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EXPLORING THE GAP BETWEEN POTENTIAL AND ACTUAL RICE YIELD IN THE PHILIPPINES†

In the initial flush of enthusiasm that followed the development and release of the first tropical semi-dwarf, highly fertilizer-responsive rice varieties it was common to read predictions of imminent self-sufficiency for many of the developing countries. The Philippines was one country mentioned prominently among those expected to achieve self-sufficiency. But after a brief period in 1970 without imports, demand has again regularly exceeded production. Apparently there have been some problems or constraining factors that were not appreciated when the "seed-fertilizer revolution" first burst upon the scene. We explore some of the possible constraints to Philippine rice production in this paper to understand better why rice yields and therefore rice production have not increased more rapidly.

As used in this paper, constraints to rice production include the important factors that keep rice yields low. We briefly review constraints to the adoption of yield-increasing technology on existing rice lands, and explore in detail the constraints to increasing yields on existing rice land. We are primarily concerned with production constraints that affect farmers and that can be modified, not those which appear at the present time to be entirely outside the scope of man's influence.

The objective is to learn why on-farm yields are, on the average, so much lower than the yield levels demonstrated under experimental conditions. The approach is to focus on farm level constraints, using Philippine data. Similar analyses could be carried out for other countries, if the data were adequate.

The first section of the paper briefly discusses some issues relevant to the spread of new technology, the second part of the paper examines the possible physical constraints responsible for the gap between potential and actual yields, and the third part examines the results from a number of multi-factor experiments to determine the possible effect of economic forces.

THE SPREAD OF IMPROVED TECHNOLOGY

The flow of new technology being produced by experiment stations must overcome physical, economic, and social constraints before the ideas are adopted as "improved technologies" by farmers. First, for adoption to occur, the new technology must result in greater production per unit of inputs used than the previously existing technology provided under farmers' environments. Second, given the costs, prices, tenure, and possible market discrimination that exist for particular individuals or locations, the technology must result in higher returns to family-owned resources than existing technology or it will not be adopted. Third, the inputs, credit, markets, and the "social technology"[1] consisting of education, information and decision-makers willing to take risks must be available for adoption to take place. Variability in yields and net returns must not be greater than with the old technology, unless the farmers affected are neutral to or have a preference for risk. And, finally, the social and personal changes as well as the output increases that result from accepting the new technology must be positively valued by both the society and the individual. There is no particular hierarchy in these requirements, but if any one is not fulfilled for a particular innovation or component of improved technology then that innovation will not be adopted.

It appears that these conditions have been largely fulfilled for the modern varieties[2] of rice in the Philippines since adoption has been quite rapid. The varieties were first released in 1965. In 1967/68, the first year for which data are available, modern varieties were planted on 21 percent of the rice area and by 1969/70 they covered 44 percent of the area.[3] The proportion increased to 56 percent by 1971/72 and decreased to 54 percent in 1972/73. Hence, it appears that the process of adoption has been fairly rapid and complete. However, despite rapid adoption of new varieties, increases in Philippine rice production have been disappointing to researchers, policy-makers, and the public.

PHYSICAL AND BIOLOGICAL CONSTRAINTS TO YIELDS

An examination of the data on actual yields of the modern varieties under farm conditions in the Philippines shows why total rice production increases have been disappointing. On the average, modern varieties yielded 0.3 t/ha (tons per hectare), or about 16 percent more than traditional varieties under irrigated conditions, and practically the same as traditional varieties under rainfed[4] conditions (Table 1). Those yields are consistent with crop-cut pilot studies, like those conducted in 1969–70 on 300 irrigated farms in Central Luzon and Laguna which revealed a 14 percent yield difference between traditional and modern varieties (8, p. 161). Absolute yield levels of the irrigated modern varieties averaged 2.1 t/ha, far below the 6, 8 or 10 t/ha which was talked about during the early days of IR8 (5).

Why is there such a difference between what was expected and what has

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[1] We are indebted to Dr. Gelia Castillo of the University of the Philippines at Los Baños, for this concept.
[2] We prefer the term "modern varieties" to "high-yielding varieties" because the varieties are not high-yielding under all conditions.
[3] Data supplied by the Bureau of Agricultural Economics, Government of the Philippines.
[4] "Rainfed" rice refers to rice grown in flooded, puddled fields dependent on rainfall for water. "Upland" rice also depends on rainfall but it is grown on non-flooded, non-puddled fields.

TABLE 1.—AREA AND YIELD OF MODERN AND TRADITIONAL RICE VARIETIES
IN THE PHILIPPINES, 1968–72*

	Area (1,000 ha)		Yield (t/ha)a	
	Modern	Traditional	Modern	Traditional
		Irrigated		
1968	445	864	2.0	1.6
1969	913	570	1.8	1.6
1970	826	519	2.2	1.9
1971	985	485	2.0	1.9
1972	977	355	2.1	1.7
		Rainfedb		
1968	256	1,257	1.3	1.2
1969	439	968	1.1	1.1
1970	527	828	1.5	1.5
1971	580	697	1.6	1.6
1972	850	698	1.4	1.4

* From L. J. Atkinson and D. E. Kunkel, "HYV in the Philippines, Progress in the Seed-Fertilizer Revolution" (U.S. Dept. Agr., ERS, preliminary draft, Dec. 11, 1973, processed). Derived from data of the Bureau of Agricultural Economics.

a Assuming conversion at 44 kg/cavan of rough rice. Yields are reported in cavans (a volume measure) in the Philippines.

b This refers to lowland transplanted rainfed rice, and does not include upland rice.

occurred? We hypothesize five possible reasons: (1) reporting of yields by farmers is biased; (2) expectations were unrealistically high and the "true potential yield" is considerably lower; (3) potential yields of the modern varieties are not fully expressed under poor environmental conditions; (4) farmers strive for economic optimum, not maximum yields; and (5) the supply of certain inputs is less than is needed to achieve the economically optimum yield.

Three factors may bias reported yields. First, farmers count only what they actually recover after threshing, and may report their yields after deducting shares paid for harvesting (although care is taken to eliminate this source of error). Second, errors arise because farmers tend to report the area of their farms to the nearest hectare or half hectare. Since yield is computed by dividing area into production, yields are miscalculated. This is serious if the tendency is to report the next higher instead of simply rounding, but there is no evidence on this point. A third factor is the obvious incentive to underreport of farmers who pay their land rentals as a percent of the harvest. The official data are therefore likely to understate actual yields and even careful survey techniques are likely to have the same problem (7, p. 197). Each of these errors should bias reports of yields from traditional and modern varieties in the same way so that reports of relative increases in yield would be little affected. But even if they led to large underestimation of yields it is not obvious that this alone would be enough to account for the difference between potential and actual yields of the modern varieties.

Undoubtedly the original yield expectations were very high. Typical of the enthusiastic optimism was this comment by Montague Yudelman: "Where the new varieties of wheat, rice and corn have been used with appropriate complementary inputs, the yields per acre have risen by as much as 100 percent..." (9, p. 282).

Those associated with the technological developments were only slightly more cautious. Yields 100 to 150 percent higher than prevailing averages were commonly reported, implying if not explicitly stating the widespread possibility of such yields. Others were somewhat more circumspect. In his 1969 discussion of prospects, M. A. Abel indicated that it was likely that the Philippines "could maintain physical self-sufficiency or have an exportable net surplus in rice for a number of years" (*1*, p. 113). Clearly, these expectations were too optimistic, but the question of what the actual potential of the modern varieties is still remains.

Physical Constraints

Yields of 8 to 10 t/ha have been repeatedly observed at the International Rice Research Institute (IRRI), and have been frequently mentioned, so this provides a beginning, although admittedly arbitrary, estimate of the yield potential. The difference between 8 t/ha and the present Philippine national yield of about 1.7 t/ha is assumed to be the gap between the potential yield and the actual yields, given the technology available.

Examining the conditions under which 8 t/ha or more have been obtained, one soon wonders if this is *typical* of maximum yields even under those conditions, or if it is only possible in dry seasons with exceptional weather even with the ideal water control that exists at IRRI. That is, one wonders if it is typical of maximum yields even under ideal conditions. To determine the maximum yields possible taking into account year-to-year variability we assembled data from the nitrogen response experiments on IR20, conducted cooperatively by IRRI and the Bureau of Plant Industry (BPI), over three to five dry seasons at four locations.[5] Maximum yields of IR20 averaged 6.8 t/ha for all locations and years with 120 kg N/ha (Table 2). Mean yields of IR8 were slightly higher, but IR8 is not presently being grown by farmers and no longer appears to be a practical component of improved rice technology. These data indicate that with present technology the average maximum potential yield is 6.8 t/ha.

This, however, is the average maximum yield for the dry season, when the high-solar radiation clearly has a favorable influence on rice yields (*4*; *6*, p. 187). In the Philippines most rice is grown during the wet season, when adequate quantities of water are more readily available. About two-thirds of all rice is harvested between July and December, maturing during the low-solar-intensity wet season. One-third is harvested between January and June and matures during the dry season. In many parts of the country, of course, there is considerable rain between January and June and it is not a true dry season, but for present purposes the approximation of one-third in the dry and two-thirds in the wet season will be used.

The maximum yield potential for the wet season was also calculated from the nitrogen response experiments at IRRI and the three BPI locations. Maximum wet season yields were generally obtained at 90 kg N/ha on IR20, and the mean wet season yield at that level, averaged for four to six seasons and four locations, is 5 t/ha (Table 2). Calculating a weighted average of wet and dry season maximum

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[5] While these locations are in four different regions of the country, they cannot represent the entire range of diversity in a country with as much climatic and soil variability as the Philippines. Hence our analysis is indicative only.

TABLE 2.—AVERAGE YIELDS OF IR20 BY SEASON AND AMOUNT OF NITROGEN
APPLIED AT FOUR PHILIPPINE LOCATIONS, 1968–73*

(Tons per hectare)

Nitrogen (kg/ha)	IRRI	Maligaya[a]	Pili[a]	La Granja[a]	Average[b]
		Dry season			
0	4.7	4.0	5.0	4.1	4.4
60	6.2	5.1	6.6	5.7	5.9
90	6.8	5.1	7.7	6.1	6.4
120	7.1	5.6	7.8	6.9	6.8
150	6.8	5.4	7.6	6.6	6.6
180		5.1	7.3	5.9	
Seasons (number)	5	4	5	4	
		Wet season			
0	4.0	3.8	3.5	3.8	3.8
30	4.3	4.6	3.8	4.7	4.4
60	4.4	5.1	4.4	5.5	4.8
90	4.4	5.1	4.5	6.1	5.0
120	—	5.0	3.8	5.8	4.7
150	—	4.4	3.6	5.4	
Seasons (number)	4	6	6	6	

* Compiled from data supplied by IRRI Agronomy Department.
[a] BPI rice research station in Maligaya, Nueva Ecija; Pili, Camarines Sur; and La Granja, Negros.
[b] Weighted by the number of years.

yields results in an average maximum potential yield of 5.6 t/ha, leaving a gap between actual and potential yields of 3.8 t/ha.

These data reflect average maximum yields with irrigation, but less than half of the rice area in the Philippines is irrigated. About 45 percent is rainfed lowland and 13 percent is upland. To determine the maximum potential yields for rainfed rice, yield data from a number of 1972 and 1973 experiments carried out by the IRRI Agronomy Department and Applied Research Program were examined. All the experiments examined were rainfed trials growing IR20, IR22 or IR1529–280-3 (an experimental line). Most of the trials were grown at a number of locations in Central Luzon. All were trials in which inputs were supplied at their maximum yield levels except for the specified variables being tested. The treatment giving the maximum yield at the most locations was selected, and yields averaged over all locations. The average maximums ranged from 3.7 t/ha to 5.8 t/ha (Table 3). The entries in the table were then averaged over years and trials to give an estimate of potential maximum yield under rainfed conditions of 4.7 t/ha.

There are less data on maximum yields using modern varieties under upland conditions, but some are available showing fertilizer response of upland IR5 (Table 4). These data, covering three locations, two seasons, and a number of planting dates show that maximum yields generally occurred with 120 kg N/ha, and that maximum yields ranged from 1.3 to 7.0 t/ha with an average maximum of 4.1 t/ha.

Having recognized the influence of irrigated, rainfed, and upland water regimes on maximum yields, we take the next step to ask how realistic it is to expect farmers to obtain these maximum yields. They may not be within their reach,

TABLE 3.—MAXIMUM REPORTED RAINFED YIELDS FOR IR20,
VARIOUS TRIALS, 1972 AND 1973*

Location and year of trial		Main treatments in trial	Number of levels, each treatment	Average yield (t/ha) of treatment with	
				Maximum yield	Minimum yield
IRRI	1972	Land preparation	3	4.8^a	3.2^b
		Planting method	2		
		Water availability	2		
	1973	Nitrogen	5	4.7^b	3.5^b.
		Variety	16		
	1973	Source of nitrogen	3	5.8^a	3.5^a
		Water availability	2		
		Variety	2		
		Time of application	2		
Central Luzon	1972	Variety	2	5.0^b	2.0^b
		Location	2		
		Elevation	13		
	1972	Soil type	5	3.9	3.4
		Nitrogen	4		
		Phosphorus	3		
		Potash	3		
	1972	Package of fertilizer, insecticide, weedicide	5	5.5	3.6
	1973	Nitrogen	3	3.7	1.9
		Insecticide & herbicide	2		
		Soil type	4		
	1973	Nitrogen	4	4.7	4.0
		Soil type	5		
	1973	Insecticide	8	4.1	3.5
		Location	9		
Nueva Ecija	1973	Source of nitrogen	3	4.5^b	2.6^b
		Variety	2		
		Time of application	2		
		Average		4.7	3.1

* Data from IRRI, *Annual Report, 1972, ibid., 1973.*
^{a} For rainfed IR20.
^{b} For IR20.

since farmers frequently have neither the control over water that exists in experiment stations nor the favorable rainfall and moisture conditions represented by the rainfed and upland maximum yield trials.

In recent years, much of the work of IRRI's Agricultural Economics Department has been directed at examining the adequacy or inadequacy of irrigation and its implications. Among the important findings are: (a) farmers near the source of irrigation systems get relatively good service; (b) those distant from the source get less water and suffer greater yield losses due to drought; (c) shortages of water are more extensive in the dry season; and (d) yield reduction from comparable durations of water shortage is greater in the dry season than in the wet season.

The data shown in Table 5 document some of these effects for a 5,000-hectare command area within the Peñaranda River Irrigation System in Central Luzon. The area was classified into quarters and the mean water availability for each quarter was determined as of a certain date during the dry season. Crop-cut yields were taken at the end of the season. All measures were most favorable for the

TABLE 4.—RESPONSE OF IR5 TO NITROGEN UNDER UPLAND CONDITIONS*

Location	Seeding date	Grain yield (t/ha) Kg N/ha		
		0	60	120
IRRI	5/31/70	2.5	3.2	4.2
	6/15/70	2.3	3.1	4.2
	6/30/70	1.9	2.5	3.0
	7/23/70	1.6	2.1	2.6
Maligaya[a]	6/2/70	4.9	6.1	6.7
	6/17/70	4.1	5.8	7.0
	7/2/70	4.7	5.8	5.9
	7/17/70	4.6	6.1	5.8
Maligaya[a]	6/9/71	2.7	4.2	4.9
	6/29/71	2.4	3.9	5.0
	7/29/71	1.4	2.5	2.8
La Granja[a]	5/21/71	1.0	1.5	2.3
	6/17/71	0.4	1.0	1.3
	7/12/71	0.3	1.2	1.6
Average		2.5	3.5	4.1

* Data supplied by the IRRI Agronomy Department.
[a] BPI rice research station in Maligaya, Nueva Ecija, and La Granja, Negros in the Visayas.

TABLE 5.—AREA ADEQUATELY IRRIGATED ON MARCH 24, 1973,
AND MEAN GRAIN YIELDS*

Sections[a]	Total (hectares)	Command area		Planted area	
		Planted (percent)	With water (percent)	With water (percent)	Yield (t/ha)
1[b]	1,559	91	82	91	2.5
2[b]	1,171	82	55	67	2.2
3	873	59	20	35	1.5
4	1,907	22	0	0	0.4
Total	5,510	60	56	61	2.0

* Data are for consecutive sections served from Lateral C, Peñaranda River Irrigation System, Gapan, Nueva Ecija, 1973 dry season.
[a] Section 1 is at the beginning of the lateral, Section 4 at the end.
[b] Includes 274 hectares in Section 1, and 168 hectares in Section 2, which are outside the command area of those sections but were fully irrigated by pumps drawing water from the lateral.

first quarter, and decreased with distance along the canal. Average yields in consecutive quarters of the lateral were 2.5, 2.2, 1.5 and 0.4 t/ha.

In another study, conducted in 1969–70, eleven irrigated sites in Luzon were classified as to their location along the first, second, or last third of the distribution canal (7, p. 201). Yield losses, calculated on the basis of moisture stress days, showed that those sites located in the first third of the canal suffered 7 percent loss of yield due to moisture stress, those in the second third lost 20 percent of yield, and those in the last third lost 25 percent of yield in the dry season. The average of 17 percent is considerably less than for the 1973 Peñaranda study, but is more broadly representative; therefore, we assume that dry season yields will average 17 percent lower than the maximum attainable under good water condi-

tions. This conservative estimate of yield reduction due to moisture stress gives an average maximum attainable dry season yield of 5.6 t/ha.

Yield reduction due to moisture stress in the wet season was also measured in the study, and was found to be considerably less than in the dry season. In the eleven sites the reduction was 4 percent in the first third of the canal systems, 4 percent in the second third, and 8 percent in the last third, for an average reduction of over 5 percent. This pulls the average maximum attainable wet season yield down from 5 t/ha to 4.7 t/ha.

Similar estimates of the attainable maximum yields under rainfed conditions should be made because the previously quoted data were collected from carefully selected rainfed plots. Research information on this aspect of rice production is extremely sparse. One available study relates to conditions prevailing in the sharply sloping areas adjacent to drainage creeks. In that study, plots were located at varying elevations in two well-defined small watersheds in Central Luzon. The yield of IR20 was reduced by 0.8 t/ha in one area and 0.9 t/ha in the other for each one meter increase in elevation above the drainage outlet. This relationship may exaggerate the prevailing conditions in rainfed areas because the slopes in the study areas were much higher than the average for all rainfed areas. However, it seems reasonable to assume that moisture stress in unfavorably located rainfed areas reduces yields by approximately 20 percent below the levels observed experimentally. This would result in a maximum attainable yield under rainfed conditions of 3.7 t/ha.

There are essentially no data measuring similar effects under upland conditions, but at a minimum they would reduce the maximum possible yield by at least as much as under rainfed conditions, considering the poor soils and extreme slopes on which most upland rice is grown. With this assumption the average maximum attainable yield under upland conditions is reduced by 20 percent, from 4.1 t/ha to 3.3 t/ha.

The data on yields and area in different water regimes are summarized in Chart 1. The distribution of rice area by type of culture is shown on the left side of the figure, with maximum attainable yields and actual yields (1969–72) for each type shown on the right. Forty-five percent of the area is rainfed with actual yields of 1.6 t/ha and maximum attainable yields of 3.7 t/ha. Twenty-eight percent of the rice is wet season irrigated, with actual yields of 2.0 t/ha and maximum attainable yields of 4.7 t/ha. Fourteen percent is dry season irrigated with actual yields of 2.0 t/ha and maximum attainable yields of 5.6 t/ha.[6] The remaining 13 percent is upland, with actual yields of about 0.9 t/ha and maximum potential yields of 3.3 t/ha. Given these approximations, average actual yield is about 1.7 t/ha and the maximum attainable average yield for the country is about 4.2 t/ha. The maximum attainable is, under present conditions, more than double actual yields, but it is not quadruple actual yields as might be implied by the 8 t/ha "potential."

Our estimate of the maximum attainable national average yield (4.2 t/ha)

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[6] In 1966/67 The Bureau of Agricultural Economics reported that 67 percent of all irrigated rice was grown during the wet season. A 1969/70 estimate by the Bureau showed 62 percent was wet season, 38 percent dry. Data assembled for the World Bank by the Philippine National Irrigation Administration show 70 percent of the irrigated rice area is single cropped and 30 percent is double cropped. On the basis of these estimates, we conclude that two-thirds of all irrigated palay is grown during the wet season, one-third during the dry.

CHART 1.—ESTIMATES OF CURRENT ACTUAL YIELDS, MAXIMUM ATTAINABLE YIELDS,
AND SHARE OF RICE AREA FOR FOUR TYPES OF RICE CULTURE,
PHILIPPINES, 1973
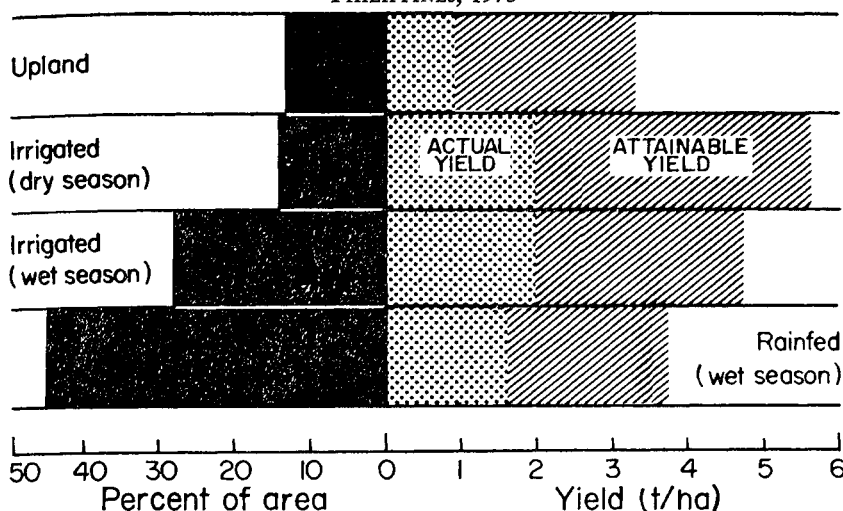
takes into account year-to-year fluctuations in sunlight, rainfall, diseases, insect
pests, and planting dates; seasonal variation and the fact that most of the rice
is produced during the wet season when solar radiation is low; existing levels
of water control in the irrigation systems of the country; the present proportion
of rice grown under irrigated, rainfed, or upland culture; and the biological
yield potential of today's technology.

Biological Constraints

The above discussion has analyzed how physical factors associated with season
and water availability reduce attainable potential yields below the level that is
achieved under ideal conditions. In addition to these constraints, it is well known
that farmers' use of inputs is far below the level necessary for maximum yields.
This behavior appears to result from farmers' ignorance of the effects of certain
inputs on yield, especially insect and weed control; from the unavailability of
inputs or cash with which to purchase the inputs where and when they are
needed; and from the economic calculations involved in using inputs.

Experimental data provide some insight into the effect of chemical control
of insects and weeds just as they do for fertilizer. In IRRI insecticide experiments
during 1971 and 1972, in which IR20 or a more recently released variety was used,
yields were 36 percent higher when insecticide was applied. The relative differ-
ence between treated and untreated plots was the same in the wet and dry seasons.

Experimental data intended to measure the effect of weed control are in-
conclusive. Yields of unweeded plots are usually very low because weed growth
is stimulated by the substantial fertilizer application used in the experiments.
Typically, farmers who apply fertilizer also attempt to control weeds to some
degree so a comparison of weeded and unweeded plots in experiments overstates
the additional benefits of weed control. Hence, there is some question as to
whether available weed control experiments accurately reflect the effect of lack
of weed control under farmers' conditions.

The yield contribution of individual inputs cannot be measured by simply considering the difference in yield "with and without" each input. A joint determination of the effects of various inputs is required, which in turn requires a carefully controlled multi-factor experiment. Such work is under way but results are not yet available.

<div align="center">ECONOMIC CONSTRAINTS TO YIELDS</div>

Farmers are influenced to aim for less than maximum yields by profit considerations and risk avoidance. Elementary production theory shows that because of diminishing returns profits are always lower at maximum yield than at some lower level of input use. It may be, however, that farmers hesitate to use even the profit maximizing levels of inputs because the greater cost of inputs might leave them badly in debt if the crop failed.

Although it seems certain that risk and diminishing returns both lead to reduced input use and, therefore, to lower yields, no one is sure exactly how farmers make their decisions, and no one is sure of the precise impact of those decisions.

Knowledge about how profit, risk, labor requirements, and other factors affect the decisions a farmer makes about the inputs he uses is extremely deficient. While most economists are convinced that farmers do not try to maximize yields, we are less sure what they do maximize. Some may attempt to maximize profits, or net returns over cash costs, others may seek a given rate of return or a given benefit-cost ratio for cash investments. In the following analysis the results that might occur if farmers followed a conservative cash use rule, a profit maximizing rule, or a maximum yield rule are considered.

Expected net returns is used as the measure of profit. Since farmers make input decisions without knowing the price at which the crop will sell, they must depend on experience with price movements and on prices at planting time to judge what future prices will be. In most of the Philippines, prices have historically fallen an average of 20 percent from the time the wet season crop is planted until it is harvested in November. Hence, expected net returns are calculated using the prices of inputs at planting time, and a rice price 20 percent lower than the price at planting time.

Other factors to consider in measuring profitability include share rental agreements and the cost of harvesting, which increase as yields increase. As Alfred Marshall pointed out long ago, share tenants will cultivate much less intensively than owner operators or cash tenants if they must pay the full cost of purchased inputs but share with their landlords the increased revenues that result from them. This is becoming less a matter of concern in the Philippines as more and more farmers switch to fixed rents under land reform. Nevertheless, rent, seasonal price movements, the cost of harvesting, and interest on purchased inputs must be included in calculations of profitability.

A second difficulty arises because the level and combination of inputs that should be applied is not known regardless of what the farmers' objective function is. To determine this, data that relate the response of production to varying amounts of each input are needed. Many single factor experiments relate one input to output, but usually other factors are held constant at levels needed for maximum yield. For example, in experiments designed to test response to nitro-

gen, a high level of phosphorus, potash, weed control, and insect control is usually maintained to insure that these factors are not limiting. But to maximize profits, or to follow any decision rule other than yield maximization, farmers need to know the optimal combination of inputs. This can only be derived by analyzing varying combinations of input.

A number of such experiments are available, and while they do not provide data adequate to determine the effect of separate factors, they can yield some insights into the economic questions. IR20 was used in all but one of the six multi-factor trials analyzed below. Four of the trials were conducted by the Agricultural Economics Department and two by the Rice Production Training and Research Program of IRRI. Each was carried out at three or more locations in Central Luzon under farm conditions, i.e., except where included as a treatment, protection against insect, disease; water stress and other pressures were those usually provided by farmers.

The first experiment analyzed was designed to test 36 different combinations of water control, weed control, and nitrogen and phosphorus applications. The experiment was conducted in three irrigated and three rainfed locations during the wet season of 1973. Analysis of the results showed that location was of overwhelming importance, application of 60 kg/ha of P_2O_5 (either basal or top-dress) was significantly better than no P_2O_5, and no significant yield improvement resulted when 2,4-D herbicide was supplemented with one handweeding. Chart 2

CHART 2.—YIELD RESPONSE TO NITROGEN IN MULTI-FACTOR EXPERIMENT UNDER FARMERS' CONDITIONS, THREE LOCATIONS IN NUEVA ECIJA, IRRIGATED, WET SEASON, 1973
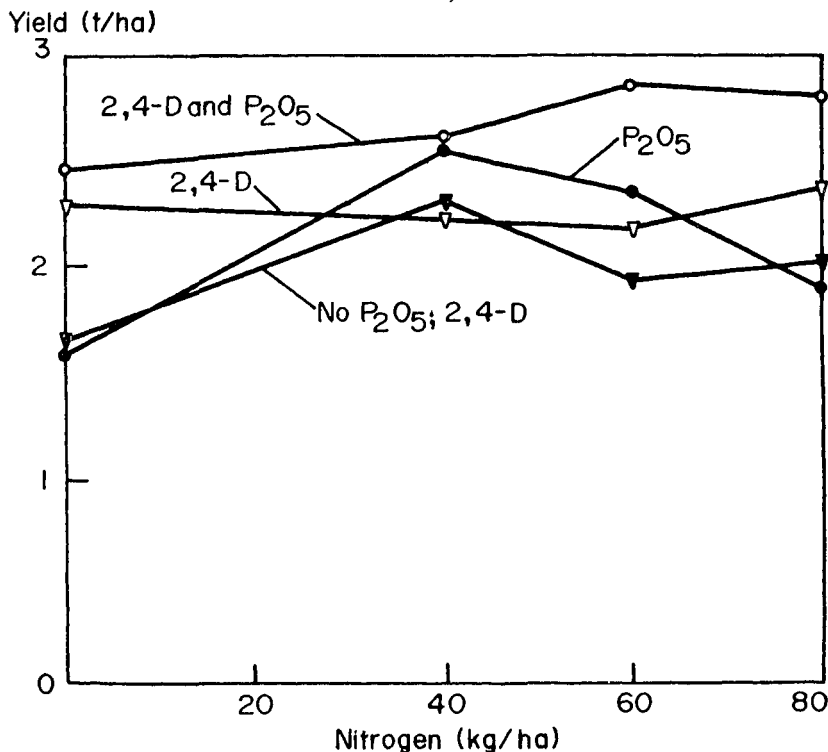
TABLE 6.—INPUTS, YIELDS, AND NET RETURNS OF EXPERIMENTS ON IRRIGATED
FIELDS OF THREE FARMS IN NUEVA ECIJA, 1973

Treatment number	Inputs				Total yield (t/ha)	Increase over control		
	N	P_2O_5	2,4–D	Cost (P/ha)		Yield	Net return (P/ha)	Net return per peso cost
	(kg/ha)							
1	0	0	no	0	1.6	—	—	—
2	40	0	no	60	2.3	0.7^b	^{b}	4.5
3	60	0	no	90	1.9^a	0.3	^{a}	—
4	80	0	no	120	2.2^a	0.6	^{a}	—
5	0	60	no	102	1.6	0^b	^{b}	—
6	40	60	no	162	2.5	0.9^b	^{b}	1.6
7	60	60	no	192	2.3^a	0.7	^{a}	—
8	80	60	no	222	2.0^a	0.4	^{a}	—
9	0	0	yes	20	2.3	0.7	310	15.5
10	40	0	yes	80	2.3^a	0.7	^{a}	—
11	60	0	yes	110	2.2^a	0.6	^{a}	—
12	80	0	yes	140	2.4	0.8^b	^{b}	1.7
13	0	60	yes	122	2.5	0.9	303	2.5
14	40	60	yes	182	2.7	1.1	338	1.8
15	60	60	yes	212	2.7^a	1.1	^{a}	—
16	80	60	yes	242	2.9	1.3	372	1.5

^{a} Treatment with more input and the same or lower yield than another treatment.
^{b} Treatment with higher cost and the same or lower yield than another treatment.

shows the four resulting nitrogen response curves. Basal and top-dress P_2O_5 treatments were pooled since their cost and effect is approximately the same, but the 2,4–D plus handweeding treatments were eliminated since they gave no higher yield but cost more than 2,4–D alone.

Yields without P_2O_5 or 2,4–D are lowest and those with both are highest. Nitrogen levels above 40 kg/ha generally resulted in lower yields unless both P_2O_5 and 2,4–D were used, illustrating clearly the production complementarity among these inputs.

Economic analysis is not required to eliminate all nitrogen treatments beyond the point of maximum output for given P_2O_5 and weed control levels (Treatments 3, 4, 7, 8, 10, 11, 15 in Table 6). This leaves nine treatments, but four of those are obviously uneconomic because they cost more than another treatment giving the same or higher yield (Treatments 2, 5, 6, 12).[7] Yields from the remaining five treatments ranged from 1.6 t/ha for zero inputs to 2.9 t/ha with the highest level of inputs. The highest level of inputs was still modest, in keeping with the objective of examining farmers' levels of inputs in this experiment.

Calculations of costs and returns for the remaining treatments show that the highest yielding treatment (*16*) is also the most profitable. It gave P372/ha increase in net returns over the control, but Treatment 9 gave P310/ha and was much cheaper. There is relatively little difference in the profitability of Treatments 9 and 16, although the latter increases the yield almost twice as much. The cash cost of Treatment 16, which is a reflection of the possible loss faced by

[7] Changes in the prices of inputs or of rice would require new consideration of which treatments are uneconomic in this sense.

CHART 3.—YIELD RESPONSE TO NITROGEN UNDER FARMERS' CONDITIONS,
NUEVA ECIJA, THREE LOCATIONS, RAINFED, 1973

Yield (t /ha)
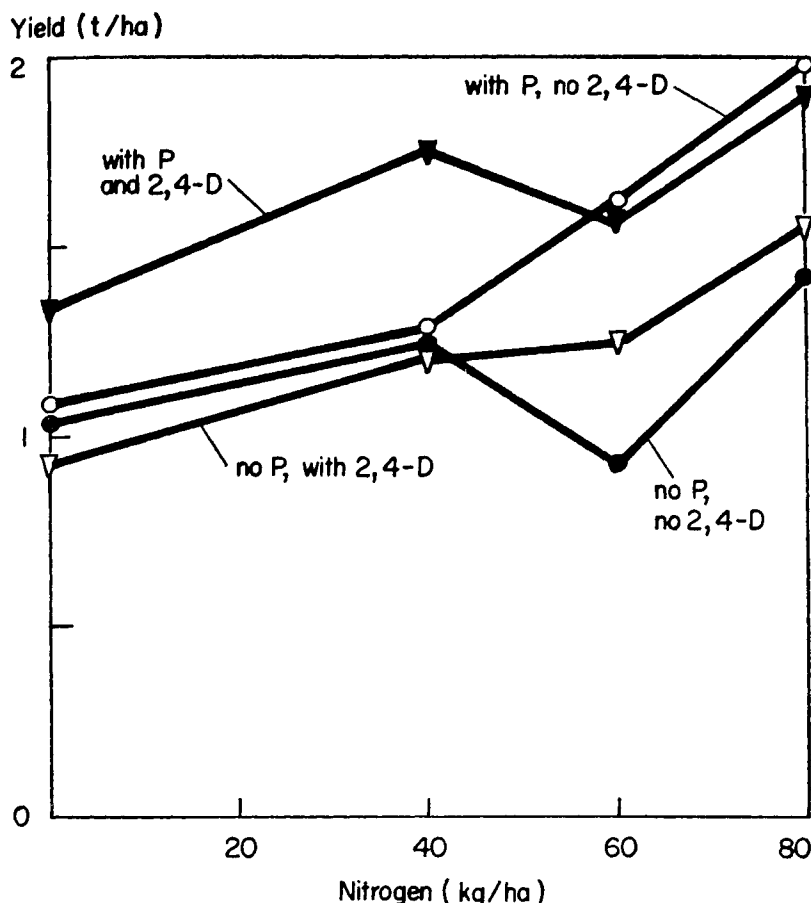
the farmer, is ten times as great as the cash cost of Treatment 9. The return per
unit of cash cost is ten times as great with Treatment 9 than with Treatment 16.
With these alternatives, a farmer might quite rationally choose Treatment 9
instead of 16.[8]

The same experiment carried out on rainfed fields gave similar results
(Chart 3). Some of the high input treatments again gave less output than lower
input levels leaving 11 treatments for analysis. Seven of those 11 are uneconomi-
cal because they either give a lower yield with a greater cost or they give the same
yield with a greater cost. The most profitable level of input use is again at the
highest yield, with 60 kg/ha of N, and 60 kg/ha of P_2O_5, and with chemical weed
control (Table 7). The rate of return, however, was highest at a lower input level
(Treatment 9).

A related dry season experiment with combinations of N, P_2O_5, and weed

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[8] There is relatively little difference in the results if they are recomputed at today's prices since
input and output prices have both increased.

TABLE 7.—INPUTS, YIELDS, AND NET RETURNS OF EXPERIMENTS ON RAINFED
FIELDS OF THREE FARMS IN NUEVA ECIJA, 1973

Treatment number	Inputs				Total yield (t/ha)	Increase over control		
	N (kg/ha)	P₂O₅	2,4–D	Cost (P/ha)		Yield	Net return (P/ha)	Net return per peso cost
1	0	0	no	0	1.0	—	—	—
2	40	0	no	60	1.2	0.2^b	b	—
3	60	0	no	90	0.9^a	−0.1	a	—
4	80	0	no	120	1.4	0.4^b	b	—
5	0	60	no	102	1.1	0.1^b	b	—
6	40	60	no	162	1.3	0.3^b	b	—
7	60	60	no	192	1.6	0.6^b	b	—
8	80	60	no	222	2.0	1.0	250	1.1
9	0	0	yes	20	1.4	0.4	169	8.5
10	40	0	yes	80	1.8	0.8	297	3.7
11	60	0	yes	110	1.6^a	0.6	a	—
12	80	0	yes	140	1.8^a	0.8	a	—
13	0	60	yes	122	1.4	0.4^b	b	—
14	40	60	yes	182	1.7	0.7^b	b	—
15	60	60	yes	212	2.1	1.1	307	1.4
16	80	60	yes	242	2.1^a	1.1	a	—

^{a} Treatment with higher input and the same or lower yield than some other treatment.
^{b} Treatment with higher cost and the same or lower yield than another treatment.

TABLE 8.—ECONOMICS OF A MULTI-FACTOR EXPERIMENT, GAPAN, NUEVA
ECIJA, DRY SEASON, IRRIGATED, 1972

Treatment number	Increases over farmers' treatments			Expected net returns per peso cash cost
	Cash costs (P/ha)	Expected net returns (P/ha)	Yield (t/ha)	
1 (farmers')	—	—	(3.9)^a	—
2	50	325	0.5	6.5
3	107	308	0.6	2.9
4	155	470	1.2	3.0

^{a} Yield of farmers' treatment.

control gave results shown in Table 8. There was no zero cash input level since
farmers' treatments (using N and weeding) were taken as the level of com-
parison. The best treatment yielded 1.2 t/ha more than the lowest yielding treat-
ment. The highest yielding treatment gave the best returns, but it was not much
more profitable than the somewhat lower input treatments. Treatment 2 gave
net returns of 6.5 per peso cash cost compared to 3 per peso cost for Treatment 4.

In a simple 1972 trial comparing only two improved management packages
with farmers' treatments, the highest yielding package consisted of additional
fertilizer and 2,4–D weed control that cost P170 more than the farmers' treatment
(Table 9). It resulted in an increase of P610/ha in net returns. The lower cost
input package was two-thirds as profitable, but cost only one-third as much and
gave a rate of return nearly three times greater.

TABLE 9.—ECONOMICS OF A MANAGEMENT PACKAGE TRIAL, GAPAN,
NUEVA ECIJA, WET SEASON, IRRIGATED, 1972

| Treatment number | Increase over the farmers' treatments | | | Expected net returns per peso cash cost |
	Cash costs (P/ha)	Expected net returns (P/ha)	Yield (t/ha)	
1 (farmers')	—	—	(3.2)[a]	—
2	50	450	0.7	9.0
3	170	610	1.3	3.6

[a] Yield of farmers' treatment.

TABLE 10.—ECONOMICS OF A MANAGEMENT PACKAGE TRIAL, GAPAN,
NUEVA ECIJA, RAINFED, 1972

| Treatment number | Increase over the control treatment | | | Expected net returns per peso cash cost |
	Cash costs (P/ha)	Expected net returns (P/ha)	Yield (t/ha)	
1 (control)	—	—	(2.1)[a]	—
2	106	143	0.6	1.3
3	209	137	0.8	0.7
4	296	102	0.9	0.3
5	422	100	1.2	0.2

[a] Yield of control plot.

All of the above experiments depended exclusively on farmers' pest-control techniques, which is one reason for their relatively low yields.

Two trials involving high levels of insect control as treatments in addition to fertilizer and weed control were also examined. A 1972 rainfed trial of five management packages resulted in yield increases over the lowest input packages ranging from 0.6 to 1.2 t/ha (Table 10). The maximum yield treatment cost P422/ha more than the control and gave net returns of P100/ha more. Maximum profit, however, was recorded with Treatment 2, which cost P106/ha more than the control, and resulted in P143/ha greater net returns than the control. It had the highest rate of return as well.

In 1973 a modification of this trial was conducted with three levels of insect and weed control and three levels of nitrogen. Yields were substantially higher than the other rainfed trials partly because high levels of P and K were used, and because the plots were located where moisture stress would not be a problem. A few input treatments resulting in uneconomic yields were automatically elimi-nated, leaving four treatment combinations for which costs and returns are com-puted (Table 11). The maximum profit occurs with Treatment 2, with a yield increase of 1.3 t/ha over the control. The maximum yield treatment (*4*) is less profitable than the low input one because the costs of the latter are much lower—only P70/ha compared to P363/ha. The rate of return on the low-input treatment is also considerably higher.

The economic analysis of all six experiments is summarized in Table 12. The increased profits and increased costs of the treatments with highest yield, highest

TABLE 11.—ECONOMICS OF A MANAGEMENT PACKAGE TRIAL, GAPAN,
NUEVA ECIJA, RAINFED, 1973

| Treatment number | Increase over the control treatment | | | Expected net returns per peso cash cost |
	Cash costs (P/ha)	Expected net returns (P/ha)	Yield (t/ha)	
1 (control)	—	—	(1.9)[a]	—
2	70	620	1.3	8.9
3	330	521	1.6	1.6
4	363	600	1.8	1.6

[a] Yield of control plot.

TABLE 12.—INCREASES IN EXPECTED NET RETURN AND COSTS OF CASH INPUTS OF
THREE TREATMENT LEVELS COMPARED TO CONTROL LEVELS IN SIX MULTI-
FACTOR EXPERIMENTS IN CENTRAL LUZON, 1972 AND 1973
(Pesos per hectare)

| Regime[a] | At maximum yield | | At maximum net returns | | At maximum returns per peso cash cost | |
	Net returns	Cash costs	Net returns	Cash costs	Net returns	Cash costs
IGW	400	212	400	212	360	20
RF	300	235	300	235	300	235
IGD	470	155	470	155	325	50
IGW	610	170	610	170	450	50
RF	100	422	143	106	143	106
RF	600	363	620	70	620	70
Average	413	259	423	158	366	88

[a] RF indicates rainfed; IGW, irrigated wet season; and IGD, irrigated dry season.

net returns, and highest returns per peso cash cost compared to their respective control plots are shown. In four of the six trials the maximum yield treatment was also the maximum profit treatment. In the other two, a lower-yielding treatment gave higher profits. The maximum yield plots average 1.2 t/ha higher yields than the control plots while the maximum profit plots average 1.1 t/ha more than the control. The plots with the maximum returns per peso cash cost averaged 0.7 t/ha more yield than the control plots. Moreover, the high-rate-of-return plots were 85 percent as profitable as the maximum profit plots, while the latter required almost twice the cash input. The maximum yield plots gave the lowest rate of return, giving P1.6 per peso invested, while the maximum profit plots averaged 2.7 and the high-return-per-peso-cash plots gave 4.2

One may summarize the pattern that emerges from these experiments as follows:

1. In an experiment designed to obtain maximum possible yield, the treatment giving that yield may not give the maximum net return.
2. The most profitable treatment will often be achieved at modest input levels and a somewhat lower yield—say 25 to 30 percent—than the maximum yield treatment.

3. A low level of input use will, under most circumstances, be nearly as profitable as the maximum profit treatment and may give a higher rate of return. It will usually require considerably less cash investment, but may increase yields over the zero input level only half as much as would the maximum yield treatment.

Given this general pattern, we will venture the guess that for economic reasons farmers' yields are 25 percent less than the previously defined attainable maximum of 4.2 t/ha. If this assumption is accepted, the economically attainable average yield using modern varieties, with existing water control, seasonal distribution of production, and normal weather variation, is about 3.1 t/ha, leaving an unexplained gap of 1.3 t/ha between actual and attainable yield.
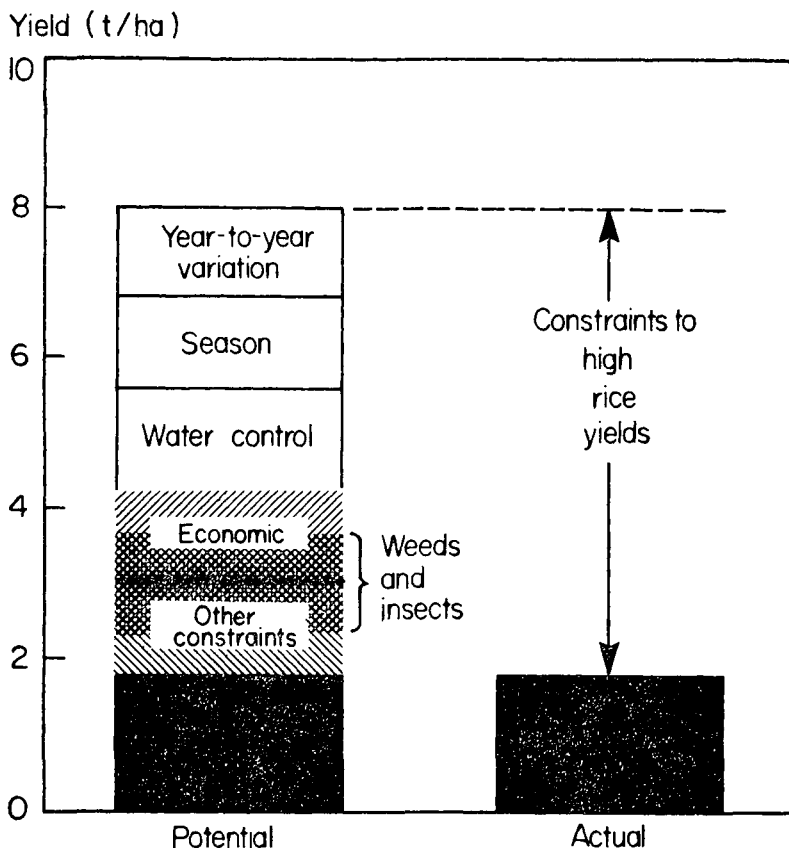
Other Constraints

This final difference between the economically attainable national average yield and the reported actual yield in the Philippines can be attributed to yield losses due to pests and diseases that could be economically prevented, response bias, poorer soils than represented in the experiments, unavailability of inputs, economically irrational unwillingness to use available inputs, and to the fact that 40 percent or so of the rice area is still planted with lower-yielding traditional varieties. Lack of insect and weed control by farmers probably represents the major portion of the final difference. In experiments, insect control can contribute 1.5 t/ha additional yield and weed control as much more. Part of the reason for non-control is, of course, economic. It is likely that present levels of control are far below the economic optimum, but the levels of control used in experiments probably exceed the economic optimum. Perhaps a total of 1.5 t/ha higher yield could be economically obtained from both practices in the Philippines. It is impossible to defend very vigorously the breakdown among factors, but it is a beginning toward identifying the factors keeping yields low.

SUMMARY AND CONCLUSIONS

In this analysis the major factors which appear to be keeping Philippine national rice yields more than 6 t/ha below demonstrated levels have been analyzed. The results are summarized in Chart 4. Lack of control over water is the single biggest yield constraint. If all rice was fully irrigated, yields might average 5.6 t/ha. Because much rice is rainfed or upland, and because much of the irrigated area suffers moisture stress during part of the growing season, lack of water control reduces the attainable yield by 1.4 t/ha. This factor is responsible for 23 percent of the difference between maximum possible and actual yields. Available solar radiation and other factors associated with season account for another 1.2 t/ha or 19 percent of the difference. Lack of irrigation is indirectly responsible for a portion of this "season" effect also, because with more irrigation capacity a greater proportion of the crop would be grown in the dry season. Economic factors including risk account for about 1 t/ha or 17 percent of the difference. Other constraints accounting for the difference between maximum possible and actual yields are combinations of factors, including year-to-year variability in weather and damage by pests and diseases (1.2 t/ha or 19 percent), and a residual including

CHART 4.—A PRELIMINARY IDENTIFICATION OF FACTORS CONSTRAINING
RICE YIELDS IN THE PHILIPPINES

Yield (t / ha)

the lack of availability of inputs and non-adoption of new technology (22 per-
cent). Part of these constraints could be overcome through the use of practices
that are economical, but to which farmers may not have access.

It should be recognized that many of these constraints can be reduced by ap-
propriate investment, research, or policy actions. Investments in the construction
of irrigation and drainage systems, and modification of their management, can
alleviate the constraints imposed by poor water control. Policy measures to insure
favorable prices and to make credit available may ease the economic constraints.
Research to develop varieties with a higher degree of resistance to unfavorable
environmental conditions will result in less year-to-year variability. Properly
focused research may develop some rice genotypes resistant to drought, some that
produce high yields under deep water, some that give higher yields under the low
radiation monsoon season, and even some that, with the aid of microbes, produce
a greater proportion of the nitrogen they require for high yields. Extension ac-
tivities aimed at teaching farmers about available technology and steps to improve
the distribution of inputs would make more inputs usable on farms. The ability
to manipulate most of the constraints exists, provided that those responsible for
policy, research, and extension seize the opportunity.

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