-tolerant indica rice (in their lowland and middle-elevation regions) as well as for japonica rice (for their highland regions) are major factors as well.

In Yunnan, the first hybrid variety developed was Nanyu #2, introduced from Guangzhou (Guangdong). In 1979, it was decimated by disease, accounting for reduction in hybrid area in 1980 and 1981 (see Table 3-7).[14] In Guizhou, the early hybrid varieties introduced were susceptible to cold fall winds which were especially severe in 1980, accounting for hybrid area declines in 1981 and 1982.[15]

In both cases, recovery was based largely on the introduction in 1982-83 of Xianyou #63, but the relatively late start with a suitable variety accounts for the low proportions of coverage in these provinces in 1986. Table 3-7 shows that hybrid rice area has expanded rapidly in both provinces since prior to the mid-1980s.

A logical question for those interested in diffusion is whether the increase is confined to relatively wealthy areas of these provinces, or whether diffusion is proceeding throughout Yunnan and Guizhou, including their poorest regions.

Table 3-8 indicates that hybrid diffusion has occurred and is increasing in all prefectures of Yunnan except Diqing, yet there are major differences in the proportions of paddy area covered and the speed of its increase in the 1980s. While the economic status of Yunnan's regions is not unrelated to these differences, the primary determinant is the agroclimatic environment, the most critical aspect of which is elevation. The administrative units with the highest average incomes, for example, as listed in Table 3-8, are Kunming and Dongquan Municipal Areas, and Yuxi and Dali Prefectures,[16] with low-to-average proportions of hybrids, each predominantly dependent on japonica varieties. Of the four, Yuxi, with the highest proportion of indicas, has the highest proportion of hybrids.

Table 3-7.

Area Sown with Hybrid Corn and Hybrid Rice Varieties, Selected Southern Provinces, 1976–95

	Hybrid Corn Area				Hybrid Rice Area				
	Yunnan	Guizhou	Hubei	Hunan	Yunnan	Guizhou	Hubei	Jiangxi	Jiangsu
				(thousand hectares)					
1976					...				
1977					0.2				
1978					2				
1979	98	53			24				
1980	116(10)	117(16)			16(2)	69(11)	165(6)	765(23)	656(25)
1981	89	87			12	decline			
1982	99	decline			14	decline			
1983	128	110			23	recovery			
1984	184	157			55	recovery			
1985	207	153			87	110			
1986	191(20)	169(27)			109(10)	113(15)	666(26)	868(27)	741(31)
1987	192(20)	178(29)	307(78)	53(47)	151(15)	160(22)			819(34)
1988	257(27)	233(39)	307(80)	70(63)	202(20)	302(41)	1200(47)		
1989	322	246	316	85	212	347	1400	1386	
1990 (plan)	333–366	300			233				
1995 (plan)	533								

Notes: Numbers in parentheses indicate the percentage of total provincial area sown with the specified crop that was sown with hybrid varieties.

Sources: Except for Yunnan and Guizhou, the 1980 (lower estimates) and 1986 data for hybrid rice are from Table 3-5. Sources for other data are:

Yunnan: Yunnansheng Zhongzi Guanlizhan [Yunnan Province Seed Management Station], *Yunnansheng zhuyao zuowu liangzhong tuiguang mianji (1979–1988)* [Yunnan Province Extension Area Statistics for Improved Varieties of Important Agricultural Crops (1979–1988)] (Kunming: Yunnan zhongzi guanlizhan, 1989), 1, 3, 7, 20, 28, 39, 55, 68, 87, 97, 119, 126, 145, 155, 174, 184, 206, 209 and Appendix tables (hereafter YZZLTM); Zhou Guorong and Cao Bingyi, Director and Deputy Director, Yunnan Province Seed Corporation, Kunming, January 9, 1990.

Guizhou: Wu Sikai, Production Dept., and Hong Ceyu, Agricultural Extension Station, Guizhou Province Bureau of Agriculture, Guiyang, January 2, 1990.

Hubei: Xiong Fengming, Hubei Seed Corporation, Wuhan, November 13, 1989.

Hunan: Liu Houau, Upland Grain Dept., Hunan Bureau of Agriculture, Changsha, November 24, 1989.

Jiangxi: Jiangxi Seed Corporation, Nanchang, December 2, 1989.

Jiangsu: "Hybrid Rice Harvested in Jiangsu," *The China Daily*, November 6, 1987.

Provincial data used to calculate hybrid area percentages: ZGNYNJ 1981, 23, 24, 27; ZGNYNJ 1987, 213, 216; ZGNYNJ 1988, 231, 234; ZGTJNJ 1989, 194.

The six prefectures with the greatest total area sown with hybrids are in the two southern rice zones, where most rice is grown at elevations below 1,500 meters (m) and where indica varieties predominate: Wenshan, Honghe, Xixuangbanna, Simao, Dehong, and Lincang. Some portions of Yuxi and Baoshan, with the seventh and eighth greatest areas under hybrids in 1988, are occasionally included with the northernmost of these two zones.[17]

Half of the hybrid area in Yunnan is sown with the indica hybrid Xianyou #63, originally introduced from Fujian Province in 1982 and now bred throughout much of the mountainous areas of the southern provinces. More than half of the remaining hybrid area in the province is sown with D-you #63, another indica variety.[18] These varieties increase yields by around 1,500 kilograms/hectare (kg/ha) over those of the improved varieties previously grown under similar conditions; and in the southern part of the province, by as much as three tons/ha.[19] An even newer hybrid, D-you #64, reportedly performs better than these two below 1,000 m and may become more dominant in the far south and lowland areas, but as of 1988, it was limited to 3,120 hectares.[20]

Guizhou's experience is roughly similar to Yunnan's with Xianyou #63 dominating the plantings (65 percent of total hybrid area in Guizhou) below 1,000 m, and Weiyou #64, another indica hybrid (accounting for 25 percent) predominant above 1,000 m. Availability of these two varieties over the past five years has substantially improved Guizhou's participation in the benefits from hybrid technology.

But not all of South China's mountainous areas are likely to grow even these shorter-season, cold-tolerant indica hybrids. There are no suitable hybrid varieties for northwest Guizhou, where (mostly japonica) rice is cultivated up to 2,000 m and which includes Guizhou's poorest counties.[21] Yunnan's North Central Japonica/Indica Paddy Zone includes most or all of Qujing, Chuxiong, Dali, Yuxi, Baoshan Prefectures, and Kunming Municipal Area. This region grew single-season indica rice almost exclusively until the 1970s, when japonica varieties partially replaced them owing to their superior taste and their greater ability to withstand cold, indispensable for the higher localities of the region. Most japonicas in this zone are grown between 1,700 m and 1,900 m (but 1,600-1,700 m in Baoshan),[22] which is beyond the most effective range of the leading indica hybrids. But the development of japonica hybrids has come later and more slowly. And the inferior taste characteristics of most hybrids relative to alternative japonica varieties may account for especially slow development in the wealthier areas of Kunming and Dali. The wealthier portion of the region grows japonicas even where indicas (and thus indica hybrids) could be grown.

This explains why the proportional coverage of hybrids is as great or

Table 3-8.

Area Sown with Hybrid Rice and All Improved Varieties in Yunnan Province, 1981–88, by Prefecture

	Area Sown with All Improved Varieties 1981	Area Sown with Hybrid Rice 1981	1982	1983	1984	1985	1986	1987	1988	Area Sown with All Improved Varieties 1988	Total Paddy Area Compiled 1988
	(thousand hectares)										
Kunming Munic. Area	33.23	–	–	–	–	–	0.02	–	0.05	63.03	64.91
Dongquan Munic. Area	–	–	–	–	–	0.01	0.08	0.11	0.23	1.47	1.87
Zhaotong Prefecture	18.19	1.42	1.23	1.45	2.03	2.43	3.07	4.94	8.61	25.94	31.72
Qujing Prefecture	55.33	–	–	–	–	0.43	1.88	1.89	4.65	66.56	73.38
Chuxiong Yi Minority Region	52.98	–	–	–	–	0.62	1.79	3.19	4.27	65.47	73.58
Yuxi Prefecture	42.13	1.60	2.63	4.79	6.80	5.94	6.36	7.99	8.75	41.64	48.70
Honghe Hani-Yi Minority Region	66.31	2.33	2.16	4.79	10.13	17.34	23.07	28.60	36.53	84.21	92.51
Wenshan Zhuang-Mao Minority Region	36.68	1.00	1.37	2.58	8.67	14.87	19.07	23.59	28.48	45.86	60.56
Simao Prefecture	17.92	0.65	0.93	3.25	7.16	11.80	12.21	20.33	28.00	62.86	87.06
Xixuangbanna Dai Minority Region	18.67	–	–	0.07	6.20	8.55	10.57	11.80	16.29	16.29	47.05
Dali Bai Minority Region	54.66	0.03	–	–	–	0.22	0.56	0.92	1.19	74.80	74.80
Baoshan Prefecture	43.26	0.65	0.59	0.73	1.35	2.51	3.95	6.87	11.08	68.65	68.65
Dehong Dai-Jingpo Minority Region	32.70	2.69	3.20	3.37	7.57	11.47	15.42	24.41	33.33	53.33	57.95
Lijiang Prefecture	11.57	–	0.17	0.24	1.19	2.07	1.64	1.80	2.33	15.37	22.69
Nujiang Lisu Minority Region	0.95	0.82	0.88	0.98	1.13	1.09	1.20	1.43	1.74	3.10	6.37
Diqing Zang Minority Region	2.13	–	–	–	–	–	–	–	–	2.67	2.90
Lincang Prefecture	13.86	1.00	0.73	0.66	3.07	7.72	8.07	13.47	16.00	16.00	69.10

Yunnan Province											
Hybrids	500[a]	12.37	13.89	22.89	55.29	87.08	108.95	151.29	201.54	707.26[a]	–
Total Paddy (compiled)	1,078	1,078	938	927	951	922	912	890	884	883.79	883.79
Total Paddy (official)	1,104	1,104	1,078	1,107	1,130	1,075	1,049	1,020	1,009	1,008.80	1,008.80

Note: Improved varieties include, but are not limited to, hybrids. Area sown with improved varieties reached 500,000 hectares or almost half paddy-sown area in 1979 and 1981, and exceeded 600,000 hectares in 1980. These compiled data exclude minor varieties sown on less than 66.7 hectares in a given year. They therefore underestimate the prefectural and national totals for both hybrids and improved varieties. Both the compiled totals for paddy areas in each year (whether sown with traditional or improved varieties) as well as the total for all paddy areas, including minor varieties and adjustments for underestimates, as given in Ministry of Agriculture and State Statistical Bureau publications, are listed at the bottom of the table. [a]Refers to all improved varieties, including but not limited to hybrids.

Sources: YZZLMT, 1, 7, 28, 55, 87, 119, 145, 174, 206 and Appendix tables (hereafter YZZLTM). Official SSB totals are from ZGNYNJ 1981, 24; ZGNYNJ 1983, 56; ZGNYNJ 1984, 85; ZGNYNJ 1985, 146; ZGTJNJ 1986, 176; ZGTJNJ 1987, 166; ZGNYNJ 1988, 231; and ZGTJNJ 1989, 194.

greater in Zhaotong, Lijiang, and Nujiang, with generally higher elevation but poorer inhabitants than in the North Central Zone. The Northeastern Zone includes Zhaotong, Dongquan Municipal Area, northern Qujing, and northeastern Kunming, while Nujiang, Diqing, and most of Lijiang and northern Dali comprise the Northwestern Zone.[23] Most of the hybrids grown in the three northern zones are in areas low enough in elevation to grow cold-tolerant indicas. The main hybrid varieties, even in these three higher elevation regions, are Xianyou #63 and D-you #63,[24] grown predominantly in relatively lower-elevation localities. The (japonica) paddy areas of Diqing are generally above 2,000 m and are completely out of reach of indica hybrids

But varieties for even the more demanding locations are being developed. A team from the Tropical Agricultural Research Institute in Japan has been cooperating with local breeders to produce a series of twenty-five japonica hybrids for extension between 1,700 m and 2,000 m in the Kunming area, of which four exhibit superior disease and cold resistance, as well as desirable taste characteristics. These may prove extendable to other North Central Zone locations,[25] but were still limited to less than 5,000 hectares in 1989.[26] Expansion is planned for approximately 30,000 hectares, although some features of these varieties have made extension more difficult.[27]

For more southerly locations Xunjiao #29 is an experimental japonica hybrid grown in Jianshui County of Honghe (Yunnan), which performs well up to 2,000 m and increases yields by 1.5-2.25 tons per hectare over varieties it replaces. And for more northern areas and especially high altitudes, He #16, developed in Dali, can grow well even above 2,000 m.[28] Although He #16 has been extended in 1988 to only 1,500 ha, entirely within the prefecture,[29] development of such varieties suggests that even Diqing may join the hybrid revolution before long.

It is one thing to move technology into poor regions, which is clearly occurring in Yunnan and Guizhou; it is another to extend it to the poorest people within those regions. Poorer inhabitants of a poor region are less likely to have paddy area, or as much paddy area; and even if they do, they are less likely to grow hybrids because they farm environmentally marginal fields (in Yunnan and Guizhou, usually at higher elevation) for which hybrids are only now being developed. They are also more likely to stand toward the end of the line of recipients as scarce hybrid seed is distributed. Seed distribution is governed more by local political considerations and the public interest in increased marketings than by poverty relief or equity.[30]

In Yunnan, the disadvantage of the poor in having access to technology is exacerbated by racial and language issues. Yunnan includes large populations of twenty-four officially recognized minority groups, concentrations of which are greatest in mountainous regions. If Han Chinese are farming as well as administrating and engaging in industry and commerce in a minority region, they are apt to be concentrated in the low-lying

paddy fields near the rivers and towns rather than in highland areas. These areas get first crack at new technology because they supply the towns with food, the paddy cultivation conditions are relatively good, and they can more easily afford to finance the complete package of complementary inputs, combining with hybrid technology to greatly raise yields. But there are also barriers of race and language.

Chinese-run administrative, technical, and commercial organizations deal more readily with Chinese speakers, and especially with Han Chinese. While a portion of minority group populations attend Chinese schools, and some who become fully bilingual are then trained to be extension agents,[31] the technical extension coverage in minority regions is unquestionably poorer. During the 1980s, 1,005 new technical stations were established in Yunnan at the township level; but in roughly 500 townships, such stations have not yet been established, all in areas dominated by minorities primarily cultivating upland rather than paddy or other irrigated crops.[32] Of the hundreds of farmers contacted as part of Winrock International's technical development projects located in mountainous regions of Wenshan (SE), Simao (SW), Zhaotong (NE), and Nujiang (NW), heavily populated with minorities, none had ever met an extension agent.[33]

To some extent, extension shortcomings arise from and are reinforced by a research bias. The technical problems and local economies of such regions are very poorly understood because they have not been seriously researched. Even the seed breeding organizations have tended to concentrate on the major agricultural areas that supply Han Chinese-dominated urban areas. Early in the 1980s, however, the Chinese Academy of Agricultural Sciences officially reestablished priorities in favor of poorer environments and the crops that are more suited to them. Several of the provincial academies followed suit. It must be recognized, however, that this is generally a much more difficult scientific task than to develop varieties for areas where conditions are more favorable.

While there is still relatively little research leading toward productivity improvements for many locally specific highland crops, there is generally more research activity in China than in most developing countries. Among crops widely planted throughout the world in both highland and lowland areas and for which technical improvements are achieved with relative ease, corn and potatoes hold particular potential for China's highland areas.

Historically, the most important productivity limitations for potatoes in China have been the lack of high-yielding genetic stock, late blight, and various forms of potato virus. The varietal problem was addressed between the 1940s and the early 1960s, with imports from Japan, the United States, Poland, the Soviet Union, and East Germany. Several of the imported varieties exhibited resistance to late blight, and were widely propagated and distributed, and used extensively in the nascent Chinese breeding system. One such variety, Mira, introduced from East Germany in the mid-1950s, still covers 400,000 hectares in China,[34] including 80 per-

cent of Yunnan's area planted with potatoes. However, it is susceptible to virus and after three decades its resistance to late blight has considerably diminished.[35]

The momentum in Chinese potato research dissipated in the late 1960s and did not revive until the development of virus-free stock in the late 1970s. The first virus-free seed farm in China was established in 1975 in Heilongjiang. By 1979, six others had been set up in Shanxi, Hebei, Shandong, Liaoning, Gansu, and Inner Mongolia, claiming yield increases of 150 percent for some forty virus-free cultivars. By 1982, one hundred such cultivars existed, and by 1987, ten farms provided seed to more than 114,000 hectares of fields.[36] Yet this accounted for less than 5 percent of the area planted with potatoes and, while these farms are continuing to serve new areas each year, the seed farm area is no longer expanding. This indicates that a greater portion of "virus-free" stock being used is of fourth, fifth, and sixth generation, no doubt losing its disease-resistance properties.[37]

In Yunnan, the only virus-free seed farm is located in Kunming and serves the relatively affluent surrounding areas. In northeastern and northwestern Yunnan, virus-free stock could improve yields with no additional inputs, by a factor of five or more, but none is available. Only very recently has this situation begun to improve. The International Potato Center (CIP) has provided forty varieties to a single potato scientist working at Yunnan Normal University. After two years of tests, he has identified three varieties that are promising for breeding and extension in east and central Yunnan. With limited funding from the Yunnan provincial government and the Qujing Prefectural Seed Corporation, and with assistance from a single staff member from the Kunming Municipal Bureau of Agriculture, along with farmers, county staff, and university students, Professor Wang Jun has set up a virus-free seed production base in a village at 2,500 m in Huize County (Qujing). Fifty thousand virus-free tubers were produced in 1989, primarily for local use. As the operation expands, the Qujing Seed Corporation will purchase the seed tubers for redistribution throughout the prefecture.[38]

This example shows the modest scale of research and dissemination of technology for even an important highland crop in poor areas of Yunnan and the role of serendipitous factors. It also demonstrates that human capital and institutions were already available to make rapid progress. In addition to the base at Huize, the selected virus-free CIP varieties have been sent on request to Xinping, Fuyuan, Guoshan, Menghai, Yuxi, Tengxiong, and Luquan Counties in Yunnan Province and to a few county leaders in Guizhou Province. Wang Jun has made contracts with Yunnan Agricultural University, Yunnan Genetic Engineering Laboratory, and Kunming Municipal Extension Station for rapid, including in-vitro, seed propagation.[39]

The long-term research picture for sweet potatoes has not been as

spotty as for white potatoes. China's breeding system has continued to crank out improved varieties bred for, or adaptable to, more and more areas, gradually including some poorer ones still dependent on sweet potato as a major staple crop and for food security. Yet Xushu #18, a variety bred in northern Jiangsu in 1972, still covers 45 percent of the sweet potato area throughout the country, demonstrating the much slower rate of varietal turnover than for wheat, rice, and corn.[40] Critical problems of postharvest technology (as well as market imperfections) are not being addressed in many provinces: in some, losses can reach 60 percent under extreme conditions.[41] The ambivalence of the authorities in further developing potato and sweet potato production in advanced areas where surpluses have appeared has tended to inhibit research on these commodities, despite their importance for poorer localities and the difficulties in transferring those surpluses to poorer areas. The unresolved postharvest problem has led planning authorities to emphasize corn rather than sweet potatoes in low-cost feed development plans, even in areas more environmentally suited to sweet potato cultivation.[42]

The most energetic effort to develop and disseminate HYVs of staple crops, which could greatly benefit poor areas, has involved hybrid corn. In Hubei, hybrid corn yields average five to six tons per hectare as compared with three to four tons for the varieties it replaces, under similar conditions. In the poorer provinces of Guizhou and Yunnan, increments cited for hybrid corn are sometimes greater still.[43]

According to agricultural ministry and academy specialists in Beijing, hybrid corn now covers around 90 percent of China's corn area. Table 3-7 shows that dissemination is increasing in many southern provinces, including the poorest ones, and Table 3-9 shows that dissemination of hybrids is increasing in most prefectures of Yunnan. Yet the regions with the lowest proportions of hybrids are generally among the poorest.

In Yunnan, where most prefectures are poor, hybrid coverage for Kunming and Dongquan Municipal Areas, and for the Yuxi, Chuxiong, Dali, and Lijiang Prefectures all surpassed 44 percent in 1988, all but Lijiang among Yunnan's more prosperous jurisdictions (see Table 3-8). In Guizhou, significant inroads have been made during the 1980s, with hybrids covering around 40 percent of provincial corn area in 1988 and 1989 (see Table 3-7). But in Guizhou's poorest prefecture, Bijie, where most corn is grown at around 1,700 m, and with some fields above 2,000 m, there are no suitable varieties. Yet Bijie is one of Guizhou's principal corn-growing prefectures and is highly dependent on corn and potatoes. During the last two years, hybrids have been adopted at lower elevations in Bijie, with the use of plastic sheeting to protect early growth.[44]

In the somewhat wealthier provinces of Hunan and Hubei, corn is most heavily concentrated in the poorest, most mountainous prefectures with the lowest proportion of hybrids: Xiangxi, with 50-60 percent of Hunan corn area, and Woxi in Hubei. Yet the data presented in Table 3-7

Table 3 – 9.

Area Sown with Hybrid Corn and All Improved Corn Varieties in Yunnan Province, 1981 – 88, by Prefecture

	Area Sown with All Improved Varieties 1981	Area Sown with Hybrid Corn 1981	1982	1983	1984	1985	1986	1987	1988		Area Sown with All Improved Varieties 1988		Total Corn Area Compiled 1988
	(thousand hectares)									(%)		(%)	
Kunming Munic. Area	3.07	1.20	1.33	1.47	18.05	17.73	17.95	19.11	24.87	(71)	31.42	(90)	35.01
Dongquan Munic. Area	–	–	0.20	0.03	0.79	2.67	2.60	1.13	2.47	(55)	3.20	(71)	4.50
Zhaotong Prefecture	112.84	11.93	10.67	15.67	21.33	21.33	20.49	18.49	29.93	(20)	100.65	(68)	147.61
Qujing Prefecture	94.00	27.63	42.61	62.04	63.33	73.13	43.58	39.23	50.47	(44)	50.47	(44)	115.91
Chuxiong Yi Minority Region	33.20	7.95	10.69	10.21	11.33	14.87	14.57	15.80	19.29	(52)	20.26	(54)	37.28
Yuxi Prefecture	11.40	4.28	3.11	3.80	8.20	7.67	9.98	8.94	12.01	(57)	20.13	(96)	20.89
Honghe Hani-Yi Minority Region	65.41	4.08	4.94	5.74	11.13	11.87	8.52	13.63	16.90	(21)	63.10	(80)	79.03
Wenshan Zhuang-Mao Minority Region	65.70	3.77	0.45	0.27	0.80	4.00	5.12	5.31	5.57	(5)	60.01	(50)	120.33
Simao Prefecture	1.40	2.47	0.73	0.80	3.87	3.67	5.88	6.93	12.08	(10)	26.30	(31)	84.60
Xixuangbanna Dai Minority Region	–	0.42	–	0.53	0.20	0.73	4.61	2.59	2.77	(17)	4.00	(24)	16.78
Dali Bai Minority Region	47.29	9.15	7.20	10.67	18.67	19.00	20.31	22.27	27.38	(45)	51.58	(84)	61.30
Baoshan Prefecture	40.58	1.65	1.67	3.77	6.20	9.00	9.95	10.67	14.89	(29)	50.96	(99)	51.70
Dehong Dai-Jingpo Minority Region	–	0.01	–	0.10	0.03	0.13	0.83	1.04	0.85	(9)	0.85	(9)	9.58

Lijiang Prefecture	12.99	8.40	6.11	8.22	16.53	12.82	15.25	17.77	20.20	(59)	23.77	(69)	34.27
Nujiang Lisu Minority Region	2.33	2.31	2.00	0.80	1.40	0.13	0.24	0.19	3.78	(4)	11.00	(13)	87.66
Diqing Zang Minority Region	–	1.04	1.89	2.17	1.33	3.73	5.13	4.54	2.67	(18)	7.66	(51)	14.94
Lincang Prefecture	3.66	1.76	5.71	2.00	0.43	4.20	5.57	4.00	11.00	(13)	11.00	(13)	87.66
Yunnan Province													
Hybrids	494[a]	89	99	128	184	207	191	192	257	(27)	537.35[a]	(57)	–
Total Corn (compiled)	1,087	1,087	1,048	1,019	975	920	937	953	945		945.08		945.08
Total Corn (official)	1,087	1,087	1,048	1,019	975	920	937	953	945		945.07		945.07

Note: Percentages indicate area in each prefecture sown with hybrids, and with all improved varieties (including hybrids), respectively, in 1988. Corn area is apt to be underestimated in compiled and official data, particularly in highland areas where it is cultivated on slopes not included among official cultivated area statistics.

[a] Refers to all improved varieties, including but not limited to hybrids

Source: YZZLTM, 3, 20, 39, 68, 97, 126, 155, 184, 209, and Appendix tables thereafter. Sources of official data are cited in Table 3 – 8.

suggest that rapid dissemination of hybrids must have occurred even in these prefectures during the last few years.

The breeding system has not yet been adapted to the needs of many poor areas that face unusual environmental constraints, even though existing technology can considerably improve yields in such localities. These areas are lagging for a number of reasons, in addition to environmental difficulty and to shortcomings in research and extension.

The successful adoption of existing hybrid varieties is more apt to require the use of plastic sheeting in highland areas, and the returns are greatest when additional fertilizer is used. The allocation bias against poor areas for either of these complementary inputs can inhibit adoption. In most provinces, price subsidies are provided to the poorest counties, recognizing that farmers in such areas are less able to afford them at market prices. Most provincial governments, however, try to hold down their subsidy burdens, which results in low levels of allocations to poor counties.

The complementarity is even more pronounced with hybrid rice varieties which often achieve lower yields than the varieties they replace at low fertilizer application levels. The high price of hybrid rice seed makes the survival rate of seedlings, considerably increased with plastic coverings for seedbeds, an important consideration. In Fugong County (Nujiang Prefecture, northwest Yunnan), the survival rate averages 90 percent with plastic sheeting and 20 percent without.[45]

Guizhou Province has recognized the urgent need for plastic sheeting to facilitate yield-increasing hybrid adoption in its poor, mountainous localities. In 1989, 43.6 percent of Guizhou's plastic for agriculture was allocated to the province's 17 poorest counties. But total coverage amounted to only 33,800 hectares, a tiny fraction of the requirements.[46]

An even more fundamental problem for hybrid adoption in poor localities is the availability of hybrid seed. When hybrid seed is imported from other provinces, it usually costs the provincial seed corporation several times what it pays within-province farmers, and the same difficulties with increasing the extension of other expensive inputs to poor areas apply to seed. Yet while within-province production has increased considerably in most provinces, the more advanced areas where seed production is centered lay claim to a large share of the seeds produced. Furthermore, the inability of seed corporations to guarantee seed farmers adequate and assured quantities of grain at stable prices has inhibited specialization of seed production among seed-producing farmers and, consequently, has slowed down the growth of hybrid seed production area.[47]

The above discussion shows that in southern China, there are a variety of factors that contribute to the slower rates of technological adoption in the poorer areas. In China's case, difficulties other than farmer risk avoidance and low cash availability seem to be the most inhibiting. Yet the data show that despite these limitations, adoption of hybrid corn and rice is proceeding in poor southern counties.

Chinese Reforms and the Diffusion of Staple Crop Technology

The exceedingly rapid growth in foodgrain production during the latter part of the 1970s and the first half of the 1980s was predominantly the product of technical change: the result of gains from investment in first-stage technological transformation in the previous decades, including improved water control, development of research, breeding, and seed production, and extension of high-yielding and early-maturity staple crop varieties. Some returns on investment followed immediately, as improved varieties and better water control were made available, yet much fuller realization of the gains came with the elimination of the final constraint, the insufficient availability of soil nitrogen and phosphate. With the fulfillment of this last basic requirement, dating from the late 1970s, the difference between actual and potential yields from HYV staple crops quickly narrowed throughout China's major growing areas. Yield growth, calculated in terms of national averages, accelerated to high and unsustainable rates, and then, inevitably, slowed down.[48]

As the data indicate, some of the growth involved more complete extension throughout China of fertilizer-responsive and stress-resistant varieties; another part, especially for rice, can be associated with further varietal improvements on farming areas already planting HYVs. But the largest share of the gain was accomplished by significantly narrowing the gap, over vast regions of China's nutrient-deficient soils, between the nutrient requirements of HYVs and nutrients actually provided by soils, manures, and manufactured fertilizers.

Production progress for staple crops during the last fifteen years has consisted primarily of progress with yields, while sown area for staple crops as a whole and for most individual categories actually declined during the 1980s. The fastest growing yields have been those for sweet potatoes, white potatoes, and the principal Green Revolution crops (rice, wheat, corn, and sorghum). An examination of their yield trends in Figure 3-3 suggests four general observations: 1) the yield patterns of these crops are strikingly similar; 2) they reflect sustained and fairly rapid growth for almost three decades; 3) ignoring the poor weather years, 1959-61, there appear to be at least two and probably three important points of inflection for the major cereals (rice, wheat, and corn)—one between the late 1950s and the mid-1960s and another in the mid-to-late 1970s; 4) only the first point of inflection is relevant for sorghum and sweet and white potatoes; if anything, there is a slight deceleration of yield growth in the root and tuber crops in the mid-1970s; and 5) a third common inflection point, in this instance a deceleration, appears to have occurred between the early and late 1980s, generally after 1984.

When linear trends are fitted to this data, it is discovered that the inflection points marking the beginning of the fastest period of yield growth all predate the institution of the household responsibility system (early 1980s) and even the beginning of the reform period (1979). (Chapter 2 examines the agricultural reforms in China, particularly the household responsibility system.) The closest linear approximations are achieved when the breaking point is around 1972 for corn, 1973 for wheat, and 1978 for rice.[49] In fact, a linear trend is not really ideal for the 1970s: the data for rice, wheat, corn, and sorghum yields more closely describe a hyberbolic acceleration typical of technological change. Thus the causes of this acceleration are likely to be found among technical developments originating during the previous decade.[50]

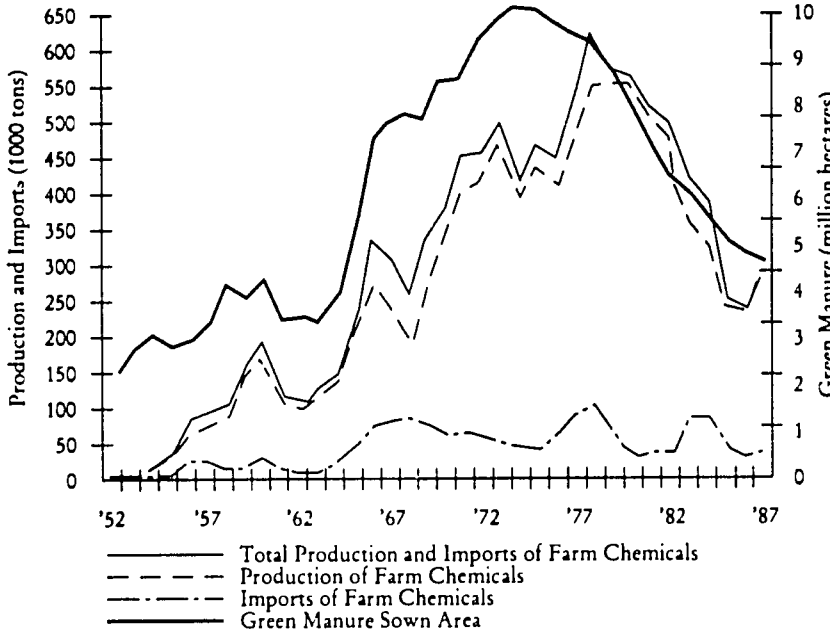
Some analysts[51] point to the dissolution of the communes and the introduction of the household responsibility system as important factors in bringing about the 1980s' staple crop growth. The argument is made that farmers' incentives to produce were greatly increased by the establishment of household rather than collective accounting and the return to something akin to private farming. Unfortunately, the attempts at estimating these effects in a country as complex as China are still too crude to be relied on for aggregate quantitative accuracy. Further, the degree to which the current Chinese system resembles private farming without state control and the degree to which the former system could operate in complete disregard of local income incentives have been exaggerated in these accounts.[52]

There is no question that the responsibility system, initiated between the late 1970s and mid-1980s, was fundamental to rapid growth in nongrain foodcrops, noncrop farming categories, and nonfarming rural categories of economic growth. But the effect on foodgrain production, in and of itself, could easily have been, and probably was, negative. Fertilizer purchases in previous decades were constrained not by demand but by inadequate supplies.[53] Green manure cultivation on foodcrop land plummeted (see Figure 3-7), as many farmers were doing more immediately profitable things with their time in the winter. Large quantities of land were taken out of foodgrain production during the period — 10.5 million hectares, between 1978 and 1988,[54] a decline of 8.7 percent — and converted to more profitable economic crops, or retired as marginal land, or developed for construction purposes. Multiple cropping reductions occurred as individual farmers found the degree of foodgrain cropping intensity promoted by local authorities, particularly triple cropping, to be uneconomical. All of these trends can be linked to the responsibility system, related adjustments, and to greater decentralization of authority.

While the population continued to grow in rural areas, there was a massive withdrawal of hundreds of millions of people, occasioned by the reforms, from concentrated attention to staple crop farming. The argument is made that there was nevertheless a net increase in effective labor,

Figure 3-7.

Production and Imports of Farm Chemicals and Area Sown with Green Manure Crops, 1952–87



Notes: According to two other sources, green manure area reportedly peaked at around 13.2 million hectares sometime in the 1970s, but the exact date was not mentioned. Also reported for 1980 were 9.961 million hectares, and 6.6 million hectares for 1987. These may refer to an expanded definition of green manure crop inclusion. Regardless of definition adopted, the general pattern of long-term rise and recent decline is certain.

Sources: Green manure: Zhongguo Nongyebu Turang Feiliaosi, "A Decade of China's Chemical Fertilizer Work," *Zhongguo nongbao* 17 (1959): 25; *Renmin ribao*, June 5, 1965; ZGNYNJ 1980, 96, 97, 349; ZGTJNJ 1981, 138, 141; ZGNYNJ 1981, 22; ZGNYNJ 1982, 81; ZGNYNJ 1983, 48; ZGNYNJ 1984, 83, 96; ZGNYNJ 1985, 143, 157; ZGNYNJ 1986, 176, 191; ZGNYNJ 1987, 208–209, 227; ZGTJZY 1988, 25; NYJJZL 1949–83, 133–39; "Land Sterility," *The China Daily*, May 15, 1988. Area data for 1966–69 are estimated from data for "other crops" for those years, including vegetables, melons, green manure, and green fodder crops. The proportions attributable to green manure crops are derived by linear interpolation using pre-1966 and post-1969 data. Data in notes are from "Land Sterility"; Zhang Xiaohua, "Tuiguang dong lüfei" [Extension of Winter Green Manure], ZGNYNJ 1981, 149; Sun Han, "Organic Farming—Growing Plants the Organic Way," in Sylvan Wittwer, Yu Youtai, Sun Han and Wang Lianzheng, eds., *Feeding a Billion* (E. Lansing. University of Michigan Press, 1987), 116.

Farm chemicals: ZGNYNJ 1980, 40; AGTJZY 1988, 42, 87; NYJJZL 1949–1983, 293. PRC SSB, *China Trade and Price Statistics in 1987* (Beijing: China Statistical Information and Consultancy Service Center, 1987), 199–200.

because the intensity, duration, and quality of work improved with the responsibility system incentives.[55] But the critical question is whether foodgrain production in China was more constrained by shortages of labor or of fertilizers. On China's nitrogen- and phosphate-depleted soils,[56] with limited quantities and limited effectiveness of recyclable organic manures, the fertilizer-responsive varieties fundamentally lacked soil nutrients. A large part of this deficiency could only be addressed by manufactured fertilizers.

If technological change (including water control, HYVs, fertilizer use, and other techniques and industrial inputs) has been the principal basis for staple crop production growth in China, how has this process been affected by reforms? In addition to the household responsibility system and rural economic diversification, the reforms explicitly included: the institution of relatively free markets, supplementing the governmental marketing activity; a 20 percent increase in procurement prices, plus a 50 percent increase for over-quota deliveries; and regional reallocation of cropping specialization. To this list must be added various other institutional adjustments, including decentralization of financing for agricultural investments such as water control and extension systems and efforts to make such systems (including fertilizer deliveries) more financially self-supporting. These adjustments were made necessary by the immense food subsidy burden which followed the increases in procurement prices, foodgrain production, and urban populations (1979–84), without a commensurate increase in urban sales prices. The government's role as buyer of last resort for foodgrain products was formally eliminated in 1985, and state procurement was placed on a contract system which directly linked farmer deliveries of grain crops with government provision of specific fertilizers and other inputs.[57]

Regional Specialization

Regional specialization in cropping has had an important positive effect on economic crops. Along with foodgrain sales guarantees, higher purchase prices, tied fertilizer deliveries, and other measures, it has brought about a tripling of output in many economic crop categories between the mid-1970s and the late 1980s.[58] But aside from the large net loss of staple crop land to economic crops, the regional reorganization has had relatively little aggregate effect on foodgrain production. The principal increases have been for soybeans and several lower-valued coarse grains more suited to marginal areas, in which government-sponsored wheat and corn expansion had displaced them. Such adjustments have generally been sensible and important to local, often poorer, communities, particularly when accompanied by greater farmer choice in crop selection. Yet the aggregate impact has been relatively small and probably does not counterbalance the reassignment of higher-quality staple crop land to economic crops.

Price Changes

Price changes certainly helped to maintain incentives to concentrate sufficient labor and inputs, especially fertilizers, on grain crops, despite the liberalization of more profitable economic activities. Without price increases, the absorption of massive quantities of fertilizers required for the yield increases would have been much more difficult. Some of the most important price adjustments in promoting fertilizer application to staple crops were indirect ones, and were supported by market restrictions. Of particular significance was the tying together of deliveries at subsidized prices of a large amount of high quality fertilizer to grain sales.[59]

Adjustments in Markets

Price increases helped to maintain grain production incentives, but probably were larger than necessary and contributed to the budgetary problems which forced the government in 1985 to eliminate its role as guaranteed buyer of staple crops. For some lower-valued foodcrops, this had a depressing effect in surplus areas. In a single year the marginal rate dropped from a very high level to a very low level, inasmuch as local market prices in surplus areas were not adequately buoyed up for lower-valued crops,[60] and excess demand arose in deficit areas, owing to a low level of national market integration. This underdevelopment resulted from poor transportation and communication infrastructures, local administrative and policy barriers, and from lagging development of private marketing institutions.

The availability to farmers fulfilling their contract obligations of private market alternatives for more highly valued foodcrops undoubtedly had a positive effect on farmer incentives to produce them. Since yields were constrained primarily by inadequate fertilizer supplies, the appropriate interpretation is that the availability of private markets helped to maintain incentives to increase production in the face of rapidly rising availability of fertilizers and access to other income-earning activities.

Budgetary Adjustments

More importantly, the price increases were accompanied by major budgetary adjustments. State investment in agriculture declined from 10 percent of the capital construction budget during most of the 1960s and 1970s, and 14 percent in 1978, to 3 percent in the period 1985–88.[61] The decline was particularly significant for water control projects, which declined, according to official data, by 2.1 percent (1978–85).[62] While some regions and localities were able to handle the decentralization in financing, many, including the poorest areas, were not. These financial problems were exacerbated by the greater difficulty of organizing cheap or free farm labor to maintain irrigation systems. The pace of new irrigation construction

declined considerably, while deterioration and capacity reduction in existing systems accelerated, especially in poor areas (see Table 3-6).[63]

Investment in thirteen large-scale synthetic ammonia/urea complexes in the early 1970s made possible a rapidly increasing supply of nitrogen fertilizers in the late 1970s and early 1980s. But by the mid-1970s, national investment in new fertilizer production capacity had fallen precipitously. From 1979 to 1985, budgetary problems brought on by the price increases insured that investment in new capacity remained at low levels through the mid-1980s. Reliance on imports, requiring scarce foreign exchange, to maintain supply increases has kept distribution excessively focused on market-oriented areas where fertilizer use is already intensive and marginal response is relatively low.[64]

There were also important effects on fertilizer prices. The effort to reduce the budgetary drain from fertilizer subsidies in market-oriented areas led to high marginal prices for fertilizer delivered at above contracted quantities.[65] This was especially disadvantageous for middle-level and poor localities where fertilizer is generally scarce, and which are less linked into abundant high-quality supplies through the public farm product marketing system.

The task of the extension system was made considerably more complicated by the dissolution of collectives. Seed production and distribution were placed on a commercial basis. Although these organizations typically run large deficits, economic factors have led to a concentration on seed distribution for highly valued crops (including hybrid rice and corn seeds) for major commercial areas. Provision of improved seeds for non-maize coarse grains and for root and tuber crops in the poorer areas has clearly fallen further in priority. There is also evidence that economic factors, including the high price of hybrid seeds imported from outside the province, and the expense of providing guaranteed quantities of subsidized grain to within-province farmers specializing in seed production, have inhibited the rate of expansion of supplies of hybrid seed.[66] Despite these limitations, area under cultivation with corn and rice hybrids has increased, even in poor areas.

The foregoing suggests that the whole package of reforms, including budgetary adjustments, had divergent and complex effects on foodgrain production. The overall effect, net of higher prices and private market opportunities, was almost certainly negative. Even these positive measures must be viewed in terms of maintaining rather than creating incentives to purchase fertilizers and to apply them to foodcrops. As fertilizer supplies rapidly increased, rural economic activities were liberalized, and labor was withdrawn from staple crop production.

Grain Production Stagnation (1985-89)

How then should grain production stagnation be viewed? One can suggest in general that this should be viewed without too much alarm. Diversifica-

tion away from excessive concentration on staple crops was, after all, a specific goal of the reforms. Gross value of agricultural output, calculated at constant prices, even during these "stagnation" years, increased by an average of 4.4 percent per year.[67] Grain output value actually increased between 1984 and 1988 (even without considering adjustments for quality improvements within crop categories) and has set a record in total quantitative terms in 1989, despite economic retrenchment.

There are a wide variety of causes for the deceleration in grain production growth during the 1985–89 period. The most important is that the differential between potential and actual yields had closed substantially in China's major market-oriented foodgrain areas, as the required fertilizers had been supplied. Thus a significant deceleration from the unsustainably high rates of the 1978–84 period was inevitable. Further growth in foodgrain yields will depend on increased distribution of fertilizers to middle-income and poorer areas, continued technical change in all three basic categories throughout China, and (inevitably slower) improvements in the efficiency of these systems and in the quality of associated inputs. There is ample evidence that progress in these areas is continuing.[68]

Several special conditions also contributed to grain production stagnation during the 1985–89 period: a decline since the late 1970s in multiple cropping (recovering since 1985) and in irrigated area (recovering since 1986) due to financial retrenchment and decentralization (see Table 3–1); decline since the mid-1970s in fertilizer production capacity completions (recovering since 1985); massive dislocation in foodgrain and fertilizer markets (1985–86);[69] nationwide hybrid seed shortage (1988); a farm credit crisis (1985–89); failure of the government to pay cash for grain deliveries (intermittent throughout 1985–89);[70] net deterioration of foodgrain purchase prices (1985–88); periodic exclusion of grain from free markets (1986–89);[71] and an increase in the marginal price of several fertilizers (especially since 1986), hybrid seed, and plastic sheeting. Yet most of these problems have become less serious at the close of the decade.

China as a Source of Technology and Agricultural Innovation

Some of the world's earliest agricultural civilizations existed within the area of modern China. China is the genetic center of origin for numerous foodcrops of global significance, including rice, several millets, Chinese sorghum, soybeans, and other bean crops. China's size, geographic diversity, and its historic and present barriers to the movement of people and products have combined to allow the development of genetically diverse plantings of several other important foodcrops, such as wheat, corn, and sweet potatoes, imported centuries ago from other parts of Asia and the

western hemisphere. China, in addition, enjoys a wealth of unusual varieties of medicinal herbs, fodder grasses and legumes, tropical fruits, tree crops, and edible roots. Thus, collection, taxonomy, and presentation of China's genetic resources and the continued development of genetic exchange with China is of considerable importance.

It is less well appreciated that China is an important innovator of agricultural technology, especially in applied research, development, and extension of simpler and inexpensive forms of imported technology, and with regard to sophisticated farmer practice under conditions of low capital/labor and low land/labor ratios. It is currently fashionable to point to the inefficiency of socialist systems, yet China's generation and diffusion of technology are worthy of closer study by the rest of the world. A partial listing of significant innovations may be useful.

Hybrid Rice

An area of research investigated and then dropped by scientists in Japan, the United States, and Europe during the first half of the twentieth century, hybrid rice development has been pursued aggressively in China since the 1960s. Several Chinese hybrids now have the highest per unit yield potential of all rice varieties. While reservations have been expressed regarding the economic viability of hybrids outside of China, continued research and development in China over the past fifteen years, and improvements in subsequent varieties, have ameliorated many of the shortcomings. The difficulty and expense of breeding work remains a limitation for some other national systems, but the greatest costs have already been borne by China, where breeding procedures are continually being streamlined.

HYVs for Other Cereals and Distant Crosses

Yield potentials of Chinese-bred varieties for wheat, corn, and sorghum, as well as on-farm yields in high-input regions, match the best in the world, while average-yield levels already surpass those of most developing nations and several developed countries. China is a center for work on distant crosses, including proven successes such as triticale, wheat-elytigia, and indica-japonica rice, as well as more exotic crosses like rice-sugarcane and rice-sorghum. Substantial work on upland rice varieties for North China is being planned.

Sweet Potatoes

Sweet potato research in the advanced countries has almost disappeared, along with cultivation, while the overworked breeding and research sys-

tems of countries where the crop is of greater economic and food security importance rarely allocate sufficient resources to sweet potato development. China has a large and active sweet potato research and breeding system and produces four-fifths of the world's output. This consists primarily of short-maturation period varieties, often planted in less hospitable seasons, with modest use of inputs and often on poor quality land. Yet mean yields for sweet potatoes in China are substantially above the national averages of other major producers. China is working with the International Potato Center on promising crosses between domesticated and wild species.

Varieties Resistant to Environmental Stress

Of particular interest to many regions of developing countries are the Chinese varieties tolerant of, or resistant to, various forms of environmental stress, including waterlogging, flash floods, hot winds, heavy rain and hail storms, low temperatures, various types of poor soils, insects, diseases, and, particularly, lodging and drought. A few significant breakthroughs occurred during the 1970s; since the early 1980s crop research and development on behalf of environmentally stressed areas have become an official priority of the Academy of Agricultural Sciences.

Significant improvements in varieties in the last few years have been extended to several poor regions. China's ability to marginally adjust cropping systems and seasonal timing, combined with varietal improvement aimed at minimizing losses from locally defined environmental stress, is an underappreciated contribution to improvements in stability and mean levels of grain production.

Rapid Application of Research Results

For new seed technology, China's system for moving research results through development, testing, and registration procedures and on to seed production and extension is perhaps the most rapid in the world. This involves between three to five years for wheat and rice in the fastest regional systems, as opposed to the seven to twelve years that is more typical internationally. During the 1950s and 1960s there were substantial penalties paid for overhasty extension, repeated on a smaller scale in the late 1970s and the early 1980s with hybrid rice and corn. But China has now substantially reduced the riskiness of the system. This has been an extremely important factor in prolonging growth in cereal yields in advanced regions where farm yields quickly approach experimental potential. In such regions, major varietal turnover may occur every two to three years, though the national average is twice this interval.

Plant Tissue Culture

The speedy turnover process is, in part, the result of aggressive development of tissue culture research, collapsing generational time requirements and increasing breeding precision. Such techniques are skilled-labor-intensive but require relatively inexpensive equipment, making them especially attractive to capital-poor countries with good educational systems in agricultural sciences. Important tissue culture results date from the early 1970s in China and now cover all major foodcrops, economic crops, fruit, vegetables, fodder crops, and medicinal herbs.

Intercropping

China, where the technique originated and first developed as a subscience, is still unquestionably the intercropping center of the world. The difficulties it presents for mechanization of on-field activities seem to have dampened interest in developed countries. Chinese farmers use intercropping as a way of maintaining soil health while generating greater output value per unit of land. Judiciously selected pairs of crops compete less for soil nutrients when planted in alternating rows. But the technique is also used for control of insects and disease transmission. As environmental problems and production sustainability issues receive greater attention, enthusiasm for the growing fund of Chinese research and farmer experience may increase. The potential attractiveness for less developed countries is especially clear.

Plastic Sheeting and Plastic Soil Mulch

Polyvinyl chloride and polyethylene plastic films used as seedling covers transmit sunlight for plant growth while at the same time protecting plants from cold and freezing temperatures, hot desiccating winds, and excessive rain and hail, all of which present problems in regions of China. Used primarily to protect high-priced vegetables and fruit in the West, plastic sheeting was first employed in China in 1958 as cover for rice seedling beds. By 1965, use had spread to selected localities throughout China[72] as a means of extending the growing season, reducing cold weather risk, facilitating increased crop intensity, and extending the range of several important crops to higher elevations and more northern latitudes. But it was not until 1979 that China's Agricultural Inputs Corporation began to supply plastic sheeting on a large scale. Within two years, sheeting covered an area of 2.2 million hectares. In 1989, 300,000 tons of plastic sheeting were supplied to farmers.[73] This provides for an incremental coverage of 0.8-2.0 million hectares, depending on the thickness of plastic provided.

Plastic sheeting is now widely used on a variety of field crops during the early stages of plant growth. A recently developed Chinese product is

capable of blocking or diffusing intense sunlight but intensifying weaker sunlight. The price, supply, and product durability of standard types of plastic sheeting now rival the quality and quantity of fertilizer and hybrid seed, in terms of farmers' input concerns in temperate rice-growing regions. While supply to many poorer regions is inadequate or nonexistent, plastic sheeting is almost ubiquitous in most rice regions, is becoming widespread in highland areas in order to extend hybrid corn, and is frequently observed elsewhere.

A logical extension of plastic sheeting for conserving resources is the construction of plastic greenhouses, not only for high-priced fruit and vegetable crops, but also for rice seedlings in areas with cold spring weather. Even Guizhou, one of China's poorest rice growing provinces, had in 1987 plastic greenhouses for rice seedlings covering 11,300 hectares, and 26,700 hectares by 1989.[74]

Plastic soil mulch was introduced from Japan during the 1970s for use on municipal vegetable gardens, and its use spread quickly: from 5,000 hectares in 1980 to 1.3 million hectares in 1984, primarily on cotton (64 percent), peanuts (12 percent), and vegetables and fruit (10 percent). During the latter half of the 1980s, its use has increased on corn, potatoes, and sugar crops so that application in China is now more varied and extensive than anywhere in the world.[75]

Soil mulches, like sheeting, increase and stabilize soil temperature and are useful for raising production by allowing earlier planting of longer-season, higher-yielding varieties, or the substitution of shorter-season varieties. These mulches can facilitate the cultivation of an additional crop within the year and limit soil desiccation in arid areas. Mulches are also used increasingly in advanced areas for weed control, as rising opportunity costs for labor combine with poor factor mobility to reduce traditional hand weeding. Weed control is particularly important because of the quantities of fertilizers applied, at a time when herbicide supply remains limited, uncertain, and expensive.

Biological Control of Diseases and Pests

From the mid-1960s to the late 1970s, the development of biological plant protection techniques was given emphasis as research-intensive control mechanisms that would obviate the need for industrial and imported inputs. Much of this emphasis dissipated in the early 1980s as the new leadership embraced internationally popular chemical products to improve soil fertility and control pests and diseases, just as alarm over farm chemical use was growing in the rest of the world. Nevertheless, China banned DDT and BHC on edible crops in 1978, finally enforcing a total ban, complete with import controls and moratoriums on supply of basic chemicals to factories in 1982–83. China purchased additional biological technology

from several American firms that went bankrupt from the expensive registration procedures matching those for chemical industry products at the time. But despite an apparent decline in output from factories, as reflected in official data (Figure 3-7), more potent and dangerous farm chemicals were imported or produced illegally, causing serious problems in China in the mid-to-late 1980s.

Research and development emphasis on biological controls has reintensified, and China already is one of the world's leaders in both variety of techniques and extent of farm coverage. One type or another of control now covers twenty million hectares—roughly one-fifth of Chinese farmland.[76] The most broadly extended technique is the mass breeding and release of predatory and parasitic insects, such as Trichogramma wasps. Others include the fabrication of insect and disease resistant natural pollens, bacterial and viral control, techniques for flooding combined with innovative use of frogs and ducks, and the use of beneficial insect varieties.

Organic Manures and Other Soil Treatments

China is by far the world's leader in the application of organic manures, as measured by the quantities and varieties applied, extent of adoption and technical sophistication of the average farmer, and by scientific research. The almost ubiquitous use of organic manures is one of the principal reasons growth in nitrogen use and average yields have increased so rapidly during the 1970s and 1980s. This also explains why Chinese soils can be farmed so intensively and productively on a sustainable basis. The total use of organic manures is estimated at 25-30 million tons of nutrients annually, or around ten tons of materials per cultivated hectare.[77]

In sophisticated farming areas, techniques for storing, fermenting, disinfecting, and applying manures have improved, partly as the result of the development of cheap but effective biogas generators. While the biogas fad flourished and then disappeared throughout much of the world, China reached extension levels of approximately twelve million family-size units concentrated in Zhejiang, Hunan, and Sichuan, where climatic conditions are favorable, and developed a few large and successful municipal units. Predictably, the extension efforts failed in areas outside the optimal climatic zones.

As with other areas of research, China has continued with biogas development and is successfully extending the practical frontier, now enclosing all central and southern provinces, and even much of North China.[78] Biogas digesters not only furnish cheap energy for household and modest production uses, but also provide hygienic anaerobic housing for wastes, limit the spread of disease, reduce nitrogen volatilization losses from manures, and add absorbable proportions of other nutrients through fermentation gains.

Traditional Chinese green manure crops such as sesbania, astragalus, alfalfa, clovers, legumes, and vetches have suffered substantial area losses during the 1980s as a result of greater individual control over cropping decisions, closer links between farm production value and farmer income, and higher food and economic crop prices (see Figure 3-7). But China remains one of the principal areas of research and on-farm use of azolla and nitrogen-fixing algae, which have not experienced on-farm declines. China also is an important source of research, development, and practical experience involving a variety of soil additives and inorganic soil treatments.

Fresh Water Aquaculture

Japan is the unquestioned technological and production leader in marine aquaculture, yet China reigns in fresh water fish farming and has done so for most of recorded history. Treatises on the construction of ponds, collection, hatching, and growth augmentation techniques date from at least the fifth century B.C. Integrated aquaculture development, exploiting the ecological and symbiotic relationships among varieties within a single system, is most closely identified with the Ming Dynasty some five hundred years ago.

During the People's Republic period, most of the popular edible carp varieties were domesticated, and considerable research and development on new feed materials, artificial breeding, and interregional crossbreeding were carried on. Aquatic product yield in the most productive Chinese areas exceeds ten tons per hectare, with average yields around 750 kilograms nationally.[79]

During the 1980s, simplified aquaculture techniques, developed during the previous decade, were extended to new regions with little or no farmer experience with aquaculture. Economic liberalization and commercial expansion within China's prime aquaculture areas (Guangdong, Hunan, Hubei, and Jiangsu) and other southern and central provinces, coupled with briskly rising rural incomes, created a boom in supply and demand for aquaculture products. This increased from an annual average of only 755,000 tons per year (1975-78) to 3.90 million tons in 1988. Even marine aquaculture products rose from a stagnant 420-460,000 tons (1977-81) to 1.42 million tons in 1988.[80]

Now that much of the Chinese population has reached the diversification stage of food consumption, the demand for fish will continue to grow rapidly with rising incomes. With continued depletion, eutrophication, and pollution of Chinese coastal and natural freshwater resources, already advanced and practically irreversible in major population regions, the dependence on aquaculture will increase as will emphasis on continued development of cheap, easily extendable, and increasingly productive technology.

Other Areas of Innovation

Chinese innovations indirectly related to agriculture, or related to farming more broadly, include acupuncture and moxibustion for animals, decentralized energy development, and hydraulic engineering aimed at overcoming various kinds of special water-related problems.

International Transfer of Chinese Technology

The listing above is only partial but indicates the variety and dimensions of China's ongoing contribution to technical development in agriculture. Does the rest of the world appreciate and profit from this development?

To a certain extent the answer is yes. The Food and Agriculture Organization (FAO) has sponsored exploratory studies in a number of the above areas. Nine of the thirteen institutes that comprise the Consultative Group for International Agricultural Research have cooperative activities with China, some of which are extensive. The International Bank for Plant Genetic Resources and the International Potato Center have established program offices at the Academy of Agricultural Sciences in Beijing. The cooperative activities of the International Rice Research Institute (IRRI), Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Centro Internacional de Agricultura Tropical (CIAT), and International Food Policy Research Institute (IFPRI) are considerable and long standing. Most of these institutes exchange genetic materials with China and undertake other forms of technological cooperation. IRRI and IFPRI conduct cooperative economic research on Chinese technology and related issues.

IRRI assisted in establishing the China National Rice Research Institute in Hangzhou, modelled in conception, if not realization, after IRRI. An International Freshwater Aquaculture Center has been established in Hunan, with FAO's cooperation. There has been, in some areas, commercial interest: both Japanese and American companies are now working with China's hybrid rice. IRRI has had a hybrid rice research program for most of the decade, and there exists experimental hybrid rice cultivation in India and in the Philippines.

There is university-based technical cooperation between North American, European (especially German), and Japanese universities and Chinese counterparts. Foreign governmental organizations, notably the Australian Center for International Agricultural Research (ACIAR) and the German Technical Assistance Organization (GTZ), have funded numerous technical research projects in China. The flow of technology, however, is primarily toward China, although non-Chinese have the opportunity to work on Chinese problems in a Chinese setting and become more familiar with Chinese approaches.

Yet it is difficult to avoid the conclusion that too little use has been

made of China as a generator of technology. And it is important to ask ourselves why that is so. There are several obvious reasons. Relatively few Chinese speak English or other foreign languages with any degree of facility. Chinese is a difficult language and few non-Chinese speak it. China has been open to relatively easy foreign contact only recently, and this opening is still incomplete. Chinese research and development institutions are highly compartmentalized and geographically dispersed, and information flow among them is inefficient, making it difficult to understand the state of the art or the degree and experience of extension of technologies. But there are additional problems which warrant consideration.

Although south-south interchange between China and other developing countries is not unknown, it rarely gets very far. Occasional technical delegations are organized, but there is too little follow-up. Developing countries evidently do not have the resources and technical manpower to devote to low-priority activities such as interchanges with other developing countries. China's advanced position in agricultural technology is poorly appreciated within that community.

Among industrialized countries, there appears to be an approach-avoidance problem with respect to China. Western enthusiasm for and interest in China, culturally and economically, is cyclical. A similar pattern can be detected with technological research, even within international organizations. There have been several waves of enthusiasm with and interest in particular aspects of Chinese agricultural technology which are invariably followed by the discovery of limitations to the technology. The conclusion is drawn that particular items are not very practical or applicable to the rest of the world. Yet in instance after instance, Chinese scientists and institutions continue to work on these technologies, and in many cases problems are resolved and the limitations are substantially reduced. Western countries still maintain their outdated evaluations as a result of the failure to follow-up and monitor developments in China. Hybrid rice is an excellent example, but there are others for which valuable time has been lost, or is still being lost, by other countries for whom Chinese technologies could prove useful.

There is generally little Western technical or commercial interest in Chinese innovations, outside the relatively small community which specializes in work related to developing countries. The participation of donor and other international organizations associated with developing countries is relatively limited. This lack of interest in the West is particularly related to differences in factor proportions. Most Chinese innovations are particularly appropriate for countries with low capital-to-labor and low land-to-labor ratios. Several of these innovations also require for their development a relatively large and sophisticated research community and a fairly well functioning extension and monitoring system. The absence of these capabilities in a number of developing countries hinders their receptivity to Chinese technological models.

Summary

China has entered a new stage of food consumption development, as the current consumption of basic staple crops for the large majority of the population has reached adequate levels. Progress is now more appropriately focused on dietary diversification and improvements. Thus growth in agricultural output value, which has continued at a reasonable pace, even during the recent years of staple crop production stagnation, is a more appropriate indicator of success.

Yet further growth in staple crop production continues to have strategic importance in China for a variety of reasons. China has now entered a second stage of technical transformation of its agricultural sector, with further yield progress in advanced areas depending increasingly on improvements in efficiency and quality of inputs and services related to farm productivity. Continued attention has to be paid to bringing China's poorer areas through the first-stage transformations, with an emphasis on basic irrigation and flood control, and adequate HYV and fertilizer availability. This process for less-advantaged areas will remain important for the foreseeable future, despite necessary efforts to diversify poor-area income sources away from excessive dependence on agriculture and to liberalize factor and product markets.

The process of diffusion of basic technical change for staple crop products in China's poor regions and localities has always lagged behind progress in wealthier areas, and more obstacles to this diffusion process have arisen in the 1980s. Yet progress in supplying needed fertilizers throughout such areas has increased considerably in the 1980s. Supplies of appropriate HYV staple varieties have increased in many poorer counties and complementary plastic sheeting has been introduced in some. Water control has suffered, however, with new facilities opening in only a few localities, while capacity has deteriorated in most of China's poorer areas.

China is an important source of technological innovations related to agricultural productivity. Yet international mechanisms are weak in evaluating and transferring those technologies for the benefit of other developing countries that are characterized by low capital-to-labor and low land-to-labor ratios. An exception is the increasing inclusion of Chinese varietal diversity into international banks for genetic resources. As the world approaches the twenty-first century, China's experience will provide an increasingly important source of knowledge and of unrealized potential for facilitating agricultural progress in developing countries.

Notes

1. For a review of the theoretical elements of this strategy, see John W. Mellor, "Agriculture on the Road to Industrialization," in *Development Strategies Reconsidered*, U.S. Third World Perspectives no. 5, ed. John W. Mellor and Valerina Kallab (New Brunswick: Transaction Books, 1986). For a summary of the relationship of this body of theory to China's agricultural development, see Bruce Stone, "Chinese Socialism's Record on Food and Agriculture," *Problems of Communism* 35 (September-October 1986): 63-72.

2. Classic 1960s treatments quantifying developments in Asian countries include Shigeru Ishikawa, *Economic Development in Asian Perspective* (Tokyo: Kinokuniya, 1967); and John W. Mellor, *The Economics of Agricultural Development* (Ithaca: Cornell University Press, 1966).

3. See Shigeru Ishikawa, "China's Food and Agriculture: A Turning Point," *Food Policy* (May 1977): 90-102; and Reitsu Kojima, "Possibility of Expansion of Scale of Farm Operations," *The China Quarterly* 116 (December 1988).

4. For a full discussion of these stages, see Bruce Stone, "The Next Stage of Agricultural Development: Implications for Infrastructural, Technological and Policy Priorities," a paper presented at the Colloquium on Agricultural Reform and Development in China, held in conjunction with the Annual Meetings of the American Society of Agronomists, Las Vegas, October 18-19, 1989 (publication forthcoming, 1990).

5. Bruce Stone, "Chinese Socialism's Record on Food and Agriculture"; Bruce Stone, "Foodcrop Production and Consumption Performance in China and India," a paper prepared for the Annual Meeting of the American Association for the Advancement of Science, Chicago, February 15, 1987.

6. Bruce Stone, "Developments in Agricultural Technology," *The China Quarterly*, no. 116 (December 1988): 767-822; see also Anthony M. Tang and Bruce Stone, *Food Production in the People's Republic of China*, Research Report no. 15 (Washington, D.C.: International Food Policy Research Institute, 1980).

7. For detailed treatment, see Stone, "Developments in Agricultural Technology," 771-90; and James E. Nickum, "Dam Lies and Other Statistics: Taking the Measure of Irrigation in China, 1931-1988," a paper prepared for the International Food Policy Research Institute, Washington, D.C., November 1989.

8. "Foodgrains" (*liangshi*) include rice at paddy weight, wheat, corn, sorghum, millet, other minor cereals, soybeans, broad beans, mung beans, peas, and other minor bean crops, and, valued at one-fifth fresh weight, sweet potatoes and white potatoes. Calculations are based on Statistical Yearbook of China, Chinese edition, 1989 (hereafter, ZGTJNJ), 198.

9. Bruce Stone and Gunvant Desai, "China and India: A Comparative Perspective on Fertilizer Policy Requirements for Long-Term Growth and Transitional Needs," in *China's Rural Development Miracle*, ed. John Longworth (St. Lucia: University of Queensland Press, 1989).

10. Ibid.; and Bruce Stone, "Chinese Fertilizer Application in the 1980s and 1990s: Issues of Growth, Balance, Allocation, Efficiency, and Response," in *China's Economy Looks Toward the Year 2000*, ed. U.S. Congress Joint Economic Committee (Washington, D.C.: U.S. Government Printing Office, 1986).

11. In this paper, Hainan Island, which has recently been accorded independent provincial status, is treated as part of Guangdong Province for the entire period.

12. For detailed analyses of the 1980-86 period, see the sources cited in n. 7. This subsection updates and summarizes that treatment.

13. Based on review of materials on Chinese wheat varieties organized and summarized in Bruce Stone, Charles Greer, Tong Zhong, Clark Friedman, Mary McFadden, and Melanie Snyder, "Agro-Ecological Zones for Wheat Production in China: A Compendium of Basic Research Materials," a compendium prepared for the International Center for Maize and Wheat Improvement (CIMMYT), International Food Policy Research Institute, Washington, D.C., 1985.

14. Information provided by Zhou Guorong and Cao Bingyi, Director and Vice-Director, Yunnan Province Seed Corporation, Kunming, January 9, 1990.

15. Information provided by Hong Ceyu, Agricultural Technical Extension Station, Guizhou Provincial Bureau of Agriculture, Guiyang, January 2, 1990.

16. Guojia Tongjiju Nongcun Shehui Jingji Tongjisi [State Statistical Bureau, Division of Rural Social and Economic Statistics] (eds.), *Zhongguo fenxian nongcun jingji tongji gaiyao, 1980–1987* [Statistical Abstract of China's Rural Economy, by County, 1980–1987] (Beijing: Zhongguo tongji chubanshe, 1989).

17. Li Yuecheng et al. (eds.), *Yunnansheng shuidao zaipei jishu guifan huibian* [Yunnan Province Official Compilation of Paddy Rice Cultivation Technology] (Kunming: Yunnansheng jingji weiyuanhui nongyechu, Yunnansheng nongye kexueyuan keji kaifachu, 1987) (hereafter YSZJGH).

18. Yunnansheng Nongyeting, *Yunnansheng Zaidao Zaipei yu Liyong Tuiguang Mianji 1978–1988* [Yunnan Province Hybrid Rice Cultivation Use and Extension Area] (Kunming, 1989) (hereafter, YZZLTM); also discussions with Li Yuecheng, Yunnan Academy of Agricultural Sciences, Kunming, January 12 and 14, 1990.

19. Zhou Guorong and Cao Bingyi; according to a 1986 survey of hybrid rice areas in 47 counties, covering 42.2 percent of the provincial total, 29 percent of surveyed area averaged yields between 5.25 tons/ha and 6 tons/ha, 60 percent averaged more than 7.5 tons/ha, and 38 percent averaged more than 8.25 tons/ha. This development has helped to pull up the provincial average for all rice (including hybrids) from 4.2 tons/ha (1982) to 4.536 tons/ha (1988). Agricultural Yearbook of China, Chinese edition, 1983 (hereafter, ZGNYNJ), 37, and ZGTJNJ 1989, 194 and 202.

20. YZZLTM, 206; Zhou Guorong and Cao Bingyi.

21. Discussions with Guizhou Province Agricultural Bureau staff, Guiyang, August 1989; with Hong Ceyu, Agricultural Technical Extension Station, Guiyang, January 2, 1990; and with Li Jiaxiu, Grain Production Institute, Guizhou Academy of Agricultural Sciences, Guiyang, January 5, 1990.

22. YSZJGH, 26–68; and discussions with Li Yuecheng, Kunming, January 14, 1990.

23. YSZJGH, 109–135.

24. YZZLTM, 206.

25. Discussions with Li Yuecheng, Kunming, January 12 and 14, 1990; and with Zhou Guorong and Cao Bingyi, January 9, 1990.

26. Zhou Guorong and Cao Bingyi.

27. Although the varieties produce many shoots from each plant, the kernels themselves have low weight. Average per-hectare yields in some areas are higher, and in some, lower, although superior disease and cold resistance protects against large shortfalls. Also, separation of the grain from the plant is more difficult unless accomplished by machine, impeding farmer acceptance in Yunnan where separation is normally done by hand (Li Yuecheng).

28. Zhou Guorong and Cao Bingyi.

29. YZZLTM, 208.

30. See, for example, Bruce Stone, "Relative Foodgrain Prices in the People's Republic of China," in *Agricultural Pricing Policy for Developing Countries*, ed. John W. Mellor and Raisuddin Ahmed (Baltimore: Johns Hopkins University Press, 1988).

31. Discussions with Yunnan Province Poor Area Development Office staff, and various officials in Fugong County, Gongshan County, and Nujiang Prefecture governments, northwestern Yunnan, September 1989.

32. Director, Agricultural Development Research Group, Yunnan Province Bureau of Agriculture, Kunming, January 9, 1990.

33. Nicholas Menzies, Director of Beijing Office, Winrock International.

34. Charles Gitomer and Bruce Stone, "Sweet Potato and White Potato Development in China," a report prepared for the International Potato Center, Lima, March 1990.

35. Professor Wang Jun, Yunnan Normal University, Kunming, January 16, 1990.

36. Stone, "Developments in Agricultural Technology."

37. Gitomer and Stone, "Sweet Potato and White Potato Development in China."

38. Field notes, Nujiang Prefecture, September 1989, interview with Professor Wang Jun; and in January 1990.

39. Wang Jun.

40. Gitomer and Stone, "Sweet Potato and White Potato Development in China."

41. Peter Gregory, Masa Iwanaga, Ed French, Romeo Opena, Bruce Stone, and Charles Gitomer, *Sweet Potato Technology in China* (Lima: International Potato Center, 1987).

42. Niu Ruofeng, Director, Agricultural Economic Institute, Chinese Academy of Agricultural Sciences, Beijing, November 1, 1987.

43. Xiong Fengming, Hubei Seed Corporation, November 13, 1989; other field visits in South China, August 1989–January 1990.

44. Wu Sikai and Hong Ceyu.

45. Fugong County Vice-Chairman Fu, Nujiang Prefecture, September 1989.

46. Wu Sikai and Hong Ceyu.

47. Field visits in six provinces, August 1989–January 1990.

48. See Stone, "Developments in Agricultural Technology," and sources focusing on inputs and on varietal improvement for various foodcrops, cited therein.

49. For more detailed statistical treatment see Stone, "The Next Stage of Agricultural Development."

50. Stone, "Developments in Agricultural Technology."

51. For example, Justin Yifu Lin, "Farming Institutions, Food Policy, and Agricultural Reforms in China," included in this volume, and papers cited therein.

52. See, for example, Bruce Stone, "Fertilizer Marketing and Allocation in China," a paper prepared for the World Bank, June 1984; Stone, "Relative Foodgrain Prices in the PRC"; Scott Rozelle, "Village-Level Decision Making in Jiangsu," doctoral dissertation for the Agricultural Economics Department, Cornell University, 1990; Terry Sicular, "Ten Years of Reform: Progress and Setbacks in Agricultural Planning and Prices," *The China Quarterly* 116 (December 1988).

53. Stone and Desai, "China and India: A Comparative Perspective on Fertilizer Policy"; Stone, "Chinese Fertilizer Application in the 1980s and 1990s."

54. ZGTJNJ 1989, 192.

55. These ideas were developed by Jaroslav Vonek, *General Theory of Labor-Managed Market Economies* (Ithaca: Cornell University Press, 1970); the ideas were first applied to Chinese reforms of the late 1970s in Bruce Stone, "China's 1985 Foodgrain Production Target," in Tang and Stone, *Food Production in the PRC.*

56. Virtually all Chinese soils are deficient in nitrogen, and as of 1981–83, 73.4 percent were tested deficient in phosphate, of which the majority are seriously

deficient. There are growing potash deficiencies on 23–47 percent of China's farmlands, depending on the standard applied, and scattered deficiencies of micronutrients. Stone, "Developments in Agricultural Technology," 813 (table 9).

57. This system actually dated from the 1950s, but was formalized in explicit contracts beginning in 1984 with cotton, and in 1985 for staple crops.

58. These include cotton, peanuts, sesame, sugarcane, fruit, tea, and tobacco. Production quadrupled for jute and ambary hemp, rapeseed, and sugarbeets. Vegetable crop area has also grown rapidly. For details, see Stone, "The Next Stage of Agricultural Development"; or ZGTJNJ 1989, 200–201.

59. Stone, "Relative Foodgrain Prices"; Stone, "Chinese Fertilizer Application in the 1980s and 1990s"; Stone and Desai, "China and India: A Comparative Perspective on Fertilizer Policy Requirements."

60. This has been especially important in depressing production of root and tuber crops, although local governments stopped purchasing these crops as early as the late 1970s in some important producing provinces. Gitomer and Stone, "Sweet Potato and White Potato Development in China."

61. ZGTJNJ 1988 (English edition), 504.

62. ZGTJNJ 1989, 183.

63. For details see Stone, "Developments in Agricultural Technology," 771–90.

64. Stone, "Chinese Fertilizer Application in the 1980s and 1990s"; Bruce Stone, "Systemic and Policy Adjustment in the Administration of China's Fertilizer Development," a paper prepared for the World Bank, December 1986. Fertilizer production capacity decreased from 1.18 million metric tons (mmt) of nutrients per year (1976–79) to 0.32 mmt per year (1980–85) (ZGTJNJ 1989, 538).

65. Ibid.

66. Interviews with provincial officials in Guizhou, Yunnan, Hubei, Hunan, Jiangxi, and Guangxi, August 1989–January 1990.

67. Even including the stagnation period, the annual growth rate of agricultural output value, calculated in 1980 constant prices, averaged an impressive 7 percent per year (1980–88). Calculations are based on Robert Michael Field, "Trends in the Value of Agricultural Output, 1978–1988," a paper prepared for *The China Quarterly* Workshop on Food and Agriculture in the Post-Mao Era, Hong Kong, December 30, 1989–January 2, 1990, table 3A.

68. For the improvements in efficiency and quality, see Stone, "Chinese Fertilizer Application"; Bruce Stone, "Agricultural Production and Fertilizer in China (Parts I, II, and III), *Agro-Chemicals News in Brief*, October 1988, January 1989, and April 1989.

69. Sicular, "Ten Years of Reform"; Bruce Stone, "Chinese Fertilizer Sector Review, 1986/1987," a paper prepared for the World Bank, December 1987; Bruce Stone, "Fertilizer's Greener Pastures," *The China Business Review* 16 (September-October 1989): 46–55.

70. Sicular, "Ten Years of Reform"; *The China Business Review*, January-February 1985; for impact on fertilizer purchases, Bai Nansheng, "Guanyu nongcun zijin zhengci di jige wenti" [Several Issues Related to Rural Financial Policy], and Zhuang Musheng and Liu Chunbin, "Kongji nongcun xindai guimo yao qubie duidai zhangwo liangda" [Control of the Scale of Rural Credit Should Be Conducted on a Realistic Basis], Research Center for Rural Development reports, Beijing.

71. Field, "China: Trends in the Value of Agricultural Output"; and Sicular, "Ten Years of Reform."

72. "The Plastics Revolution," in *Feeding a Billion*, Sylvan Wittwer, Yu Youtai, Sun Han, and Wang Liazheng, eds. (East Lansing: Michigan State University Press, 1987).

73. "Farm Ties Boost Growth" and "Sheeting for Farms Tops Production List," *The China Daily*, February 11, 1990, p. 4.

74. Tan Xiaohong, Plant Protection Dept., Guizhou Province Bureau of Agriculture, Guiyang, January 3, 1990.

75. "The Plastics Revolution," in *Feeding a Billion*.

76. "The War on Pests," in *Feeding a Billion*.

77. Zhongguo Nongye Kexueyuan, Turang Feiliao Yanjiusuo [Chinese Academy of Agricultural Sciences, Soil and Fertilizer Research Institute], *Zhongguo huaxue quhua* [China's Chemical Fertilizer Regionalization Plan] (Beijing: Zhongguo nongye chubanshe, 1986).

78. ZGTJNJ 1988 (English edition), 199.

79. Wittwer et al., *Feeding a Billion*.

80. ZGTJNJ 1989 (Chinese edition), 219.