The Impact of Environmental Degradation on Grain Production in China, 1975–1990*

Scott Rozelle

Food Research Institute, Stanford University, Stanford, CA 94305

Gregory Veeck

Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA 70803

Jikun Huang

Center for Chinese Agricultural Policy, Chinese Academy of Agricultural Sciences, Beijing, China 100081

Abstract: The sluggish rate of growth for China's grain production during the past decade is a major concern for agricultural planners. At the national level, the average rate of production fell to 1.8 percent per year from 1985 to 1990, after an average growth rate of 4.7 percent per year from 1978 to 1984. Supplies and application rates of critical farm inputs during 1985 to 1990 reached record levels, but had a disappointing effect on both yields and gross production. We hypothesize that environmental degradation has had a major effect on grain production in many of China's agricultural areas. In this article, we introduce a nationwide fixed effect grain-yield function which incorporates both traditional input variables and an additional set of variables that reflect trends in environmental degradation at the provincial level. The model is estimated using time-series data for the period from 1978 to 1990. The analysis suggests that environmental degradation may have cost China as much as 5.7 million metric tons of grain per year in the late 1980s. Results also indicate that the projected losses due to environmental stress are not evenly distributed throughout China, but that regions which brought considerable amounts of marginal land into cultivation during the earliest years of the reform period now face the greatest problems. Xinjiang and Gansu in the Northwest, the Loess Plateau provinces, and Yunnan and Guizhou AR in the Southwest reported stagnant production despite significant increases in technical inputs. We conclude that this stagnation should be credited to the increasing degradation of agricultural land in these areas.

Key words: agriculture, China, environmental degradation, grain production.

Issues of land degradation and environmental pollution in China have received an increasing amount of attention during the past 15 years (Smil 1984; He 1991; Qu 1989; Ross 1988). Although this trend no doubt reflects greater access to reliable information, in many areas signs indicate that conditions are getting worse (Glaeser 1990; Shouse 1993; Ruddle 1993; Smil 1993; Zheng and Yu 1990). We believe that real increases in land degradation and pollution have occurred in the postreform period, despite efforts of environmental-

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ists to influence land use policies. The intensification of agriculture and the rapid growth of rural industry, housing stocks, and transport systems have focused attention on changes in land use and declining land quality in the countryside, but solutions have been slow in coming (McDowell 1990).

Of particular concern to agricultural planners is the growing problem of land degradation and its impact on agricultural productivity. Structural and economic changes in China's agricultural sector, stimulated in part by the rural reforms, have brought about the increasing intensification of cropland use, as well as the continued cultivation of marginal and degraded land for production (Sun 1988). While a number of policies have been developed to combat these problems, existing measures routinely are not enforced and their implementation often flies in the face of ambitious production and economic growth targets (Ross 1989; Glaeser 1990). Many provinces, particularly those on the periphery, are facing severe land constraints as a result of growing populations and increased demand for agricultural and forestry products. In many areas, the use of marginal land for crop production is vital to meet subsistence grain requirements (Glaeser 1990). In other provinces, higher-quality land is being cropped more intensively to meet the demand for cash crops as well as to meet high production quotas (Zheng and Yu 1990). Researchers agree that, over time, environmental problems are multiplying in China and the areas affected by them are increasing as well (Smil 1993; Ross 1988).

While further measures must be taken to protect and restore China's arable land stocks, it is difficult to introduce such proposals given current economic conditions (Sun 1988). Part of the problem is that the interests of those involved are so broad and diverse that even rational and systematic assessments of the problem are difficult. An even more fundamental problem, however, is the difficulty in estimating the real costs of land degradation (Barrow 1991).

The first step in assessing these costs is to understand where the different types of environmental problems are most serious. The type and extent of land degradation varies throughout China's agricultural regions and provinces. In the Huang-Huai-Hai Plain, located in northern Jiangsu, eastern Anhui, and southern Shandong, the problem of erosion is minimal, but salinized cropland is increasing. In China's Southwest, the opposite is true; eroded surfaces are the greatest threat to agriculture, while salinity problems are quite minor. Other problems currently leading to reduced yields and gross production include soil compaction, reductions in soil fertility, the collapse of irrigation systems from siltation and poor maintenance, and the increase in flood- and drought-prone land because of deforestation and other local environmental problems (Ministry of Agriculture 1991).

Data limitations preclude an exhaustive study of the long-term economic and environmental costs of land degradation and land reclamation at this time. An assessment of how environmental problems affect China's capacity to produce food is possible, however. In this paper we estimate changes in foodgrain productivity over time; our estimation not only incorporates the contributions of improved technology and increased supplies of critical inputs, but also evaluates the actual impact of environmental degradation. To this end, we introduce a provincial-level model designed to measure the contribution to grain yields of increases in traditional inputs since the mid-1970s, as well as the corresponding reductions in output that might result from various types of environmental degradation during this period. We seek to identify, at the provincial level, what might be seen as a "geography of land degradation" by identifying the main forms of environmental problems as they exist throughout China's agricultural lands; we then estimate the effects of these problems on grain production. The data span the years from 1975 to 1990.

Our goal is to understand the interregional changes of *major environmental problems* during the postreform period in China and to analyze the relationships among grain yields, input usage, and environmental degradation of cropland. To accomplish these objectives, we initially review changes in grain productivity and the use of key inputs in China. We then briefly discuss changes in several types of land degradation at the national and provincial levels. Finally, we specify an empirical model and estimate a grain-yield function with cross-section provincial data covering a 16-year period. A decomposition analysis is used to estimate the contribution of productive inputs and environmental variables to yield growth, and an attempt is made to identify the source of degradation in the provinces where land quality has suffered the most. The final section provides a discussion of the study's major policy implications.

Changes in Grain Production in China, 1952–90

The increases in China's grain production and yields during the past four decades are impressive, particularly in light of the relatively static amount of arable land cultivated throughout this period (Fig. 1). The annual rate of increase has not been uniform during this period. In particular, the 1978 rural reforms form a benchmark of sorts to both earlier and later periods. For a variety of reasons, which we discuss later, the reforms stimulated both grain production and yields for most crops. From 1952 to 1978, production grew at an annual rate of 2.5 percent. In the immediate wake of the reforms, however, this annual rate almost doubled to 4.7 percent. During these same periods, yield growth rates averaged 2.8 percent and 5.9 percent, respectively (Table 1).

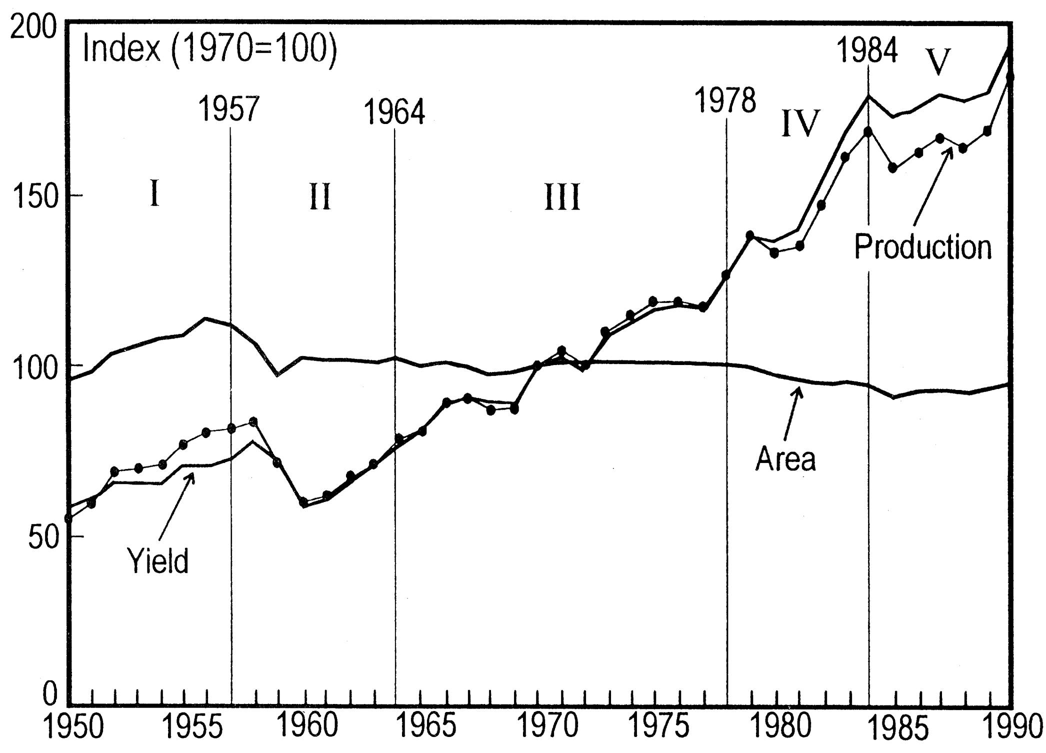

Figure 1. Grain production, sown-area, and yield trends, 1950–90. *Source*: ZGTJNJ (various years).

Table 1

Annual Growth Rates of Major Components of China's Grain Economy, 1952–90

Period	Production	Area	Yield
1952–57	4.0	1.7	2.3
	(100)[a]	(43)	(58)
1957–64	−2.0	−0.9	−0.9
	(100)	(51)	(49)
1964–78	3.5	0.1	3.3
	(100)	(3)	(97)
1978–84	4.7	−1.1	5.9
	(100)	(−23)	(123)
1984–90	1.8	0.2	1.6
	(100)	(11)	(89)

Source: ZGTJNJ (various years).
[a] Figures in parentheses are the percentage of growth in grain production due to changes in area or yield. Growth rates are computed by regression using the data in the period indicated.

Increases in production were by no means evenly distributed throughout China's provinces in the early postreform era. The annual rate of increase for grain yields in Jilin jumped a remarkable 14 percent from 1980–84 to 1975–79 (Fig. 2). Other areas with significant increased growth in yield rates include Yunnan, the Loess Plateau provinces, and Anhui. These provinces, which had some of the fastest growth in yields during the early reform period, are also the ones that are now facing the greatest problems of land degradation.

The magnitude of these increases in yield and production from 1952 to 1990 should properly be credited to China's ongoing efforts to improve agricultural organization, infrastructure, and technology (Stone 1988; Fan 1991; Huang and David 1992). While the commune system is often treated as a pariah in light of recent developments, certain infrastructural goals were well served by the system and should not be overlooked. The organization of China's rural areas into collectives contributed to the expansion of irrigated area from 18.49 percent in 1952 to more than 45 percent in 1978, an increase of nearly 20 million hectares. Mechanized tillage and harvesting on state farms in areas such as the Northeast and Inner Mongolia permitted enormous areas of land to be brought into production quickly despite regional labor shortages.

The utilization of chemical fertilizers by farmers rose monotonically throughout the 1950s and 1960s, from virtually zero in 1952. In the 1960s, most of the increase in chemical fertilizer came from small, domestically engineered ammonium bicarbonate plants (Ye 1992). After a number of large urea plants were built in the mid-1970s, rates of nitrogen fertilizer use jumped more than 50 percent in the late 1970s (Table 2). Achievements were also made regularly in the improvement of rice, wheat, soybean, and maize varieties (Stone 1988). In 1976, Chinese scientists began extending F_1 hybrid rice, a technology with a potential 15 to 20 percent yield advantage over conventional high-yielding varieties (He et al. 1984; Yuan and Chen 1988).

These earlier gains, however, paled by comparison with those of the late 1970s and early 1980s. Grain production increased by a total of 102.5 million metric tons between 1978 and 1984, growing at 4.7 percent per year. Grain yields grew at an even higher rate of 5.9 percent per year (Table 1). The introduction of the Household Responsibility System in 1979, through which production decisions were shifted from the collectives to individual households, had a significant impact on the performance of China's farms as

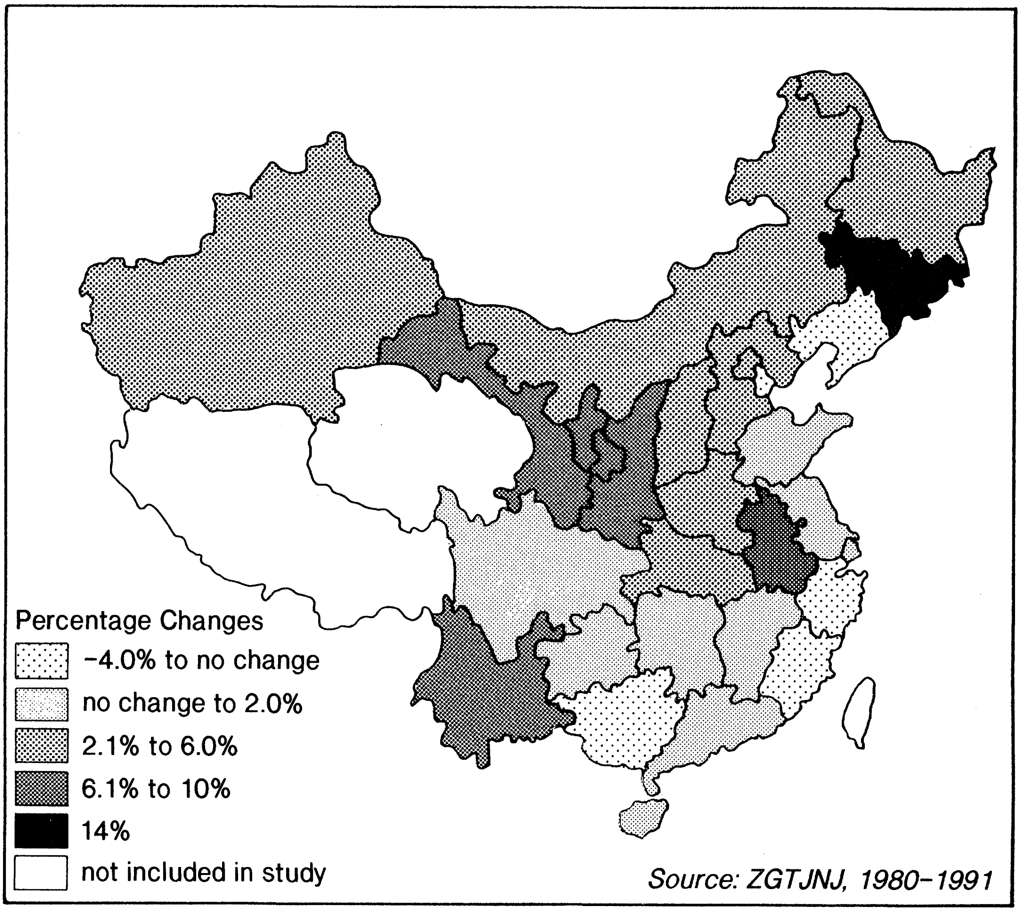

Figure 2. Changes in average annual growth rates in grain yields in China between 1975–79 and 1980–84. *Source*: ZGTJNJ (1980–91).

production incentives were improved dramatically (Zhu and Seldon 1993; Lin 1992b; McMillan, Whalley, and Zhu 1989).

The continuation of earlier trends in the development and introduction of technological innovations and applications of basic agricultural research also contributed to the growth of yields in the early 1980s. Hybrid rice varieties quickly spread across China during the early reform period, increasing from 12 percent of rice-sown area in 1978 to nearly 25 percent in 1984 (Table 2). This technology, unique to China, has had an important impact on yields and gross output (Lin 1992a). As China's new agro-manufacturing capacity was coming on-line in the postreform era, the use of chemical fertilizer doubled between 1978 and 1984 (Table 2).

Just as China's agricultural future seemed secure, however, production stagnated. After hitting a peak in 1984, the annual growth rates for grain production and yields declined for the first time since the early 1960s. The annual growth rate for the national average grain yield dropped sharply to 1.6 percent during the period 1985 to 1990 (Table 1). At the same time, growth rates for grain production declined to 1.8 percent, and grain produc-

Table 2

Growth of Agricultural Technology in China, 1952–90

Year	Fertilizer Use Per Crop Area[a] (kg/ha)	Proportion of Area Irrigated[b] (%)	Proportion of Hybrid Rice Area[c] (%)
1952	0.55	18.49	0
1957	2.37	24.45	0
1962	4.49	29.68	0
1965	13.55	31.91	0
1970	24.48	35.60	0
1972	28.44	37.77	0
1974	32.68	41.31	0
1976	38.93	45.26	0.41
1978	58.89	45.24	12.58
1980	87.17	45.21	14.61
1982	104.60	44.80	16.94
1984	120.65	45.43	24.71
1986	133.88	45.96	27.89
1988	147.82	46.36	38.77
1990	174.59	49.55	48.17

Sources: Hybrid rice area is from China National Rice Research Institute. Others are from ZGNCTJNJ (various years).
[a] Fertilizer use is measured in nutrient form and deflated by total crop area.
[b] Effectively irrigated area divided by total cultivated area.
[c] Proportion of rice area planted to hybrid rice.

tion itself fell short of national planning targets in each year of the seventh five-year plan (1986 to 1990). The relatively constant level of yields and gross production has led some of China's agricultural scholars to question the continued capacity of China to feed itself given rising incomes and an annual rate of population increase of 1.2 percent (Mei 1992; Ministry of Agriculture 1991). China's arable land base is also declining, and if improvements in yields are insufficient to make up the difference, either consumers will experience food shortages and price increases or increasing amounts of foreign currency will have to be used to import grain.

This slowdown in the growth of yields and production is even more remarkable since the decline has occurred at a time when the use of modern inputs has continued to expand and improve in quality. Chemical fertilizer use expanded by 64 kilograms per hectare between 1984 and 1990 (Table 2). Nitrogen fertilizer use alone increased from 48 million tons in 1985 to more than 64 million tons in 1990. Proportional increases in the use of phosphorous, potassium, and compound fertilizers are even greater than for nitrogen (ZGNYNJ 1986, 1991). With increasing levels of inputs, the quality of chemical fertilizer and other farm chemicals also improved in the late 1980s. Reversing the declines of the early 1980s, the proportion of cultivated area under irrigation increased to 49.5 percent in 1990 (ZGNYNJ 1986, 1991). The introduction of modern technology into the agricultural sector continued steadily throughout the late 1980s as well (Stone 1988). The sown area for hybrid rice, for example, doubled in coverage to almost 50 percent by 1990 (Table 2).

The changes in yield growth rates and production for the period from 1985 to 1990 are not evenly distributed throughout China. While all provinces (except Gansu and Guangxi) experienced declines in annual rates of growth when compared to the early 1980s, the most severe reductions in yield growth rates were recorded by the Loess Plateau provinces and Inner Mongolia (Fig. 3). A compari-

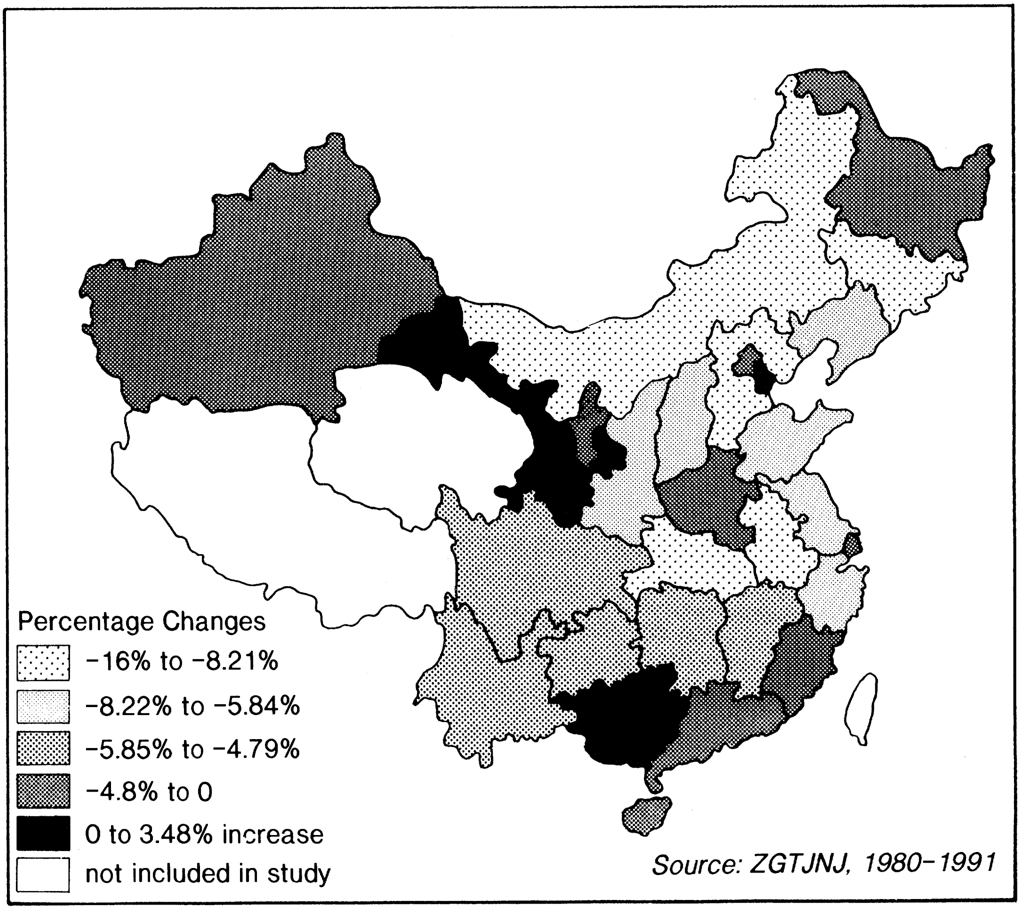

Figure 3. Changes in average annual growth rates in grain yields in China between 1980–84 and 1985–90. *Source*: ZGTJNJ (1980–91).

son of Figures 2 and 3 reflects an interesting sequence of events. With the advent of the reforms, many poorer interior provinces experienced rapid increases in production and unit yields, but within a decade some of these same areas were reporting considerable slowdowns (Inner Mongolia, Shaanxi, Shanxi). Such changes parallel the farmland degradation experienced after the initial cultivation of the virgin lands of Russia and Khazakistan and the plains of Australia (Boardman, Foster, and Dearing 1990).

Since the declining rates of increase for grain yields and output in the late 1980s cannot be credited to declines in fertilizer use, irrigated area, or modern technologies, other factors must be identified. It may be that the intensification of China's agricultural practices and other rural activities have caused an increase in environmental stress that is creating a drag on the growth of yields. Recent research indicates that China's land and water resources experienced serious environmental stress, particularly in areas where marginal land was brought into production (Smil 1984; Glaeser 1990; World Bank 1992; Rozelle and Jiang 1993). The accumulation of these pressures may be responsible for part of the recent slowdown in the rate of grain-yield growth.

Environmental Damage to the Cultivated Land

The major types of environmental degradation on arable land are erosion, salinization, soil exhaustion, and the increase of land stocks that are prone to natural disasters because of some combination of these factors and because of deforestation in areas surrounding arable land. China has experienced a dramatic increase in total eroded area in the 1980s (Fig. 4, Panel A).[1] Deforestation, induced by population pressures and the increased demand for wood in the 1980s, has contributed to the soil erosion problem (Ministry of Agriculture 1991). Degradation of China's grasslands—especially in the Northwest and Inner Mongolia—is a major cause of increased erosion (Tang 1991; Shouse 1993). Soil erosion in the northeast region of the country has also increased dramatically in recent years, primarily as a result of agricultural expansion, overgrazing, and poor management of the forested areas surrounding major agricultural zones (Liu, Findlay, and Watson 1992).

The impact of soil erosion on agricultural productivity is now well documented in the

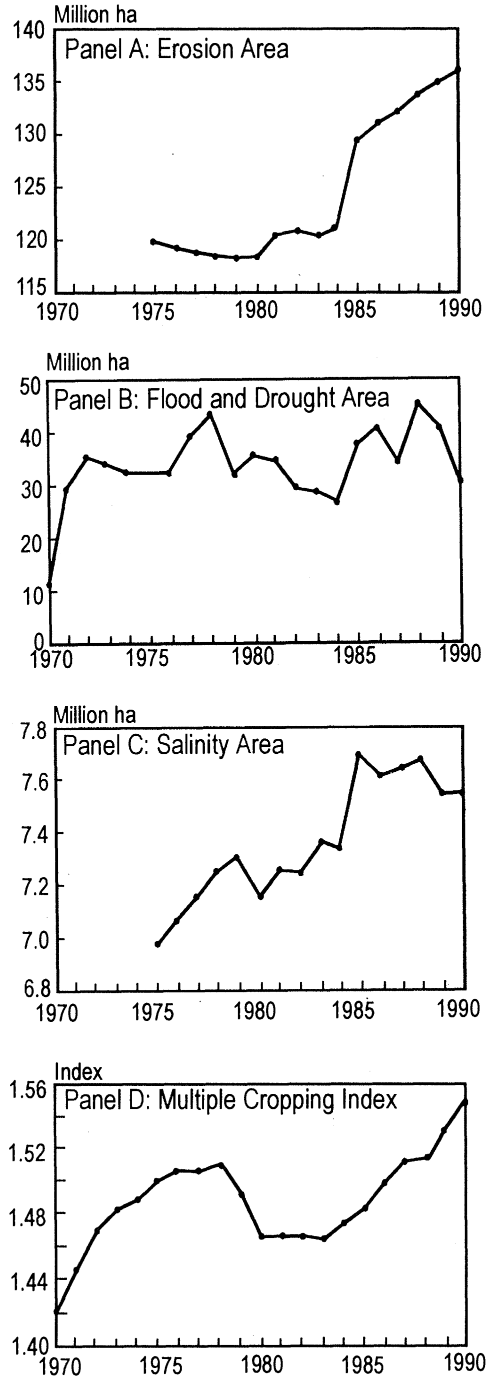

Figure 4. Trends of environmental stress, 1970–90. *Source*: ZGTJNJ (1980–92); MWREP (1988, 1989, 1990).

[1] Concerned that the rise between 1984 and 1985 might be a statistical artifact, two of the authors conducted a series of interviews in December 1993 with Bureau of Water Conservancy officials in Hunan, Gansu, Yunnan, and Hubei provinces, the regions where most of the increase occurred. In Yunnan and Hubei, officials charged with collecting these data explained that most of the increases were clearly tied to the massive cutting of forest associated with the ill-fated forestry reforms in the early 1980s. In Gansu, provincial leaders reported that the erosion was due primarily to overgrazing (as reported by Liu, Findlay, and Watson 1992). Even if these jumps are a statistical anomaly, the results of subsequent analytical work do not change when these years and outlying observations are excluded.

international setting (Pingali and Rosegrant 1993). Masicat, de Vera, and Pingali (1990) describe the externalities of soil erosion, concluding that the main impact is on irrigation infrastructure through the siltation of reservoirs and canal systems. Soil erosion in China is clearly a problem that impinges on agricultural productivity (Ministry of Agriculture 1991). While soil erosion may directly affect productivity in some areas by reducing soil fertility (Veeck, Li, and Gao 1993), many agricultural officials in China believe that the most serious impact occurs through its negative effect on irrigation systems (World Bank 1992). Guangxi provincial officials, for example, claim that more than 14.4 percent of their provincial irrigation systems have been destroyed or completely silted up by erosion, leading to marked declines in grain yields (Liu 1991).

In 1990, the Loess Plateau and Inner Mongolia recorded the highest proportions of eroded land to cultivated land, but the Southwest and the hilly portions of Jiangxi, Hubei, and Liaoning all reported more than 144 percent as highly eroded (Fig. 5). These figures may be greater than 100 percent because all land—cultivatable or not—can be classified as eroded. Luk (1991) estimates that at the present time an average of 1 centimeter of soil is lost from the entire Loess Plateau each year.

While fluctuating year by year, the

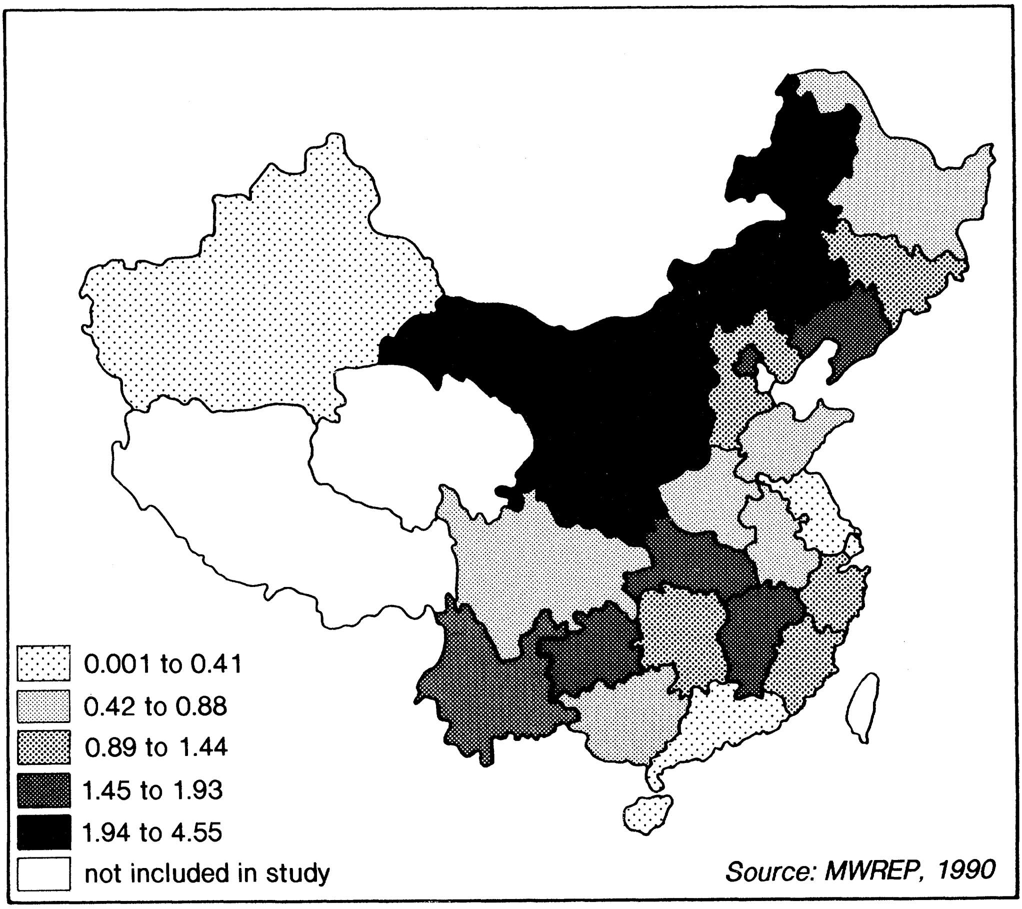

Figure 5. Ratio of total eroded land to total cultivated land, 1990. *Source*: MWREP (1990).

average area classified as "easily flooded and drought damaged" in China can be seen to rise to nearly 40 million hectares during the period from 1985 to 1990 from less than 30 million hectares in the early 1980s (Fig. 4, Panel B).[2] Some officials in China also see an increasing frequency in the occurrence of floods and droughts (Ministry of Agriculture 1991). Losses from these natural disasters probably have increased in recent years in part because of the deterioration of the environment. Flooding has been linked to erosion, deforestation, and inappropriate agricultural expansion, and drought in some areas is also thought to be tied to changes made to the local landscape (He 1991; Tivy 1990; Smil 1984). Erosion creates a higher probability that an area will experience a drought through the breakdown of irrigation systems, the loss of "A" horizon organic materials, and reduced water storage capacity (Luk 1991).

Salinization is another problem that has affected an increasing amount of cropland. Salinization is typically associated with poorly constructed irrigation systems or a locally high water table (National Research Council 1990; Glaeser 1990). The amount of land area affected by salinization has increased in the last 16 years, with Xinjiang and the Huang-Huai-Hai Plain provinces being the most severely affected regions (Fig. 6). The total area officially classified as saline-stressed land increased from about 7.3 million hectares in the early 1980s to more than 7.6 million hectares in the late 1980s (Fig. 4, Panel C). Salinization problems can come from either side of the hydrological balance sheet—from limitations on the availability of water to flush salts from the land or, alternatively, from an inadequate drainage system where salts precipitate from standing water or where such water promotes the upward movement of salts in groundwater. The jump in salinized area experienced in the mid-1980s might be attributable to reduced efficiencies of irrigation systems in areas where the waning influence of collective leaders during the early years of the reforms led to reduced control over surface water (a way to reduce the seriousness of salinization).[3] Moreover, salinization of cultivated land can cause a significant drop in land productivity long before land is officially classified as "salinized" (Mei 1992). Hence, while the increase in salinized land is certainly not of the same magnitude as the rise in eroded land, these data may suggest that salinization is increasingly becoming a serious problem in important agricultural regions such as the North China Plain and the Huang-Hai-Huai Plain.

In recent years, China has been able to produce an adequate food supply on a land endowment that is limited relative to

[2] An area in China is deemed "easily flooded or drought damaged" if it cannot withstand a three-year flood or drought with no loss of yield. In other words, this number would move up if a region originally classified as *not* "easily flooded" (since it had previously not sustained damage during earlier three-year rains) suddenly experienced a loss during a three-year event. Three things can lead to an area moving from outside to the inside of this category: (1) a change in the irrigated area; (2) reduced efficiency of the irrigation and drainage systems due to things such as erosion; and (3) the increased impact of a "three-year" event because of deterioration of the environment. In the subsequent analysis, since changes in irrigated area and the efficiency of the irrigation drainage systems are already accounted for by other variables in the equation, we believe this variable is a proxy for the increased impact of floods and droughts.

[3] While appearing large in relative terms, the jump from 1984 to 1985 represents a rise in salinized land of 400,000 hectares, which is only about 0.4 percent of cultivated land. Interviews in the Ministry of Agriculture and in counties of several of the most susceptible provinces revealed that the radical changes in the management of the irrigation systems associated with the rapid decollectivization in the mid-1980s (especially 1983 and 1984) led to the abnormally large increases in salinization in 1985.

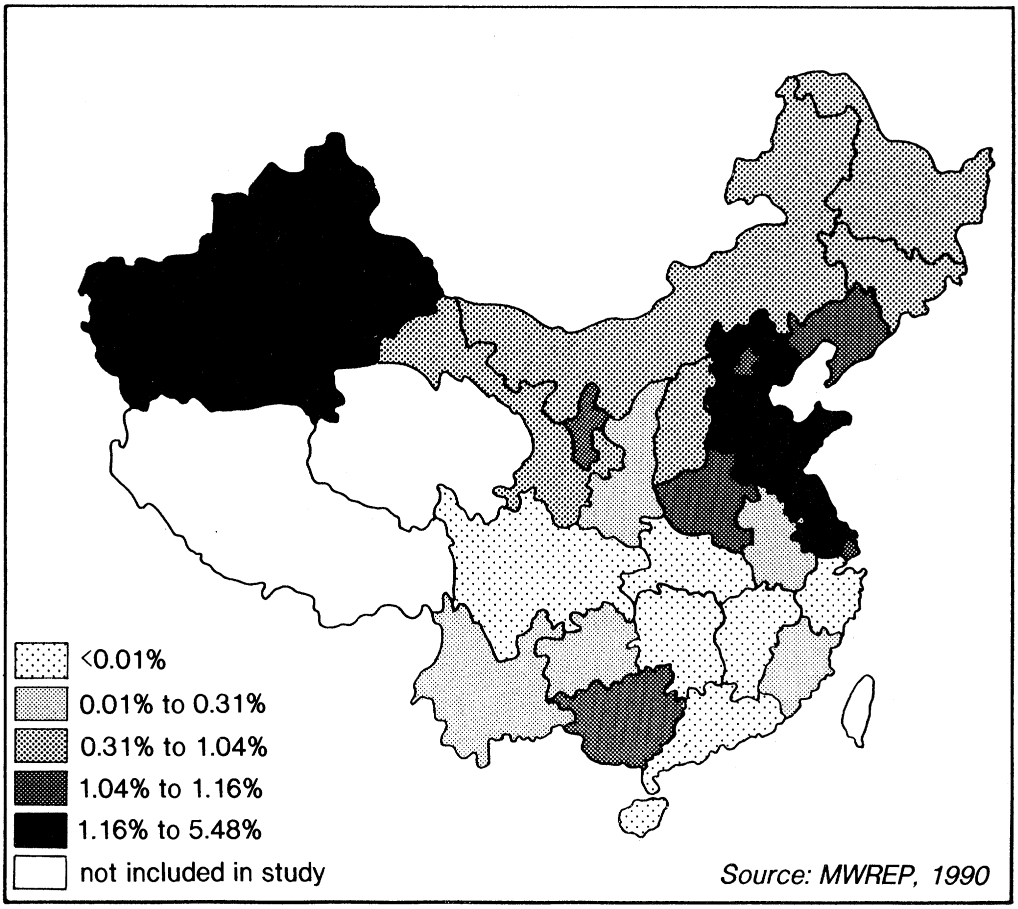

Figure 6. Percentage of total arable land classified as salinized land, 1990.
Source: MWREP (1990).

the size of the nation's population. This success stems from various measures taken to increase cropping intensity (measured as sown area divided by cultivated area) as well as from increases in technological and physical inputs (Fig. 4, Panel D). When cropping intensity becomes too high, however, it can lead to a deterioration in soil quality (Xu et al. 1980; Glaeser 1990; Sun 1988). Moreover, intensive use of land may cause periodic delays in the planting of some crops because of local labor "bottlenecks" (in the second or third cropping seasons of the year), which can seriously affect yields.

As China's land is being subjected to more intensive farming practices, many agricultural officials also fear that farmers are engaging in fewer of the practices that traditionally have protected land from soil exhaustion. In China's densely populated Yangtze Valley and other more developed areas, farmers applied high levels of organic manures only in response to strict rules set by regional officials and enforced by local collective leaders (Rozelle 1994). Increasingly, chemical fertilizers have been substituted systematically for organic manures as opportunities for off-farm labor increase and the attention of local leaders has shifted to rural industrialization (Ye 1992). The role of green manure crops in replenishing the structure and nutrient base of the soil has also diminished sharply throughout the 1980s. The area planted to green manure crops declined significantly from 9.92 million hectares in 1975 to 7.54 million hectares in 1980. This trend accelerated in the postreform period, with the area sown to green manure crops dropping to only 4.20 million hectares in 1990, less than half of its 1975 level (ZGTJNJ 1991).

Yield declines may also be due to other managerial and environmental factors, such as increasing water pollution in rural areas from the expansion of rural industries (Chang 1987), soil toxicity problems caused by continuous monocropping and rising use of pesticides (Stavis and Misner 1982), and soil compaction from the increasingly popular use of tractors for land preparation. The subsequent analysis, however, does not incorporate these factors because we lacked data on the impact that these additional factors might have on grain yields.

A Provincial-Level Model of Grain Yields

The preceding discussion and Figures 4 through 6 suggest the differential impact of environmental degradation on grain production over time and across space. A model based on annual data from 1975 to 1990 for 23 provinces can be used to estimate a grain-yield function for China during this time period.[4] The general form of the function describing grain yields, Y, may be specified as

$$Y_{it} = f(X_{it}, T_{it}, Z_{it}, E_{it}, D_i), \quad (1)$$

where i and t represent the ith province in year t; X is a set of inputs that includes fertilizer use and labor input; T is a set of technology shifters, such as irrigation and modern varieties; Z is a dummy variable representing the impact of institutional change from 1980 to 1984, as the rural responsibility reforms were not instituted at the same time throughout China's provinces; E is a series of variables measuring environmental stress, including soil erosion area, salinized area, the intensity of land use, and the frequency of natural disasters; and D is a set of 23 provincial dummy variables designed to identify the presence of province-specific agroeconomic conditions, including differences in land use policy and reclamation efforts. Because data are not available in China for the proportion of fertilizer, labor, and irrigated area used in grain production, total fertilizer use (chemical fertilizer measured in the nutrient form), total net irrigated area for all crops, and total agricultural labor were used.[5] In the

[4] Six provinces were excluded: Tibet, Qinghai, Inner Mongolia, Beijing, Tianjin, and Shanghai. The first three provinces are excluded because of data limitations in the earlier years. The latter three were dropped because of the limited role that agriculture plays in their economies; they are industry-dominated, urban-oriented cities. Data for Hainan province are aggregated with those of Guangdong province.

[5] We recognize the problem associated with using total inputs in a grain-yield function, but these are the only complete time-series, cross-section data available. These data have been used by others in the literature (e.g., Fan 1991; Zhang and Carter 1993). Also, most fertilizer use is on the grain crop, and the proportion of fertilizer devoted to grain has remained fairly constant over time. The correlation between fertilizer use on the four largest grain crops (rice, wheat, corn, and soybeans—which accounts for an average of 80 percent of total grain area in 1975–90) is high. A regression of fertilizer use for China's four major grain crops (measured on a per hectare basis) on total fertilizer use per hectare yields an R-square of 0.95. The data for the independent variable in the regression comes from the State Price Bureau's cost of production data and is available for 17 provinces for 1975–88. The data for the total fertilizer use per hectare are the same as those used in the paper and are available from published statistical yearbooks. We did not use the State Price Bureau's data in our study because the data are not complete for all provinces for all grain

yield equation, fertilizer and agricultural labor use are standardized by total cropped (sown) area and net irrigated area is divided by cultivated land area. The agricultural labor variable is nearly equivalent to the total labor force in the rural areas and has been used by a number of analysts of Chinese grain (Lin 1992b; Fan 1991; Huang and Rosegrant 1992). Since the early 1980s, agriculture has begun to play a less important role in the rural economy of some coastal areas, and much of the rural labor is employed in the off-farm sector. Because changes in the quantity of labor in coastal regions can be expected to have a different effect on yields than they do in noncoastal areas, an interaction term between the coastal province dummies and the agricultural labor input variable is included in the model. A time trend variable is used as a proxy for technology development, which, given the steady adoption of hybrid rice and new varieties of maize in the reform era, is a reasonable assumption. All production data are from the State Statistical Bureau (ZGTJNJ 1980–91; ZGNYNJ 1980–91) or were collected from the statistical bureaus of the individual provinces.

To measure the effect of environmental impacts, the multiple-cropping index (MCI) is used to measure the intensity of land use. Salinized area, deflated by cultivated area, is also included in the yield equation. Because the major influence of soil erosion on grain yield is through its effect on irrigation infrastructure, the model includes an interaction term between the irrigated land and erosion variables. The interaction term is specified in log form to reflect the fact that significant damage may happen in the early stages of erosion. This may be expected since if siltation caused by erosion affects the upper reaches of an irrigation system, the entire system may be affected. "Easily flooded and drought damaged" area (deflated by cultivated area) is included to measure the impact of the deterioration of the local environment and its ability to withstand relatively mild weather shocks. Soil erosion, salinity, and natural disaster figures are taken from secondary sources provided by the Ministry of Water Resources and Electric Power (MWREP 1988, 1989, and 1990). The MCI variable is created by dividing observations on sown area (taken from ZGTJNJ 1980–91) by cultivated area statistics (from the MWREP). See Appendix A for a more detailed discussion of these variables.

The Determinants of Chinese Grain Yields

The parameters of Equation (1) are estimated using ordinary least squares (Table 3). About 93 percent of the interprovincial and time-series variations in grain yield is explained by the independent variables incorporated in the model. The parameters were generally robust to changes in specification and functional form.

In assessing the performance of the production inputs, the coefficients on the variables representing fertilizer, irrigation, and technological innovation all display the expected sign and, with the exception of the coefficient associated with the irrigation variable, are statistically significant at $p = .01$. A positive and significant effect of the implementation of the Household Responsibility System (HRS, decollectivization policies) in rural China in 1980–84 was also indicated. This finding is consistent with other studies (McMillan, Whalley, and Zhu 1989; Fan 1991; Lin 1992b; Huang and Rosegrant 1992). The coefficient of the dummy variable representing noncoastal provincial location (0.19, measuring the impact of labor on yields in noncoastal areas) is

crops (e.g., only fertilizer use on rice is available for certain southern provinces, and the amount being used on other grain crops is excluded, even though those crops may be contributing more than 40 percent of grain output).

Table 3

Estimates of Grain-Yield Equation in China, 1975-90

Explanatory Variable	Grain-Yield (tons/ha) Net Reg. Coefficient
Constant[a]	3.8547***
	(4.48)
Fertilizer (kg/ha)	0.0058***
	(8.01)
Agrlab (person years/ha)	0.1942*
	(1.66)
Coast*Agrlab	−0.4014*
	(−1.83)
Time trend	0.0695***
	(8.17)
Irrigation (%)	0.0189***
	(3.33)
Ln{Irri*(Ero/Cultland)}	−0.4583***
	(−4.52)
Salinity/cultland (ratio)	−0.1089*
	(−1.66)
Diaster/crop area	−0.0140***
	(−6.93)
MCI (ratio)	−0.5765**
	(−2.36)
Decollectivization dummy	0.0576*
	(1.73)
Adjusted R^2	0.931

[a] Provincial dummies are not reported.
* Statistically significant at 0.10.
** Statistically significant at 0.05.
*** Statistically significant at 0.01.

positive and significant at $p = .10$. The negative sign of the coefficient on the coastal slope variable (-0.40) is consistent with the expectation that additional labor in coastal areas does not contribute to agriculture, but may be moving into off-farm sectors, an effect similar to that found by Ye and Rozelle (1994).

The positive impact on provincial grain yields of the increasing use of productive inputs, however, is partially offset by the negative influence of increasing environmental degradation. When erosion enters the model as an interaction with irrigation, the coefficient is negative and highly significant. The magnitude of the effect of erosion on grain yield is greater than that of salinity. This result probably reflects the fact that if the saline level of the soil rises past some critical point, grain production will be zero. Hence, when salinization is so extreme that the land is removed from production, that land is not counted in the cultivated area base, and average yields rebound somewhat. The negative and significant coefficient for the MCI variable demonstrates that increases in the intensity of land use lead to a decline in grain yields. The intensification of Chinese agricultural land use may either be causing soil deterioration or disrupting established cropping patterns (Bian et al. 1993). The disaster variable is also negative and significant, meaning that yields were more affected by mild flood and drought conditions in the reform period. Since the effects of the level and quality of irrigation have already been accounted for, this negative coefficient may mean that a deteriorating environment is making China more flood and drought prone.

Yield Response Elasticities

To assess the proportional change of grain yields when the input factors vary, elasticities of grain yield with respect to various inputs and environmental stress are computed based on the estimated parameters (Table 3). The elasticity of grain yield with respect to the productive inputs—0.129 for irrigation, 0.130 for labor, and 0.191 for fertilizer—are all relatively low (Table 4). These figures, however, are consistent with those estimated by Fan and Pardey (1992), who report agricultural production elasticities for irrigation of 0.13 to 0.25, for labor of 0.13 to 0.15, and for fertilizer of 0.26 to 0.28. The low elasticity of labor in the noncoastal provinces is typical of labor elasticities in other labor-rich Asian countries (Rao 1988).

Grain-yield elasticities with respect to environmental factors are all negative, supporting our initial hypothesis (Table 4). The elasticities for soil erosion (-0.146) and natural disasters (-0.106) are both negative and larger than 0.10 (in absolute value terms). The elasticity of grain yield to salinized area is -0.003. The highest elasticity is found for the MCI (-0.276). If

Table 4

Grain-Yield Elasticities Evaluated at Mean, 1975-90

Variables	Mean	Elasticities
Grain yield (ton/ha)	3.130	—
Fertilizer use (kg/ha)	103.041	0.191
Labor in noncoast[a] (person years/ha)	2.100	0.130
Irrigation (%)	45.682	0.129
Erosion/cultland (ratio)	1.273	−0.146
Salinity/cultland (ratio)	0.075	−0.003
Disaster/crop area (%)	23.749	−0.106
MCI (index)	1.496	−0.276

Note: All elasticities are estimated at the sample mean, based on the model (3) in Table 3.
[a] The elasticity for the coastal provinces is not computed because of the low reliability of agricultural labor data used as proxy for labor input in grain production in the coastal provinces.

the MCI were to increase by 10 percent (to 1.65, the target in the eighth five-year plan (Liu 1991)), average provincewide grain yields would drop by nearly 3 percent. The sum of these four elasticities is high, -0.431, indicating the important combined impact of environmental stress on grain yields in the period 1975 to 1990. These findings support our proposition that the declining rates of increase for grain production, even at this level of aggregation, can be credited to a variety of environmental problems which are growing increasingly severe in the 1990s.

Sources of Growth in Grain Yields

A decomposition analysis permits an evaluation of the individual contribution of various inputs, technology changes, and environmental stress on grain yields for different periods. To minimize the sensitivity of the analysis to yearly grain-yield fluctuations, we use three-year averages. Grain yield increased by a total of 1,297.5 kilograms per hectare between 1975 and 1990 (Table 5, bottom row). On the positive side, increases in chemical fertilizer use and improvements in technology (plus other factors picked up from the

Table 5

Sources of Growth in Grain Yield During 1975–90

Variables	Changes in 1976–89[a]	Yield Changes by Sources (kg/ha)	Yield Changes by Sources (%)
Fertilizer/use (kg/ha)	114.013	661.3	51.0
		(82.6)[b]	(6.4)
Labor in noncoast (person year/ha)	0.247	47.9	3.7
		(28.9)	(2.2)
Irrigation (%)	2.341	21.3	1.6
		(18.3)	(1.4)
Technology (time)	13.000	903.5	69.6
		(110.6)	(8.5)
Erosion/cultland (ratio)	0.199	−75.4	−5.8
		(16.7)	(1.3)
Salinity/cultland (ratio)	0.007	−0.8	−0.1
		(0.5)	(0.0)
Disaster/crop area (%)	1.016	−14.2	−1.1
		(2.1)	(0.2)
MCI	0.025	−14.4	−1.1
		(6.1)	(0.5)
Sum of environmental stress		**−104.8**	**−8.1**
		(25.3)	(2.0)
Residual		−231.7	−17.9
Grain yield (kg/ha)	1297.5	1297.5	100.0

[a] The values are three-year means centered in the years (1976 and 1989) indicated.
[b] Figures in parentheses are the standard errors of the estimated yield changes.

time trend variable) have contributed to grain-yield growth by 1,634 kilograms per hectare (Table 5, the sum of rows 1 to 4). Environmental stress problems, however, caused the grain yields to decline by 104.8 kilograms per hectare, about 75 percent of which is accounted for by the erosion effects (-75.4 kg/ha). Grain yields would have risen an additional 8.1 percent between 1976 and 1989 if the rural sector had not experienced soil erosion, salinity, natural disasters, and soil deterioration.

A separate decomposition analysis can identify the differences between two subperiods (Table 6). Between 1977 and 1983, 91.4 percent of the total yield change of 967.5 kilograms per hectare is due to the contribution of productive inputs, technology, institutional changes, and residual factors (Table 6). Improvements in the environment (in particular, from relatively low levels of flood- and drought-related disasters and a decline in the MCI) accounted for 9.6 percent of the growth in grain yields. Only erosion detracted from growth in the first period (and then only minimally, -1.3 percent); salinization had no effect.

In sharp contrast, the results for the second period (1983 to 1989) are consistent with the hypothesis that the trend toward grain-yield stagnation is due to increasing levels of environmental stress. The contribution of "all other factors" to

Table 6

Effects of Environmental Stress on Growth in Grain Yield between 1977–83 and 1983–89

Variables	Changes	Yield Changes by Sources (kg/ha)	Yield Changes by Sources (%)
1977–83[a]			
Erosion/cultland (ratio)	0.033	−12.6	−1.3
	(2.8)[b]	(0.3)	
Salinity/cultland (ratio)	0.002	−0.3	−0.0
		(0.1)	(0.0)
Disaster/crop area (%)	−5.948	83.3	8.6
		(12.0)	(1.2)
MCI	−0.039	22.3	2.3
		(9.5)	(1.0)
Sum of environmental stress		**92.7**	**9.6**
		(24.5)	(2.5)
All other factors		874.8	91.4
Grain yield (kg/ha)	967.5	967.5	100.0
1983–89[a]			
Erosion/cultland (ratio)	0.181	−62.9	−19.1
		(13.9)	(4.2)
Salinity/cultland (ratio)	0.005	−0.5	−0.2
		(0.3)	(0.2)
Disaster/crop area (%)	6.963	−97.5	−29.5
		(14.1)	(4.3)
MCI	0.064	−36.7	−11.1
		(15.6)	(4.7)
Sum of environmental stress		**−197.6**	**−59.9**
		(43.9)	(13.3)
All other factors		527.6	159.9
Grain yield (kg/ha)	330.0	330.0	100.00

[a] The values are three-year means centered in the years indicated (1977, 1983, and 1989).
[b] Figures in parentheses are the standard errors of the estimated yield changes.

grain-yield growth in this period is 159.9 percent, whereas that of environmental factors is -59.9 percent. These figures indicate that actual increase in grain yields would have been nearly 60 percent higher had the agricultural environment not deteriorated. In contrast to the first period, all four of the environmental variables combined to keep yields from growing faster. Increasing floods and droughts account for about one-half (29.5 of the 59.9 percent) of the decline. Soil erosion and environmental problems associated with increasingly intense use of the land are also important. The 95 percent confidence interval around the point estimate (197.6) shows that grain-yield losses resulting from environmental degradation range between 109.8 and 285.4 kilograms per hectare.

Regional differences in the impact of environmental problems are evident in Figures 7 and 8. A strong relationship emerges between those provinces with the lowest reported yields in 1990 (Fig. 7) and those areas that (according to the predictions of the model) have suffered the greatest yield losses from environmental stress (Fig. 8). Xinjiang, the Southwest, and the Loess Plateau all report low to moderately low yields in 1990 and have high to moderately high model predictions of "drags" on productivity from environmental degradation.

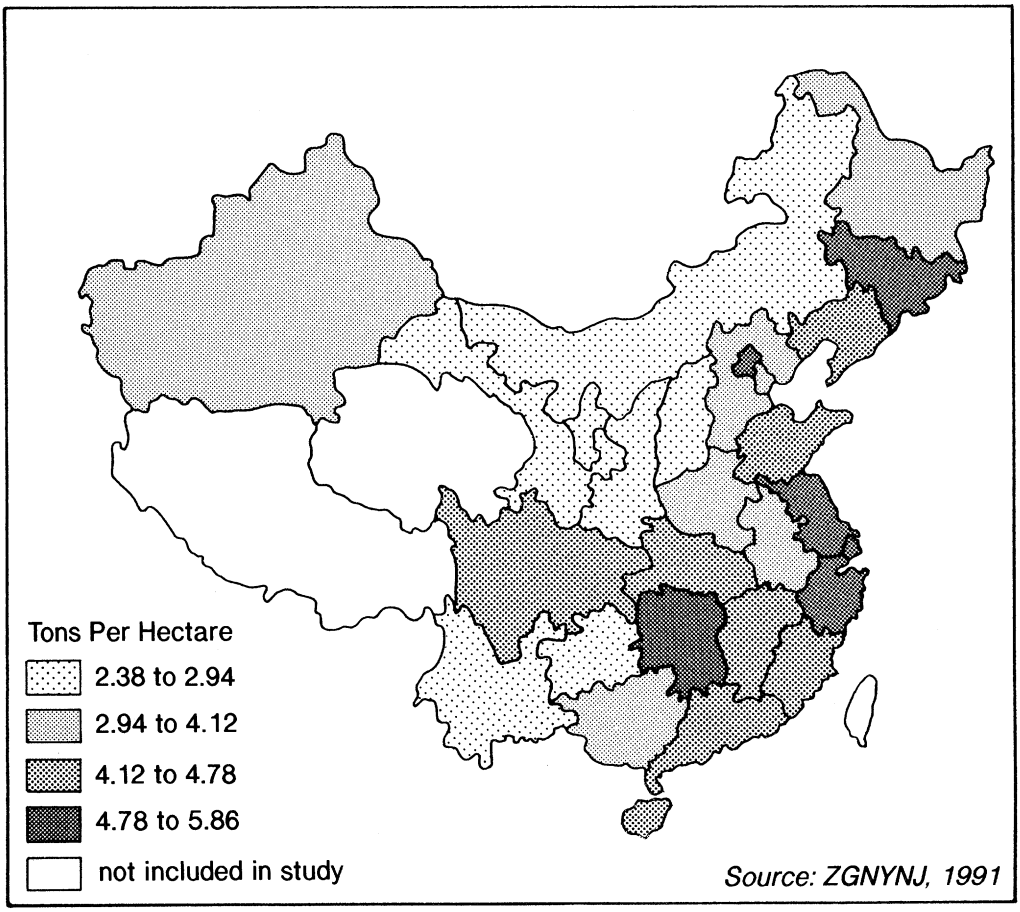

Figure 7. Average grain yields in China, 1990. *Source*: ZGNYNJ (1991).

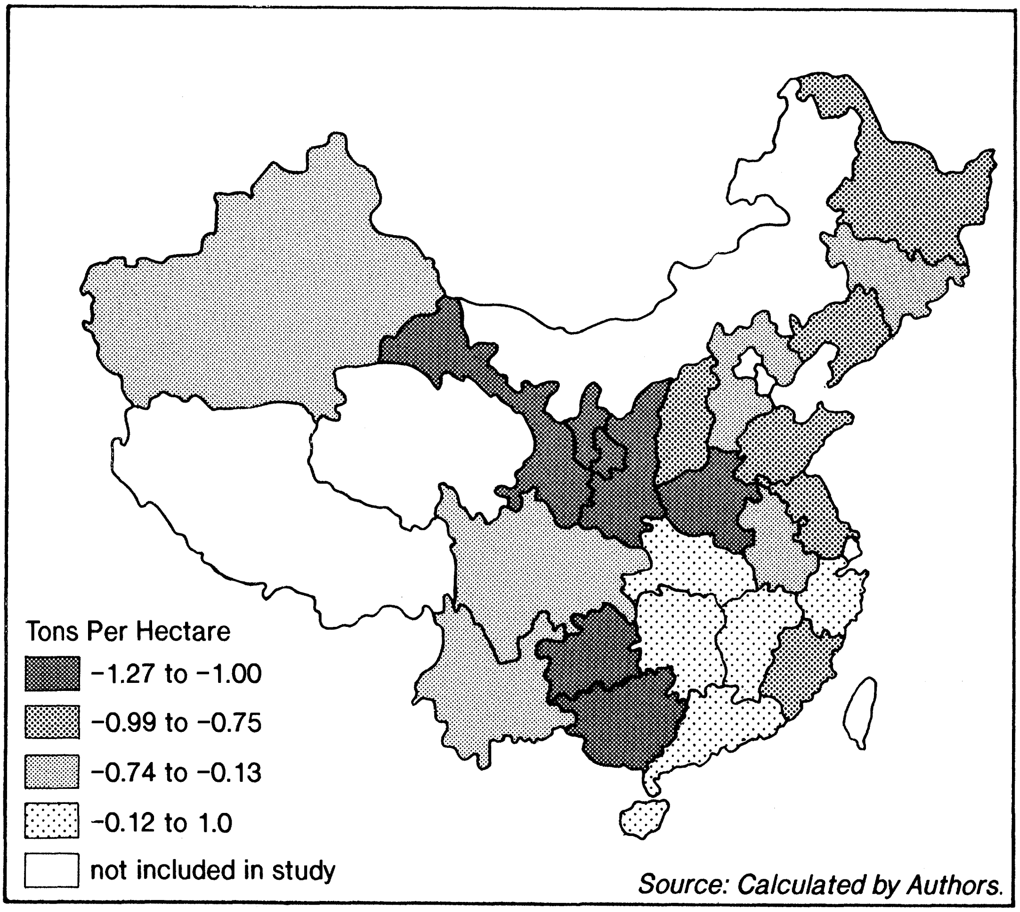

Figure 8. Grain-yield loss due to environmental stress in China, 1990.

Many of the provinces that reported the highest yields for 1990 (Guangdong, Hunan, Hubei, Jiangxi, Fujian) reported only minor impacts, if any, from environmental stress. Of particular interest are Guangdong, Fujian, Hubei, Hunan, and Jiangxi, where environmental protection policies have been both expanded and enforced in recent years.[6] Reforestation efforts in Fujian, for example, have taken considerable areas of slope land out of production, thus raising overall yields. In Guangdong, local cadres were required to sign contracts guaranteeing the protection of forests. In addition, the growth of rural industrial employment in these regions has considerably reduced pressure to use marginal land.

Provinces facing significant problems with salinization such as Shandong and Jiangsu continue to register high yields, but our results suggest that provincial-

[6] This does not imply that these southern provinces do not have environmental problems. It is only saying that some progress has been made in relative terms in recent years. Some problems, such as the loss of cultivated area, have been noted to be of particular concern to environmentalists in southern China. Such a problem would be more relevant to a study on area or production decisions rather than to this study on yields.

level yields could rise by as much as one ton per hectare if and when this problem is addressed. The Loess Plateau region is perhaps the most alarming example of environmental degradation. With low yields and severe environmental problems, food deficits in this area will continue and quite possibly worsen. Based on results from this model, efforts to improve environmental conditions in the affected provinces could increase grain production by as much as 36 percent (deduced from Fig. 8).

Conclusions

Despite a population exceeding 1.1 billion, China has generally been able to supply enough food for its population from a limited land endowment over the course of the past several decades. This accomplishment has been achieved primarily by increasing the level of modern inputs and the intensity of farming systems. Officials predict that even greater increases in production are needed in the future to meet the growing grain demand of China's still growing and increasingly "wealthy" population. Certainly as incomes rise diets will change, and even greater amounts of grain will be shifted from consumption markets to agro-processing for livestock. Continued growth based on recent production strategies, however, may be difficult.

This study suggests that environmental stress has adversely affected yields. This issue deserves the close attention of policymakers. This analysis and the resulting maps reflect a common, if unpleasant, story that has occurred in many nations throughout recent and modern history. The reform era triggered more intensive use of the land in many areas of China (especially in marginal regions). Short-term gains were realized until declines in natural fertility and poor management practices began to create environmental havoc. Although most local officials are certainly aware of these problems, growing demand from a number of sources (increased population, continuing high quotas, changing consumption patterns, and shifts in the work force) has made land retirement policies difficult to legislate, justify, and enforce. We believe that on many levels the problem is vividly and clearly understood, but the solution is a costly one.

Marginal land must be restored to earlier, less demanding uses through reforestation and pasture restoration. Areas prone to salinization must either be treated or fallowed. Irrigation and drainage infrastructure must be restored and renovated. Erosion-prone areas must be stabilized through terracing, contouring, or other methods. The impact of environmental degradation on grain production has been substantial. Our analysis shows that, given the levels of modern inputs, grain yields could have increased by nearly 160 kilograms per hectare between 1983 and 1989 if environmental stresses had not increased during the period. Environmental degradation may have cost China as much as 5.7 million metric tons per year during the late 1980s. This figure is equivalent to nearly 30 percent of China's yearly grain imports in the early 1990s (ZGTJNJ 1992). The value of this loss, roughly U.S. $700 million (at 1990 prices), is about equal to China's entire annual budget for rural infrastructural investment. Moreover, if the current period is the beginning of a long-term trend, an even more radical policy response may be required.

Realistically, modern inputs and new technologies necessarily cannot and will not be discontinued. China will continue to depend on future technological breakthroughs to meet the nation's grain demand. But an intensive research effort is needed to understand how contemporary practices can be modified to minimize deleterious environmental and agricultural effects.

It seems clear that greater investments are required in key areas of rural China to protect the land resource base. The analysis here clearly underscores problems in the Southwest (Yunnan and Guizhou), the Loess Plateau, and Xinjiang. Rapidly growing populations in these areas in the past 20 years have led to inappropriate land conversions. These areas are poor, and it is not realistic to assume that such places can adequately fund needed reclamation and maintenance projects. Support must come from Beijing or international relief and development agencies. Many of these projects, such as improvements to irrigation systems to minimize salinization or terracing to control erosion, may be complementary to economic development and lead to higher grain yields in the long run.

Effective environmental measures must also be made compatible with the interests of regional officials and local leaders who are responsible for implementing policies. Jurisdiction over rural environmental policy currently is held by the production ministry most closely related to the area where the problem might likely occur (Rozelle and Huang 1993). For example, the forestry ministry is in charge of forest protection; the agricultural bureau oversees the protection of farm environment. The relatively weak position of environmental staff members within these regional bureaus makes it difficult to carry out measures properly when they are in conflict with production goals. A major weakness in current Chinese rural environmental policies is the lack of sufficient incentive for local leaders to carry out protective rules, regulations, and plans because there is no tangible benefit for a leader who studiously carries out environmental measures (Rozelle and Jiang 1993). China's new experiments with an environmental responsibility system, which tries to overcome some of the weaknesses of the current system, may provide the beginnings of an institutional framework that can reverse environmental degradation and lead to a new upsurge in agricultural productivity (Bishay 1993).

Appendix
Description of the Environmental Variables

To our knowledge, the disaggregated variables from the Ministry of Water Resources and Electrical Power (MWREP) have never been used in a rigorous statistical study published outside of China. Since these variables are the key element in the effort to measure the impact of environmental stress on grain yields, in this appendix we include a short discussion of the content of each variable and how it was collected. This description is based on several sources (Ministry of Water Resources and Electric Power 1993) and numerous interviews conducted by the authors with those responsible for collecting, creating, and using these data. These environmental variables are enumerated at the county level each year by trained county technicians. The county data are then aggregated to the provincial and national levels. Interviews with a number of those actually engaged in the annual tabulation of these series revealed that the data collection procedures are clearly outlined in a technical and administrative sense, and that there is a concerted effort to come up with consistent data series. County-level officials reported that they received little outside pressure to either under- or overreport these variables in any given year. Since the "easily flooded and drought-damaged" data are distinctly separate from the disaster variables collected by the agricultural system to assess weather-induced crop loss, local leaders have no incentive to bias these figures.

Eroded Land

Land is classified as "eroded" if the topsoil, substratum, or underlying rocks on any relatively large piece of mountainous or hilly terrain is exposed to any significant degradation or disturbance and exhibits signs of loss of soil. The erosion may be caused by natural means or by the actions of humans. Total eroded area consists of all land previously eroded, land recently subject to erosion, and "successfully treated erosion land." Eroded land is "successfully treated" when any number of methods are used to reduce the exposure of degraded or disturbed soil or rock, including terracing, creating silt dams, bunding, planting trees (with more than 4,500 trees per hectare that have a survival rate of more than 80 percent), and planting new pasture (with a coverage rate of more than 70 percent). Measured in this way, it is clear that eroded area is not confined to cultivated area and the ratio of eroded to cultivated area can be greater than one.

Easily Flooded and Drought-Damaged Area

In China's statistical system, an area is classified as easily flooded or drought damaged if it cannot withstand a three-year flood or drought with *no* loss of yield. In other words, this measure rises when a region that previously withstood a three-year disaster suffers weather-induced yield reductions when facing mild flooding or dry conditions. Three elements can lead to an increase in easily flooded and drought-damaged area: a change in irrigated area; reduced efficiency of the water conservancy systems (due to some problem such as erosion); and the increased impact of a "three-year" event due to a deterioration of the environment.

Salinized Land

Land is classified as "salinized" if 70 percent of the plants in any given area do not grow to maturity because of the salinity and alkalinity content of the soil. The salinity or alkalinity of land can be either naturally occurring or due to factors related to farm management practices (e.g., poor irrigation management or drainage, waterlogging, or use of abnormally saline or alkaline water). Salinized land also includes "land successfully treated for salinization"—which means that due to irrigation management practices or the development of new infrastructure, the salinity and alkalinity in the soil has been reduced so that more than 70 percent of the seedlings survive until maturity.

Multiple-Cropping Index

The multiple-cropping index (MCI) is a measure of the intensity of land use, created by dividing sown-area by cultivated area. A figure of 1.00 means that all land is planted once and only once during an agricultural year. A figure of 2.00 means that the average piece of land is double cropped. In our paper, the sown-area statistics for 1979 to 1990 are from ZGTJNJ (1980–91). The sown-area statistics for before 1979 were provided to us by the Ministry of Agriculture's statistical department. Officials in charge of administering the data told us that there was no significant difference in either the collection or reporting methods between the published and unpublished data.

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