RESPONSE OF UPLAND RICE TO NITROGEN AND SUPPLEMENTAL IRRIGATION APPLIED AS A CONTINUOUS WATER VARIABLE[1] */

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Resumen

Se estudió la respuesta de arroz secano al riego suplemental y a la fertilización nitrogenada durante las estaciones lluviosas de 1974 y 1976 en el noroeste de El Salvador. La lluvia fue abundante y bien distribuida para la producción de arroz en el primer año del estudio. Se cosecharon más de 6 500 kg/ha del grano de parcelas tratadas con 90 ó 120 kg/ha de N. Sin embargo, se registró un acame de 23% en los lotes donde el nivel de N aplicada fue 120 kg/ha. La distribución de lluvia fue irregular durante la estación de 1976. Los rendimientos tendían a aumentarse con cantidades crecientes de N y agua aplicada, pero se observó una interacción significativa en la respuesta del arroz a las dos variables. La producción de arroz fue de aproximadamente 6 000 kg/ha donde se aplicaron las cantidades máximas de N y riego suplemental en el segundo año del estudio.

El agua se aplicó como una variable continua de riego, por el uso de un solo aspersor ubicado en el centro de cada repetición. De una área relativamente pequeña, se recogió gran cantidad de datos. Los recursos necesarios para llevar a cabo el estudio fueron mínimos. Los resultados del ensayo de arroz de 1976 demostraron bien el valor de riego suplemental en una estación lluviosa caracterizado por precipitación irregular.

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Introduction

Prior to 1971, much of the rice produced in El Salvador was exported. Greater profits were obtained for grain sold abroad rather than locally. Legislation to prevent the exportation of rice was enacted in an attempt to increase the supply of rice within the country. However, the number of hectares of land utilized for rice culture sharply declined as a result of the new law. Production decreased by more than 40% between 1971 and 1974. A subsequent priority of the Ministry of Agriculture was to encourage more extensive land use for cultivation of rice as well as increased unit productivity through improved agricultural technology (2, 3). Irrigation has been cited as a means of achieving both of these goals.

Temperatures of El Salvador are conductive to crop growth throughout the year. The climate is characterized by alternating periods of abundant rainfall and extreme drought that last for approximately six months. Upland rice is extensively cultivated during the rainy season in some areas of the country. Production gains that can be made through installation of irrigation systems to permit land use in the dry season are well appreciated. The additional benefit of irrigation to supplement rainfall in the rainy season has received little attention in El Salvador, although yields for rice and other crops are often reduced due to droughts which sometimes occur during this period.

Crop management is altered appreciably with the inclusion of irrigation into production systems. A profound interaction exists between soil moisture and fertility which is reflected in crop yields. Unless these factors are studied simultaneously, optimum levels of either factor cannot be defined. Management of nitrogen fertilizer requires special attention because, under upland conditions, inorganic soil N converts rapidly to the nitrate form and can be leached from the root zone with irrigation.

Irrigation studies require large areas and intensive labor in order to maintain precise water control. Treatments must be separated by wide borders to avoid movement of soil moisture from wet to dry plots. The amount of data generated for the development of crop response curves to applied water is usually less than that of field tests of equal area and management intensity designed to measure the influence of most other farm practices. Agricultural researchers of El Salvador, as in other countries, are often restricted in their use of improved technology by limited resources, including land, labor and time.

Fox (6) described the response of sweet corn to nitrogen fertilizer using a continuous function experimental design. Nitrogen was increased from 0 to a maximum of 240 kg/ha in 5.5 kg/ha increments from plant to plant along the row. Corn harvested from each plant was treated as an individual observation with rows analyzed as replications. According to Fox, response curves obtained through a design of this nature can be plotted with confidence due to the large number of samples involved. Border effects can be ignored for certain crops if the unit increase of the variable studied is small in relation to the overall range. Fox emphasized that the area and labor required to conduct the experiment was greatly reduced from that normally utilized to obtain the same information using standard field plot techniques.

Bauder *et al* (1) used a continuous variable design involving both irrigation and nitrogen to develop production functions for dry weight yield of corn. A soil moisture gradient was established through regulation of trickle lines for adjacent rows. Nitrogen fertilizer in sequential and progressively increased amounts was applied at right angles to the water variable. Results were compared to data obtained according to a split plot design which considered distinct levels of nitrogen and irrigation. Analyses of both experiments led to the same conclusions. The area necessary to conduct the split plot tests was four or five times greater than the plot space used for the continuous variable design.

Trickle systems are expensive and require considerable labor to operate. Hanks *et al* (7) utilized a single line of closely spaced sprinklers to create a continuous water variable. Progressively less water was measured with increased distance at right angles from either side of the line. Dry matter and grain yield for corn were related to evapotranspiration as influenced by irrigation from the sprinkler system. The authors concluded that the line source sprinkler method as described appeared to be a reliable and convenient method for developing crop yield functions. Wind distortion of the sprinkler discharge pattern was noted as a principal limitation of the system.

Problems associated with continuous variable designs including statistical analysis and deviation from conventional field plot methods have been discussed by several researchers (1, 6, 7, 8). Hanks *et al.* (8) state that statistical analyses for the effect of continuum irrigation levels on yield are not available due to the lack of randomization, but that valid error terms are possible for the interaction of irrigation with other variables if these treatments are randomized within the test. Since irrigation effects are usually large, assignment of a probability level for this factor may not be critical. They propose a design similar to the split-block arrangement for the line-source sprinkler method. The method is not recommended in tests where irrigation differences are expected to be small.

The purpose of this study was to determine rainy season yield estimates for upland rice according to nitrogen fertilizer levels and supplemental irrigation applied as a continuous water variable. The convenience with which information of this nature could be obtained utilizing sprinklers in a manner similar to that reported by Hanks *et al* (7) was of principal concern.

Materials and methods

The study was conducted on the Agricultural Demonstration Farm of the Atiocoyo Irrigation District in northwestern El Salvador. Elevation of the test site is 270 m above sea level. Average annual temperature and relative humidity of the region are 25°C and 63%, respectively. Rainfall is measured at about 1.5 m annually with 90% or more occurring from May through October (4). Soil of the test area to a depth of 40 to 50 cm is classified as a Chalatenango silt loam and is underlain by a 10 to 15 cm layer of coarse sand. A heavy clay lies below the sandy layer. Analyses carried out by laboratories of the Instituto de Ciencia y Tecnología Agrícolas (ICTA), Guatemala, for samples collected from the 0-40 cm portion of the horizon, showed the soil to contain adequate amounts of both phosphorous and potassium for the production of rice. A pH Of 7.0 was recorded.

Field tests were established during the 1974 and 1976 rainy seasons. X-10 variety rice was planted at a rate of 130 kg/ha on June 4 and June 17 of 1974 and 1976, respectively. The rice was seeded in circular rows of progressively greater circumference. The first row was one m from the center of the area with subsequent rows occurring at 30 cm intervals to a radius of 15.5 m. There were three replications.

Each replication was divided into six equal parts which increased in width from the center of the circle to the outermost row according to a 60°C angle for nitrogen treatments. Plots for nitrogen were separated by one m borders. Nitrogen in the form of ammonium sulfate was broadcast uniformly over the plot. Treatments consisted of 30, 60, 90, 120 and 150 kg/ha of N divided in three equal amounts and applied at approximately 25, 50 and 75 days following emergence. Control plots (no nitrogen) were also included. The pattern of nitrogen randomization was fixed for the three replications, but rotated 120°C from one to the next in an attempt to offset wind effects on the water distribution pattern. Plot size was 91.3 m^2 for N treatments.

Supplemental irrigation was applied as a continuous water variable by positioning a sprinkler in the center of each replication. Rainbird model No. 30 sprinklers with 3/16 inch range by 1/8 inch (20°C) spreader nozzles were utilized for the tests. Sprinkler application depths were measured during each irrigation with cups spaced at 90 cm intervals from the center to the outer edge of the replication in the borders between nitrogen plots. Water distribution profiles were developed. Values of the profiles on both sides of the nitrogen plots were averaged and irrigation depths assigned to each row.

Water application was greatest approximately five m from the center of each replication. Soil moisture was maintained at or near field capacity in these areas of the plots until a week before harvest. Tensiometers installed to depths of 15, 30 and 45 cm in the zone where maximum water was applied in each replication were utilized as guides to initiate irrigation following periods of limited rainfall. Depending on the availability of irrigation water, subsequent applications during these periods were arbitrarily scheduled at two-day intervals until significant rainfall occurred.

Harvests were initiated 133 days after planting for both the 1974 and 1976 tests. Starting four m from the center of the replication, 36 rows were individually harvested along the water gradient within each nitrogen plot. Yields were converted to g/m of rough rice at 14% seed moisture for statistical analysis and treated as split-block experiments. Nitrogen levels were considered as whole plots with distance from the water source (to reflect irrigation effect) as non-randomized strip treatments across the N plots. Plant height and % lodging data were obtained immediately prior to harvest. Response to nitrogen as reflected by these observations was analyzed as a randomized complete block design which ignored the water gradient for the 1974 data. Plant height and % lodging measurements for the 1976 test were limited to areas of the plots that received maximum irrigation.

Potential evapotranspiration (ETP) was calculated from climatic data collected at the experimental site according to the Hargreaves and Christiansen equation (9). Crop coefficient values (kc) used for estimation of actual evapotranspiration (ETA) of rice were taken from those listed for wet season, humid South America by Doorenbos and Pruitt (5).

Results and discussion

The field arrangement used for the development of a continuous water variable with individual or widely separated sprinklers and circular plots is illustrated in Fig. 1. The relationship between accumulated irrigation depth and distance from the sprinkler measured during the 1974 and 1976 rice tests are presented in Fig. 2.

Total rainfall was 25 to 50 cm in excess of the calculated ETA for rice both years of the study (Table 1). Natural precipitation was uniformly distributed throughout the 1974 test. Irrigation was terminated early several times due to the initiation of rainfall. The maximum accumulated depth of applied water was 7.7 cm. In contrast, the 1976 rainy season was characterized by erratic rainfall distribu-

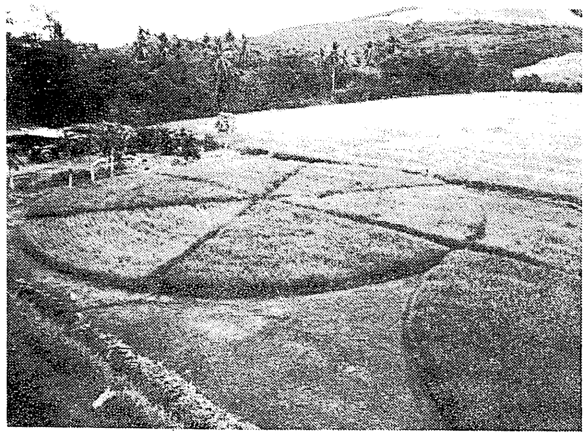

Fig. 1. View of rice plots with sprinkler in the center or a replication for development of the irrigation variable. The six plot divisions represent different nitrogen levels.

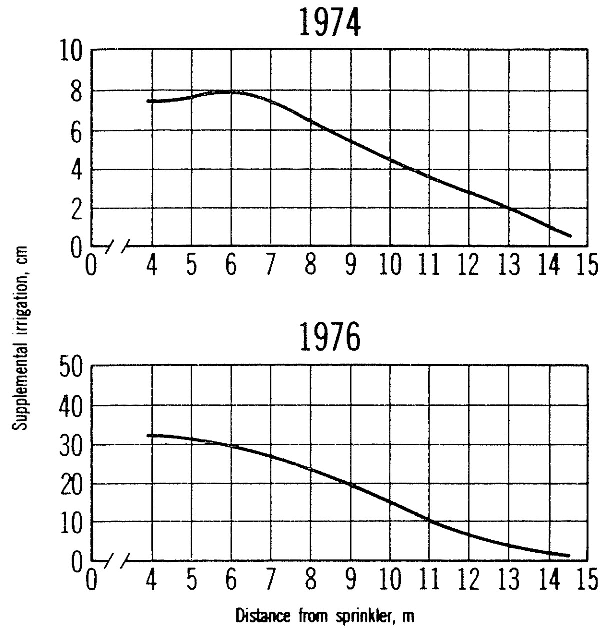

Fig. 2. Accumulated depth of supplemental irrigation applied as a continuous water variable for the 1974 and 1976 rainy seasons.

tion. The rice was irrigated on 14 occasions. The average total depth of sprinkler irrigation in the area of the plots of maximum application was 32.5 cm. Rainfall and maximum depth of supplemental irrigation for the 1976 season are presented on a daily basis in Table 2.

A response to nitrogen was recorded both years of the study. Increases in plant height were measured where greater amounts of nitrogen had been applied both rainy seasons (Table 3). Percent lodging followed a trend similar to that of plant height for the 1974 test. No lodging occurred in control plots as compared to 36% where 150 kg/ha was used. Lodging was not observed during the 1976 test. Rice yields were higher in 1974 than in 1976. An equivalent of more than 6 500 kg/ha of grain was harvested from plots where 90 or 120 kg/ha of nitrogen had been applied in 1974. Maximum yields were about 4 400 kg/ha for the 1976 test as main plot averages.

Supplemental irrigation decreased sequentially with increased distance from the center of each replication. A relationship between rice yield and accumulated irrigation depth was not found the first year of the study. However, statistical dif-

Table 1. Irrigation, rainfall and estimated water requirement for X–10 rice of the 1974 and 1976 rainy seasons.

Rainy season	No. of irrigations	Ave. depth applied/ irrigation[1] (mm)	Total depth applied[1] (cm)	Accumulated rainfall (cm)
1974	9	8.6	7.7	115.8
1976	14	23.2	32.5	100.6
	Irrigation plus rainfall		Estimated requirement	
	Per day basis (mm)	Season (cm)	Daily (mm)	Season (cm)
1974	9.0	123.5	4.6	63.5
1976	9.6	133.1	5.4	75.0

1 Represents maximum depth of the continuous water variable.

Table 2. Average maximum depth of supplemental irrigation and rainfall in millimeters measured during the 1976 rice test. Parentheses indicate applied water.

Day	June	July	Month Aug.	Sept.	Oct.
1	0.1	–	5.1	–	(22.0)
2	8.6	25.1	–	9.9	15.0
3	0.7	5.0	(22.8)	4.3	19.0
4	4.0	–	–	13.4	–
5	38.3	39.2	28.3	8.2	–
6	18.6	8.8	1.4	–	9.9
7	5.1	1.0	6.0	–	23.8
8	39.8	0.8	9.4	11.2	18.5
9	54.2	8.0	–	–	–
10	38.0	7.4	(23.8)	–	1.4
11	13.2	–	4.3	–	–
12	18.2	–	4.5	0.5	–
13	81.4	0.2	(27.6)	(24.2)	–
14	–	–	6.5	–	(23.1)
15	1.8	23.3	28.3	20.4	–
16	4.5	–	–	–	(22.8)**
17	21.2*	–	29.2	(25.2)**	–
18	0.2	–	28.9	–	(29.7)**
19	26.3	–	9.7	–	–
20	–	–	–	(21.9)	0.3
21	0.7	(22.7)	33.3	–	(5.1)
22	0.2	–	36.4	(25.3)	–
23	41.1	(33.2)	104.4	16.5	–
24	17.5	–	–	9.2	–
25	32.9	–	–	40.6	–
26	–	16.8	4.6	15.5	16.8
27	2.5	12.6	–	0.2	–*
28	9.4	–	0.5	0.9	10.8
29	36.6	36.0	0.2	0.9	–
30	10.3	0.7	19.6	0.4	–
31	–	–	1.2	–	–

* Plots were seeded on June 17; harvest was initiated on October 27.

** Depths listed for September 17, October 16 and October 18 include 1.0, 0.3 and 0.4 mm of rainfall, respectively

ferences in the amount of grain harvested according to distance from the water source as well as a distance/nitrogen interaction were determined through analysis of the 1976 data (Table 4). Yield data plotted as a function of accumulated irrigation depths for the season and nitrogen levels are illustrated in Fig 3 The regression model developed to describe the yield response is a follows:

$Y = -6.13 + 4.94\,I + 1.02\,N - 0.11\,I^2 - 0.0049\,N^2 + 0.0198\,NI$ where Y = yield in g/m; I = accumulated irrigation depth in cm; N = applied nitrogen in kg/ha; $R^2 = 0.77$.

The response curves generally demonstrate uniform production increases with corresponding increases in depth of applied water for all nitrogen levels. For example, yields (g/m x 33.33 = kg/ha) of the 150 kg/ha N treatment increased from approximately 1 500 kg/ha for rice with the minimal amount of supplemental irrigation to about 6 000 kg/ha at irrigation depths more than 30 cm.

Table 3. Plant height, % lodging and yield of X–10 rice according to nitrogen treatments for the 1974 and 1976 rainy seasons[1].

	Rainy season	Nitrogen treatments (kg/ha)					
		Control	30	60	90	120	150
Plant height (cm)	1974	71 c[2]	83 b	93 a	92 a	96 a	97 a
	1976	69 d	78 c	85 b	94 a	97 a	99 a
% Lodging	1974	0 c	3 bc	13 bc	15 bc	23 ab	36 a
	1976	0	0	0	0	0	0
Yield (kg/ha)	1974	4673 b	6301 a	6408 a	6585 a	6893 a	6108 a
	1976	1328 b	2122 b	3278 a	4207 a	4406 a	4353 a

1 Means of the 1976 test for plant height and % lodging represent data obtained at maximum irrigation depths of the water gradient

2 Means followed by different letters are significantly different at the 5 % level of probability according to Duncan's multiple range test.

Table 4. Analyses of variance for yield of X–10 rice according to nitrogen treatments and distance from the sprinkler as a reflection of supplemental irrigation depth for the 1974 and 1976 rainy seasons.

Souce of variation	Degrees of freedom	Mean square	
		1974	1976
Replications	2	–	–
Nitrogen (N)	5	58 576 19*	163 958 75*
Error a	10	5 389.11	12 459 09
Distance (D)	35	2 275 87	15 713 25**
Error b	70	1 705 70	692 48
N x D	175	1 382 09	670.20*
Error c	350	1 704 01	259.01
Total	647	–	–

* Significance at the 5% level of probability, or less

\+ Non-randomized treatment

Grain harvested from plots which received 150 kg/ha of nitrogen was less than that obtained with 90 to 120 kg/ha of N where supplemental irrigation rates were low. This trend was reversed, however, for that portion of the irrigation gradient of maximum water depth. The response curves suggest that irrigation totals greater than 32.5 cm would not have resulted in higher yields for the 0 to 90 kg/ha nitrogen range and only slight increases in the 120 to 150 kg/ha N range.

Robins *et al.* (10) have reviewed the work of several investigators concerning the sensitivity of rice to drought stress. While abundant soil moisture is necessary throughout the growing season to assure maximum production, yield reductions are relatively more severe if moisture is limited during seedling establishment, tillering or a period extending from

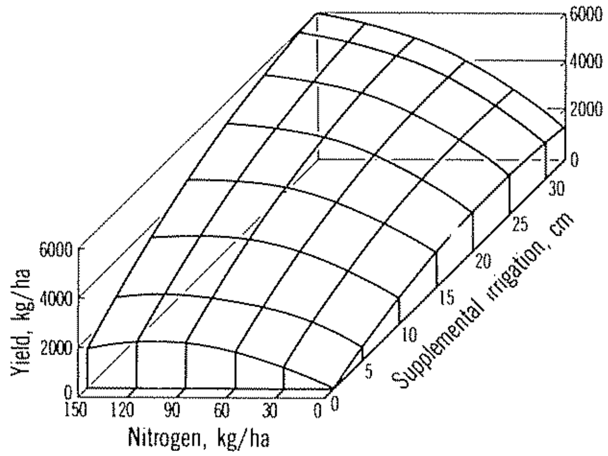

Fig. 3. Rice yield as influenced by nitrogen treatments and accumulated depth of supplemental irrigation for the 1976 rainy season.

about 20 days prior to heading until five days afterwards. Depressed yields may also result from moisture stress as rice approaches maturity.

Rainfall was abundant prior to and following seeding accomplished on June 17 for the 1976 test (Table 2). Tillering was in progress from approximately July 5 until August 5. Irrigation was applied on three occasions during this period. The development stage of critical moisture need associated with heading extended from late August through early October. Water was applied on four dates for an accumulated depth of 95.6 mm in September. The rice was irrigated five times between heading and the initiation of harvest.

Yield increases corresponding to greater amounts of supplemental irrigation for the 1976 rice test were based on seasonal depths of applied water (Fig. 3). However, water distribution profiles for each irrigation date were highly similar in form to that representing the seasonal total. Increases in rice yield resulting from increasing amounts of applied water as demonstrated in Fig. 3 could have been related equally well to any of the individual irrigations.

Moisture stress of sufficient magnitude to limit yields may have developed on occasion in areas of maximum irrigation between water applications and/or rainfall under the criterion utilized for irrigation scheduling. Yield reductions would be more pronounced at all points along the water variable if stress of this nature was present during periods of critical moisture need by rice as described above. Hanks *et al.* (7) have pointed out that all irrigation must be added at the same frequency to any given plot when using sprinklers to apply the continuous water variable, a disadvantage of the system.

In the interest of conserving space as well as other resources, a modified version of the line source sprinkler method (7) was utilized for the rice work presented here. Designs of this nature are characterized by small sampling units. Rows were harvested individually within each nitrogen plot and treated as sample observations, requiring considerable time.

Length of row harvested ranged from around eight m at distances farthest from the sprinkler, where grain production was extremely sparse in the 1976 test, to as little as one m for the row nearest the sprinkler. Shorter row lengths approaching the sprinkler decreased the time necessary for harvest, but probably increased variability in the sample. However, plant vigor and grain production along the rows were obviously more uniform as moisture conditions improved with less distance to the water source the second year of the study. Harvesting greater row lengths as grain production became more limited due to moisture stress contributed to the consistency of the data in 1976.

Irrigation was delayed on occasion to avoid or reduce the influence of wind on water distribution. Nitrogen plots were rotated from one replication to the next in an attempt to offset wind effects. Wind distortion of the sprinkler pattern was minor in this study. Error introduced by a prevailing wind could probably be accounted for statistically in field tests of this type involving equal numbers or whole plot treatments and replications. For example, arrangement of whole plots to insure that each treatment occurred in all possible areas of the replications should permit consideration of position effect.

A large amount of data was generated from a relatively small area for the rice tests. A minimum of power and irrigation equipment was required to conduct the study. Harvest of the plots was time-consuming, but the large number of observations permitted the development of clearly defined response curves. Response to both water and nitrogen by the rice was highly visible in the field during the latter part of the 1976 rainy season.

Conclusions

X–10 rice is commercially produced in El Salvador as an upland crop and by flood irrigation. According to information obtained through regional trials primarily with flood irrigation, yields should range from 6 500 to 7 800 kg/ha (11). Production at maximum supplemental irrigation rates for this study approximated the lower limit of this range, but should provide a reasonable estimate of yields that can be attained by farmers operating under similar conditions of moisture and soils to those of the Atiocoyo district.

Further research should be conducted on nitrogen utilization and water management to substantiate the results of this report. Yields could probably be increased significantly with a minimum of lodging using around 90 kg/ha of nitrogen under favorable moisture conditions by improving the timing of the split application in relation to plant development. The value of supplemental irrigation in a wet season characterized by uneven rainfall distribution was well demonstrated by results of the 1976 test.

The use of sprinklers to impose a continuous water variable from a point source was found to be a convenient research technique for the study of water and nitrogen effects on rice. Although application of standard statistical analysis to obtain an error term for the irrigation component is questionable, yield response curves for the water/nitrogen variables the second year of the study were considered reliable due to the obvious differences between treatments visible in the field and the large number of observations used for development of the regression model. Methods of this type appear to be highly practical for establishing limits for more intensive research and for extension demonstration purposes.

Summary

The response of upland rice to nitrogen fertilizer and supplemental irrigation was studied during the 1974 and 1976 rainy seasons in northwestern El Salvador. Rainfall was abundant and well distributed for rice production the first year of the study. More than 6 500 kg/ha of grain was harvested from plots treated with 90 or 120 kg/ha of N. However, lodging was recorded at 23% for the 120 kg/ha N level. Rainfall distribution was erratic during the 1976 test. Yields tended to increase with increased amounts of both N and applied water, although a significant interaction was found for response to these variables. Rice production was measured at approximately 6 000 kg/ha where maximum amounts of N and supplemental irrigation had been applied the second year of the study.

Water was applied as a continuous irrigation variable from a single sprinkler in each replication. A large amount of data was generated from a relatively small area. Minimal resources were required to conduct the study. The value of supplemental irrigation in a wet season characterized by uneven rainfall distribution was well demonstrated by results of the 1976 rice test.

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