AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AF25-0000-0000

B. SECONDARY: Soil fertility,fertilizers,and plant nutrition

2. TITLE AND SUBTITLE

High-yielding cereals and fertilizer demand

3. AUTHOR(S)

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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1970	23p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

TVA

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

(In NFDC bul.Y-4)

9. ABSTRACT

10. CONTROL NUMBER

PN-RAA- 195

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Cereals
Estimates
High-yield-varieties

13. PROJECT NUMBER

14. CONTRACT NUMBER

PASA TA (QA) 6-69 GTS

15. TYPE OF DOCUMENT

AID 890-1 (4-74)

High-Yielding Cereals and Fertilizer Demand

1970

TENNESSEE VALLEY

Prepared for the

AGENCY FOR INTERNATIONAL DEVELOPMENT

By

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HIGH-YIELDING CEREALS AND FERTILIZER DEMAND

SUMMARY

Yield responses to fertilizer are reviewed for high-yielding and native varieties of rice, wheat, maize, and grain sorghum. Universally, these cereals respond to nitrogen but less frequently to phosphorus and potassium. Generalized yield curves were computed for the response of high-yielding and native varieties of rice, wheat, maize, and grain sorghum to nitrogen but not to phosphorus or potassium because of the scarcity of data. The curves define no specific response of either type of variety for any country but are examples of expected relative responses between high-yielding and native varieties.

Optimum rates of nitrogen fertilization for high-yielding varieties of rice and wheat are about 3 times greater than for native varieties. This difference is less with maize and grain sorghum. Yields at optimum levels of nitrogen fertilization are 1.5 to 2 times greater with high-yielding than native varieties. The monetary return to optimum fertilization of high-yielding varieties is about 1.5 times greater than for native varieties because of the greater marginal yield for initial increments of applied nitrogen. Thus, acceptance of high-yielding varieties satisfies the farmer's goal of maximum income as well as a country's goal of maximum production.

The relative fertilizer requirement to produce a given quantity of grain from high-yielding and native varieties is determined by the amount of substitution of fertilizer for land. More grain may be produced with less fertilizer and less land with high-yielding than native varieties. But, as more fertilizer is substituted for land and rates of fertilization approach optimum levels for high-yielding varieties, the fertilizer requirement to produce a given quantity of grain becomes greater with high-yielding than native varieties.

INTRODUCTION

Green revolution, miracle grain, breakthrough in agriculture, whatever descriptive words are most appropriate, the new, high-yielding cereals are having an impact on agriculture in the less developed countries. So much impact, in fact, that those who dolefully predicted famine now are discussing feast and surplus. Hopefully, production of rice, wheat, maize, and sorghum can be increased so that famine does not threaten, yet controlled so that unmanageable surpluses do not result.

It is the control aspects that now are becoming of concern. The new cereal varieties appear to respond so dramatically to fertilizers that excess production is a distinct possibility. The difficulty arises in assessing the magnitude of the response that can be expected and in devising measures to control the introduction and adoption of the new varieties. Information that might be useful in developing guidelines has been widely scattered. No information seems to have been developed specifically for the purpose of guiding national planners.[1]

OBJECTIVES OF THE STUDY

The principal objective of the study is to determine the effect of high-yielding varieties of rice, wheat, maize, and sorghum on fertilizer requirements for cereal production. This broad objective is subdivided into three more specific components:

1. If a specified quantity of each cereal grain is to be produced by the use of fertilizer, how much fertilizer would be required for native varieties and for high-yielding varieties?
2. If a specified area is to be planted to each cereal and fertilized at the optimum rate, how much fertilizer would be required for high-yielding vs native varieties?
3. If a specified quantity of cereal grains is to be produced, what would be the proportion of rice to wheat to maize to sorghum considering both high-yielding and native varieties, what would be the optimum rates of fertilization, and how much fertilizer would be needed?

The purpose of this study is related to the efficiency with which cereals use fertilizers rather than the efficiency of fertilizers *per se*. Therefore, detailed discussions of time and method of application and of type of fertilizer are not presented. Neither are the effects of water control, weed control, timeliness of planting and harvesting, or a host of other factors on the yield considered. The data used in constructing fertilizer response curves were obtained by researchers who provided the best management possible. In general, it can be assumed that deviations from top management will decrease yields and reduce the response to fertilizers.

Response to nitrogen fertilization is considered before response to phosphorus and potassium. All four cereals are more likely to respond to nitrogen than to phosphorus or potassium and the responses generally are more pronounced. This in no way negates the need for

[1] Implications of new varieties were considered in AID's 1969 Spring Program Review. This information was available to the authors, but generally is not available to national planners.

phosphorus and potassium and such needs are considered near the close of the paper.

RICE RESPONSE TO NITROGEN

Rice varieties differ widely in their potential to respond to high fertility conditions (14). The traditional *Indica* varieties generally do not respond well to added fertilizer. These varieties are tall, weak-stemmed, late-maturing, sensitive to photoperiod, heavy-tillering, and droopy-leafed; they lodge readily (8, 26, 27). When subjected to improved management practices, they respond slightly (41). When fertilized with nitrogen, they show vigorous vegetative growth and marked increase in tillering. This high growth rate in early growth stages produces crowding and heavy competition. Serious mutual shading sets in and lodging results (8) Grain yields are increased only slightly at low rates of fertilizer application and usually are decreased at high rates.

Attempts to improve these native varieties through selection and breeding programs had only limited success in the tropics until introduction of a dwarf gene into the pedigree. This work, mostly by the International Rice Research Institute, resulted in dwarf and semi-dwarf varieties with stiff stems, erect leaves, early maturity, low sensitivity to photoperiod, and a high resistance to lodging. These varieties respond well to high rates of fertilization (8).

Most data suggest that varieties and selections with an improved plant type will outyield a tall, leafy, traditional variety at a given management and at any level of applied nitrogen (15). Yields of the improved varieties tend to be higher even with no nitrogen applied, particularly in the wet season when lodging generally is more severe due to the lower light intensity which causes taller plants.

Dry season yields of both types of varieties tend to be higher than those in the wet season (3). Experiments indicate that with adequate irrigation dry season yields should exceed wet season yields by 25 to 50%. This is due to the close correlation between increased yield and light intensity (16, 34).

Returning to the response of rice varieties to nitrogen fertilization, it can be noted in tables A1 and A2 (in the Appendix) that data were obtained from experiments conducted under a variety of conditions in several countries. In all cases, however, the data were included only when one or more high-yielding varieties were compared to one or more native varieties in the same experiment. Due to the way in which the tables have been prepared here, this criterion is not readily noted. Generalized yield response curves for high-yielding and native varieties in dry and wet seasons were determined by multiple regression. Because the data are so variable among experiments, only a small amount of the variation is explained by curves fitted to the simplest quadratic equation, i.e., $y = a + b_1x - b_2x^2$. No doubt better fit could be obtained by introducing variables such as variety, year, and country. However, for the purposes of this study the simple quadratic sufficiently describes the response function. Tables A1 and A2 show that the predicted yields are very close to the arithmetic means at various rates of applied nitrogen.

Figures 1 and 2 show the generalized yield response to nitrogen for native vs high-yielding varieties by season. The optimum rate for nitrogen appears to be about 120 kg/ha for the improved, high-response varieties. This may be somewhat low, particularly for the dry season, for the better of the improved varieties, such as IR-8, which has yielded in excess of 10 ton/ha in some experiments. However, the average yield response tends to be reduced by the inclusion of data from varieties that do not have the yield potential or lodging resistance of IR-8, particularly at very high nitrogen levels.

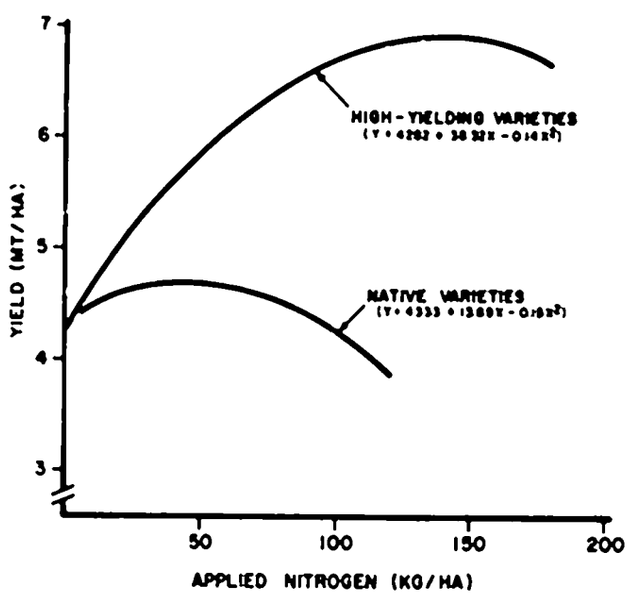

Figure 1. Generalized curve for the response of rice to nitrogen applications in the dry season

For the native varieties the optimum rate of nitrogen application is about 30 to 40 kg/ha in the dry season and no nitrogen in the wet season. The decrease in yield with added nitrogen for the native varieties is due primarily to lodging and mutual shading as discussed previously.

It should be pointed out that in the experiments from which the data were taken, residual fertility levels were likely higher than would be found in most

rice fields. Therefore, rice yields where no nitrogen was applied tend to be much higher than the average in many countries. Responses to fertilizer on the improved varieties, therefore, should be much more dramatic in areas of low fertility. Aside from absolute values the response curves do tend to show the much higher comparative response to nitrogen applications by the improved, high-yielding varieties. Yields of the improved varieties should average about twice those from traditional varieties (8) and with good fertilization and management practices where fertility levels are low the improvement would likely be even more dramatic.

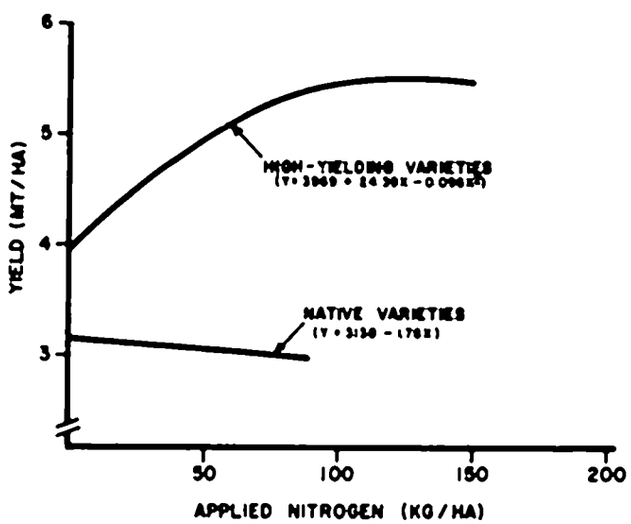

Figure 2. Generalized curve for the response of rice to nitrogen applications in the wet season.

Presently, native varieties have such a long growing season that a second planting is not practical. By using varieties less sensitive to day lengths, such as the dwarf varieties, double cropping is feasible. Without fertilizer, dry season yield differences between the high-yielding and native varieties are insignificant. But in the wet season, improved varieties yield about a third more grain than native varieties and nearly as much as they do in the dry season. Thus, a change only in variety theoretically could approximately double production. A 100% adoption of a new practice in a reasonable period of time is not very likely, however.

Nitrogen fertilization of native varieties during the wet season, if double cropping is attempted with such varieties, cannot be justified. Some of the better selections will respond in some years but usually yields will be reduced by fertilization. Even dry season production is not greatly increased by fertilizer. The limit is about 30 kg/ha of nitrogen which increases yields only 10%. It should be re-emphasized, however, that this discussion pertains to better-than-average soils and management. No-nitrogen rice yields average about 4000 kg/ha in table 1, but national averages for many countries are only of the order of 1000 kg/ha. On farmer fields, then, the actual increase in yield may be comparable to the 4000 kg/ha obtained on the experimental fields and thus the percentage increase would be much higher.

The high-yielding rices produce 135% more grain from an initial 30 kg of nitrogen than do the native varieties. Further additions of nitrogen do not increase the yields of native varieties and are of decreasing effect for the improved varieties. Nevertheless, the high-yielding varieties use the fourth 30-kg increment of nitrogen nearly as efficiently as the native varieties use the first increment (marginal yield of 11.0 vs 13.3 kg grain/kg N). Both marginal yields are above the general world average of 10 kg grain/kg of plant nutrient.

Table 1. Average response of rice to nitrogen fertilization (from tables A1-A2)

	High-Yielding Varieties			Native Varieties		
Rate of N (kg/ha)	Yield (kg/ha)	Marginal Yield (kg/ha)	MY/kg N (kg)	Yield (kg/ha)	Marginal Yield (kg/ha)	MY/kg N (kg)
			Dry Season			
0	4340	–	–	4120	–	–
30	5280	940	31.3	4520	400	13.3
60	6010	730	24.3	4500	–	–
90	6620	610	20.3	4200	–	–
120	6950	330	11.0	3840	–	–
150	6790	–	–	3250	–	–
180	6630	–	–	2590	–	–
			Wet Season			
0	3960	–	–	3000	–	–
30	4490	530	17.7	2945	–	–
60	5010	520	17.3	2725	–	–
90	5380	370	12.3	2580	–	–
120	5550	170	5.7			
150	5460	–	–			

WHEAT RESPONSE TO NITROGEN

An assured yield of wheat has been the goal of generations of husbandmen. Over time, then, varieties have been selected so that yields fluctuate little except when disaster strikes the yield to zero. Imposition of New World technology, such as fertilization and deep plowing, has little effect on plants with inbred insensitivity. Coincident with

selection for assured yield has been an apparent selection for long stems because straw also is prized. This long stem is responsible for the downfall of native wheat when fertilized. As with rice, the introduction of a dwarf gene into a wheat's pedigree has greatly increased its yield potential. Lodging is supplanted by disease resistance as the major problem. Although the dwarf gene orginated in Japan (31), most of the credit for introducing dwarf and semi-dwarf wheat varieties to developing countries belongs to O. A. Vogel of the U. S. Department of Agriculture at the Washington Agricultural Experiment Station and the Centro Internacional de Mejoramiento de Maiz y Trigo in Mexico.

The dwarf varieties have broad, green leaves and an efficient photosynthetic ability. They also have well developed root systems that tend to grow deeper than those of tall varieties. The dwarfs have a high tillering ability and because of this the short plant height does not necessarily lead to less straw (38). Frequently, they produce more straw (37).

The generalized yield response curves in figure 3 were determined by multiple regression. The response function for native varieties was computed by Saxena and Sirohi (37) and the function for high-yielding varieties was determined from data in table A3. Comparisons of response of native and high-yielding varieties to applied nitrogen are practically non-existent outside India.

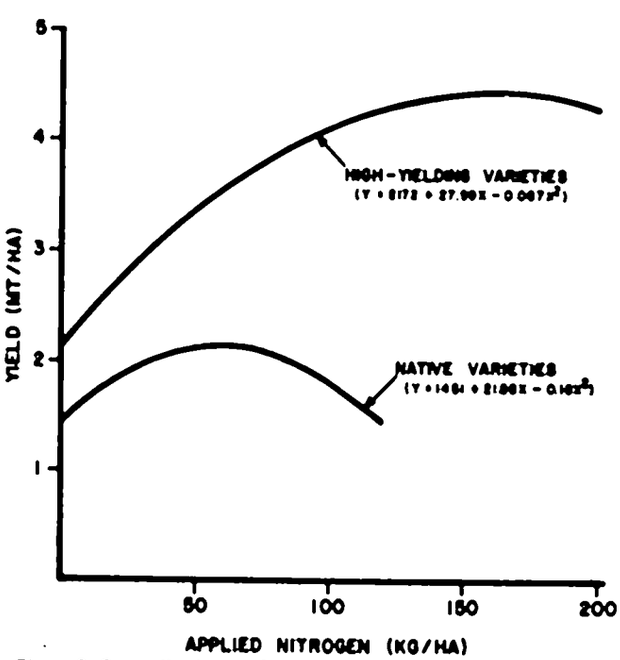

Figure 3. Generalized curve for the response of wheat to nitrogen applications.

The high-yielding wheat varieties respond to two to three times more nitrogen than do the native varieties, as shown in figure 3. To attain this difference in response, however, more attention must be paid to management practices. Especially important are proper seeding depth and rate (6, 26, 38), adequate moisture or irrigation water (15), and weed control (6, 38). The time of nitrogen application—all at planting time or split between planting time and topdressing—requires further investigation. A split application offers the possibility of hedging against severe drought and avoids some leaching losses under irrigation. Countering this are the possibility of prolonged delay in application due to seasonal rains at topdressing time, decreased availability and higher prices for nitrogen in the spring, and failure even to plan for a topdressing application.

Without fertilizer, yield of the improved varieties is 50% greater than of the native varieties. Not all this increase should be attributed to variety alone. Some is due to management practices that produce higher yield with improved than with native varieties. Response of native and improved varieties to nitrogen is shown in table 2.

Table 2. Average response of wheat to nitrogen fertilization (from table A3)

Rate of N (kg/ha)	Yield (kg/ha)	Marginal Yield (kg/ha)	MY/kg N (kg)
		High-Yielding Varieties	
0	2100	–	–
40	3270	1170	29.3
80	3900	630	15.8
120	4200	300	7.5
160	4350	150	3.8
200	4350	–	–
		Native Varieties	
0	1450	–	–
20	1815	365	18.2
40	2030	215	10.8
60	2105	75	3.8
80	2030	–	–

MAIZE RESPONSE TO NITROGEN

The primary reason for the replacement of open-pollinated maize with hybrids in the United States was the superior yielding ability of the hybrids. This was true for the zero to low levels of fertilization in use when hybrids were introduced and is still true for the much higher rates now in use. United States yields increased from 1900 kg/ha in 1939 to 3500 kg/ha in 1961. It is estimated

that use of new hybrid varieties accounted for over a third of the increase even though a half or more of the maize acreage in the Corn Belt already was planted to hybrids in 1939. Fertilizer use contributed another 30% to the yield increase. Changes in production location and other technology accounted for the remainder of the increase (12). Development of hybrids adapted to the climates of various developing countries is leading to replacement of open-pollinated maize by high-yielding hybrids in these countries.

The ability to absorb nutrients more rapidly and efficiently is considered one of the favorable growth factors causing hybrid vigor and higher yields (43). Less tendency toward lodging and an increase in number of filled ears are other important factors (28). In order to perform to advantage, hybrid maize must be adapted to the conditions of the area in which it is to be grown. Well adapted hybrids usually must be bred locally (46).

Data comparing the response of hybrid vs open-pollinated maize to different fertility levels are limited. The generalized response curves in figure 4 were developed from United States and India data, as cited in table A4. Both the high-yielding hybrids and the native open-pollinated maizes respond to nitrogen fertilization. There appears to be no difference due to variety in the amount of nitrogen needed for maximum yield. This is a distinct contrast to the inability of native rice and wheat varieties to respond to high, or even moderate, rates of nitrogen.

As table 3 shows, marginal yields are higher for the high-yielding hybrids than for the open-pollinated native varieties. The marginal yield per kilogram of nitrogen applied is 30 to 60% higher for the hybrids.

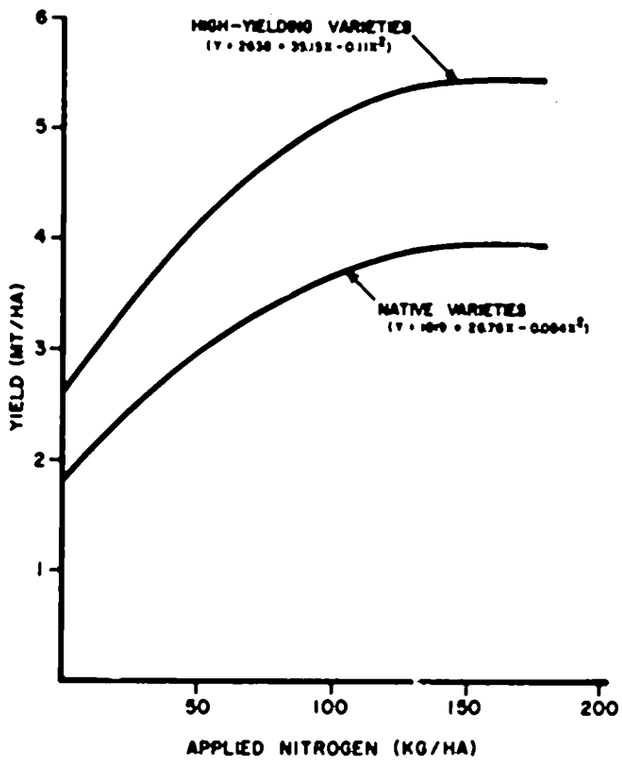

Figure 4. Generalized curve for the response of maize to nitrogen applications

Table 3. Average response of maize to nitrogen fertilization (from table A4)

Rate of N (kg/ha)	Yield (kg/ha)	Marginal Yield (kg/ha)	MY/kg N (kg)
		High-Yielding Varieties	
0	2552	–	–
45	3786	1234	27.4
90	4676	890	19.8
135	5044	368	8.2
180	5270	226	5.0
		Native Varieties	
0	1903	–	–
45	2847	944	21.0
90	3427	580	12.9
135	3676	249	5.5
180	3810	134	3.0

SORGHUM RESPONSE TO NITROGEN

World sorghum production is below that of the three cereals already discussed. The development of hybrid sorghum is not likely to change this rank. However, in those areas where sorghum is the principal cereal, introduction of hybrids may have an effect on the demand for fertilizer.

A good sorghum hybrid will give a substantial and consistent yield increase over a wide range of environmental conditions and standards of farming (20, 21). That is, grain yield can be increased substantially merely by the use of hybrid seed without any drastic change in farming practice (20). This is a distinct contrast to the requirements for attaining increased yields from the high-yielding varieties of rice, wheat, and maize. With these cereals, a "package" of practices is necessary. With sorghum, the complete package is not necessary; thus, use of fertilizer may lag behind the use of hybrid seed.

The main yield increase from the hybrid comes from the production of more grains per plant because of more spikelets per head (21). Hybrids also show a higher percentage of emergence, a larger ratio of plants forming

mature heads, and larger heads. When emergence is poor, hybrids compensate even more than native varieties in producing still larger heads. Stover yields of the hybrids, however, are the same as or lower than those of non-hybrid varieties (11).

Again, the data for comparisions of native and hybrid varieties to applied nitrogen are obtained from India. The yield response data are shown in table A5. There is much variability in initial yield as well as response to applied nitrogen for both native varieties and the hybrid. The means for hybrid sorghum are lower than average grain sorghum yields in the U. S. for similar rates of fertilizer. This is in contrast to the other crops studied. Means of high-yielding rice and wheat varieties are higher than the average U. S. yield while means for corn are similar to the U. S. average.

Little fertilizer is used on native sorghum in most countries because of the low cash value of sorghum and the relatively high cost of fertilizer. As shown in figure 5, the native varieties, although tolerant to nitrogen fertilization, are not very responsive. Marginal yields are quite low (table 4). Hybrid sorghums, however, are responsive to nitrogen.

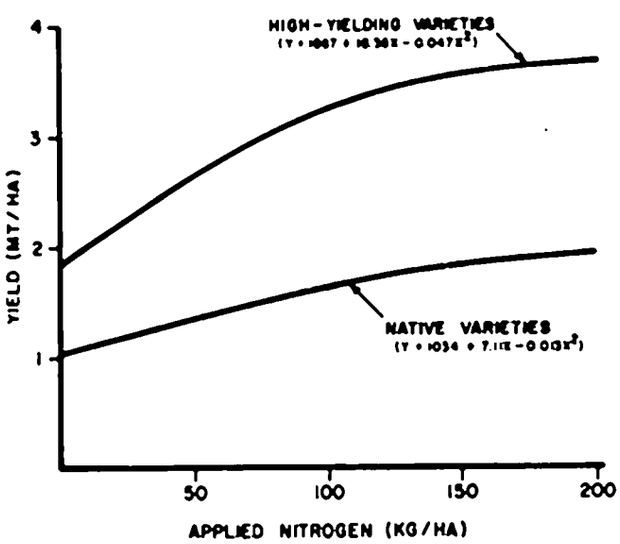

Figure 5. Generalized curve for the response of sorghum to nitrogen applications.

Table 4. Average response of sorghum to nitrogen fertilization (from table A5)

Rate of N (kg/ha)	Yield (kg/ha)	Marginal Yield (kg/ha)	MY/kg N (kg)
		High-Yielding Varieties	
0	1870	–	–
50	2660	790	15.8
100	3225	565	11.3
150	3600	375	7.5
200	3660	60	1.2
		Native Varieties	
0	1030	–	–
50	1370	340	6.8
100	1610	240	4.8
150	1810	200	4.0
200	1950	140	2.8

OPTIMUM RATES OF NITROGEN FERTILIZATION

Discussions to this point have considered only the physical response of the four cereals to nitrogen. Yield responses have been graphed without comment about the economics of producing such yields. In this and the following sections, economics of production is considered.

The economic optimum rate of fertilization is variable because it depends on the cost of the fertilizer and the value of the increased grain produced. On a world-wide basis, both of these values fluctuate widely. These fluctuations are documented and could be reported here but the information would not necessarily be useful. As an alternative, the marginal revenue per kilogram of nitrogen used has been prepared for a range of cereal grain values. As a basis for prices of the four cereals, the 1966 wholesale price in India was used, as published by FAO (4). (For sorghum the latest prices were rounded to the nearest whole U. S. cent per kilogram of grain.) For the range, values of approximately plus or minus 50% were used. Marginal revenue information is given in tables 5-8.

As an example of how optimum rates of nitrogen fertilization may be determined from the tables (and how they vary), Thai farmers in 1964-65 paid from 24.1 to 40.6 U. S. cents per kilogram of nitrogen, depending on the form (4). Assuming that the price of maize was expected to be five cents (U. S.) per kilogram, the optimum rates of fertilization for both high-yielding and native maize varieties are given in the following tabulation:

Form of N available	Cost of N (US¢/kg)	Optimum rate of N (kg/ha) HYV	(MR)*	NV	(MR)*
Sodium nitrate	40.6	135	(.41)	90	(.64)
Calcium nitrate	30.7	135	(.41)	90	(.64)
Ammonium sulfate	27.9	135	(.41)	135	(.28)
Urea	24.1	180	(.25)	135	(.28)

*Marginal revenue for rate of nitrogen shown as given in table 7.

Table 5. Marginal revenue from nitrogen fertilization of rice (US$/kg N).

Rate of N (kg/ha)	MY/kg N from Table 1 (kg)	Value of grain (US$/kg) .06	.13	.20
	High-yielding varieties - dry season			
0	–	–	–	–
30	31.3	1.88	4.07	6.26
60	24.3	1.46	3.16	4.86
90	20.3	1.22	2.64	4.06
120	11.0	.66	1.43	2.20
150	–	–	–	–
	Native varieties - dry season			
0	–	–	–	–
30	13.3	0.80	1.73	2.68
60	–	–	–	–
	High-yielding varieties - wet season			
0	–	–	–	–
30	17.7	1.06	2.30	3.54
60	17.3	1.02	2.25	3.46
90	12.3	.74	1.60	2.46
120	5.7	.34	.74	1.14
150	–	–	–	–
	Native varieties - wet season			
0	–	–	–	–
30	–	–	–	–

Table 6. Marginal revenue from nitrogen fertilization of wheat (US$/kg N).

Rate of N (kg/ha)	MY/kg N from Table 2 (kg)	Value of grain (US$/kg) .06	.12	.18
	High-yielding varieties			
0	–	–	–	–
40	29.3	1.76	3.52	5.27
80	15.8	.95	1.90	2.84
120	7.5	.45	.90	1.35
160	3.8	.23	.46	.68
200	–	–	–	–
	Native varieties			
0	–	–	–	–
20	18.2	1.09	2.18	3.28
400	10.8	.65	1.30	1.94
60	3.8	.23	.46	.68
80	–	–	–	–

PRODUCTION OF A SPECIFIED QUANTITY OF A CEREAL

Assume that the goal is to produce 250,000 metric tons (250,000,000 kg) of wheat. If there is no restriction in the amount of land available for wheat production, the least cost production would be with native varieties grown without fertilizer. Thus,

Table 7. Marginal revenue from nitrogen fertilization of maize (US$/kg N).

Rate of N (kg/ha)	MY/kg N from Table 3 (kg)	Value of grain (US$/kg) .05	.10	.15
	High-yielding varieties			
0	–	–	–	–
45	27.4	1.37	2.74	4.11
90	19.8	.99	1.98	2.97
135	8.2	.41	.82	1.23
180	5.0	.25	.50	.75
	Native varieties			
0	–	–	–	–
45	21.0	1.05	2.10	3.15
45	21.0	1.05	2.10	3.15
90	12.9	.64	1.29	1.94
135	5.5	.28	.55	.82
180	3.0	.15	.30	.45

Table 8. Marginal revenue from nitrogen fertilization of sorghum (US$/kg N).

Rate of N (kg/ha)	MY/kg N from Table 4 (kg)	Value of grain (US$/kg) .04	.09	.14
	High-yielding varieties			
0	–	–	–	–
50	15.8	0.63	1.42	2.21
100	11.3	0.45	1.02	1.58
150	7.5	0.30	0.68	1.05
200	1.2	0.05	0.11	0.17
	Native varieties			
0	–	–	–	–
50	6.8	0.27	0.61	0.95
100	4.8	0.19	0.43	0.67
150	4.0	0.16	0.36	0.56
200	2.8	0.11	0.25	0.39

$$\frac{250{,}000{,}000 \text{ kg}}{1450 \text{ kg/ha}} = 172{,}413 \text{ ha of land}$$

$$(172{,}413 \text{ ha})(0 \text{ kg N/ha}) = 0 \text{ mt of N}$$

However, population increases are placing such a pressure on land that hectarage generally is not unlimited. The minimum area required for producing the wheat would require the maximum use of technological advances: high-yielding varieties fertilized with the maximum amount of nitrogen that still produces a yield response. Thus,

$$\frac{250{,}000{,}000 \text{ kg}}{4350 \text{ kg/ha}} = 57{,}471 \text{ ha of land}$$

$$(57{,}471 \text{ ha})(160 \text{ kg N/ha}) = 9195 \text{ mt of N}$$

Between these two extremes are various alternatives. For contrast to the situations immediately above, assume that the 250,000-ton goal will be attained by fertilizing native wheat with the optimum rate of nitrogen. Optimum rates are based on input/output values; therefore, assume the wheat will be worth 12¢/kg and the nitrogen will cost 40¢/kg. In table 6, then, note that the optimum rate of fertilization is 60 kg/ha, and from table 2 note that the yield at this rate is 2105 kg/ha. Thus,

$$\frac{250{,}000{,}000 \text{ kg}}{2105 \text{ kg/ha}} = 116{,}279 \text{ ha of land}$$

$$(116{,}279 \text{ ha})(60 \text{ kg N/ha}) = 6977 \text{ mt of N}$$

From a practical viewpoint, it is not likely that the production goal will be fulfilled with all high-yielding wheat or with native wheat fertilized at the optimum rate. A mixed system is more realistic. No guidelines can be offered for making reliable estimates of the mix components. For illustration purposes, assume that the production goal still is 250,000 metric tons, wheat is worth 12¢/kg, N costs 40¢/kg, 25% of the planted area will be in unfertilized native wheat, 25% of the area will be planted with native wheat fertilized at one-half the optimum rate, and the remaining area will be planted to high-yielding varieties fertilized with three-fourths the optimum rate of nitrogen. From table 6 it is determined that the optimum rate of nitrogen is 160 kg/ha for the improved varieties and 60 kg/ha for native varieties. Actual rates will be 160 kg/ha x 0.75 = 120 kg/ha and 60 kg/ha x 0.50 = 30 kg/ha. From table 2 it is determined that the yield of the high-yielding varieties will be 4200 kg/ha and, by interpolation, 1925 kg/ha for fertilized native varieties. Unfertilized native varieties will yield 1450 kg/ha. Using X to represent hectarage, the following relationships are solved,

$$(.50X)(4200) + (.25X)(1925) + (.25X)(1450) = 250{,}000{,}000$$
$$X = 84{,}947 \text{ ha of land}$$
$$(.50)(84{,}947)(120) + (.25)(84{,}947)(30) = 5{,}734 \text{ mt of N}$$

PRODUCTION FROM A SPECIFIED QUANTITY OF LAND

Two views are probable in this situation—the farmer's and the government's. The farmer's interests are confined to an assured, and hopefully maximum, income. The old varieties almost assure him of some production but the new varieties may increase his income. Government has some concern for production costs, especially if the inputs require foreign exchange. Its primary interest, however, is more likely in maximum production. To illustrate that the goals of both the farmer and the government are identical, assume that one hectare is available for the production of rice. Nitrogen costs 40¢/kg and the rice is expected to be worth 6¢ /kg. The production and the profit from alternative methods of using the hectare, based on data in tables 1 and 5, are shown in the following tabulation.

Variety	Rate of N (kg)	Yield (kg)	Value of yield ($)	Cost of fertilizer ($)	Net income ($)
Native	0	4120	247.20	0	247.20
Native	30	4520	271.20	12.00	259.20
Improved*	0	4340			
	0	3960			
		8300	498.00	0	498.00
Improved*	120	6950			
	90	5380			
		12330	739.80	84.00	655.80

*Double cropping is possible with the high-yielding rices.

As the above tabulation shows, regardless of variety used, fertilization increases both the yield and the net income. The government and the farmer have congruent interests: to use both fertilizer and the best varieties available.

PRODUCTION ALTERNATIVES

Few nations are so limited in area, climatic conditions, and food preferences that only a single cereal is produced. In many countries all four cereals can be produced and the "best" allocation of resources to each of the cereals becomes of interest. The best allocation is defined here as that which provides the highest return on an investment in a cereal production program. Resources include both the monies required for seeds and fertilizers and the technical personnel needed to develop and conduct the program.

The discussion here must be limited to the use of nitrogen on the four cereals. Available data are adequate to determine the best stepwise rates of nitrogen fertilization for both high-yielding and native varieties of rice, wheat, maize, and sorghum. Rates of fertilization are dependent on the value of the grain and the cost of the nitrogen. Thus, resource allocations could change from year to year. Since changes disrupt educational programs, price trends should be considered as a cereal production program is being developed. Prices should trend downward as increasing production of a particular cereal changes the supply/demand ratio.

For illustrative purposes here, grain prices were US$ 0.13/kg for rice, 0.12 for wheat, 0.10 for maize, and 0.09 for sorghum. Marginal returns per kilogram of nitrogen used are given in tables 5-8 at these prices. In table 9, the same marginal returns are listed in a descending order of magnitude. Incremental rates of nitrogen fertilizer are given in tables 5-8 whereas table 9 lists the number of increments and the total rate of nitrogen.

Table 9. Priority of use of nitrogen on rice, wheat, maize, and sorghum

Production Priority	Cereal	Variety[1]	N fertilizer (kg/ha) Increment	Total	MR/kg N (US$)[2]	Benefit/cost ratio[3]
1	Rice (dry)	HYV	1st 30	30	4.07	16.3
2	Wheat	HYV	1st 40	40	3.62	14.1
3	Rice (dry)	HYV	2nd 30	60	3.16	12.6
4	Maize	HYV	1st 45	45	2.74	11.0
5	Rice (dry)	HYV	3rd 60	90	2.64	10.6
6	Rice (wet)	HYV	1st 30	30	2.30	9.2
7	Rice (wet)	HYV	2nd 30	60	2.25	9.0
8	Wheat	NV	1st 20	20	2.18	8.7
9	Maize	NV	1st 45	45	2.10	8.4
10	Maize	HYV	2nd 45	90	1.98	7.9
11	Wheat	HYV	2nd 40	80	1.90	7.6
12	Rice (dry)	NV	1st 30	30	1.73	6.9
13	Rice (wet)	HYV	3rd 30	90	1.60	6.4
14	Rice (dry)	HYV	4th 30	120	1.43	5.7
15	Sorghum	HYV	1st 50	50	1.42	5.7
16	Wheat	NV	2nd 20	40	1.30	5.2
17	Maize	NV	2nd 45	90	1.29	5.2
18	Sorghum	HYV	2nd 50	100	1.02	4.1
19	Wheat	HYV	3rd 40	120	.90	3.6
20	Maize	HYV	3rd 45	135	.82	3.3
21	Rice (wet)	HYV	4th 30	120	.74	3.0
22	Sorghum	HYV	3rd 50	150	.68	2.7
23	Sorghum	NV	1st 50	50	.61	2.4
24	Maize	NV	3rd 45	135	.55	2.2
25	Maize	HYV	4th 45	180	.50	2.0

[1]HYV = high-yielding variety; NV = native variety
[2]Rice = US$ 0.13/kg, wheat = US$ 0.12/kg, maize = US$ 0.10/kg, sorghum = US$ 0.09/kg
[3]Nitrogen = US$ 0.25/kg

An alternative method of determining production alternatives is based on benefit/cost ratios. These are determined by dividing the marginal return per kilogram of nitrogen used by the value of the nitrogen. In table 9, a value of US$ 0.25/kg was used for the nitrogen. An examination of the benefit/cost ratios shows why farmers readily fertilize the stiff-strawed rice varieties but are reluctant to fertilize native varieties of sorghum. Returns in the first case exceed 16 to 1 but in the latter are only 2 to 1. All production alternatives listed in tables 5-8 are not given in table 9. When the benefit/cost ratio was less than 2, as would be the case for higher rates of nitrogen on native sorghums, no entry was made in table 9. Even U. S. farmers do not choose alternatives with such low return potentials. The benefit/cost ratios given here are not precise. Increased application, harvesting, and marketing costs have not been determined and included in the calculation. Normally, a benefit/cost ratio of 3 is used in the United States as the lower limit in recommending a practice.

Fertilization of high-yielding rice varieties is listed five times in the first seven priority choices in table 9. Use of nitrogen in both the dry and the wet season is recommended. The other two priorities (in the top seven) are fertilization of wheat and maize. If personnel to plan and conduct a cereal production program are severely limited, then rice becomes the only cereal that should receive attention. When resources are somewhat greater, a wheat fertilization program would be added to the rice production program. Since the returns from both a rice and a wheat fertilization program are extremely high, every effort should be made to establish both programs. Maize fertilization is nearly as good.

Within a rice program, fertilization of native varieties should not have a high priority. Note in table 9 that this practice ranks 12th in priority but produces only 30¢ more marginal return than use of 120 kg of nitrogen per hectare on high-yielding varieties in the dry season. Sales and educational personnel already will have been working intensively with farmers who are growing the high-yielding varieties. It will be much, much easier for them to promote use of more nitrogen on these varieties than for them to promote the entirely new practice of fertilizing native rice. Fertilization of native rice should not be discouraged; returns from this practice are very good. Spread of practice from fertilization of high-yielding varieties to fertilization

of native varieties can be expected and fertilizer should be allocated to all farmers who want to use it on rice. Nevertheless, extension personnel can more profitably use their time in promoting the production of rice from the high-yielding varieties.

Wheat fertilization presents a different aspect than rice fertilization. Again in table 9 note that the use of 40 kg/ha of nitrogen on stiff-strawed wheat ranks 2nd in priority. The next wheat entry is at priority rank 8 and is for 20 kg/ha on native varieties. Wheat fertilization also is ranked 11th and 16th, again with both high-yielding and native varieties listed. Thus, nearly equal emphasis can be given to the use of nitrogen on the two types of wheat. Maize is similar to wheat while a sorghum fertilization program should be confined, nearly like rice, to only the hybrid varieties.

It is emphasized that a table of benefit/cost ratios should be followed explicitly only when resources are unlimited. Any limitation in personnel, quantity of fertilizer available, amount of improved seed, production required for self-sufficiency, etc.–would require that the priorities be reviewed carefully.

Personnel strictures are a very real limitation in developing countries, but so also is the availability of improved seeds. In this latter case, fertilizer supplies, although rarely excessive, may be more than adequate for the hectarage of new varieties. Obviously, the remaining fertilizer should be allocated to the native varieties or to other cereal crops as the priority rank indicates. Fertilizer allocations are more difficult to decide when nitrogen supplies are limited. In most countries, farmers will be using nitrogen on their native cereals because of various fertilizer promotion programs. Theoretically, these farmers should be denied a nitrogen allocation until all the high-yielding varieties have been fertilized to the point that the native variety becomes the most profitable alternative. Practically and politically, this would not be the correct decision. Farmers who already have adopted the practice of fertilizing native varieties are the ones most likely to shift to the high-yielding varieties as more seed and fertilizer become available. Their interest and participation in fertilizer programs should be preserved.

NITROGEN NEEDS WITH HIGH-YIELDING VS NATIVE VARIETIES

As the rate of nitrogen application increases, the quantity of grain produced per unit of nitrogen decreases. The high-yielding varieties, regardless of which cereal is considered, respond to higher rates of nitorgen than do the native varieties. As shown in tables 1-4, production per unit of nitrogen has an inverse relationship to the rate of application. Theoretically, then, a country whose farmers switched to high-yielding varieties might well require more nitrogen fertilizer than would be needed if only native varieties were fertilized.

In the first flush of adopting the new varieties, it is extremely likely that fertilizer demand will exceed forecasts that were based on native varieties. Almost without exception, the high-yielding varieties are being introduced via the package approach. That is, along with new seed, farmers are taught the need for fertilizer, pesticides, timeliness of operations, etc. Fertilizer recommendations are higher than for native varieties. Adoption of the package by farmers inexorably leads to a demand for more nitrogen than would have been used if only native varieties were planted and fertilized.

The long term needs for nitrogen do not necessarily coincide with short term demands. As shown in tables 1-4, marginal production by the native varieties for the first increment of nitrogen is in most situations about equal to the optimum rate of fertilization. A comparable rate of production per unit of nitrogen is not reached by the high-yielding varieties until nearly three times more nitrogen has been applied. Although the optimum rate of nitrogen may not yet be attained, total cereal production generally will already have doubled.

As long as it is possible to produce a certain cereal requirement by fertilization of a given land area with either native or high-yielding varieties, less fertilizer is required with high-yielding varieties. It is also possible to produce the grain requirement with high-yielding varieties on less land area and with less fertilizer. However, as farmers approach the economic optimum level of fertilization, it requires more fertilizer to produce the total grain requirement with high-yielding than with native varieties. This is illustrated in the following table for a total wheat grain requirement of 250,000 mt.

Variety	N Rate (kg/ha)	Yield (mt/ha)	Area (ha)	Needed Fertilizer (mt)
Native Varieties	40	2.03	126,500	5,060
High-Yielding Varieties	0	2.10	119,000	0
High-Yielding Varieties	40	3.27	76,500	3.060
High-Yielding Varieties	80	3.90	64,200	5,140
High-Yielding Varieties	120	4.20	59,600	7,150

The relative quantity of nitrogen needed to produce a given quantity of grain with native or high-yielding varieties depends upon the land area used and the rate of fertilization.

PHOSPHORUS AND POTASSIUM NEEDS WITH HIGH-YIELDING VS NATIVE VARIETIES

Phosphorus fertilization studies on rice have not received as much attention as those with nitrogen. This is likely due to the lack of response to phosphorus by rice in many areas even though upland

crops in the same areas may show a positive response (8). The response of rice to phosphorus is far from universal and varies widely from area to area.

Response to phosphorus is less frequent than to nitrogen but more frequent than to potassium (31). The relatively small applications of P_2O_5 usually suggested are a reflection of the remarkably low phosphorus requirement of rice (a 4000-kg crop removes only 20 kg of P/ha) and the increased availability of soil phosphorus in flooded soils (8). The reducing conditions caused by flooding the soil activate forms of phosphorus (mainly iron and aluminum phosphates) that are normally insoluble in well drained soils (29, 34). This results in more phosphorus being available to a flooded rice crop than would be the case for an upland crop. Hence, lowland rice is not as likely to respond to additions of phosphorus as are upland crops (34).

Due to the great variability in response to phosphorus applications it is futile to suggest an average application rate for most rice soils without first delineating those areas where a response to phosphorus can be expected. This can best be accomplished by local fertility trials. Where responses to phosphorus are obtained applications of from 30 to 60 kg P_2O_5/ha are normally suggested. Using varieties which are capable of responding to nitrogen, this would suggest approximately a 2 or 3:1 nitrogen to P_2O_5 ratio. Although there is no direct evidence showing that high-yielding varieties have a higher phosphorus requirement, the observations of Yamasaki that the nutrient uptake/ton of rice grain yield is nearly the same regardless of yield would suggest that higher phosphorus levels are needed by these varieties for high yields (48).

As with phosphorus, response of rice to potassium is quite variable. In general, potassium increases yields of rice significantly under rather limited conditions (30). The greatest need for potassium is likely to be on highly leached sandy soils, with little response being obtained on lowland clay soils.

The rather infrequent response to potassium is surprising in view of the fact that the requirement of the rice plant for potassium is much greater than for either nitrogen or phosphorus (8). In The Philippines a rice crop producing 4000 kg/ha was found to have absorbed 219 kg potassium, 20 kg phosphorus and 90 kg nitrogen; of this about one-half of the nitrogen and phosphorus was in the panicle compared to only about 5% of the potassium (8). Since 80 to 90% of the potassium is found in the straw, a high proportion of the potassium can be recirculated if plant residues are returned to the soil. This, however, is not a common practice in tropical rice culture.

Evidence suggests that the high-yielding varieties have a lower potassium concentration than the native varieties. This may be related to the high water content and soft character of the leaves in the low-response types (45). Since the high-yielding varieties produce about the same amount of straw, but have a higher grain-straw ratio, and thus produce more grain than do the low-response varieties, there is little reason to suggest the potassium requirements of the improved varieties would be higher.

Response to phosphorus fertilization is more certain with wheat than with rice. Release of phosphorus from iron and aluminum phosphates as a result of anaerobiosis is not as likely on wheat land, even under irrigation, as it is in paddy. Wheat also appears to have a higher requirement for phosphorus than rice but phosphate fertilizer studies are not very extensive with wheat in developing countries. Presently, phosphorus requirements (as P_2O_5) for wheat in developing countries are considered to be approximately half those for nitrogen (2, 22).

Potassium fertilization of wheat is not a common practice in developing countries. However, it is anticipated that, with more intensive use of the high-yielding varieties and with the higher levels of production resulting from the use of more nitrogen and phosphorus, there will be an increasing need for potassium fertilization (2, 14). A 2:1:1 ratio ($N:P_2O_5:K_2O$) has been suggested (40), but again the answer can best be obtained through adequate research.

In the United States Gaines wheat, a high-yielding semi-dwarf variety was introduced into the Pacific Northwest in 1961. In 1960, the average $N:P_2O_5:K_2O$ ratio for the State of Washington was 11:3:1. By 1968, the ratio had narrowed to 6:2:1 (23). The increasing needs for phosphorus and potassium cannot, of course, be entirely ascribed to the Gaines wheat. General increases in yields of most crops, particularly as a result of a doubling of the amount of nitrogen used, were responsible for ever increasing demands for phosphorus and potassium fertilizers.

Response of hybrid maize to phosphorus and potassium is well documented in the United States but not in tests that compare hybrids with open-pollinated varieties. In developing countries information of this type is almost non-existent.

Prior to the availability of adapted hybrids in Rhodesia, maize was fertilized with 1:5:2 fertilizer plus nitrogen from legumes and green crops. Because hybrid maize responded so well to nitrogen, use of commercial nitrogen steadily increased and averaged 90 kg/ha by 1964. P_2O_5 applications also increased to about 45 kg/ha. The continuous increase in intensification of land use, the rising yields, and the extensive use of only nitrogen and phosphorus resulted in a rapid and serious depletion of the potassium reserves in maize soils. Common fertilizers for maize in Rhodesia now have $N:P_2O_5:K_2O$ ratios of 1:2:1 to 3:4:3 supplemented by straight nitrogen and potash when these are needed (47).

Precise data of fertilizer use prior to and following complete acceptance of hybrids in the U.S. Corn Belt are not available. However, estimates have been made from time to time. In 1950, maize was fertilized with an average of 9-28-20 kg/ha of N-P_2O_5-K_2O. By 1954, the rate of application had increased to 26-31-31 (25). In 1967, the rate was 86-63-59 compared to a recommended of 128-77-72 (44).

Maize requires annual applications of all three primary nutrients and may require secondary and micronutrients as well. As plantings change to the high-yielding hybrids, nitrogen requirements increase the most but phosphorus and potassium requirements also increase substantially.

Response to nitrogen by hybrid sorghums is generally universal whereas response to phosphorus and potassium is spotty and less frequent. There is as yet no indication that hybrids have a higher or lower requirement than native sorghums for these two nutrients.

Though not derived specifically from tests of high-yielding vs native varieties, there are several lines of evidence that suggest substantial phosphorus and potassium needs for the high-yielding varieties. Crops need phosphorus at all stages of growth but at two stages requirements are very critical: at the seedling stage and when the grain is being filled. At the seedling stage it is unlikely that high-yielding varieties will differ much from native varieties in their phosphorus needs because the dry matter content of both varieties is so nearly the same. Varieties with the highest root/top ratio at the seedling stage likely will absorb the most phosphorus from the soil so long as there is phosphorus available in the soil. An adequate supply of phosphorus must be available – either from minerals already in the soil or from fertilizer added to the soil – for the high-yielding varieties to establish quickly the root and top growth needed to support high yields. Later in the growing season, as grain is synthesized, total phosphorus requirements will indeed be higher for high-yielding varieties than native varieties. Phosphorus fertilizer needs may not increase in the same proportion as nitrogen requirements until available phosphorus in the soil is depleted. At the yields anticipated from the high-yielding varieties, not many years will be required to deplete soil phosphorus to very low levels.

Crops contain very little potassium in the grain but need very large amounts for straw or stover production. For those cereals whose high-yielding varieties produce more dry matter than native varieties, potassium needs are higher. Whether or not this need must be satisfied with potash fertilizers is dependent upon still other factors. Recycling of potassium through return of straw to the field is more feasible than recycling of phosphorus. Thus, potassium may be depleted from the soil at a rate slower than for phosphorus. On the other hand, large amounts of potassium can be lost from the soil through leaching whereas phosphorus leaching losses are negligible. Only constant surveillance, either through field experiments or by means of soil tests, will provide adequate warning of impending needs for potash (and phosphate) fertilizers.

One final type of evidence supporting the need for increased quantities of all plant nutrients as high-yielding varieties are introduced is the historical. Already cited has been the increased use of nitrogen, phosphorus, and potassium in various regions of the United States and in Rhodesia. Similar changes in fertilizer use have occurred in Japan and Taiwan, two countries that have made monumental advances in agriculture since World War II. Between 1956 and 1967 per capita consumption of plant nutrients increased nearly 50% while the N:P_2O_5:K_2O ratio changed from 6:3:4 to 3:2:2 in Japan and 8:3:2 to 8:2:3 in Taiwan.

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APPENDIX

Table A1. Response of rice to nitrogen in the dry season (kg/ha).

Variety	Rate of Nitrogen (kg/ha) 0	30	60	90	120	150	180	Reference
			High-yielding Varieties					
T(N)-1	3830	5590	6450	6970	6590			17
IR-8	3560	5070	5510	6990	7830			17
C4-63	3710	4850	5890	6780	6930			17
IR-5	4260	5100	6380	6990	7170			17
IR-8	4750	7000	8150	8600	9450			19
T(N)-1	4900	6250	7000	7600	7400			19
IR-8	5750	6800	8250	8300	9400			16
IR-5	5900	6500	7600	7800	8550			16
C4-63	5400	6800	7300	7400	8000			16
T(N)-1	5400	6650	6750	7000	7800			16
IR-8	3920	4800	5880	6620	7770	6350	7760	16
IR-5	4000	4560	5160	6870	6480	7260	7260	16
T(N)-1	2360	2750	3250	3750	4100	4230		14
T(N)-1	2360	2750	3250	3750	4100	4230		14
T(N)-1	3920	4710	4780	5250				42
ACC-6993	6140	7540	7180	7690	7400	8050	7650	18
IR-8	7800	8750	10000	9900	9800	9500	9300	18
IR-8	6800	7000	7300	7450	8100			41
IR-8	5400	6250	7200	7750	8100			15
BPI-76	2850	4390	5230	6120	5840			17
BPI-76	4200	5100	6400	6750	6500			16
BPI-76	2950	3330	3710	4170	4830	5850	5570	16
Ch-242	5400	5700	5400	6100	6400			16
IR-8	3560	5070	5510	6990	7810			17
T(N)-1	3830	5590	6450	6970	6590			17
C4-63	3710	4850	5890	6780	6930			17
IR-5	4260	5100	6370	6990	7170			17
BPI-76	2850	4390	5230	6120	5840			17
IR-8	4990	5310	5620	7230	6890	7110	7340	17
T(N)-1	4090	4470	4840	6080	6390	6770	6610	17
IR-5	4800	5060	5320	5990	6280	6070	6080	17
C4-63	3830	4330	4820	5060	5830	6150	5970	17
BPI-76	3280	3520	3750	4570	5240	5350	5130	17
T(N)-1	3780	4620	5450	5960	6310	6930	6390	17
IR-8	3470	4580	5690	5660	5750	6270	5670	17
C4-63	3660	4520	5380	5480	6160	6230	5260	17
IR-5	2930	4080	5220	5610	6120	5790	5760	17
BPI-76	3330	4320	5310	5290	5810	5900	5530	17
IR-8	6190	6850	7500	8350	9000	9890		17
C4-63	5090	5740	6380	7470	8210	7480		17
Observed Mean	4340	5216	6010	6620	6950	6790	6630	
			$Y = 4282 + 38.32x - 0.14x^2$					
Predicted Value	4282	5306	6077	6597	6884	6880	6644	

Table A1. Response of rice to nitrogen in the dry season (kg/ha). (continued)

Variety	Rate of Nitrogen (kg/ha) 0	30	60	90	120	150	180	Reference
			Native Varieties					
Peta	4400	5150	3300	3500	2600			19
Peta	6100	6100	5600	4200	4100			16
Peta	4260	4470	4670	5270	4280			16
Peta	5040	5410	6130	5860	5600			17
S-1043	4100	4610	4910	4530	4200			42
Intan	3710	3690	2910	2010	1640			18
H-4	5600	5900	5950	5500	4800			41
Peta	5040	5400	6130	5860	5590			17
Peta	4380	4810	5230	4480	4300			17
Peta	3180	3720	4260	3770	4490			17
Bengawan	4650	4900	4250	3250	3000			19
Binato	4000	4600	5250	5000	4750			19
Tjermas	4250	5850	4800	3700	3000			19
EK-70	1680	1850	2100	2100	2350			14
Sigadis	3900	4100	4500	5000	4400			15
Observed Mean	4120	4704	4500	4200	3840			
			$Y = 4333 + 13.89x - 0.15x^2$					
Predicted Value	4333	4615	4632	4368	3840			

Table A2. Response of rice to nitrogen in the wet season (kg/ha).

Variety	Rate of Nitrogen (kg/ha) 0	30	60	90	120	150	Reference
			High-yielding Varieties				
IR-8	3000	4400	5750	6100	6000	6000	17
IR-5	3750	4900	6000	6500	7100	7250	1
IR-8	5160	6250	7120	7270	7820		17
T(N)-1	5340	6060	6950	6880			18
ACC-6993	4660	5380	6010	6310			18
IR-8	5200	5500	6050				19
T(N)-1	3600	4000	4200				19
IR-8	3250	3400	4000	4400			41
IR-8	4000	4750	5400				17
T(N)-1	4350	4500	4610				17
C4-63	3920	4400	4160				17
BPI-76	3190	3700	4000				17
IR-5	4420	4750	4130				17
IR-5	3990	4530	5470	5120	5280	5100	17
IR-8	3740	3910	4640	4980	5950	5260	17
C4-63	3680	4310	4810	5030	5360	5070	17
BPI-76	2700	3470	4130	4330	4260	3650	17
IR-8	5120	5250	5680	6500	6300	6650	17
C4-63	3840	4100	4860	5380	5360	5160	17
IR-5	4530	5180	5950	5590	5580	4740	17
BPI-76	4000	4160	4110	4930	4620	4510	17
BPI-76	3500	3550	3850				19
BPI-76	3600	4250	4000	3750			45
Tianan 3	4000	4400	4750	4500	4400	---	45
Observed Mean	3960	4490	5010	5380	5550	5460	
			$y = 3969 + 24.39x - 0.096x^2$				
Predicted Value	3969	4614	5087	5386	5513	5468	
			Native Varieties				
Peta	3150	3750	4500	4250			17
Kangini 27	3618	3828	3578	3728			1
H-4	1850	2200	1000	1100			41
Intan	2530	1690	1630				18
Peta	2700	2200	1700				19
Peta	3750	3000	3000	2700			45
Peta	2970	2550	2630				17
Peta	4110	4330	4280	4570			17
Peta	3810	4140	4050	4100			17
H-4	2700	2750	2400	2050			17
Observed Mean	3000	2945	2725	2590			
			$y = 3138 - 1.76x$				
Predicted Value	3138	3085	3032	2981			

Table A3. Response of wheat to nitrogen (kg/ha).

Variety	Rate of Nitrogen (kg/ha) 0	40	80	120	160	200	Reference
			High-Yielding Varieties				
S64	1450	3120	3590	3920	4160	4260	9
LR	1590	2980	3490	3750	3870	4150	9
S64	1660	2350	2870	3280	3290	3400	10
LR	2050	2750	3490	3630	4040	3950	10
S64	2190	3540	4230	4760	4630	4930	6
LR	2030	3170	3820	4130	4090	4340	6
S227	2420	3870	4220	4230	4040	4140	6
SS	1950	3200	4050	4440	4880	4600	7
KS	2070	3360	4340	4720	4970	5060	7
S331	2610	3840	4440	4780	5030	4940	7
SL	2030	3100	3960	4240	4520	4560	7
S227	3090	3940	4300	4520	4420	4230	7
Observed Mean	2100	3270	3900	4200	4350	4350	
			$y = 2172 + 27.99x - 0.087x^2$				
Predicted Value	2172	3152	3854	4278	4423	4290	
			Native Varieties				
			$y = 1451 + 21.88x - 0.183x^2$				
Predicted Value	1450	2030	2030	1440			35

Table A4. Response of maize to nitrogen (kg/ha).

Variety	Rate of Nitrogen (kg/ha) 0	45	90	135	180	Reference
			High-yielding Varieties			
Recommended	2400	3370	4040	4530	4890	38
Gangs. 3	2140	2900	3420	3700	3720	35
Nc-27	2820	4640	6280	6370	6460	28
NC-27	2450	3890	4580	5000	5080	28
Dixie 17	3450	5150	6780	6810	6840	28
Dixie 17	2510	4020	4830	5400	5770	28
Observed Mean	2552	3786	4676	5044	5270	
			$y = 2638 + 35.15x - 0.11x^2$			
Predicted Value	2638	3999	4919	5397	5433	
			Native Varieties			
Local	2050	2790	3240	3490	3650	38
Local	1990	2460	2630	2730	2790	35
Local	2010	3500	4520	4700	4770	28
Local	1130	2820	3890	4350	4520	28
Observed Mean	1903	2847	3427	3676	3810	
			$y = 1819 + 26.76x - 0.084x^2$			
Predicted Value	1819	2853	3547	3901	3914	

Table A5. Response of sorghum to nitrogen (kg/ha).

Variety	Rate of Nitrogen (kg/ha) 0	50	100	150	200	Reference
			High-Yielding Varieties			
CHS-1	3620	5480	5770	7050	7660	5
CHS-1	470	1170	1740	2590	2850	5
CHS-1	1600	2039	2530	2500	2340	5
CHS-1	3460	4010	5240	5660	5430	5
CHS-1	1640	1940	2430	2580	2730	5
CHS-1	1090	1280	1530	1830	2160	32
CHS-1	3460	4120	4500	4580	4360	32
CHS-1	3030	4310	4990	5170	4970	32
CHS-1	870	2250	3160	3630	3640	32
CHS-1	880	1200	1470	1700	1980	32
CHS-1	380	1460	2110	2240	2160	32
Observed Mean	1870	2660	3225	3600	3660	
			$y = 1867 + 18.36x - 0.047x^2$			
Predicted Value	1867	2668	3233	3564	3659	
			Native Varieties			
Local	330	530	540	580	730	5
Local	530	610	730	850	940	32
Local	2200	2610	2820	3050	3360	32
Local	2340	3310	3900	4130	4270	32
Local	840	930	1050	1200	1390	32
Local	580	800	1260	1900	2039	32
Local	380	800	970	950	900	32
Observed Mean	1030	1370	1610	1810	1950	
			$y = 1034 + 7.11x - 0.013x^2$			
Predicted Value	1034	1357	1615	1808	1936	

Bulletin Y-4

National Fertilizer Development Center Tennessee Valley Authority Muscle Shoals, Alabama 35660