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Sustainable Agriculture Development in China: Report of A Field Visit

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SUSTAINABLE AGRICULTURE DEVELOPMENT IN CHINA:
REPORT OF A FIELD VISIT

by

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SUMMARY AND CONCLUSIONS

China has a rich history of agricultural production practices involving the intensive and regenerative use of her soil and other natural resources. The challenge of having to feed a population in excess of 1 billion people that continues to grow and has become more well-to-do, especially in the last decade, is awesome.

Because of intense pressure for added food production, China has been forced to shift toward the heavy use of externally-produced, purchased inputs to complement her traditional internally-produced inputs and farming practices. China's farming communities that once were largely self-sufficient now have many, varied linkages with the "outside world." Between 1965 and 1988, for example, the total industrialized energy used in China's agriculture increased by nearly 14 times. China is now the world's largest user of manufactured fertilizers. Chinese farmers currently purchase and use 2.5 times as much inorganic fertilizer per hectare per season as farmers do in the U.S. The overall energy intensity of Chinese agriculture, as measured by the kilo-calories of industrial energy consumed per kilogram of foodgrain produced, is now comparable with that in the U.S.

Certain destructive impacts on environment have accompanied China's efforts to meet her food production and other economic and social needs. These impacts are felt most seriously in vegetative destruction, soil erosion, land quality deterioration, water pollution, and water resource depletion. Since Independence in 1949, for example, it is estimated that (1) forest cover has dropped from 20% to less than 12% of the land area in Sichuan Province, (2) the desertified area in the country has more than doubled, (3) soil erosion along the Yangtze River has doubled, and (4) the proportion of "highly productive" farmland in China has decreased from one-third to one-fifth. A recent survey of 878 rivers in China showed 82% of the rivers to be polluted and 5% of the total river length to be fishless. The increasing demands on China's water resources is resulting in "groundwater-funnels" around urban and industrial centers and, more generally throughout the country, in declining groundwater tables and reservoir/lake levels (e.g., In Hubei Province, the total number of lakes has diminished from 1,066 in 1949 to 326 in the late 1980s and the land area covered by the lakes has decreased by three-fourths).

A key challenge in the future agricultural development of China is to determine and pursue as appropriate as possible a blend of traditional and modern agricultural inputs and practices. To move strongly and quickly away from the current use of modern inputs would almost inevitably lead to immediate production disasters. For the recent pace of adoption of certain external modern inputs to be perpetuated, however, would almost inevitably exacerbate some of the environmental problems that have already become acute.

China's search for a redefined balance between traditional and modern agricultural inputs and practices is embodied in what has come during the 1980s to be called "ecological" agriculture. "Ecological" agriculture in China is similar in several respects to "sustainable" agriculture as this term is used generally in the West. Both types of agriculture have a very definite holistic systems orientation, both are concerned with long-term environmental/socio/economic sustainability, and both give major attention to crop rotations and other soil building practices.

In some ways, however, "ecological" agriculture in China differs from "sustainable" agriculture in the West. China emphasizes (1) enterprise integration and (2) nonagricultural employment and income-generation options more than is generally true with "sustainable" agriculture in the West. On the other hand, reduced synthetic chemical (inorganic fertilizers and pesticides) use tends to receive less explicit, lower relative priority in Chinese "ecological" agriculture than in Western "sustainable" agriculture.

To some extent, trade-offs are inherent in individual producers and a nation realizing simultaneous progress toward achieving production **and** environmental goals. On the other hand, such trade-offs are not necessarily inevitable. China is searching for a common meeting ground in achieving production and environmental objectives through her "ecological" agriculture efforts. She is doing so via over 1,100 pilot ecological villages across the country.

Field visits to five of these pilot villages and a review of literature indicate an intense recycling of resources within the respective local economies of these villages and many intertwined linkages between and among enterprises in the respective villages. Levels of individual family and village production and income have increased a great deal. Though not systematically analyzed, it appears that the considerably intensified production systems may not require purchase of more external resources than were required in the before-project situations in the villages. External fuel energy resources, vegetative destruction, and soil erosion are definitely less in the after-project conditions in the pilot villages. Impacts on other aspects of the environment are known with less certainty.

A high priority need in the next generation of research is to further determine interactions between production and environment in China's pilot ecological villages. China's experience with "ecological" agriculture will almost certainly provide important insights to the community of nations struggling with challenges similar to those in China.

SUSTAINABLE AGRICULTURE DEVELOPMENT IN CHINA: REPORT OF A FIELD VISIT

by Donald C. Taylor

INTRODUCTION

This report is based on a field trip to China which I took on May 25-June 24, 1990 and a review of recent literature on agricultural development in China. My field trip involved visits to agricultural universities and research institutes and related organizations in Harbin in northeastern China, Beijing and Nanjing in east central China, Guangzhou in the southeast, and Chongqing-Beibei in the southwest (Figure 1).[1] During my stay in China on May 25-June 12, I visited Harbin, Beijing, Nanjing, and Guangzhou as a member of a People-to-People Citizen Ambassador Delegation on Sustainable Agriculture led by the late Robert Rodale.[2] During June 13-24, I visited institutions in Nanjing, Beijing, and Chongqing-Beibei on behalf of the Winrock International Institute for Agricultural Development.

The purpose of this report is to convey an overview of the development of agriculture in China, with particular emphasis on intensity of resource utilization and its possible future implications for a more sustainable agriculture in China. Attention is given to (1) China's historical practice of intensive and self-sufficient agriculture, (2) the tremendous movement over the past two decades toward an agriculture dependent on external resources, and (3) initiatives currently being taken to more intensively recycle resources within Chinese farm production units and otherwise adopt farming technologies that treat the environment more benignly.

CHINA'S AGRICULTURAL RESOURCES AND PRODUCTION IN PERSPECTIVE

China's population of 1.1 billion represents 22% of the world's population. Yet, China has only 7% of the world's arable land area (Li and Li 1990). The pressure of population on China's land resources is reflected in a per capita cropland availability in China of 0.09 ha (0.225 acre) (Table 1). This cropland availability is less than one-third of the average for the world and about one-ninth of that in the U.S.

Intense population pressure, coupled with the implications of rapidly rising per capita incomes over the past decade (Carter and Zhong 1988; Johnson 1989; Pinstrup-Andersen, et al. 1990), imply a heavy demand on China's food

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[1] *See Annex A for a list of the institutions which I visited in China.*

[2] *On September 20, 1990, Robert Rodale was killed in an automobile accident in Moscow.*

Figure 1. Map of China.

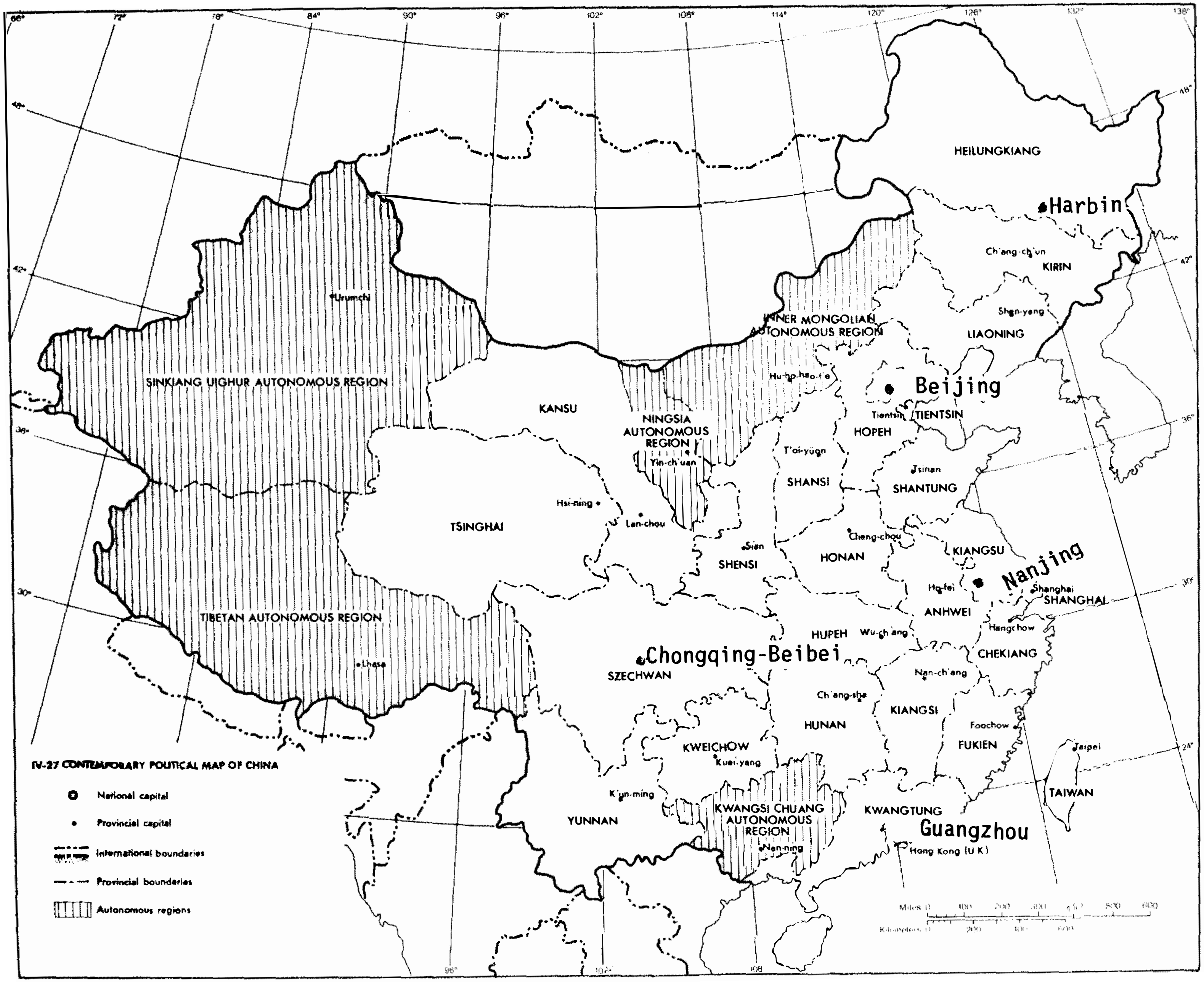

Table 1. Measures of per capita agricultural resources, cereal production, and food consumption, China and selected countries and world regions, 1987.

Country/ region	Agricultural resources: Cropland (ha)	Fertilizer use: kg/ha of cultivated land: Nitrogen	Fertilizer use: kg/ha of cultivated land: $N+P_2O_5+K_2O$	Cereal grain production (kg)	Food consumption: daily intake[a]: Total calories	Protein: Total	Protein: Animal
China	0.09	175.2	236.5	333	2,628	62.0	10.3
Japan	0.04	142.1	432.7	119	2,858	88.0	46.4
India	0.21	34.5	53.6	193	2,204	53.9	7.0
Mexico	0.30	54.4	75.3	284	3,148	82.0	29.4
U.S.A.	0.78	50.0	93.3	1,147	3,642	106.5	70.9
Western Europe	0.25	117.9	230.2	491	3,383	100.8	59.8
World Average	0.29	51.6	95.4	359	2,694	70.3	24.1

Source: FAO(1989).

[a]The data for food consumption are for 1984-86.

production capacity. To help meet this demand, China's use of chemical fertilizers has increased tremendously. China is now the world's largest user of manufactured fertilizers (Stone 1989). China's per-hectare, per-season use of inorganic nitrogen, phosphorous, and potassium is on a par with that in Western Europe, 2.5 times as much as that in the U.S. and on the average in the world, and 4.4 times as much as that in India (Table 1). China's use of nitrogen, relative to that in other countries and world regions, is even greater. These heavy fertilization levels imply (1) a substantial loading of chemicals on the soils of China every year and (2) a constraint on the possibility of heavier fertilization enabling future increases in crop yields in China.[3]

On a per capita basis, China's annual cereal production of 333 kg is only slightly less (7%) than the average for the world. China's per capita cereal grain production is 2.8 times that in Japan, 1.7 times that in India, but less than one-third as much as that in the U.S. China's per capita caloric food consumption is roughly on par with that on the average in the world and is nearly one-fifth more than that in India. China's per capita total protein consumption, however, is one-eighth less than that on the average for the world and one-eighth higher than that in India. Animal protein consumption in China, while increasing much during the past 12 years (Pinstrup-Andersen, et al. 1990), is still only two-fifths of that on the average for the world and only one-seventh of that in the U.S.

One rather unique feature of rural China is the emergence and recent rapid growth of rural nonagricultural enterprises. The 1978 Economic Reform provided a new institutional situation in which (1) rural households began to derive benefit in quite direct relation to the production efforts undertaken by them and (2) the prohibitions on nonagricultural economic activities in rural areas were virtually eliminated. Nonagricultural employment in rural areas increased from about 30 millions before 1978 to about 80 millions in 1989.[4] In 1988, the gross value of output of rural industries exceeded the gross value of farm production (Johnson 1989).

Almost all of this rural industrial expansion has been with local ingenuity and resources, rather than with investments from federal and provincial governments. A significant, though unknown, part of the increase in rural family incomes has been associated with the large transfer of labor

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[3]*Since multiple cropping (more than one crop per year on a given piece of land) is common in China, the loading of chemicals onto the soil is more extreme in China than that implied by the comparative* ***per-season*** *chemical fertilizer applications for Western Europe and the U.S. where single cropping dominates.*

National aggregate-level data are used in this paper. For illustrative regional analyses of food and feed grain production and input use in China, see Stone (1986), Carter and Zhong (1988), and Webb (1990).

[4]*This increase in employment over 10 years is equal to one-half of the U.S.'s total employment in 1980 (Johnson 1989).*

from farming into more productive rural industrial activity (Han 1989; Johnson 1989; Byrd and Lin 1990; Liu 1990). Rural nonagricultural enterprises cover all but one of the 14 principal subsectors of Chinese industry, with petroleum the exception. The most important of the 14 subsectors for rural industry are machinery, construction materials, textiles, chemicals, and food processing (Byrd and Lin 1990).[5]

AGRICULTURAL PRODUCTION

From 1949 to 1989, China's total grain production increased by about 3.5 times (Figure 2). The overall trend over the 40-year period has been strongly upward. The three most pronounced deviations from the general upward trend are (1) production dropping nearly 30% during the late 1950s due to "Great Leap Forward" policy shortcomings (Carter and Zhong 1988; Johnson 1988; Niu

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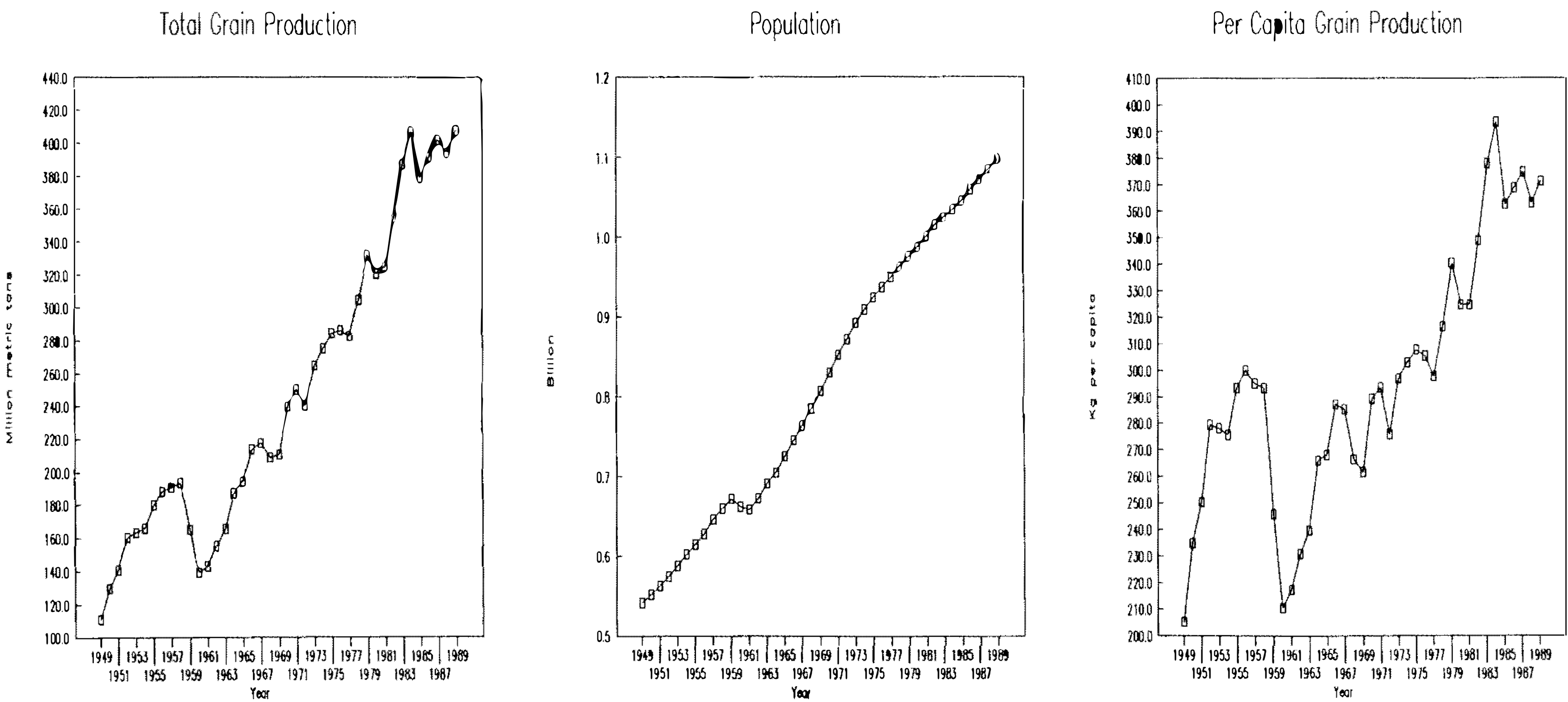
[5] *A recently published book by Byrd and Lin (1990) provides an informative and deeply insightful account of the institutional framework, historical background, and present situation and importance of China's township, village, and private enterprise (TVP) sector. On p vii, they summarize seven noteworthy features of China's TVP sector:*

> *- Dynamism: output has been doubling every 3 to 4 years and hundreds of thousands of new firms have emerged each year on average;*
>
> *- Competitiveness: the sector has gained a large share of the domestic market for many industrial goods and has penetrated some export markets as well;*
>
> *- Small scale: although enterprises of substantial size exist, especially in the more developed areas, most firms are small concerns with only a few score employees and about Yuan 100,000 ($21,000 in 1990 U.S. dollars) in assets;*
>
> *- Diversity: there is great geographic variety in ownership, institutional arrangements, level of development, and degree of industrialization;*
>
> *- Outward orientation: most output, especially of manufactured goods, is sold outside the community or locality in which it is produced;*
>
> *- Community orientation: nearly all TVPs are tied in complex ways to their rural communities, and they would not consider relocating; and*
>
> *- Factor immobility: like the enterprises themselves, factors of production and human talent are largely immobile across localities and communities.*

Figure 2. Total grain production, population, and per capita grain production, China, 1949-1989.



Sources: All data for 1949-1986, Carter and Zhong (1988, 7); total grain production data for 1987-1989, USDA (1990, 52); population data for 1987-1989 interpolated by author, based on a 1990 population estimate by Crook (1990, 37) of 1,110 million; and per capita grain production data for 1987-1989 computed by author, based on total grain production and population data for the respective years.

Note: The levels of per capita grain production during the late 1980s in this figure appear to be considerably higher than the 333 kg./capita cereal grain production reported for China for 1987 in Table 1. Whether the difference is definitional (e.g., in the commodities covered, in processed versus unprocessed grains) is not known.

1989),[6] (2) the rate of production increase accelerating between 1978 and 1984--importantly because of greater production incentives arising from the post-1978 Reform which led to the development of the rural household production responsibility system (Lin 1988; Carter and Zhong 1988; Han 1989; McMillan, et al. 1989),[7] and (3) production more or less leveling off since 1984.[8]

Except for a small interruption during the late 1960s, China's population has shown a strong upward trend since 1949. The rate of increase since 1975 has been somewhat less than during the prior 15 years.[9] The pattern of per capita grain production--reflecting the combined effects of changes in total grain production and population--shows a definite upward trend since 1949, but with several interruptions in the upward trend. Most

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[6]*Carter and Zhong (1988) also indicate that "poor weather" contributed to the substantial decline in total grain production during the late 1950s.*

[7]*Carter and Zhong (1988) indicate that, by the end of 1984, about 98% of total rural households were involved in various types of rural household production responsibility systems. For selected descriptions and analyses of the post-1978 rural economic reform in China, see Johnson (1988), Lin (1988), Johnston 1989; McMillan, et al. (1989), and Webb and Crook (1990). For an account of the operation of credit markets under the rural household production responsibility system, see West (1990).*

Tuan and Ru (1990) indicate that one of the shortcomings of the rural household production responsibility system has been a marked reduction in Central Government investment in agricultural capital construction. A reflection of this reduction is a decline in Central Government investment in agricultural capital construction, as a share of total capital construction, from 11.1% in 1979 to 3.0% in 1988. During the same time period, individual household capital investment was channeled more commonly toward housing construction than farm improvement. Johnson (1989) also notes the investment bias away from rural areas and toward urban areas and industry in China since 1978.

[8]*Of the grain produced in China in 1988, 68% is reported to have been consumed on farms, 21% sold to the state, and 11% sold on the open market (Carter 1989).*

See Annex B for (1) data on yields of grain in China versus in selected other countries and regions of the world and (2) estimated rates of growth and empirical studies of factors explaining growth over time in China's grain production.

[9]*The World Bank (1989) estimates the average annual growth of population in China to have been 2.2% during 1965-1980 and 1.2% during 1980-1987.*

See CFEPH (1988) for a recent treatment of China's population and family planning policies.

notable are a 30% decrease in per capita grain production in the late 1950s, accelerated increases during the early 1960s and early 1980s, and an approximate 6% drop since the peak of 394 kg./capita in 1984.

The course of China's trends in total grain production is closely associated with changes in per-hectare grain yields that have nearly tripled since the early 1950s (FAO 1989). An additional and subduing factor, however, has been a near 12% decline since 1952 in the area placed under grain cultivation in China (Crook 1990). This decline has been caused by a steady increase in the demand for land for non-agricultural purposes (Guo and Han 1988) and, in recent years especially, some shifting in land use from grain to cash crop and fodder production (Perkins and Yusuf 1984; Carter and Zhong 1988; Greer 1988; Johnston 1989; Liu 1989; personal communication, Cheng Xu June 19, 1990).

In addition to changes in per-hectare grain yields and the area planted to grains, changes in cropping intensity can impact overall production trends. The crop index for grains--defined as the annual cultivated area in grain divided by the total grain growing area--has increased from 128% in 1949 to 150% in 1988 (Table 2). Increases in the crop index over the past 15 years, however, have been very limited. Thus, we are left with the conclusion that the dominant factor impacting increases in total grain production over the past 15 years in China has been increases in per-hectare grain yields.

PRODUCTION INPUTS

In the search to explain increases in grain yields, other than those resulting from the 1978 institutional reform, trends in the use of fertilizer, machinery, and irrigation are examined.

Overall fertilizer use--defined as the total amount of N (nitrogen), P_2O_5 (phosphorous), and K_2O (potassium) used in million metric tons (mmt)--has increased by over nine times in China in the past 40 years (Table 2).[10] The increase has been particularly marked for inorganic fertilizer, that has increased from 0.03 mmt annually in the 1950s to 21.4 mmt in 1988. Stone (1989) and Luo and Han (1990) indicate that China now faces rather strong diminishing returns in the use of inorganic fertilizer, particularly on the country's highest producing soils.

For many centuries, organic fertilizers represented the backbone of soil fertility enhancement by Chinese farmers (King 1911; Elvin 1982; Wen and Pimentel 1986; Sun 1987a; Yu 1987; Stone 1989). While organic fertilizers continue to provide a substantial amount of plant nutrients in Chinese

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[10]*Lin (1989) estimates a 17.9% compound annual growth in chemical fertilizer utilization in China between 1962 and 1978.*

Table 2. Measures of land use intensity, China, 1949-1988.

Year[a]	Crop index for grains (%)	Grain yield (MT/ha of sowed area)	Fertilizer use: $N+P_2O_5$ Million MT Inorganic	Organic	Total	Ratio of inorganic to total	Agricultural machine power (HP/ha)	Ratio of irrigated land[b] (%)
1949	128.0	1.03	0.03	3.92	3.95	0.8	n/a	18.5
1951-60	133.0	1.37	0.29	4.68	4.97	5.8	0.02	21.5
1961-70	137.8	1.64	1.88	5.50	7.38	25.5	0.15	30.4
1971-80	147.8	2.36	6.83	9.26	16.09	42.4	1.05	42.4
1981-85	147.1	3.29	16.35	14.20	30.55	53.5	2.55	45.2
1986	149.9	3.53	20.10	16.00	36.10	55.7	3.30	45.9
1988	150.0	3.63	21.40	n/a	n/a	n/a	n/a	44.4

Source:

[a]When a range of years is indicated, data reflect the annual average for the respective ranges of years.

[b]This is the ratio to total cultivated land.

agriculture, they began to be surpassed in relative importance by inorganic fertilizers in the early 1980s (Table 2).[11]

About 55% of China's organic fertilizer--in terms of total plant nutrients--is provided by manure from pigs and draft animals (cattle, buffalo, horse, mule) (Table 3). Organic manures are applied to the soil by Chinese farmers in one of three forms: raw, composted, and as biogas-slurry (Zeng 1982; Sun 1987a). An estimated 5 million (CAY 1988) to 8 million (Wittwer 1987) Chinese rural households have biogas pits that generate methane and slurry.[12] Eighteen percent of China's organic fertilizer is provided by crop residues, 10% by night soil, and 9% by green manure (Table 3).[13]

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[11]*See Tang and Stone (1980) for a detailed presentation covering 1952-1977 data on night soil, hog manure, draft animal manure, green manure, oil cake, compost, and river/pond mud and other organic fertilizers in China.*

OECD (1985) reports about 60% of the fertilizer applied to grain in China in the mid 1980s to be organic.

The World Bank (1985) estimates no more than 60% of fertilizer nutrients applied in China in 1980 to have been chemical. For the individual nutrients, the Bank estimates the following percentages from chemical sources: 71% nitrogen, 24% phosphorous, and 4% potassium. The remainder are reported to have come from either organic fertilizers or mining the soil, with soil mining of P and K "possibly quite significant."

Stone (1986) indicates that the increasing opportunity cost of labor in rural China is one factor causing farmers to substitute chemical fertilizers for organic fertilizers. The underlying reason is the extremely time-consuming process of collecting, mixing, storing, transporting, and applying organic manure. Stone cites a study which shows a requirement of 35-45 human days plus 20-25 animal days per 100 kg. (220 lb.) of nitrogen supplied from organic sources.

[12]*Wittwer (1987) reports that China is the world's leader in methane generation from organic residues and farm wastes. While firewood and crop residues/byproducts remain as the two primary sources of energy in China for cooking, heating, and lighting, biogas-methane is becoming a close third. In addition to these general uses, Wittwer reports that biogas-methane is used to warm little pigs in farrowing units, heat greenhouses, generate electricity, pump water, run irrigation pumps, power sprayers and food processing machinery, and dry grain.*

See Qiu, et al. (1990) for a recent insightful account of innovation and diffusion in the Chinese biogas program.

[13]*Stone (1986) indicates that nitrogen (1) is highly unstable in the principal manure forms, such as human and animal wastes, and (2) is lost from crop residues when they are burned for fuel and returned to the soil as ashes, still a common peasant practice in China.*

Table 3. Organic fertilizer resources in China, 1981.[a]

Organic fertilizer source	Amount produced annually	Nutrient content N	P_2O_5	K_2O	Total	Percent
	-----------------Million MT-----------------					
Pig manure	720	2.88	2.16	3.47	8.51	31.9
Draft animal manure	504	2.02	1.51	2.50	6.03	22.6
Straw and stalks	468	0.94	0.94	2.80	4.68	17.6
Night soil	150	1.90	0.30	0.45	2.65	10.0
Green manure	225	1.13	0.23	0.90	2.26	8.5
Sheep manure	50	0.35	0.30	0.60	1.25	4.7
Urban garbage	12	0.24	0.16	0.10	0.50	1.9
Poultry manure	12	0.18	0.18	0.10	0.46	1.7
Lean oilseed meal	2	0.21	0.03	0.06	0.30	1.1
Total	2,143	9.85	5.81	10.98	26.64	100.0

Source: Chen (1989)

[a]The data for green manure are for 1980.

Green manure usage peaked in China in the 1970s (Sun 1987a) and, within the next 10-12 years, dropped to perhaps only one-half of the peak level (personal communication, Ye Qianji June 22, 1990). The main green manures used in China are milk vetch (astragalus sinicus), hairy vetch (viccia villosa), sesbania (sesbania cannabina), dogheston sweet clover (melilotus spp.), and astragalus huangheensis (Sun 1987a).

In the single-cropping northern agricultural regions of China, green manure crops are planted before the main crop each year or once every 2 or 3 years. But for most multiple-cropped areas, various intercropping systems are practiced. The intercropping may be simultaneous and (1) row by row with the main crop, (2) mixed together, or (3) relay intercropped. The latter involves sowing the green manure crop before harvest of the main crop and plowing it down before planting of the next crop. These methods of intercropping neither reduce the sowing area of the main crops nor interfere with regular plantings (Sun 1987a).

Essentially no agricultural machine power was used in Chinese agriculture prior to Independence in 1949 (Table 2). Machine power increased only modestly during the 1950s and 1960s. Since then, machine power has increased, until in 1986 an average of 3.3 horsepower/ha. is used in Chinese agriculture. The number of hand tractors is about double the number of middle- and large-size tractors (Luo and Han 1990). A major motivation for farm mechanization in China is to speed cultural operations so as to increase cropping intensity.

Chinese irrigation dates back to 256 B.C. when the first of several ancient irrigation projects was completed; this was the DuJian Weir, 40 km. south of Chengdu in Sichuan Province, which remains functional until today (Sun 1987b). The ratio of irrigated to total cultivated land in China increased from 19% in 1949 to about 45% in the 1980s (Table 2). The vast majority of this increase took place prior to 1975.

The combined effect of the various external inputs used in Chinese agriculture can be envisioned through an examination of the energy inputs required in agricultural production. From 1965 to 1988, the total industrialized energy used in China's agriculture increased by over nine times (Table 4). The dominant energy use, for manufacturing inorganic fertilizer, increased by nearly 12 times over this 23-year period. In 1988, the energy used in fertilizer manufacture accounted for 83% of the total industrialized energy used in China's agriculture.

Electricity accounts for 7% of the industrialized energy used in agricultural production in China. The primary use of electricity is for pumping irrigation water, followed by post-harvest processing, e.g., grain threshing, flour milling. The other three energy inputs--machinery manufacture, fuel, and pesticide manufacture--each account for 3-4% of Chinese agriculture's industrial energy.

The overall energy intensity of agriculture, as measured by the kilo-calories of industrial energy consumed per kg of foodgrain produced in China has grown to become about equal to that in the U.S. (Guo and Han 1988). This

Table 4. Industrial energy used in agricultural production in China, 1965 and 1988.

Energy input	Energy equivalent 1965 10"KCal	Percent	1988 10"KCal	percent	1988 as a ratio to 1965
Inorganic fertilizer	198	63.2	2,361[a]	82.9	11.9
Electricity	60	19.2	206[b]	7.2	3.4
Machinery	7	2.2	112	3.9	16.0
Fuel	10	3.2	93	3.3	9.3
Pesticides	38	12.2	76	2.7	2.0
Total	313	100.0	2,848	100.0	9.1

Source: Calculations by Chen Xu (personal communication, June 17, 1990), based on Stat Yrbk (1989).

[a]About three-fourths of this energy is used in synthesizing nitrogen in fertilizer manufacture.

[b]This electricity does not include that which is used for rural business enterprises. The latter is estimated to be about 50% more than that used in agricultural production (Stat Yrbk 1989).

feature of Chinese agriculture is far different from that described by King (1911) some eight decades ago.[14]

DEMAND FOR FOOD

Increases in national demand for food depend on (1) rates of increase in population and per capita disposable income and (2) the income elasticity of demand for food. China's population growth rate in 1987 was reported to be about 1.1%/yr. (World Bank 1989).

Real per capita incomes are estimated by Pinstrup-Andersen, et al. (1990) to have increased in China between 1978 and 1988 by more than two times for rural people and by 87% for urban residents.[15] The overall income elasticity of demand for food in China is estimated to be 0.76-0.77 (Van der Gaag 1984; Pinstrup-Andersen, et al. 1990). Pinstrup-Andersen, et al. (1990) estimate the income elasticities of demand for various foods/food categories as follows:

Superior goods, elastic demand		Superior goods, inelastic demand	
Milk	1.71	Fish	0.86
Fruits	1.36	Wheat	0.68
Beef	1.23	Edible oil	0.65
Eggs	1.18	Pork	0.63
Poultry	1.16	Rice	0.36

Grains other than wheat and rice are reported to be inferior, with an income elasticity of demand of -1.10.

The general levels of and changes in per capita rural and urban household food consumption patterns over the past 10 years in China are portrayed in Figure 3. The most important relationships shown in this data-set are the following:

- Rural households consume nearly twice as much grain as urban households do;

- In place of grains, urban households consume three to four times as much fruit, beef, poultry, eggs, milk, and fish as rural households; the margin of difference between urban and rural households is smaller for vegetables and pork;

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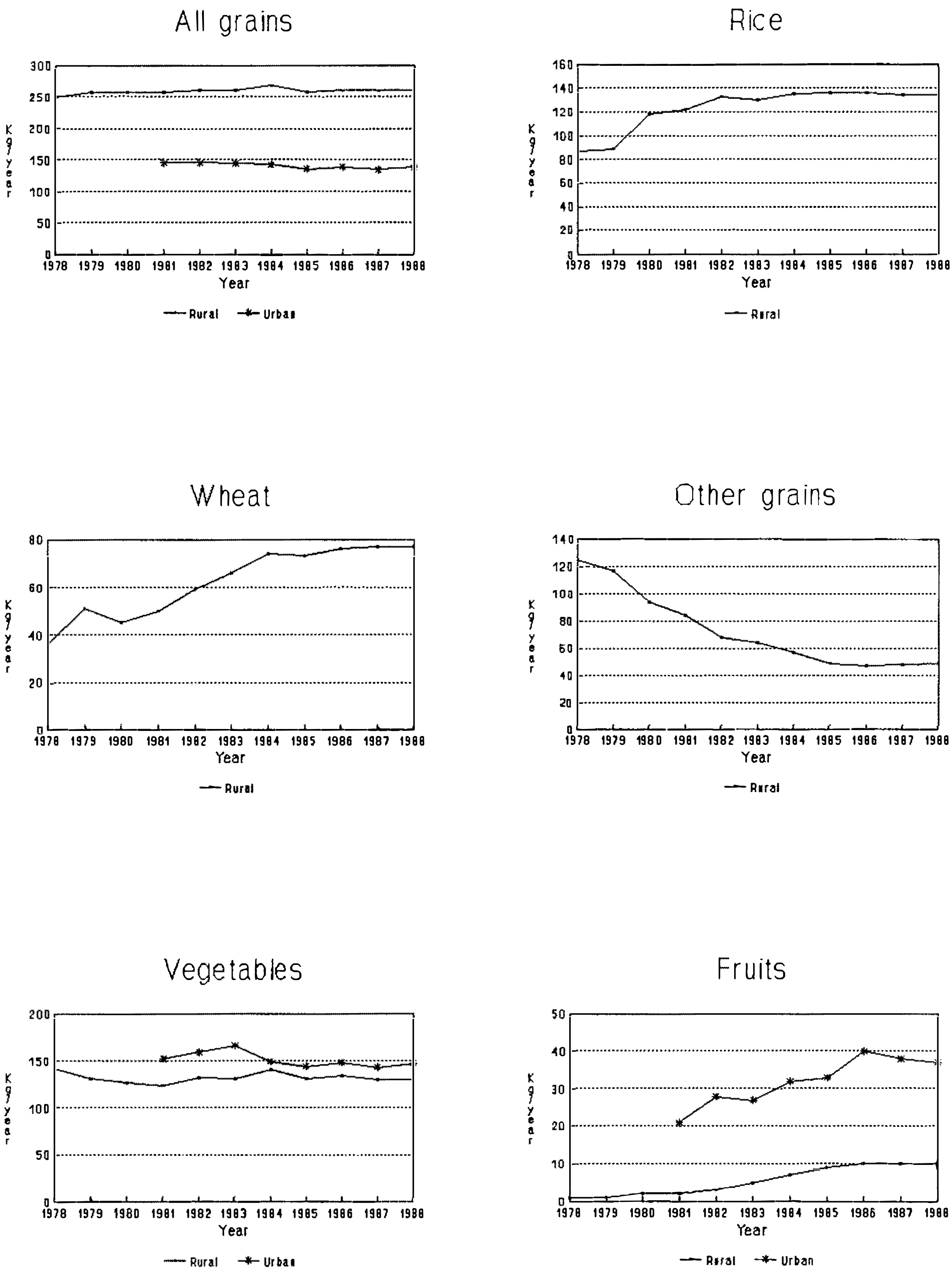
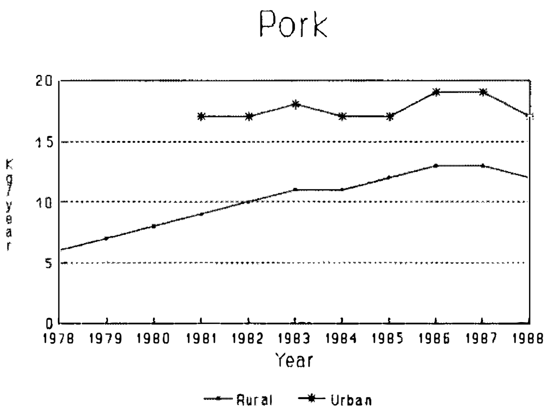
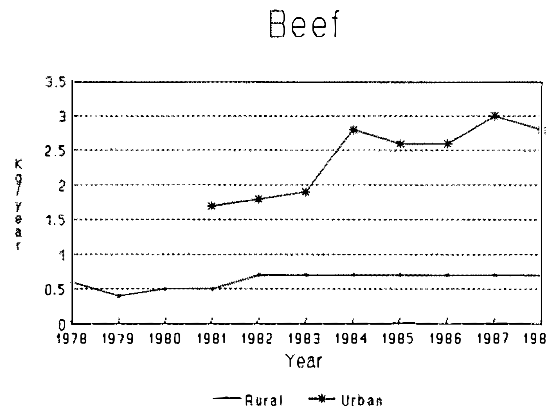
[14] *See Wen and Pimentel (1986) for an analysis of energy flows through a 17th century organic agroecosystem in eastern China and Han et al. (1985) for an energy analysis of 14 collective farms in north China.*

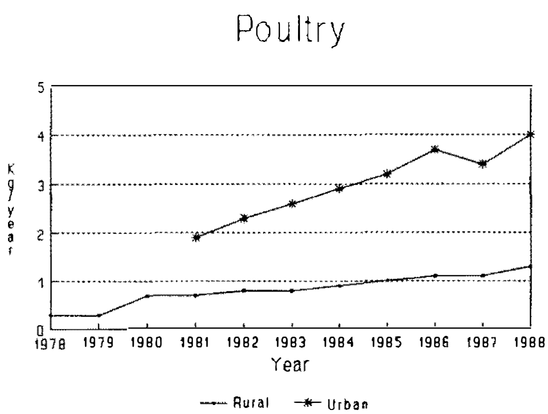
[15] *Johnson (1989) estimates that real incomes of farm families in China approximately doubled between 1978 and 1986. Carter and Zhong (1988) report that "rural incomes" rose by more than 3 times between 1978 and 1986, "which was more than the total increase for the prior 30 years."*

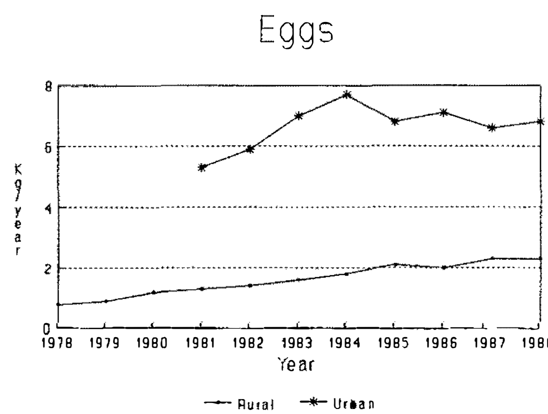
Figure 3. Per capita consumption of selected foods/food categories in China, rural and urban households, 1978-1988.

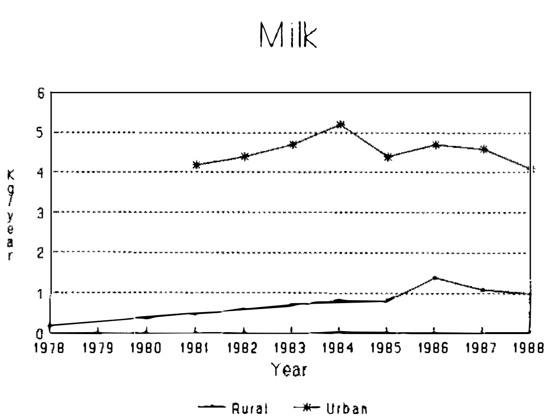


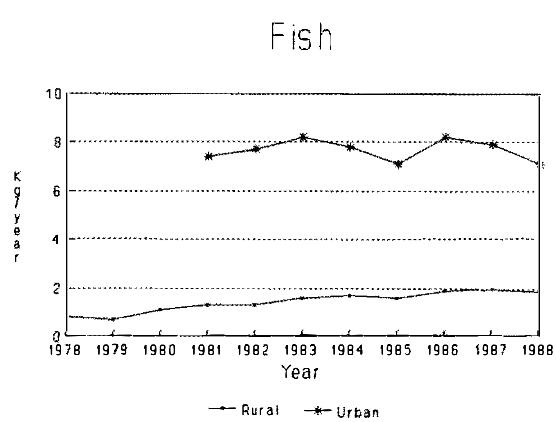












<u>Source:</u> Based on Pinstrup-Andersen, et al. (1990).

- Urban household food consumption patterns over time are relatively stable, with modest increases in fruits, beef, and poultry consumption and modest decreases in all grains and vegetables; and

- Rural households are consuming less coarse grain (e.g., sorghum and maize) over time and are replacing some of the course grain with modest increases of fruits, pork, poultry, eggs, milk, and fish.

Thus, China is following the pattern of many Third World countries with rapidly increasing per capita incomes (Yotopoulus 1985).[16] Consumption of livestock and livestock-related products has definitely begun to increase. Substantial energy losses are incurred in the conversion of feed grains into meat and related products. Thus, the substitution of livestock products for food grains is exacerbating China's already heavy population pressure on food grains (Cheng and Simpson 1989; Stone 1989; Yang and Tyers 1989; Pinstrup-Andersen, et al. 1990).

ENVIRONMENTAL CONCERNS

Many students of Chinese agricultural development believe that the success of Chinese production agriculture is being achieved at a definite cost to the environment. Guo and Han (1988) and Han (1989) indicate five main environmental concerns in China: vegetative destruction, soil erosion, land quality deterioration, water pollution, and water resource depletion. Each is covered in turn.[17]

Vegetative destruction

The main culprits of vegetative destruction in China are forest clear-cutting and grassland overgrazing. The nation's timber harvest exceeds forest replacement by an estimated 100 million cu. mt./yr. Despite a massive campaign for reforestation since Independence, the overall forest coverage of China is believed to have decreased from 13% in 1949 to 11% in the late 1980s. In Sichuan Province, forest loss has been particularly great, with forest cover dropping from 20% at the beginning of the 1950s to 12% by the end of the 1970s. This general situation has arisen from greater priority being given in mountainous areas to reaping near-term profits from timber production and resource mining than to longer-term forestry resource conservation.

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[16] *See Liu (1990) for an examination of changes in food consumption patterns in China during the past decade.*

[17] *Except as noted below, the evidence provided for these environmental concerns is taken from Guo and Han (1988) and Han (1989).*

See Cao (1989) for a treatment of air pollution and its effects on plants in China and Zhu (1989) for a discussion of issues related to nature conservation in China.

Nearly one-third of China's grassland is estimated to be overgrazed and degenerating (Luo and Han 1990). The total desertified area in the country has more than doubled since the 1950s. The problem is particularly acute in northern China, where 3.9 million ha. of cropland, 4.9 million ha. of rangeland, and 2,000 km. of railways are threatened by sand movement.

In addition to desertification, vegetative destruction has caused intensified drought and flooding disasters. The average area of the country affected by such disasters in the 1980s is 68% more than in the 1950s. A further result of vegetative destruction is, of course, exaggerated soil erosion.

Soil erosion

About 1.5 million sq. km., or about 15% of the total land area of China, suffers from soil erosion. An estimated 5 billion tons of soil are washed from the terrestrial highlands of China into the sea after long transportation by rivers. Historically, problems of soil erosion have been most severe along the upper-middle Yellow River, with roughly one-third of the nation's total erosion taking place along the Yellow River alone.

Despite efforts to counteract soil erosion since the 1940s, erosion problems have intensified, with an estimated 30% more land affected by erosion today than at the time of Independence. Areas of particular concern are (1) along the Yangtze River, in which erosion is estimated to have doubled since the 1950s, and (2) in Sichuan Province, in which erosion is estimated to have more than quadrupled since the 1950s. An estimated 44% of the area of Sichuan is undergoing erosion, with 2 million ha. of cultivated land on slopes losing an average of 110 tons of soil/ha./yr.

Land quality deterioration

In addition to the 12% loss of cultivated land since the early 1950s and the soil erosion noted above, the quality of much of China's farmland has deteriorated over the past 40 years. The deterioration in land quality has been associated with the more intensive use of external farm inputs on China's cropland and more intensive multiple cropping.

A recent national soil survey documents various dimensions of deterioration in China's land resources. For example, the proportion of highly productive farmland is estimated to have decreased from nearly one-third to one-fifth over the past 40 years. Of the country's total cultivated land, only 15% has no unfavorable production characteristics. The average soil organic matter content of China's farmland is less than 1.5%, with 11% of the land having less than 0.6% organic matter content. An estimated 59% of cropland is estimated to be deficient in available phosphorous and 23% deficient in potassium. Further, an estimated 12% of the cropland has poor soil structure and hardness.

Water pollution[18]

Water pollution in China began with the on-set of industrial development in the 1950s. Roughly three-fourths of the wastewater generated in China is estimated to be industrial in origin, with the remainder represented by human wastes. The increasing volume of wastewater discharges in the country is of major concern. To illustrate, wastewater discharges in China increased by 11% during just 6 years in the early 1980s and are projected to more than double by the year 2000.

Wastewater treatment techniques and facilities have not kept pace with the growth of industrial production and city construction. At present, only 22% of the wastewater in China is treated. About 20% of China's factories have wastewater treatment facilities. Even for factories with treatment facilities, however, the discharges may not reach required standards because of possible shortcomings in treatment processes.

Wastewaters produced by some manufacturing activities--such as pulp and paper production, printing and dyeing, leather tanning, and coal gasification --have high concentrations of pollutants which are difficult to biodegrade. Common treatment techniques tend to be inefficient; more effective techniques are costly. Technologies well-adapted to treating the wastes from China's vastly expanded small-scale rural industries tend to be limited and expensive. Problems of water pollution are now extending to the countryside, as well as to China's major urban concentrations.

As a result of these forces, rivers, lakes, and groundwater in China are subject to increasing pollution every year. A survey of 878 rivers in the early 1980s showed 82% of the rivers to be polluted. More than 5% of total river length had become fishless, while over 20 waterways were unusable for crop irrigation because of water pollution. About 50% of the groundwater in the North China Great Plain is estimated to be polluted. Recent water quality monitoring for 27 major cities showed that only 6 of the cities can provide drinking water meeting minimum required standards.

The degree of water pollution from agricultural practices in China, as in many places, is not well-documented. Two areas of major concern revolve around (1) the much increased use of fertilizers and to a lesser extent of pesticides and (2) large-scale intensive livestock production units being developed near major urban areas (Cheng and Simpson 1989). About 13 million ha. are estimated to be polluted by pesticides. Cereal grain losses from industrial pollution are estimated to be 5 mmt/yr.

Water resource depletion

China's annual total water resource availability ranks sixth in the world. On a per capita basis, however, China ranks 88th, with an availability of only one-fourth of the world average. The uneven regional and seasonal

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[18] *A major source of information for the water pollution and water resource depletion sections is Wang (1989).*

distributions of rainfall in China tend to exacerbate the problems of water shortage for people in particular areas at particular times of the year.

The major user of water in China is agriculture. The 45% of China's cropland that is irrigated requires more than 80% of the nation's total annual water withdrawals. Although the extent of irrigation has not increased in recent years, a definite increase in the demand for the nation's water supply arises from intensified industrial and human needs.

The increasing demands on China's limited water resources are causing regional drying in a large area of north China, with diminishing river-flows, a declining groundwater table, and a lowering of reservoir and lake levels--sometimes in some places to the point of a total seasonal drying up of above-ground water sources. The lowering of the water table is resulting in "groundwater-funnels" around urban and industrial centers in north China. The funnels around Beijing, for example, are estimated to cover 1,000 sq. km. Within these funnels, water tables are commonly declining 1-2 mt./yr. and up to 70 mt./yr. in the immediate vicinity of pumping centers.

Water resources are also diminishing in south China. The minimum water level of major rivers in Sichuan Province, for example, decreased during the dry season in 1987 by 0.2-0.8 mt. As a result, irrigation deliveries for rice in the Chengdu River Basin were both cut and delayed. In Hubei Province, the total number of lakes has diminished from 1,066 in 1949 to 326 today and the land area covered by the lakes has decreased by three-fourths.

ECOLOGICAL AGRICULTURE

The term "ecological agriculture" means to many Chinese professionals almost the same as what "sustainable agriculture" means to many American professionals. The Chinese very seldom use the term "sustainable." Thus, in this paper, the term "ecological" is used in relation to Chinese agriculture. Similarities and contrasts between the Chinese concept of "ecological agriculture" and the American concept of "sustainable agriculture" are discussed below.

Historical background

The late J.I. Rodale and his late son, Robert--considered by many to be the "fathers" of sustainable agriculture in the United States--have viewed traditional China as the inspiration for and substantive source of ideas that have come to be embodied in U.S. "organic" agriculture (Rodale 1990).[19]

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[19] *The term "sustainable" is used to represent situations in which producers adopt a holistic systems orientation in planning their farms. Emphasis is placed on selecting agricultural systems offering prospect of being environmentally/socially/economically sustainable over the long-term. "Sustainable" producers use crop rotations and other natural soil-building practices to at least partially replace synthetic chemicals (e.g., fertilizers, pesticides, livestock growth hormones) in their farm production*

King's (1911) book, Farmers of Forty Centuries: Permanent Agriculture in China, Korea, and Japan, provides the clearest English language exposition available on traditional Chinese agriculture. The following brief overview of selected traditional practices of Chinese farmers is based on King (1911).

To provide an overall flavor of King's perspective on Chinese agriculture, I first quote from the Introduction to his book:

> We are to consider some of the practices of a virile race of some 500 millions of people who have an unimpaired inheritance moving with the momentum acquired through 4,000 years; a people morally and intellectually strong, mechanically capable, who are awakening to a utilization of all the possibilities which science and invention during recent years have brought to western nations...
>
> We had long desired to stand face to face with Chinese and Japanese farmers; to walk through their fields and to learn by seeing some of their methods, appliances and practices which centuries of stress and experience have led these oldest farmers in the world to adopt. We desired to learn how it is possible, after 20 and perhaps 30 or even 40 centuries, for their soils to be made to produce sufficiently for the maintenance of such dense populations as are living now in these three countries.
>
> We have now had this opportunity and almost every day we were instructed, surprised, and amazed at the condition and practices which confronted us whichever way we turned; instructed in the ways and extent to which these nations for centuries have been and are conserving and utilizing their natural resources, surprised at the magnitude of the returns they are getting from their fields, and amazed at the amount of efficient human labor cheerfully given for a daily wage of 5 cents and their food, or for 15 cents, United States currency, without food. (p. 2; paragraphing mine)

Thus, a hallmark characteristic of traditional Chinese agriculture is its intensive cultivation of land resources, with twin objectives of (1) achieving high short-term production levels and (2) nurturing the land resource so as to not impair the land's long-term production capacity. King (1911) describes practices such as the following to enable accomplishment of these twin objectives.[20]

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enterprises. "Sustainable" includes, but is not limited to, "organic" production methods in which all synthetic chemicals are replaced.

[20]*Two very interesting, but especially difficult to confirm, additional features of Chinese agriculture reported by King (1911) are the following:*

> ***Concentration on work.*** *Forethought, after-thought, and the mind focussed on the work in hand are characteristic of these people. We do not recall to have seen a man smoking while at work. They enjoy smoking, but prefer to do this also with the attention*

Manure. Manure, of all kinds, human and animal, is religiously saved and applied to the fields in a manner which secures an efficiency far above our own practices...The city of Shanghai, in 1908, sold to a Chinese contractor the privilege of entering residence and public places early in the morning of each day in the year and removing the night soil, receiving there for more than $31,000 gold for 78,000 tons of waste. (p. 9)

Composting. They are a people who definitely set their faces toward the future...They have long realized that much time is required to transform organic matter into forms available for plant food and, although they are the heaviest users in the world, the largest portion of this organic matter is predigested with soil or subsoil before it is applied to their fields, and at an enormous cost of human time and labor, but it practically lengthens their growing season and enables them to adopt a system of multiple cropping which would not otherwise be possible. (p. 11)

Mulching. Such enormous field erosion as is tolerated at the present time in our southern and south Atlantic states is permitted nowhere in the Far East, so far as we observed, not even where the topography is much steeper. The tea orchards as we saw them on the steeper slopes, not level-terraced, are often heavily mulched with straw which makes erosion, even by heavy rains, impossible, while the treatment retains the rain where it falls, giving the soil opportunity to receive it under the impulse of both capillarity and gravity, and with it the soluble ash

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undivided and thus get more for their money. (p. 205)

Preserving angleworms. *For half an hour, we watched an old gardener fitting the soil with his spading hoe...Angleworms were extremely numerous, as large around as an ordinary lead pencil and, when not extended, two-thirds as long...Nearly every stroke of the spade exposed two to five of these worms but so far as we observed, and we watched the man closely, pulverizing the soil, he neither injured nor left uncovered a single worm. While he seemed to make no effort to avoid injuring them or to cover them with earth, ... we are convinced that his action was continually guarded against injuring the worms. They certainly were subsoiling his garden deeply and making possible a freer circulation of air far below the surface. Their great abundance proved a high content of organic matter present in the soil and, as the worms ate their way through it, passing the soil through their bodies, the yearly volume of work done by them was very great. In the fields flooded preparatory to fitting them for rice these worms are forced to the surface in enormous numbers and large flocks of ducks are taken to such fields to feed upon them. (p. 205)*

ingredients leached from the straw. The straw mulches we saw used in this manner were often 6 to 8 inches deep, thus constituting a dressing of not less than 6 tons per acre, carrying 140 pounds of soluble potassium and 12 pounds of phosphorus. The practice, therefore, gives at once a good fertilizing, the highest conservation and utilization of rainfall, and a complete protection against soil erosion. (p. 112)

Rotations built around legumes. Centuries of practice had taught Far East farmers that the culture and use of (leguminous) plants are essential to enduring fertility, and so in each of the three countries the growing of legumes in rotation with other crops very extensively for the express purpose of fertilizing the soil is one of their old, fixed practices. (p. 10)

Intercropping. By planting in hills and rows with intertillage, it is very common to see three crops growing upon the same field at one time, but in different stages of maturity, one nearly ready to harvest, one just coming up, and the other at the stage when it is drawing most heavily upon the soil. By such practice, with heavy fertilization, and by supplemental irrigation when needful, the soil is made to do full duty throughout the growing season. (p. 11)

Relay cropping. To save time, or lengthen the growing season of the cotton which was to follow, the seed was sown broadcast among the grain on the surface, some 10 to 15 days before the wheat would be harvested. To cover the seed, the soil in the furrows between the beds had been spaded loose to a depth of 4 or 5 inches, finely pulverized, and then with a spade was evenly scattered over the bed, letting it sift down among the grain, covering the seed. This loose earth, so applied, acts as a mulch to conserve the capillary moisture, permitting the soil to become sufficiently damp to germinate the seed before the wheat is harvested. (pp. 263-264)

Carefully leveled fields. We found almost all of the cultivated fields very nearly level or made so by grading...By this preliminary surface fitting of the fields, these people have reduced to the lowest possible limit the waste of soil fertility by erosion and surface leaching. At the same time, they are able to retain upon the field, uniformly distributed over it, the largest part of the rainfall practicable, and to compel a much larger proportion of the necessary run-off to leave by under-drainage than would be possible otherwise, conveying the plant food developed in the surface soil to the roots of the crops, while they make possible a more complete absorption and retention by the soil of the soluble plant food materials not taken up. This same treatment also furnishes the best possible conditions for the application of waste to the fields when supplemental irrigation would be helpful, and for the withdrawal of surplus rainfall by surface drainage, should this be necessary. (p. 113)

> **Fertilizing with river/canal mud.** In China, enormous quantities of canal mud are applied to the fields, sometimes at the rate of even 70 or more tons per acre. So, too, where there are not canals, both soil and subsoil are carried into the villages and there between the intervals when needed they are, at the expense of great labor, composted with organic refuse and often afterwards dried and pulverized before being carried back and used on the fields as home-made fertilizers. (p. 9) ...the spreading of canal mud broadcast over the encircled fields has had two very important effects, namely, raising the level of the low lying fields, giving them better drainage and so better physical condition, and adding new plant food in the form of virgin soil of the richest type, thus contributing to the maintenance of soil fertility, high maintenance capacity, and permanent agriculture through all the centuries. (p. 106)

Current situation

King (1911) did not assert that practices like these, which he observed during a year-long field trip, were necessarily followed everywhere in China. A field trip undertaken for only a few weeks in 1990 and a rather cursory review of literature are obviously inadequate to provide any definite confirmation of the general presence or absence of these practices in China today.

That each of the above practices is followed by at least some farmers today, however, is without question. We visited with farmers and agricultural scientists about and observed in fields the presence of organic fertilizers and composts (livestock manure, night soil, crop residues, ashes), green manures, crop rotations, intercropping, relay cropping, and carefully leveled fields. In only one instance did I observe the collection of canal mud, but some informants did confirm that in certain areas this practice does continue to be followed. Further, the statistics published in China on organic fertilizers include a "river/pond mud" category. Sun (1987a) also confirms the existence of the above organically-oriented practices in modern China.

Thus, it is clear that many of China's traditional agricultural practices continue to be followed today. Whether they are followed on as widespread a basis or so thoroughly as they once were may be open to question. The rising opportunity cost of labor, as a negative incentive to the use of organic fertilizers and other labor-intensive traditional practices, was cited above.[21] It is also clear that the use of purchased external inputs has increased tremendously in China over the past 25 years. Accompanying these and other economic and social developments in the country has been a definite deterioration in several important dimensions of the environment in China.

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[21]*During a field visit near Harbin, we found confirming evidence for labor scarcity impacting the adoption of farm technology. We were told that herbicides played a larger role, compared to mechanical cultivation, in northern than in southern Heilongjiang Province. Labor is scarcer in the north, and hence farmers used labor-saving herbicides.*

A key challenge in the future agricultural development of China is to determine and pursue as appropriate as possible a blend of traditional and modern agricultural inputs and practices. To move strongly and quickly away from the current use of modern inputs would almost inevitably lead to immediate production disasters. For the recent pace of adoption of certain external modern inputs to be perpetuated, however, would almost inevitably exacerbate some of the environmental problems that have already become acute.

China's search for a redefined balance between traditional and modern agricultural inputs and practices is embodied in what has come during the 1980s to be called "ecological" agriculture.[22] "Ecological" agriculture is a sufficiently new concept in China, just as "sustainable" agriculture is a new concept in the West, that a universal and well accepted definition for it is as yet non-existent. Nevertheless, a definite flavor of what is meant by "ecological" agriculture in China is represented by the definition given to it in 1987 by the Chinese Ministry of Agriculture: "a new type of agriculture, in which agricultural production and development are directed, organized, and managed in the light of ecological economic theory and a systems engineering approach, and in a manner combining traditional farming practices with modern agrotechnology" (Bian 1988).

Although the practice of "ecological" agriculture is location-specific, depending on the local production/economic/institutional environment, certain basic components are embodied to varying degrees in almost all cases in China.[23]

Holistic approach to natural resource use. Attempts are made to take into account and use all existing natural resources in particular localities. Emphasis is placed on producers maintaining options for switching resource-use as changes arise in natural/economic/institutional circumstances. Both production and environmental dimensions of resource use in agriculture are considered. Attention is given not only to cereal grains, but also to cash crops, vegetables, fruits, livestock, fodder crops, aquaculture, and forestry.

"Stereo" agricultural development. The multi-dimensioned use of space and time in agricultural production is promoted. One type of multi-layered cropping system consists of (1) tall trees which provide a canopy of protection to lower plants and the soil (e.g., Asian pears, rubber), (2) intermediate-sized trees (e.g., peaches) or shrubs (e.g., tea), and (3) low growing annual field crops. Another type of multi-layered system involves rice, <u>azolla</u> (nitrogen-fixing aquatic plant used for centuries in China as green manure),[24] and fish in paddy fields. Multiple-use of time in crop

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[22]*Unless otherwise noted, the following characterization of "ecological" agriculture in China is based on Guo and Han (1988), Han (1989), Li and Li (1990), and Luo and Han (1990).*

[23]*For insightful accounts of current agricultural production systems in China, see Li and Li (1990) and Luo and Han (1990).*

[24]*See Cheng and Simpson (1989) for more background on <u>azolla</u> in China.*

production is illustrated by the earlier-described systems of intercropping and relay cropping.

Integrated production systems. The internal recycling of resources with twin objectives of food and fuel energy production are emphasized. This often involves the use of organic wastes and tightly integrated crop-livestock-aquaculture production systems. The integration comes about as products from one enterprise become inputs to other enterprises. Biogas methane-slurry production units are a common component of such production systems.

Environmental management. Attention is paid in crop production to using organic fertilizers and biological controls and lowering the doses of pesticides and fertilizers. Such practices are aimed at (1) decreasing ground and surface water contamination, (2) decreasing possible human health problems from people handling chemicals and consuming products contaminated with toxic chemical substances, and (3) building up soil resources. Water purification and waste disposal systems to enable improved environmental hygiene in villages are undertaken. Energy may be generated through renewable resources such as solar, wind, and small hydro-electric projects.

Agricultural and nonagricultural options exploited. Diversification beyond agricultural enterprises, through rural industries, is encouraged. Improved production incentives arising from the household production responsibility system have resulted in fewer workers being able to maintain and, in many cases, to even increase agricultural production. Thus, workers are released for alternative employment. These released workers are encouraged to seek out industrial employment opportunities to augment family income.

In many respects, the overall goals and means of achieving the goals in Chinese "ecological" agriculture are similar to those in Western "sustainable" agriculture. Both types of agriculture have a very definite holistic systems orientation. Both are concerned about the short-term economic viability of producers and the long-term ecological-environmental and socio-economic sustainability of agricultural production systems. Both give major attention to crop rotations and other soil-building practices.

Certain areas of emphasis appear generally to differ between Chinese "ecological" and Western "sustainable" agriculture, however. The degrees of (1) enterprise integration and (2) emphasis on nonagricultural options are greater in Chinese "ecological" agriculture.[25] Further, Chinese "ecological" agriculture sometimes involves community-level resource management, rather than simply individual household management that is dominant in sustainable agriculture enterprises in Western countries.

On the other hand, reduced synthetic chemical (inorganic fertilizers and pesticides) use tends to receive less explicit, lower relative priority in Chinese "ecological" agriculture. A fundamental reason for relatively less

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[25]*These features are illustrated in some detail in the characterization of the five pilot ecological villages below.*

concentration on environmental management in China may be a much smaller current margin of difference between (1) the nutritional need/economic demand for food in the country and (2) the capacity of the country to produce food compared to that in most Western countries.

Whether trade-offs necessarily exist in realizing production versus environmental objectives is an open question.[26] One reason for expecting possible trade-offs is that individual producer decisions are most often made within the context of short-term profits, whereas environmental implications tend to be long-term and are largely external to the decision-making framework of individual producers. If trade-offs do exist between production and environment, China may be forced in the immediate-term to give greater weight to achieving production than environmental goals. To not do so could fuel fires of political instability.

On the other hand, trade-offs in realizing agricultural production and environmental goals may not necessarily be inevitable. China is searching for a common meeting ground toward achieving these objectives in her "ecological" agriculture efforts. She is doing so through over 1,100 pilot ecological villages in the 26 provinces across the country.

During my month in China, I visited four well-established pilot ecological villages--namely, Liu Ming Ying, southeast of Beijing; Doudian, southwest of Beijing;[27] Guquan, near Nanjing; and Dazu, west of Beibei in a mountainous area--and a pilot village just being established in Yingfong, also near Nanjing. Except for Dazu, these villages are all located within 50 km. of major urban centers. Some of the key features of these villages follow.

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[26]*A recent publication on agriculture and the environment by OECD (1989, 13) characterizes world agriculture to have "evolved to a state where short-term profits (are) made without maintaining the traditional harmony and interdependence between agriculture and the environment which has existed for centuries."*

O'Connell (1990) presents the view that U.S. farmers are searching for ways to achieve greater compatibility between environmental and production goals, and that the U.S. Department of Agriculture is responding to that concern. Reichelderfer (1990) presents an insightful account of historic policy conflicts in the U.S. in achieving production/income support versus environmental objectives. She goes on to indicate new policies that might be developed which would provide incentives for the integrated achievement of agricultural production and environment objectives. Stavins (1990) delineates certain policies that might be followed to provide incentives to producers for greater environmental protection.

[27]*See Cheng and Simpson (1989) for an insightful account of the biological recycle farming practiced in this pilot ecological village. See Yan, et al. (1989) and Wu, et al. (1989) for other case study reports of ecological agriculture in China.*

1. The change agents responsible for developing ecological projects for introduction into the pilot villages and working with village leadership in refining and introducing the projects in the villages are from various research institutes and universities. The specific institutions involved in the five pilot villages I visited are the Beijing Academy of Agricultural Sciences, the Nanjing Institute of Environmental Sciences, and the Chongqing Ecological-Agricultural Research Institute. The applied researchers from these institutions are in "continuous contact" with the villages to (a) assist in project implementation; (b) make changes in project planning and implementation, where necessary; (c) deal with questions/problems that arise; and (d) monitor and evaluate progress toward reaching objectives.

2. A common and fundamental feature of all five pilot villages are biogas-digesters. The digesters are at the village-level in four villages and at the individual household level in one village. Raw manure from cattle, hogs, and chickens and other organic waste products (e.g., night soil, crop residues) are placed in the digesters and allowed to ferment anaerobically. The fermentation process enables a more efficient conversion of raw materials into energy/fertilizer/feed resources in the form of biogas-methane and slurry-sludge than if the raw manure and other organic waste products were used directly. We observed or heard about biogas-methane being used as a fuel for home food preparation, lighting, water heating, egg incubation, and poultry and hog barn heating. The slurry-sludge is used as bio-fertilizer;[28] food for plankton which, in turn, is eaten by fish; and an ingredient in hog rations (up to 15% of the concentrate).

3. Crop agriculture has traditionally dominated each of the study villages. Primary emphasis has been on food grains. Newly introduced crops include various fruits and vegetables and mushrooms. Today, also, cattle, hogs, broilers, and layers[29] play an important role in the pilot village economies. In addition to producing manure--which is either applied to fields raw, composted prior to being applied, or biogas-digested prior to being applied--[30] the livestock (a) generate considerable income in the form of meat and milk sales to middle and upper-income residents of nearby urban areas and (b) provide higher protein diets for village people. The livestock consume leguminous forages, which are included in crop rotations because of the legumes' nitrogen-fixing and other soil-building properties, and crop residues (e.g., wheat straw, maize stalks).

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[28]*Some villagers use composted manure as a plow-down before planting and digested-slurry as a side-dressing during the growing season. They report realizing benefit from a slower, longer-lasting release of nutrients to the soil with compost and a more immediate release of nutrients from the digested slurry.*

[29]*Ducks and clams proved unprofitable in one village and subsequently were dropped.*

[30]*Limited quantities of dried poultry manure are included in cattle and hog rations.*

4. Four of the five villages have fish ponds; one also has eel ponds. Feed produced within the village for the fish and eels includes biogas-slurry and livestock manure (via plankton) and corn. The eels are raised in heated pools with water that flows from hot springs near to one village. The fish provide cash income from domestic sales and improved protein content in the diets of some local people. Eels are a high-value product exported live to Japan. Sludge taken from the bottom of fish ponds is used as fertilizer on cropped fields.

5. The fifth village, located in a mountainous area, is designed around a reforestation component--with terraced fruit trees, vineyards, and cedar trees intercropped with forage legumes rotated with maize, rice, wheat, and vegetables. Even with land taken out of cultivation because of the trees (about 20%) and land converted from grain production to forages, overall food grain production has increased. The forages support added livestock enterprises (e.g., pigs, rabbits, ducks, chickens, goats for milk) to the point, on the eco-farm we visited, livestock income now considerably exceeds crop income.

6. In the two villages for which labor data were reported (Doudian and Guquan), from 80% to 85% of the original agricultural labor force was reported to have since transferred from agriculture to rural industry. Rural industries observed in the villages include feed and flour mill processing; soft drink and food processing; corn starch,[31] pharmacy product, garment, brick, plastic, electric transformer, and handicraft manufacturing; and beef cold storage.

7. The capital for operating and investment purchases is almost entirely self-generated within the villages. Government subsidies and bank credit are of very limited importance.

8. Obtaining sound before- and after-project information on capital investment, labor earnings, and overall village net income is inherently difficult from oral presentations, especially when inflation and exchange rate changes need to be factored into the nominal monetary data reported. I, therefore, do not attempt to report specific information reflecting the economic benefit from the pilot ecological village experiments. It is clear, however, that since the establishment of the pilot ecological villages, investments in local capital assets have increased many-fold, grain production has increased substantially, and both non-grain agricultural production and rural industry income now greatly exceed the value of grain production in the three eastern China well-established ecological villages.[32]

In summary, the production systems in these pilot ecological villages are characterized by an intense recycling of resources within the respective local economies and many intertwined linkages between and among enterprises in

[31] *The waste from the corn starch factory is used as feed for hogs.*

[32] *Rural industry did not appear to be prominent in the Dazu experimental village in southwestern China.*

the respective villages. Levels of production and income in these pilot villages have increased a great deal. The agricultural and overall economies have become more diversified, with resultant added protection against production risks and a broader range of income-earning alternatives from which farmers and laborers can chose.

Though not systematically analyzed, it appears that the considerably intensified production systems do not require purchase of more external resources than were required in the before-project situations in the villages. Cheng (1990) reports in one of the pilot ecological villages that intensive crop and livestock farming has resulted in neither groundwater and air pollution nor a damage to basic soil fertility. Comparable information is not available for the other pilot ecological villages.

In terms of fuel energy sources, however, dependence on external sources in the pilot villages has definitely decreased in the pilot ecological villages. Vegetative cover of the soil has improved in the villages, and along with that soil erosion control has improved. Added local fish and livestock production, accompanied with increased levels of personal income, have also contributed to improved diets for at least some people in the villages.

Because proximity to urban centers can enhance the economic viability of livestock and horticultural enterprises, one must be careful in generalizing from the experience of the pilot ecological villages we visited. In these case villages, however, it appears that the sometimes reported trade-off that can make difficult the simultaneous achievement of both production and environmental goals may not apply. Production and incomes have been greatly intensified in the pilot ecological villages. In some respects, environmental conditions have improved. In other respects, environmental conditions may or may not have changed. I would suggest that determination of interactions between production and environment in pilot ecological villages is a particularly high priority topic for the next generation of research in China.

REFERENCES CITED

Barker, Randolph and Herdt, Robert W. 1985. The rice economy of Asia. Washington, D.C.: Resources for the Future.

Barker, Randolph, Sisler, Daniel G., and Rose, Beth. 1982. Prospects for growth in grain production. IN Chinese agricultural economy. Edited by Randolph Barker and Radha Sinha with Beth Rose. Boulder, CO: Westview Press.

Bian, J. 1988. Encouraging the development of ecological agriculture in China, with better understanding and more experiments. IN Ecological agriculture in China. Edited by Guo Shutian, Zhang Wenqing, and Wang Wenbin. Beijing: Zhongguo Zhanwang Pub. (in Chinese).

Byrd, William A. and Lin Qingson. 1990. China's rural industry: structure, development, and reform. Oxford: Oxford Univ. Press.

CAY. 1988. China agricultural yearbook, 1987. Beijing: Agric. Pub. House.

CFEPH. 1988, New China's population. China Financial and Economic Publishing House. New York: Macmillan Pub. Co.

Cao Hongfa. 1989. Air pollution and its effects on plants in China. <u>J. of Applied Ecology</u> 26:763-773.

Carter, Colin A. 1989. Current and prospective agricultural situation in the USSR and China. Prepared statement presented before the Joint Economic Committee, Congress of the United States and published in Agricultural reforms in the Soviet Union and China (S. Hrg. 101-353). Washington, D.C.: Government Printing Office.

Carter, Colin A. and Zhong Funing. 1988. China's grain production and trade: An economic analysis. Boulder, CO: Westview Press.

Chen Lizhi. 1989. Complimentary utilization of organic and inorganic fertilizers. Paper presented at an International Symposium on Balanced Fertilization, Beijing.

Cheng Xu. 1990. A case study of Doudian village. Beijing Academy of Agricultural Sciences. Unpub.

Cheng Xu and Simpson, James R. 1989. Biological recycle farming in the People's Republic of China: the Doudian Village experiment. <u>Amer. J. of Alternative Agric.</u> 4(1):3-7.

Crook, Frederick W. 1990. Allocation of crop sown area: Analysis of trends and outlook for the future. IN China: Agriculture and trade report, situation and outlook series. (RS 90-3). Washington, D.C.: Econ. Res. Serv., U.S. Dept. of Agric. July.

Elvin, Mark. 1982. The technology of farming in late-traditional China. IN Chinese agricultural economy. Edited by Randolph Barker and Radha Sinha with Beth Rose. Boulder, CO: Westview Press.

FAO. 1989. Production yearbook, 1988. Rome: Food and Agriculture Organization, United Nations.

Greer, Charles E. (ed.). 1988. China: Facts & figures, annual, Vol. II, 1988. Gulf Breeze, FL: Academic International Press.

Guo Shutain and Han Chenru. 1988. Problems of the environment in Chinese agriculture and a strategy for its ecological development (an overview). <u>INTECOL Bul.</u> 16:5-16.

Halbrendt, Catherine and Gempesaw, Conrado, II. 1990. A policy analysis of China's wheat economy. <u>Amer J. of Agric. Econ.</u> 72(2):268-278.

Han Chenru. 1989. Recent changes in the rural environment in China. <u>J. of Applied Ecology</u> 26:803-812.

Han Chenru, Golley, Frank, and Mou Zhengguo. 1985. Energy analysis of advanced collective farms in North China. <u>Agric., Ecosystems, and Environ.</u> 13:217-240.

Johnson, D. Gale. 1988. Economic reforms in the People's Republic of China. <u>Econ. Develop. and Cult. Change</u> 36(3):S227-S245. Apr. (supple.).

Johnson. D. Gale. 1989. Economic versus noneconomic factors in Chinese rural development. Paper presented at the Symposium on Chinese Rural Development, Amer. Agric. Econ. Assoc. 1989 Annual Mtg., Baton Rouge, LA.

Johnston, Bruce F. 1989. The political economy of agricultural development in the Soviet Union and China. <u>Food Research Institute Studies</u> 21(2):97-138.

King, F.H. 1911. Farmers for forty centuries: Permanent agriculture in China, Korea, and Japan. Madison, WI: Mrs. F.H. King

Li Zengfang and Li Youxia. 1990. Assessment of sustainable land use system research in China. Paper presented an International Workshop on Sustainable Land Use Systems, New Delhi, India, Feb. 12-16.

Lin Justin Yifu. 1988. The household responsibility system in China's agricultural reform: A theoretical and empirical study. <u>Econ. Develop. and Cult. Change</u> 36(3):S199-S222. Apr. (supple.).

Lin Justin Yifu. 1989. Farming institutions and technological choice in Chinese agriculture. Paper presented at the Symposium on Chinese Rural Development, Amer. Agric. Econ. Assoc. 1989 Annual Mtg., Baton Rouge, LA.

Liu Zhicheng. 1989. Review of a decade of economic reform in rural areas of China. Paper presented at the Symposium on Chinese Rural Development, Amer. Agric. Econ. Assoc. 1989 Annual Mtg., Baton Rouge, LA.

Liu Zhicheng. 1990. The achievements and strategy on adjustments of food structure in China. Paper presented at International Symposium on Food, Nutrition, and Social Economic Development, Beijing. June 5-8.

Luo Shiming and Han Chenru. 1990. Ecological agriculture in China. Chpt 19 in Sustainable agricultural systems. Edited by Clive A. Edwards, Rattan Lal, Patrick Madden, Robert H. Miller, and Gar House. Ankeny, IA: Soil and Water Conserv. Soc.

McMillan, John, Whalley, John, and Zhu Lijing. 1989. The impact of China's economic reforms on agricultural productivity growth. J. of Pol. Economy 97(4):781.

Niu Ruofeng. 1989. China's agricultural trade and perspectives on foreign competition. Paper presented at the Symposium on Chinese Rural Development, Amer. Agric. Econ. Assoc. 1989 Annual Mtg., Baton Rouge, LA.

OECD. 1985. Agriculture in China: prospects for production and trade. Paris: Organ. for Econ. Coop. and Develop.

OECD. 1989. Agricultural and environmental policies: opportunities for integration. Paris: Organ. for Econ. Coop. and Develop.

O'Connell, Paul F. 1990. Policy development for the low-input sustainable agricultural program. Chpt 25 in Sustainable agricultural systems. Edited by Clive A. Edwards, Rattan Lal, Patrick Madden, Robert H. Miller, and Gar House. Ankeny, IA: Soil and Water Conserv. Soc.

Perkins, Dwight and Yusuf, Shahid. 1984. Rural development in China. Baltimore, MD: Johns Hopkins Univ. Press.

Pinstrup-Andersen, Per, Yang Dongi, Xian Zu De, and Yang Ye. 1990. Changes in incomes, expenditures, and food consumption among rural and urban households in China during the period 1978-1988. Paper presented at International Symposium on Food, Nutrition, and Social Economic Development, Beijing. June 5-8.

Qiu Daxiong, Gu Shuhua, Liange Baofen, and Wang Gehua. 1990. Diffusion and innovation in the Chinese biogas program. World Development 18(4):555-563.

Reichelderfer, Katherine. 1990. Environmental protection and agricultural support: Are trade-offs necessary? IN Agricultural policies in a new decade. Edited by Kristen Allen. Washington, D.C.: Resources for the Future and National Planning Association.

Rodale, Robert. 1990. Sustainability: An opportunity for leadership. Chpt 6 in Sustainable agricultural systems. Edited by Clive A. Edwards, Rattan Lal, Patrick Madden, Robert H. Miller, and Gar House. Ankeny, IA: Soil and Water Conserv. Soc.

Stat Yrbk. 1989. Statistical yearbook, 1988. Beijing: China Statistical Publishing House.

Stavins, Robert N. 1990. Innovative policies for sustainable development in the 1990s: Economic incentives for environmental protection. (Disc. Pap. QE90-11). Washington, D.C.: Resources for the Future. Jan.

Stone, Bruce. 1986. 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. Vol.I. Washington, D.C.: Government Printing Office, pp 453-496.

Stone, Bruce. 1989. Fertilizer's greener pastures. The China Business Review. Sept-Oct.

Sun Han. 1987a. Organic farming--growing plants the organic way. IN Feeding a billion: frontiers of Chinese agriculture. Edited by Sylvan Wittwer, Yu Youtai, Sun Han, and Wang Lianzheng. East Lansing, MI: Michigan State Univ. Press.

Sun Han. 1987b. Water resources--the lifeline of Chinese agriculture. IN Feeding a billion: frontiers of Chinese agriculture. Edited by Sylvan Wittwer, Yu Youtai, Sun Han, and Wang Lianzheng. East Lansing, MI: Michigan State Univ. Press.

Tang, Anthony M. and Stone, Bruce. 1980. Food production in the People's Republic of China. (Res. Rep. 15). Washington, D.C.: International Food Policy Research Institute. May.

Tuan, Francis and Ru Shi. 1990. PRC agricultural trade developments and prospects: With emphasis on Pacific Rim countries. Paper presented at the International Agric. Trade Research Consortium, Hawaii. Aug. 1-2.

Van der Gaag, Jacques. 1984. Private household consumption in China. (Staff Wkg. Pap. 607). Washington, D.C.: World Bank.

Wang Jusi. 1989. Water pollution and water shortage problems in China. J. of Applied Ecology 26:851-857.

Webb, Shwueng H. 1990. Regional crop production patterns in China. IN China: Agriculture and trade report, situation and outlook series. (RS 90-3). Washington, D.C.: Econ. Res. Serv., U.S. Dept. of Agric. July.

Webb, Shwueng H. and Crook, Frederick. 1990. China's experience with economic reforms: Successes and failures. Paper presented at the 1990 Annual Mtg. of the Amer. Agric. Econ. Assoc. Univ. of Brit. Col., Vancouver.

Wen Dazhong and Pimentel, David. 1986. Seventeenth century organic agriculture in China: II. Energy flows through an agroecosystem in Jiaxing region. Human Ecology 14(1):15-28.

West, Lorain A. 1990. Farm household access to credit markets under the household responsibility system in China. Paper presented at the 1990 Annual Mtg. of the Amer. Agric. Econ. Assoc. Univ. of Brit. Col., Vancouver.

Wittwer, Sylvan. 1987. Energy resources in the countryside. IN Feeding a billion: frontiers of Chinese agriculture. Edited by Sylvan Wittwer, Yu Youtai, Sun Han, and Wang Lianzheng. East Lansing, MI: Michigan State Univ. Press.

World Bank. 1985. China: Agriculture to the year 2000. Annex 2 to China: Long-term development issues and options. Washington, D.C.: World Bank.

World Bank. 1989. World development report, 1989. Published for the World Bank. Oxford: Oxford Univ. Press.

Wu Shanmei, Xu Shengrong, and Wu Jiangliang. 1989. Ecological agriculture within a densely populated are in China. Agric. Ecosystems and Environ. 27:597-607.

Yan Chuanqi, Yang Weizhang, Li Chunte, Han Xiaozong, Ma Fenglin, and He Wanyun. 1989. Developing an improved agricultural economy based on ecological relationships in a soil erosion area in the north of China. Agroforestry Systems 8:83-90.

Yang Yongzheng and Tyers, Rodney. 1989. The economic costs of food self-sufficiency in China. World Development 17)2):237-253.

Yotopoulus, Pan A. 1985. Middle-income classes and food crises: The "new" food-feed competition. Econ. Develop. and Cult. Change 33(3):463-483.

Yu Youtai. 1987. Agricultural history over seven thousand years. IN Feeding a billion: frontiers of Chinese agriculture. Edited by Sylvan Wittwer, Yu Youtai, Sun Han, and Wang Lianzheng. East Lansing, MI: Michigan State Univ. Press.

Zeng Guangji. 1982. The development of organic farming in China. Harbin, China: Heilongjiang Academy of Agricultural Sciences. Unpub.

Zhu Jing. 1989. Nature conservation in China. J. of Applied Ecology 26:825-833.

ANNEX A

INSTITUTIONS VISITED WHILE IN CHINA
MAY 28-JUNE 23, 1990

Beijing

Beijing Agricultural University, Agronomy Department
Beijing Pomology and Forestry Institute
Beijing Vegetable Development Institute
Chinese Academy of Agricultural Sciences
Field trips to "eco-farms" in Liu Ming Ying and Doudian Townships

Harbin

Heilongjiang Academy of Agricultural Sciences
Northeast Forestry University
Field trip to Yanjiagong Farm

Nanjing

Nanjing Agricultural University, including the College of Agricultural Economics and Trade
Nanjing Institute of Environmental Sciences
Jiangsu Academy of Agricultural Sciences
Field trips to Guquan "eco-farm" village and to new Yingfong Township "eco-farm" research site

Guangzhou

Guangdong Academy of Agricultural Sciences
Guangzhou Municipal Agricultural Society
Field trip to Baiyunshan Group Company mechanized chicken farm and pig feeding factory

Beibei, Chongqing

Chongqing Ecological Agricultural Research Institute, Southwest Agricultural University
Field trip to Dazu "eco-farm" experimental site

ANNEX B

SELECTED DATA ON CHINA'S GRAIN PRODUCTION

China's grain yields tend to be high relative to those in many other countries and regions in the world. Comparative data for 1988 for total cereals collectively and China's three main cereals--wheat, rice, and maize--are shown in Table A.1. Relative to the world on average, China's total cereal average yield of 3.9 t./ha. is 58% higher; her individual crop yields are from 16% (maize) to 60% (rice) higher. Compared to the rest of Asia, China's total cereal average yield is 51% higher; her individual crop yields are from 33% (wheat) to 56% (rice) higher.[33]

Table A.1. Cereal grain yields, China and selected countries and world regions, 1988.

	Yield (kg./ha.)			
Country/region	Total cereals	Wheat	Rice	Maize
China	3,922	3,017	5,304	3,730
Japan	5,429	3,621	5,825	1,800
Indonesia	3,642	n/a	4,140	2,082
India	1,711	1,995	2,487	1,271
Mexico	2,200	4,111	3,500	1,735
United States	3,715	2,291	6,178	5,311
Asia	2,598	2,263	3,402	2,773
World	2,483	2,314	3,320	3,202

Source: FAO (1989).

China's total cereal average yield is 6% higher than the U.S.'s, 8% higher than Indonesia's, 78% higher than Mexico's, and 2.29 times as high as

[33] *Carter and Zhong (1988) report the area sown to hybrid rice varieties in China to have increased from 4.33 million ha. in 1878 to 6.75 million ha. (about 20% of the total rice sown area) in 1983. They report hybrid rice yields to be 17% higher than the average of total rice in China in 1982.*

Lin (1989) reports that hybrid rice started to replace dwarf varieties of rice in 1976. By 1986, 28% of the rice area was sown to hybrid rice. Barker and Herdt (1985) consider the innovation and commercialization of hybrid rice in China to be the most important achievement in rice breeding in the 1970s.

India's. The same general pattern of relationships holds for the individual crops, except that Mexico's average wheat yield is 36% higher than China's, the U.S.'s average rice yield is 16% higher than China's, and the U.S.'s maize yield is 42% higher than China's. On the other hand, China's yields are lower than Japan's for total cereals (28%), wheat (17%), and rice (9%).

Barker, et al. (1982) report a long-term 1955-1957 to 1977-1979 annual growth rate in China's grain production of 2.4%. Perkins and Yusuf (1984) report the following annual growth rates in China's grain production: 3.5%, 1952-1957; 0.0%, 1957-1965; 3.9%, 1965-1975; 2.8%, 1975-1980; 2.1%, 1957-1980; and 4.9%, 1982-1983. The World Bank (1985) reports the gross value of agricultural output in China from 1979 to 1985 to have grown at an annual average exceeding 7%, or more than twice the rate achieved over the previous two decades. Carter and Zhong (1988) report a 2.5% annual growth rate in total grain production between 1952 and 1978 and a 4.95% annual growth rate between 1978 and 1984. Johnson (1989) reports a 7.7% annual growth in gross agricultural output in China for 1979 to 1984. Greer (1989) reports China's net annual agricultural growth rate to have been 7.7% between 1978 and 1984, compared with 3.0% during 1971-1980.

Perkins and Yusuf (1984) report annual growth rates in yields in China from 1955-57 to 1979 as follows: 4.0% wheat, 3.4% corn, and 2.1% rice. Halbrendt and Gempesaw (1990) report wheat yields in China to have increased 6.9%/yr. between 1980 and 1987.

Perkins and Yusuf (1984) explain the growth of China's grain production until 1979 as being due to an increase in the use of modern biological (e.g., chemical fertilizers, improved plant varieties, timely supplies of water, pesticides and other farming practices) and mechanical inputs. Lin (1988) estimated that 45% of the increase in agricultural output in China between 1980 and 1983 was due to the adoption of the rural household responsibility system, with the remainder attributed generally to price increases and improved technology. Carter and Zhong (1988) indicate that policy changes, such as price incentives, the rural household production responsibility system, and the free market were "largely responsible" for post-1978 yield increases; they also draw attention to improved crop varieties, increased tubewell irrigation, and expanded use of inputs (primarily fertilizer). McMillan et al. (1989) estimate that 78% of the increase in agricultural productivity in China between 1978 and 1984 can be attributed to the incentive effects of the new responsibility system and 22% to the incentive effects of the higher prices. Stone (1989, 3) presents a rather contrary explanation for recent grain production increases in China: "Complementing substantial developments in water control and extended use of high-yielding crop varieties from 1950-80, increased fertilizer supplies--not prices, incentives, or the responsibility system--were primarily responsible for the remarkable performance in foodgrain production during the last decade."