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for Agricultural Development

THE ROLE OF IRRIGATION
IN THE AGRICULTURAL DEVELOPMENT OF ASIA

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ABSTRACT

The Role of Irrigation in the Agricultural Development of Asia

Throughout Asia, irrigation has been the lead input in growth of cereal yield. In the 13 Asian nations included for analysis, all of the countries appear to lie on virtually the same irrigation/fertilizer/HYV production function. Many observers believe that improved efficiency of water use through improved irrigation management and technology. This expectation may be largely unfulfilled, however, due to a fallacy of composition, since water losses measured on a local basis are often recovered in other parts of the system. Growth in total irrigated area in most Asian countries is declining. Only in India does growth exceed one percent per annum. There is a great need for data on cost of irrigation development and on the economic performance of recent irrigation investments. During the coming years, irrigation investments will have to be made with increasing care in order to maintain irrigation as a cost effective source of agricultural growth.

THE ROLE OF IRRIGATION IN THE AGRICULTURAL DEVELOPMENT OF ASIA

David Seckler*

A. Overview

Research on the subject of this paper began in 1985 with a study, sponsored by the USAID Mission in India, "Production and Poverty in Indian Agriculture" (Seckler and Sampath). The purpose of the study was to quantitatively estimate the major factors behind the "Green Revolution" in India, assess the likely future state of these factors, and relate the results of the analysis to the prospects for rural employment and poverty in India.

The study concluded that irrigation development has been the "lead input" in the green revolution in India. As shown in Section C, irrigation development directly contributed about 60% of the growth of Indian foodgrain production over the past three decades. Indirectly, it provided the stage, as it were, on which the other major inputs of fertilizers and high yielding varieties (HYVs) played their roles.

This conclusion corroborates the findings of virtually every serious student of Indian agricultural development. It also confirms the soundness of the rather heroic decision made by Indian policy-makers after the great drought of 1966-67 to concentrate scarce resources on the areas with highest food producing potential (mainly the irrigated areas of N.W. India), and to create additional high potential areas through rapid irrigation development.

It is likely that had this strategically vital policy decision not been taken--had resources been allocated to marginal rainfed areas and to poor farmers, as many urged at the time--the growth of Indian foodgrain production would have been reduced by at least one-half, and India would be in about the same situation as Sub-Saharan Africa is today.

Section B of this paper briefly reviews the basic model of agricultural production that has evolved from the India study and subsequent research. Section C presents the statistical estimation of the model in the India study.

Section D is based on research partly funded by the Rockefeller Foundation, "A Comparative Study of Agricultural Development in Asia and Africa". It generalizes the findings of the India study to 13 major Asian nations. The evidence corroborates the findings of the India study. Throughout Asia, irrigation has been the lead input in growth of cereal yield. Indeed, as shown in this section, cereal yields in these 13 Asian nations, ranging from Pakistan to Japan, appear to lie on virtually the <u>same</u> irrigation/fertilizer/HYV production function.

Section E turns to an assessment of the future of irrigation development and agricultural production in Asia. It is estimated that most Asian nations will have developed their "ultimate irrigation potential" (UIP) within the first or second decades of the next century.

Many people believe that increased efficiency of water use through improved irrigation management and technology, like sprinkler irrigation, will extend UIP indefinitely into the future. However, this is partly a composition fallacy. While it is clear that efficiency can be greatly improved in any given location, it is unlikely that it can be substantially improved in the system as a whole. The reason is because most of the water that is wasted in one location is already being reused, from underground or downstream sources, at another location in the system. Where this is true, irrigation systems are already performing at high levels of global efficiency even though their local efficiencies are low.

Thus, in the near future, what has historically been the lead input to agricultural production in Asia will end for all practical purposes, and future agricultural growth will have to be from increased yields on essentially the same quantity and quality of land. What is the prospect for Asian agricultural production under these conditions? "That is the question".

B. A Model of Agricultural Production

Figure 1 illustrates the simple model of agricultural production underlying this analysis. There is nothing unique in this model. On the contrary, it is implicit in such authoritative works as Mellor (1967), Hyami & Ruttan (1985), and Barker, Herdt, and Rose (1985).

This is a two sector model. Total agricultural production is the result of production from Gross (including multiple cropping) Irrigated Area (GIA) and Gross Rainfed Area (GRA). These are fundamentally different systems of agricultural production that should be separately analyzed and understood.

Unfortunately, national and international data bases do not provide the data necessary to analyze these two systems separately and, therefore, to

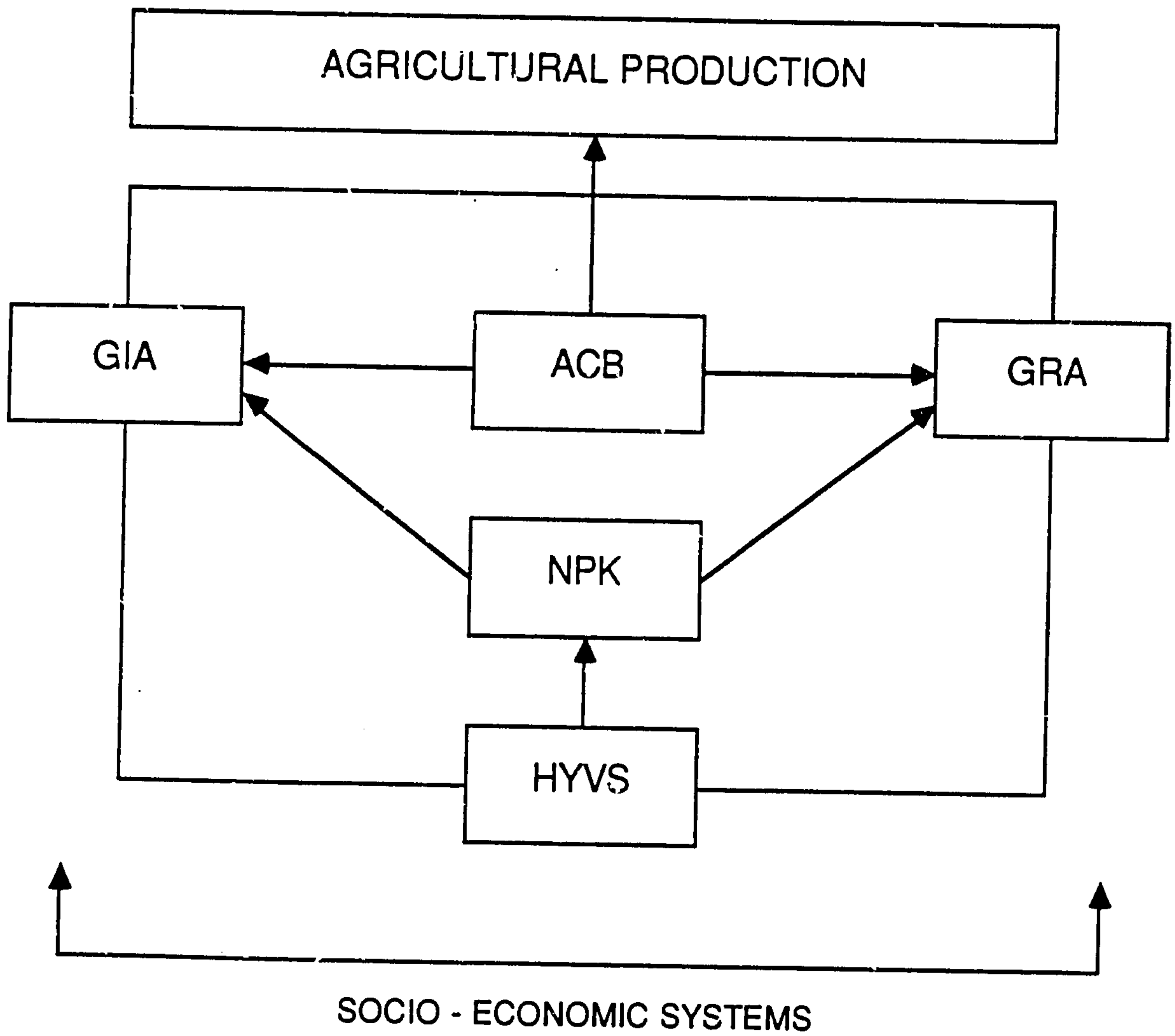


FIGURE 1

GIA - GROSS IRRIGATED AREA
GRA - GROSS RAINFED AREA
ACB - AGROCLIMATIC BASE
HYVs - HIGH YIELDING VARIETY

properly analyze agricultural production as a whole. Analysts desperately need crop-wise data on yield, area, fertilizer use, HYVs, etc., separated in terms of irrigated and rainfed areas. This information is usually collected in the basic sample observations, but then it is literally thrown away in the process of aggregation. FAO and donor agencies should take the lead in changing this data situation as quickly as possible. In the meantime, there is no alternative to working with the overly aggregated data available.

In this model, both the potential of and need for irrigation is determined by the Agro-Climatic Base (ACB) of the area. Given solar radiation, growing seasons, soil types and topography, etc., ACB reduces to indices of moisture stress of specific crops at specific times and places. There has been a good deal of fruitless debate between proponents of irrigated and rainfed agriculture because of neglect of this component of ACB. Clearly, where the water regime is favorable and reliable, irrigation is not needed (except, possibly, for paddy--mainly for weed control). Equally clearly, as the water regime becomes less favorable and reliable, expected yields under rainfed conditions decreases pari passu. The debate, in other words, is purely an empirical debate that reasonable people can quickly settle on the basis of the facts pertaining to any specific location.

Given ACB and the area of the two systems of GIA and GRA, agricultural production is a function of yield. Yield, in turn, is a function of fertilizer application rates (NPK) up to a certain level of yield, after which it also becomes a function of use of HYVs. (This model ignores many other technological inputs such as pesticides, herbicides, breeding plants for disease resistance, post-harvest technology, mechanization, etc., which are highly correlated with NPK and HYV).

Last, there is the great complex of "Socio-Economic Systems" (SES), which ultimately determines everything. However, there is an important causal distinction to be made here. First, SES determines the inputs of irrigation, NPK, and HYVs to agricultural production. The question is whether or not SES is a substantial determinant of agricultural production in other ways than through its effect on these inputs? One of the interesting results of this research is that the answer to this question, at least in Asia, seems to be "no".

This model is illustrated in terms of hypothetical production functions for agricultural areas in Figure 2. The horizontal axis is the Water Regime Index (WRI) for the area. As discussed in Section D, WRI is an index of the water regime of the area both in terms of rainfed and irrigated area. Thus, WRI improves as irrigation comprises a larger percentage of the total area. The vertical axis shows expected yield with respect to WRI. WRI increases expected yield both directly (by the favorable effect of water on plant production and reduced yield variability due to moisture stress) and indirectly (by inducing higher use of fertilizer and other inputs). The "Fs" represent various levels of fertilizer as corresponding to the values of WRI and yield.

Figure 2 can be interpreted in terms of the "vertical" and "horizontal" factors in the growth of yield. While these terms are usually used to distinguish between growth of production by increasing cultivated area

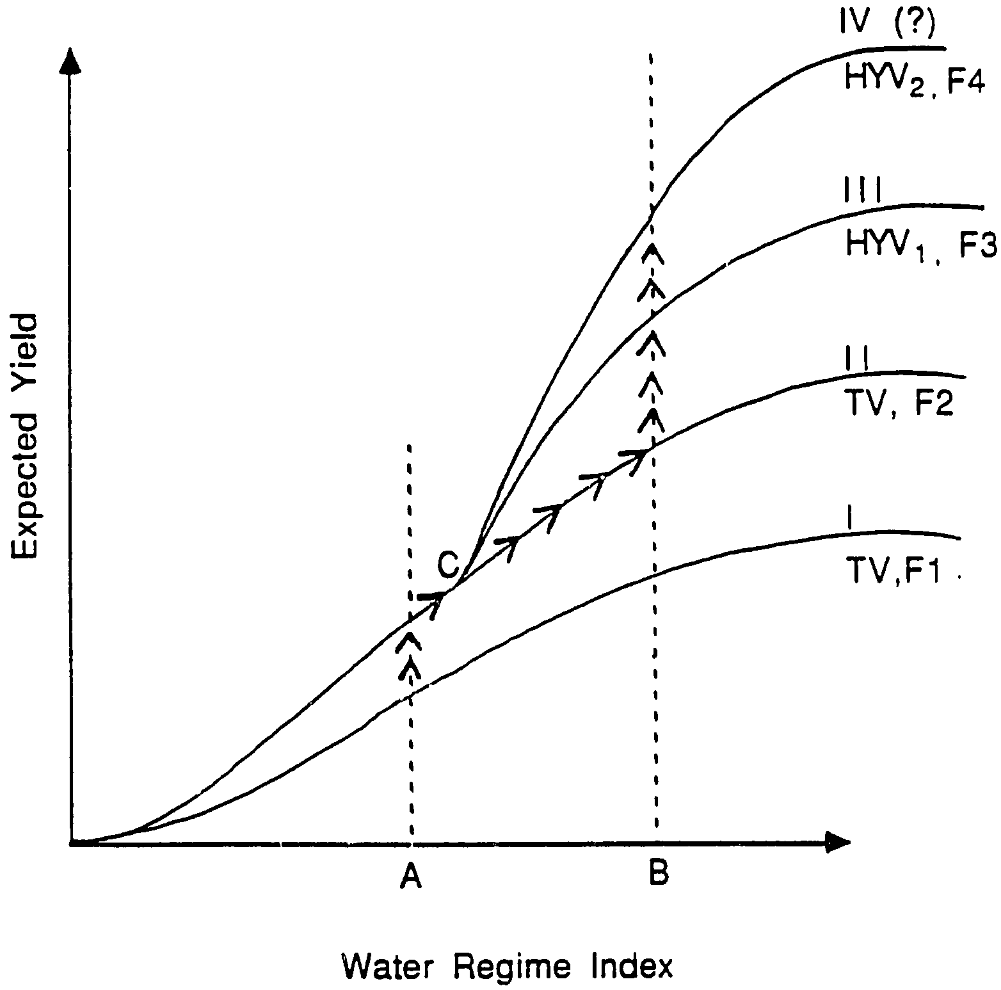


Figure 2. Physical production functions for Areas

(horizontal) and yields (vertical), they also are useful terms for discussing the two components of growth of yield itself. First, there is horizontal growth through improvements in the quality of a given area of land, primarily through irrigation development. Second, there is vertical growth through increased inputs to a given quantity and quality of land.

For example, there may be two areas, on functions I and II, with WRI at "A". Area AI has some vertical yield-growth potential, by increasing fertilizer use from F_1 to F_2. However, since AII is already on the highest function, at A, it can only increase yields by a horizontal movement, by improving WRI through irrigation development. Of course, this horizontal movement must be accompanied by a vertical movement of increased fertilizer use to stay on II.

It is important to note that in the area to the left of the critical area (C) of WRI there is no higher production function than II. Areas A & B are stuck forever at low yields, no matter how rapidly technological change may occur to the right of C. This dismal prospect may in fact be valid for the marginal rainfed areas of Asia, and of the rest of the world.

Turning to a more sanguine view, areas that are in, or can get themselves in, the area to the right of C have substantial opportunities for vertical increases in yield. Thus, if an area can get to BII, a new world of vertical growth opens because of HYVs. Once at B, the area then can move up to BIII. It may be noted that there are two paths to BIII, either along II or III, as horizontal growth proceeds. It seems that the path shown by the arrow, with fertilizer leading HYVs (as irrigation leads fertilizer)--is the most common path, although this is a matter of some controversy (Byerlee). Function III represents the existing state of HYVs (HYV_1). The question for the future of Asia is when UIP is reached and all horizontal movement has ceased, and all areas are on III will there be new HYVs (HYV_2) to create substantially higher functions, like IV?

This question is beyond the scope of this paper, but Herdt's excellent review of the evidence to date does not provide a rational basis for a sanguine outlook. Indeed, it reminds one of the definition of "Pessimist": "The same as 'optimist', only better informed."

C. Foodgrain Production in India

The model of Section B has been applied in a two-stage regression analysis of foodgrain production in India over the 1954-1985 period (Seckler and Sampath). As shown in Table 1, foodgrain production (FG; million tonnes) is the dependent variable. The independent variables are: (a) gross irrigated area (GIRRA, million ha); (b) rainfed area (RAINAREA, million ha); (c) two rainfall indices, one squared, (RAIN and $RAIN^2$); and, last, (d) fertilizer consumption per ha of foodgrain area (NPK)--along with the autoregressive terms shown. (HYVs are implicitly included in this model in the NPK term.) This equation provides an exceptionally good set of statistical results--accounting for over 99% of the variance in foodgrain production over the period, with all the independent variables significant at the 0.999 level.

In this equation, the marginal productivities of gross irrigated area, rainfed area, and fertilizer all are constant. An additional ha of gross irrigated area contributes an additional 2,067 kg pa of foodgrain, compared to 1,217 kg for rainfed area.

SMPL 1958 - 1985
28 Observations
LS // Dependent Variable is FG
Convergence achieved after 2 iterations

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	-191.41324	16.677073	-11.492[illegible]89	0.000
GIRRA	2.0668041	0.1229690	16.807522	0.000
DRYAREA	1.2166963	0.1846164	6.5904007	0.000
RAIN	197.35484	40.643918	4.8557041	0.000
RAIN2	-92.554197	21.020550	-4.4029056	0.000
NPK	0.0036578	0.0006636	5.5121728	0.000
AR(1)	-0.7212512	0.2147173	-3.3590742	0.003
AR(2)	-0.8060654	0.2604611	-3.0947636	0.006
AR(3)	-0.3572204	0.2558260	-1.3963412	0.180
AR(4)	-0.4835790	0.2066514	-2.3400707	0.031

R-squared	0.992088	Mean of dependent var	102.5714
Adjusted R-squared	0.988132	S.D. of dependent var	23.77585
S.E. of regression	2.590112	Sum of squared resid	120.7563
Durbin-Watson stat	2.141200	F-statistic	250.7878
Log likelihood	-60.19226		

TABLE 1 Analysis of Foodgrain Production

An additional kg of fertilizer produces an additional 3.7 kg of foodgrain pa. The rain variables specify an optimum rainfall at 107% of normal. The most important feature of this equation is that 60% of the total change in food grain production over the period is due to the net change in gross irrigated area (after subtracting the contribution of the negative change in rainfed area). Most of the remaining 40% of the change in foodgrain production is due to NPK-- both in itself, and as an index of HYVs--and most of it occurred on irrigated land.

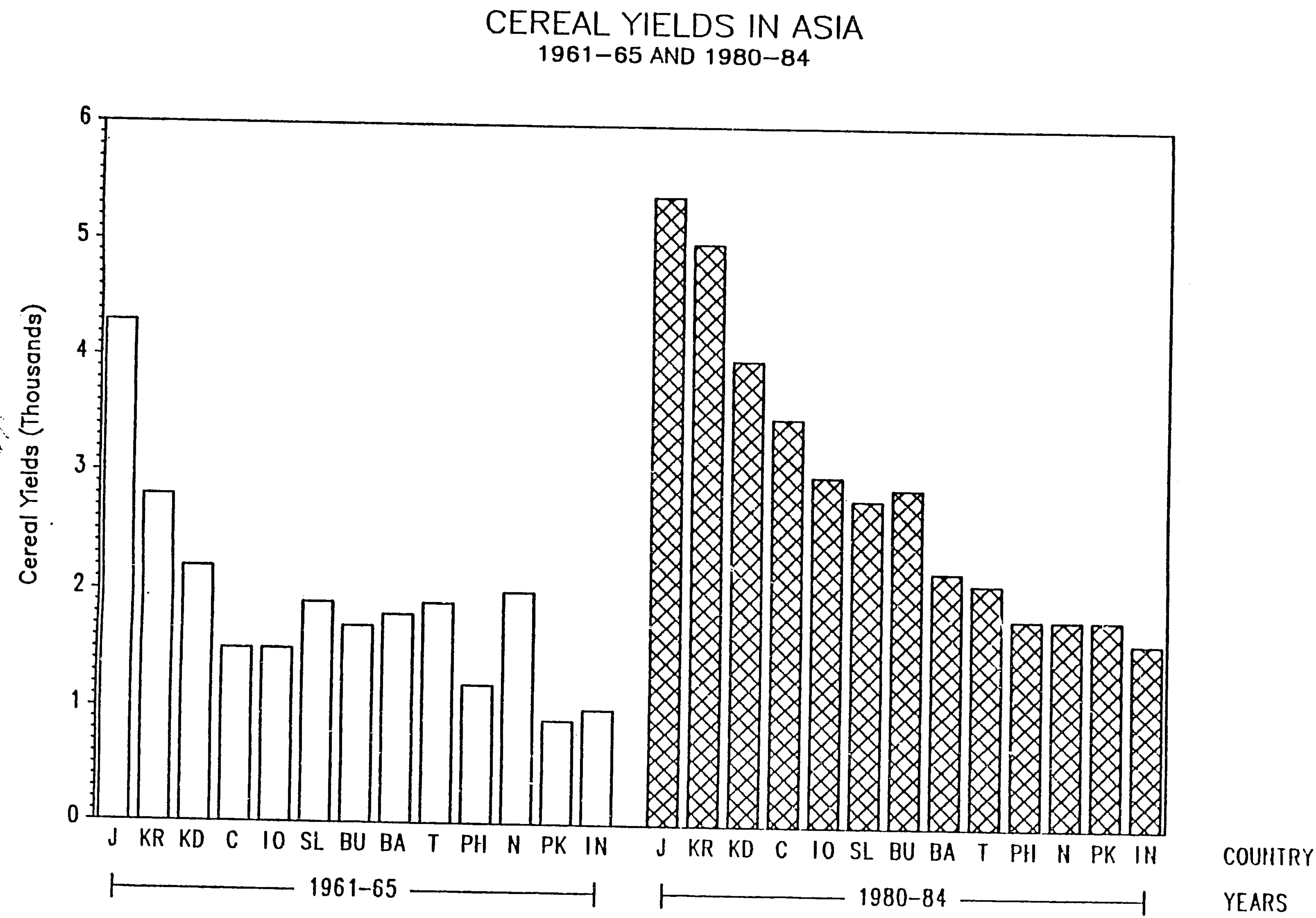
D. Thirteen Asian Countries

The model of Section B has also been applied in a study of cereal yield in the thirteen Asian countries noted, with their codes, below.

Japan (J)	Korean Democratic Republic (KD)	China (C)
Republic of Korea (KR)	Indonesia (IO)	Sri Lanka (SL)
Burma (BU)	Bangladesh (BA)	Thailand (T)
Philippines (PH)	Nepal (N)	Pakistan (PK)
India (IN)		

Figure 3 compares cereal yields in these countries in two periods: 1961-65, before the green revolution, and 1980-84, considerably after. The order of presentation of the countries is from the highest to the lowest yield in the 1980-84 period. Also, the countries have been divided into three groups according to whether they had relatively high, medium, or low yields in the 1980-84 period.

FIGURE 3

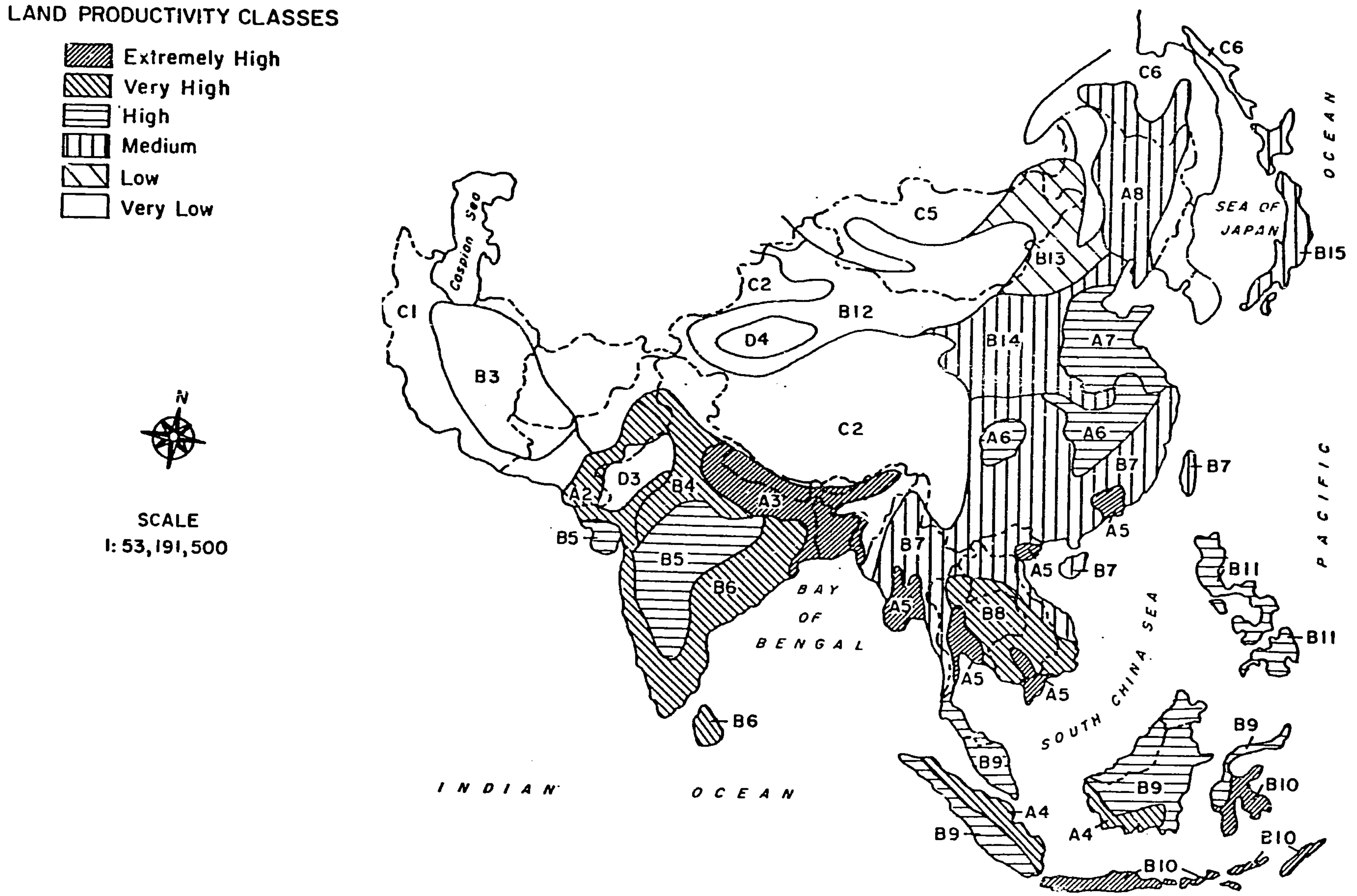

CEREAL YIELDS IN ASIA
1961–65 AND 1980–84
Cereal Yields (Thousands)
0
1
2
3
4
5
6
J KR KD C IO SL BU BA T PH N PK IN
J KR KD C IO SL BU BA T PH N PK IN
COUNTRY
1961–65
1980–84
YEARS

One of the interesting features of Figure 3 is that Japan had higher cereal yields before the green revolution presumably started than any of the Asian countries, with the exception of the Republic of Korea, has achieved after the green revolution.

Another aspect of this figure is that, generally speaking, the countries with the highest yields before the green revolution are also those with the highest yields after the green revolution. Also, they generally experienced the highest growth of yield between the two periods. These facts indicate that agro-climatic conditions, perhaps combined with socio-economic conditions, substantially affects the response of various countries to the opportunities of agricultural technology.

In order to properly compare agricultural production among various countries or regions a water regime index (WRI) is necessary. The WRI used here has two components. The first component is the "water deficiency index" used by Buringh et. al (1975) in their massive study of 222 agro-climatic zones of the world. In order to use this data the agro-climatic zones have been partitioned to conform to national boundaries (and, hence, national agricultural statistics). Also, they have been calibrated to major cereal producing regions within countries. The map of Asia from the Buringh study, with national boundaries drawn in, is shown in Figure 4. The land productivity classes are based on full development of irrigation and all other factors of production. Further agro-climatic calibrations and pertinent maps will be available in the near future.

FIGURE 4


LAND PRODUCTIVITY CLASSES
Extremely High
Very High
High
Medium
Low
Very Low
N
SCALE
1: 53,191,500
Caspian Sea
C1
B3
C2
D4
B12
C5
C6
A8
SEA OF JAPAN
B15
OCEAN
B13
B14
A7
A6
B7
A5
PACIFIC
D3
A2
B4
A3
B5
B6
BAY OF BENGAL
B8
B11
SOUTH CHINA SEA
B9
A4
B10
INDIAN
OCEAN

The water deficiency index varies from zero to unity, with unity indicating the most favorable natural water conditions. However, it does not include a measure of irrigated area in the area. To incorporate irrigation in WRI, an index of irrigated cereal area is created by dividing total gross cereal area of the country by total irrigated area (GIR). Obviously, this index errs to the extent that irrigation is applied to other, non-cereal, crops. However, given the overly-aggregated data base available, there is no better option.

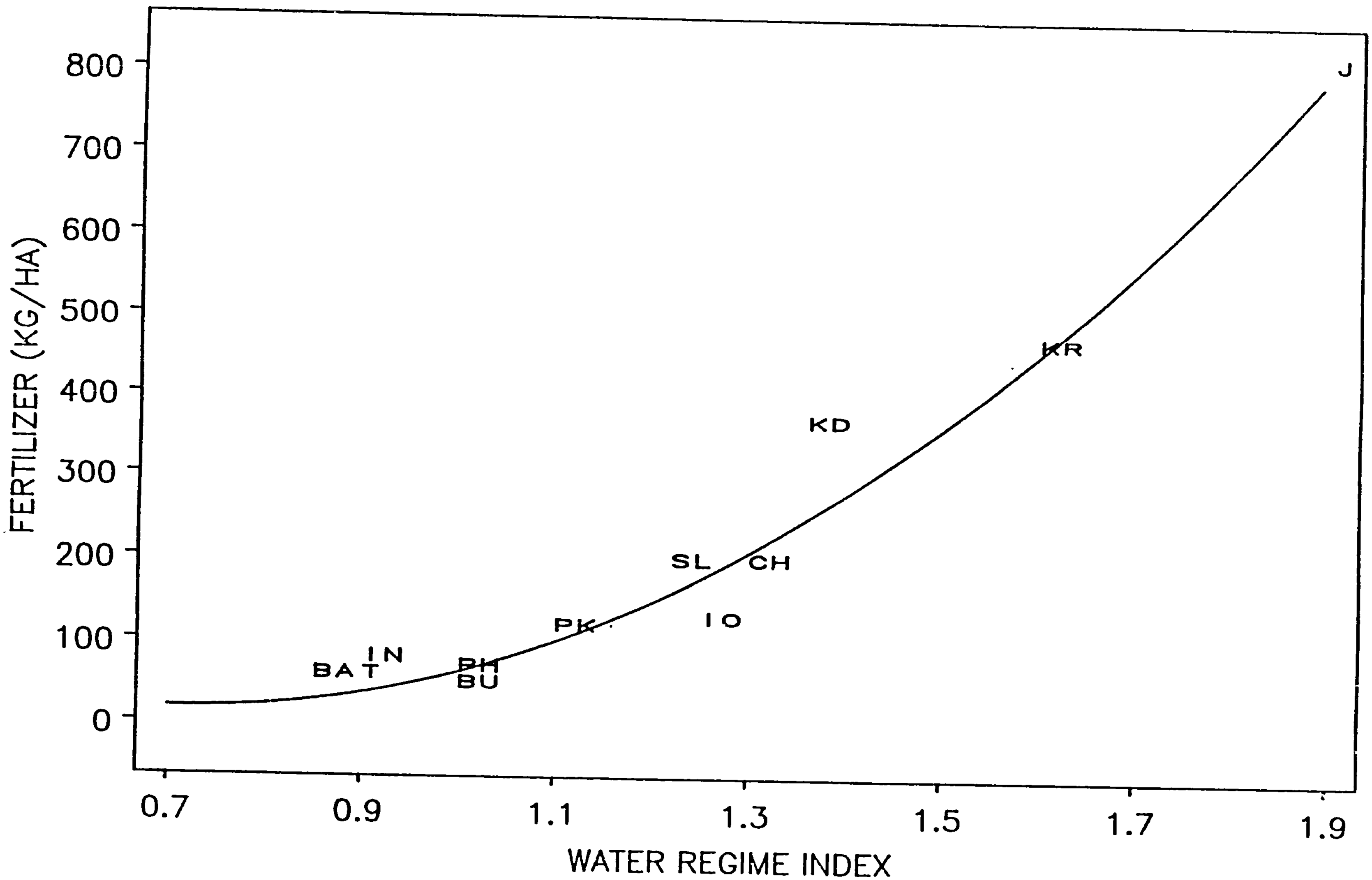
WRI is obtained by simply adding the water deficiency index to the index of irrigated cereal area. WRI ranges from zero to above unity as the additive effect of natural conditions and irrigation produces more favorable water regimes.

Figure 5 begins the analysis by showing the relationship between WRI and an index of fertilizer application per ha of cereal area. Again, this is a crude index obtained by dividing total fertilizer consumption of the country by gross cereal area; (Nepal has been deleted from this set because of very low fertilizer use and yield). Visually, the fit is very good. Table 2 shows that 97% of the variance in fertilizer application rates across these 12 Asian nations is accounted for by WRI.

Figure 6 continues the analysis by showing cereal yield as a function of fertilizer use (yield has been put on the "x" axis for reasons apparent in Figure 7). Again, with the exception of the four lowest yield countries, the visual fit is very good. Table 3 shows that, even including the low-yield countries, 94% of the variance in cereal yield is accounted for by variance in fertilizer use.

FIGURE 5

WATER REGIME AND FERTILIZER/HA FOR CEREALS



VARIABLE: FERT

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	568344.32140	284172.16070	144.109	0.0001
ERROR	9	17747.34527	1971.92725		
C TOTAL	11	586091.66667			

ROOT MSE	44.40639	R-SQUARE	0.9697
DEP MEAN	199.1667	ADJ R-SQ	0.9630
C.V.	22.29609		

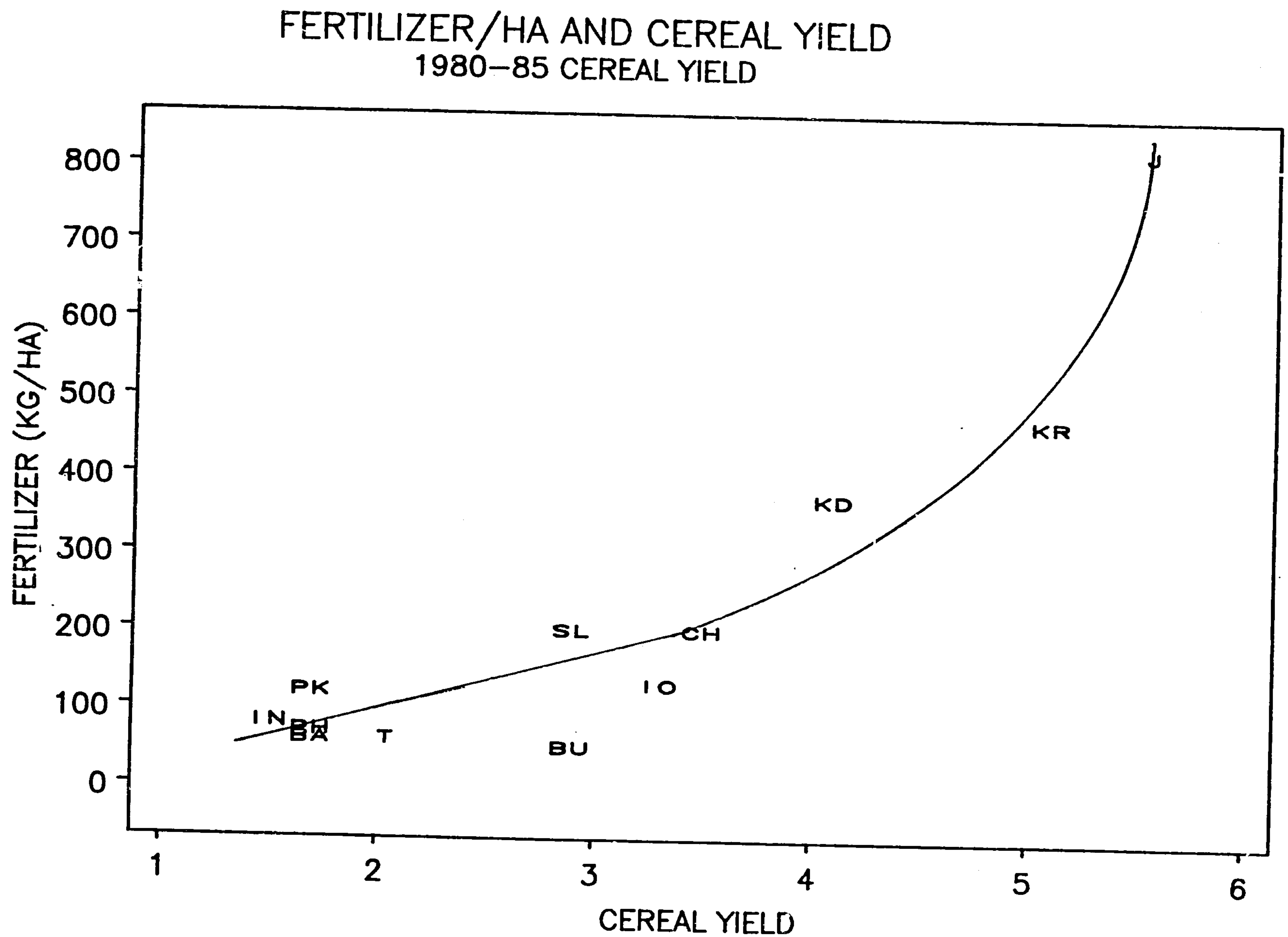
PARAMETER ESTIMATES

ARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
NTERCEP	1	307.07154212	221.84866863	1.384	0.1997
RI	1	-806.916	345.55461890	-2.335	0.0444
RI2	1	562.91107050	128.06076365	4.396	0.0017

ARIABLE	DF	VARIANCE INFLATION
NTERCEP	1	0
RI	1	65.45680721
RI2	1	65.45680721

BS	ID	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	J	800.0000	806.0405	41.8594	-6.0405	14.8230
2	KR	450.0000	457.0586	22.0690	-7.0586	38.5342
3	KD	350.0000	250.8264	20.2037	99.1736	39.5441
4	SL	180.0000	160.4711	17.7589	19.5289	40.7007
5	CH	180.0000	209.4007	19.3799	-29.401	39.9543
6	IO	110.0000	177.9754	18.4278	-67.975	40.4023
7	PK	100.0000	100.5866	15.0880	-.586578	41.7646
8	PH	50.0000	63.0668	15.3783	-13.067	41.6585
9	IN	60.0000	36.8053	20.9524	23.1947	39.1526
10	T	40.0000	36.8053	20.9524	3.1947	39.1526
11	BA	40.0000	27.8964	25.6743	12.1036	36.2320
12	BU	30.0000	63.0668	15.3783	-33.067	41.6585

FIGURE 6


FERTILIZER/HA AND CEREAL YIELD
1980–85 CEREAL YIELD
FERTILIZER (KG/HA)
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
CEREAL YIELD
J
KR
KD
SL
CH
PK
IO
IN
BA
T
BU

VARIABLE: FERT

TABLE 3

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	550954.72968	275477.36484	70.561	0.0001
ERROR	9	35136.93698	3904.10411		
C TOTAL	11	586091.66667			

ROOT MSE	62.48283	R-SQUARE	0.9400
DEP MEAN	199.1667	ADJ R-SQ	0.9267
C.V.	31.37213		

PARAMETER ESTIMATES

ARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
NTERCEP	1	247.72555260	112.52156317	2.202	0.0552
LD	1	-202.839	76.82773899	-2.640	0.0269
LD2	1	53.08794313	11.39226873	4.660	0.0012

ARIABLE	DF	VARIANCE INFLATION
NTERCEP	1	0
LD	1	31.55148625
LD2	1	31.55148625

BS		ID	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	J		800.0000	738.0218	51.3705	61.9782	35.5693
2	KR		450.0000	560.7295	35.4136	-110.73	51.4779
3	KD		350.0000	285.7770	28.6029	64.2230	55.5516
4	SL		180.0000	95.9861	26.0001	84.0139	56.8164
5	CH		180.0000	171.7699	28.9691	8.2301	55.3615
6	IO		110.0000	142.2616	28.3962	-32.262	55.6575
7	PK		100.0000	59.0884	28.0575	40.9116	55.8290
8	PH		50.0000	59.0884	28.0575	-9.0884	55.8290
9	IN		60.0000	67.8034	34.0362	-7.8034	52.3989
10	T		40.0000	54.3995	21.9870	-14.399	58.4865
11	BA		40.0000	59.0884	28.0575	-19.088	55.8290
12	BU		30.0000	95.9861	26.0001	-65.986	56.8164

Figure 7 provides causal summary of the model by relating Figures 5 and 6. Given the percentage of cereal area irrigated, fertilizer use is determined, as shown on the left. Then, given fertilizer use, cereal yield is determined as shown on the right.

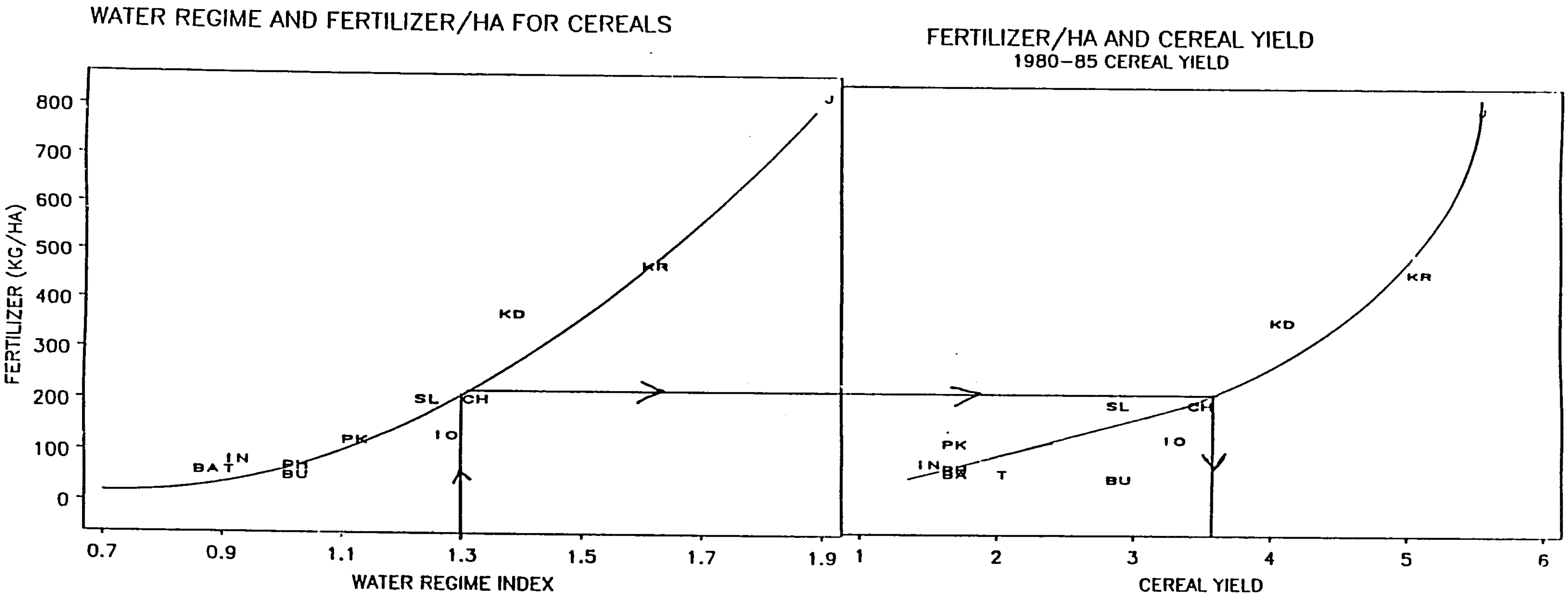
It is interesting to note that these causal connections are so tight that regression analysis fails because of the problem of multicolinearity between irrigation and fertilizer (and HYVs).

Last, it is interesting to briefly look at the average productivity of fertilizer in the Asian countries. Figure 8 shows the relationship between cereal yield per unit of fertilizer on the vertical axis and fertilizer use per ha on the horizontal axis. This relationship indicates strongly diminishing average productivity of fertilizer up to about 200 kg/ha, after which average productivity stabilizes in the range of 10-15 kg of yield per kg of fertilizer. This graph indicates that the green revolution in Asia has had a rather easy ride in terms of fertilizer productivity in the past, but that continued rapid progress is likely to be more difficult in the future.

E. The Future of Irrigation and Agriculture in Asia

It is estimated that the absolute maximum (net) irrigable area of the world (UIP) is around 470 MH, of which Asia contains 314 MH, or exactly two-thirds of the total (Buringh, et. al Table 7 p. 28). The total area actually irrigated in the world (1983) is 213 MH, of which 121 MH, or 57% is in Asia (FAO). China (45 MH), India (40 MH), and Pakistan (12 MH) constitute 80% of the Asian total.

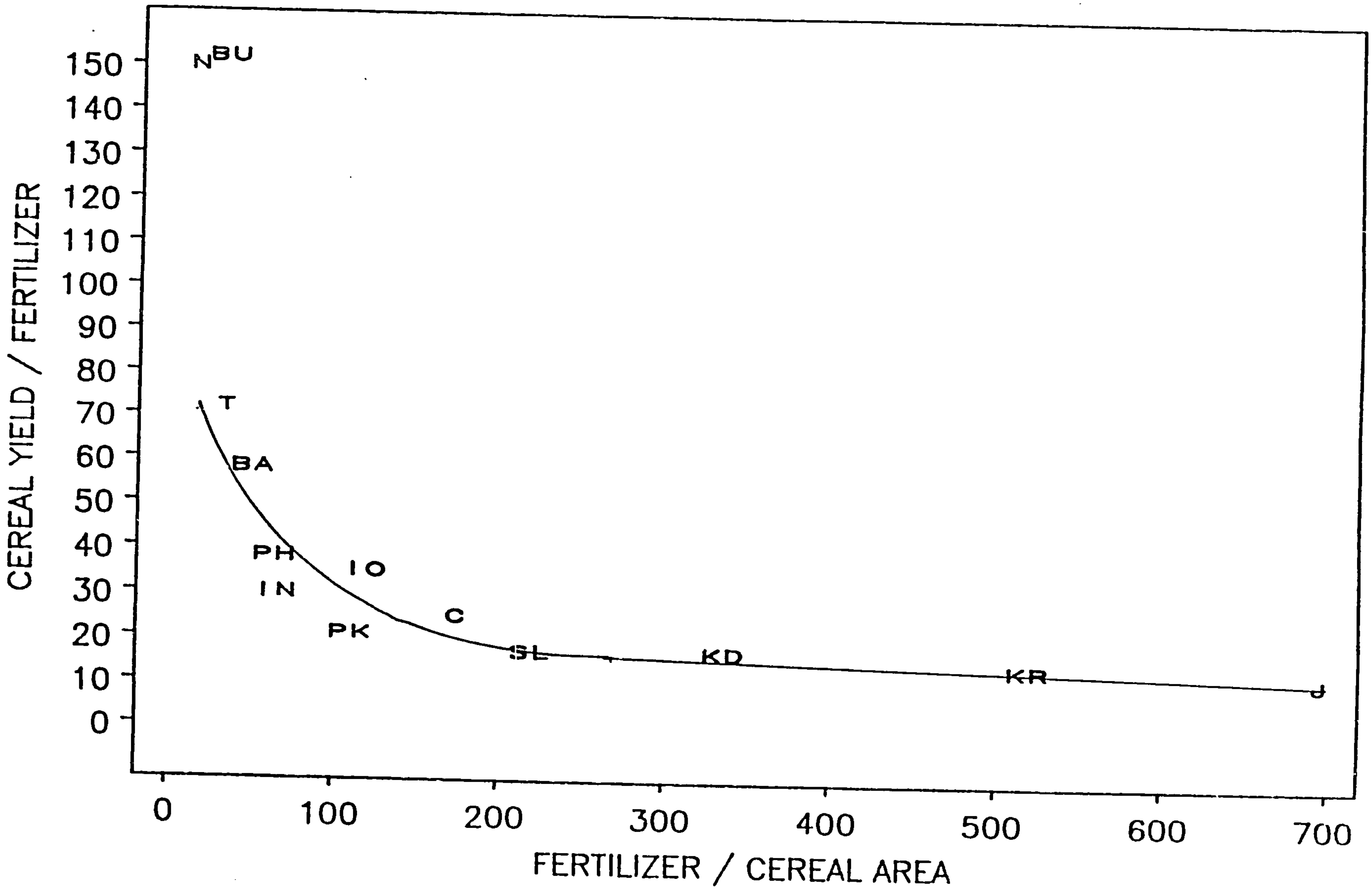
Figure 7



WATER REGIME AND FERTILIZER/HA FOR CEREALS
FERTILIZER (KG/HA)
800
700
600
500
400
300
200
100
0
J
KR
KD
SL
CH
IO
PK
IN
BAT
BU
0.7
0.9
1.1
1.3
1.5
1.7
1.9
WATER REGIME INDEX
FERTILIZER/HA AND CEREAL YIELD
1980-85 CEREAL YIELD
J
KR
KD
SL
CH
IO
PK
IN
BU
T
1
2
3
4
5
6
CEREAL YIELD

FIGURE 8

Diminishing Returns to Fertilizer
1982



It is important to realize that these figures on UIP are based on absolute maximum utilization of physical quantities of water and irrigable land, and do not include economic considerations. Any consideration of ultimate potential has to be related to economics, to real costs of food production. The question is, what economic criterion is to be used?

One criterion would be constant costs of food production in real terms, including taxes and subsidies. However, this criterion is too liberal since it implies that as per capita income increases, the percentage of income spent on food would continually decrease. This suggests an alternative criterion, that real food costs be a constant percentage of real per capita income. This criterion is too conservative because no progress in terms of the food component of real income would be made. The idea that the poorest 40% of the population of India would have to continue spending 80% of their income on food in perpetuity is intolerable.

This is not the place to attempt to strike the right balance for this criterion. It is sufficient to say that real food costs should rise more slowly than per capita real income. In poor countries, if real per capita income is increasing 1% p.a. then real food costs should not increase more than, say, 0.5% p.a. for real progress to occur.

Unfortunately, there is no good data on the real cost of irrigation development in Asia. Most experienced observers believe it has extended well into the range of increasing marginal costs. To say that the real cost of developing an additional ha of gravity irrigation is increasing on the order of 1% p.a. would perhaps not be provocative. This is probably not true of pump irrigation, where costs may be constant or even decreasing with technological advances--except where water tables are falling, or energy costs are rising.

It is also important to consider the rapidly increasing cost of maintenance of existing irrigation systems, which naturally increases as the base of aging systems increase.

On the other hand, many people believe that the scope for irrigation development through improved management and technology (e.g. sprinkler systems) is enormous because existing systems are so inefficient in water utilization. In Asia (as in the USA) the average water use efficiency of irrigation is around 30-40%. A well-managed gravity irrigation system can attain an efficiency of 60%, and sprinkler/drip systems can be 70-90% efficient. Thus, it is natural to think that something like twice the effective irrigation can be obtained from the same water resource--and, since most systems only effectively irrigate one-half or so of their designed area, this water could be used on nearby land.

The author made this argument, in the case of India, (Seckler, 1985). However, this argument is a classic case of a "composition fallacy". While it is valid for every part of a system it is not necessarily valid for the system as a whole. Most of the water that is wasted in one part of a well-developed irrigation system (as in India or China) is reused in another part of the system, either from underground or downstream sources. There is a "water multiplier" effect that makes these systems converge to high levels of system-wide efficiency, leaving very little scope for system-level gains through improved irrigation management and technology. The major exception to this rule is in areas where waterlogging and salinity is a problem.

If this conjecture is correct, then there are several implications for the policy of irrigation development. First, before large investments in improving (or "rehabilitating") existing systems are made, hydrological studies should be conducted to assure that what is gained in the project site is not lost off-site, resulting in an expensive zero-sum game.

Second, wherever unexplored ground-water potential exists--or can be created by leaky gravity systems--pump irrigation systems should be considered as promising alternatives to gravity systems. A USAID sponsored computer model of pump irrigation systems shows that the present value of all the costs of a typical pump irrigation system over a 25 year life is around $1,000 - $1,500 per ha, or about one-half the cost of a gravity system in India (Seckler, et. al 1988). Also, because of direct control of water by farmers, pump systems create more productive irrigation than do gravity systems.

In light of all these complex and ambiguous considerations, what can be said of the future of irrigation development in Asia?

Table 4 provides a brief overview of the growth of irrigation in the thirteen major Asian nations. It is notable that of the three countries China, India, and Pakistan, which constitute 83% of the

Table 4

Irrigation in Thirteen Asian Countries

Irrigated Area (1000 HA; FAO)	1974-76	1983	Compound Growth	% Total Irr, 1983
1 Bangladesh	1355	1848	3.95%	2%
2 Burma	977	1011	0.43%	1%
3 China	42707	45144	0.70%	38%
4 India	33590	39500	2.05%	33%
5 Indondesia	4855	5418	1.38%	5%
6 Japan	3282	3240	-0.16%	3%
7 Korea DPR	900	1060	2.07%	1%
8 Korea Rep	1061	1190	1.44%	1%
9 Nepal	182	230	2.97%	0%
10 Pakistan	13601	14720	0.99%	12%
11 Philipines	1098	1400	3.08%	1%
12 Sri Lanka	480	538	1.44%	0%
13 Thailand	2415	3472	4.64%	3%
Total	106503	118771	1.37%	

total irrigated area, only India is growing at a rate of over 1% p.a. In fact, since 1979 the growth in Pakistan and China has been nearly zero. Most of the growth in irrigated area in Asia as a whole will be in India. India is expected to reach its UIP in about 25 years, around the year 2015 (Seckler and Sampath). By that time irrigation development in Asia will effectively end.

The next question is what is likely to happen to food production when all future increases in yield must be from vertical movements in Figure 2 alone?

Japan provides one view of the future. Both irrigated area and cereal yields have decreased from the 1974-76 period. While yield is at a very high level (around 5,300 kg/ha) the costs of attaining this level (including subsidies) is several times world market prices.

Pakistan provides another view. Again, irrigation development basically ceased since 1979, and the growth of cereal yield abruptly slowed, even at very low levels of yield.

These and other cases, such as Egypt, should be carefully studied to obtain a view of the future of Asian food production and cost as irrigation development slows. However, from the perspective of this analysis, the best that can be said is that Asia should use the short time it has left to substantially reduce the rate of growth of its population in preparation for substantially slower growth of food production.

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