5. AGRONOMIC AND ENVIRONMENTAL CONSTRAINTS ON FERTILIZER EFFECTIVENESS

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For the average farmer in Bangladesh, the use of chemical fertilizer is most effective and profitable when he possesses technical knowledge about soil conditions, pesticides, and the importance of timing and balance in fertilizer application rates. Even small deviations from proper usage and timing of fertilizer application may result in substantially lower yields. At the national level, many field demonstrations and experiments have been done that have substantially narrowed the gap in knowledge. This paper presents many of these findings.

INTERACTION BETWEEN CROPS AND FERTILIZERS IN BANGLADESH SOILS

NPK Fertilizers

Fertilizer efficiency is determined primarily by the crop's growth rate and its nutrient demand, and, to a lesser extent, by the ability of the plant to compete effectively with other processes that draw off nutrients. By selecting an appropriate growth stage of the crop, the fertilizer can be applied when its uptake will provide maximum output. In most cases, each crop has a "grand period of growth" (GPG), which under optimum field and climatic conditions will draw heavily on the soil's nutrients. If there is a lack of required nutrients in the soil during this GPG, however, crop growth and development will be adversely affected. Thus timing of fertilizer application is a crucial element for success.

In a soil with low nitrogen (N) content, application of soluble N to the roots at planting time--basal application--will be more effective than a topdressing of N. Topdressing--scattering the fertilizer on the ground around the plant--is more efficient in high N soil where applications are made at certain intervals or growth stages of the crop. Table 1 illustrates the performance of a typical rainfed, broadcast Aus rice crop (under drought stress) when N fertilizer was applied at different growth stages of the crop. Better response was found either with two split applications (one basal application at the time of transplant and another at the time of panicle initiation) or with three "splits" (one at the early tillering stage, one at maximum tillering, and another at the panicle initiation stage). In deep-water rice (Table 2), there was practically no effect on yield due to any variation in timing or method of N application. Deep-water rice has a long life cycle (240-250 days) and thrives fairly well on the constant pool of soluble nutrients in the floodwater. Manufactured nitrogen application to rice under deep-water conditions tends to be ineffectual because the nitrogen is apt to escape in the form of ammonia gas, following conversion to ammonium bicarbonate in these typically alkaline waters. Transplanted (T.) Aman rice, on the other hand, shows variability in yield, dependent upon timing and quantity of nitrogen application (Table 3). Under wet season Boro conditions adequate N supply at the panicle initiation stage is critical in obtaining good yields (Table 4). Thus Tables 3 and 4 show that split applications of N covering the tillering and panicle initiation stages are effective. Also well established is the effect of seasonal variability on fertilizer response. Response to fertilizer is higher in the cooler but drier Rabi season, which has plenty of sunshine and fewer pests, provided there is no moisture deficit in the soil.

The crop's nutrient demands must be properly assessed in order to avoid losses. In Table 3 it seems that a much lower N dose can be applied on T. Aman rice to produce a fair yield, as revealed by treatment 7. In the case of wheat, the marginal increase in yield for each incremental increase in applied fertilizer was rather large --up to 80 kilograms per hectare--and it decreased at the highest rates (see Table 5). In Table 6, it is clear that high doses of nitrogen, phosphate, and potassium (NPK) with or without zinc (Zn) and sulfur (S) had little effect on either rainfed or irrigated wheat.

Different soil types also affect fertilizer response rates. For example, in gray and calcareous brown floodplains, wheat yields under rainfed conditions, which were given a dose of NPK of up to 60-60-0 kilograms per hectare, were only a little more than 2 tons per hectare in most locations, except at Raipura and Pakundia, where yields were higher (Table 7). When the N dosage was increased to 80-40-0 or 80-60-0, yields increased to at least 3.0 tons per hectare in three locations with gray floodplain soils and only one location with calcareous brown floodplain soils. In general, yields are distinctly lower on the calcareous soils deposited from the Ganges River alluvium. Even in the high rainfall areas of the lower Ganges Basin, soil alkalinity (pH) can be unexpectedly high. Unfortunately, alkaline soils with a pH above 7 will destabilize urea fertilization, releasing gaseous ammonia into the atmosphere. Also, if the N fertilizers are not incorporated into the soil, especially in the anaerobic zone of flooded soils, but are left on the soil surface, denitrification losses become an additional worry. Given these conditions, how much nitrogen is lost in the form of ammonia gas (volatilization) or nitrogen gas (denitrification) has not been properly assessed. Some quantitative work on nitrogen loss is presented at the end of this section.

Table 1--Effect of fertilizer application timing on yields of broadcast Aus rice

Rate and time of N application				
Basal	Early Tillering	Maximum Tillering	Panicle Initiation	Yield
	(kilograms/hectare)			(tons/hectare)
30	...	...	30	2.06
...	30	...	30	1.93
...	20	20	20	2.41
Control	...	...	...	1.66

Source: Field trials, Bangladesh Rice Research Institute, Joydebpur, 1981.

Notes: The variety of Aus rice tested was BR 203-26-2. The control application rate was 0-0-0; others received 60-40-40 kilograms/hectare of N, P_2O_5, and K_2O respectively.

Table 2--Effect of timing of N application on yields of deep-water rice

Treatment	Grain Yield
	(tons/hectare)
Control	1.73
Total N = 40 kilograms/hectare	
50 percent at basal and 50 percent before flooding	1.83
50 percent at basal and 50 percent in two foliar sprays after flooding	1.79
Four foliar sprays of 10 kilograms of N/hectare after flooding	1.64

Source: Field trials, Bangladesh Rice Research Institute, Habiganj, 1981.

Notes: The variety of rice tested was Aman IV. The control application was 0-0-0; others received 40-40-40 kilograms/hectare of N, P_2O_5, and K_2O respectively.

Table 3--Effect of timing and rates of N application on T. Aman yield

Treatment	Yield BRRI	 Jugitola	 Bariali	 Mean
	(tons/hectare)			
Basal @ 20 plus 2 topdressings each @ 20 = 60.	4.71	4.83	3.80	4.46
No basal, first topdressing @ 20 and second topdressing @ 30 = 50.	4.52	4.50	5.73	4.92
No basal, 3 topdressings each @ 20 = 60.	4.81	4.91	4.54	4.75
Basal plus 2 topdressings each @ 30 = 90.	4.70	4.47	3.96	4.38
No basal, 2 topdressings each @ 45 = 90.	5.04	5.37	4.15	4.85
No basal, 3 topdressings each @ 30 = 90.	4.78	5.19	4.40	4.79
No basal, 2 topdressings each @ 20 = 40.	4.53	4.56	3.87	4.32
Control (0-0-0).	3.74	4.26	3.27	3.76

Source: Field trials, Bangladesh Rice Research Institute, 1981.

Notes: The variety of T. Aman rice tested here was BR4. All the plots for this experiment seem to be quite fertile, as revealed by the yield of the control plot.

Table 4--Effect of timing of N application and transplanting date on Boro rice yields

Transplantation Date	Control	N 50 Percent Basal, 50 Percent at Panicle Initiation	 50 Percent at Mid-Tillering, 50 Percent 10 Days before Panicle Initiation
		(tons/hectare)	
January 24 (seedling age 45 days)	3.66	4.31	5.02
March 10 (seedling age 45 days)	3.50	4.22	4.74

Source: Field trials, Bangladesh Rice Research Institute, 1981.

Notes: The variety of Boro rice planted here is BR3. The application was 80-40-40 kilograms per hectare of N, P_2O_5, and K_2O respectively.

Table 5--Effect of N application rate on wheat yields

N Rate	Yield	Marginal Increase in Yield per Incremental Increase in Fertilizer
(kilograms/ hectare)	(tons/hectare)	(kilograms)
0	1.64	...
40	2.81	29
80	3.72	23
120	4.05	8
160	4.18	3

Source: Bangladesh Agricultural Research Institute, Wheat Production Manual, Agricultural Information Service and FAO/UNDP Project on Strengthening the Agricultural Extension Service (Dhaka: BARI, 1982).

Note: Estimated regression equation:

$$\text{Yield} = 1.66 + 1.35\ N - 0.18\ N^2.$$

Table 6--Wheat yield response to NPK, Zn, and S application

Nutrient Levels	Yield	
	Irrigated	Rainfed
(kilograms/hectare)	(tons /hectare)	
Control 0-0-0	2.9	1.09
(N) 60-0-0	3.4	1.26
(N) 120-0-0	3.8	1.76
(N-P) 120-80-0	4.0	2.05
120-80-60-30 (N-P-K-S)	4.0	2.16
120-80-60-30-4 (N-P-K-S-Zn)	4.1	2.29
180-80-60-30-4 (N-P-K-S-Zn)	4.2	2.48

Source: Bangladesh Agricultural Research Institute, Wheat Production Manual, Agricultural Information Service and FAO/UNDP Project on Strengthening the Agricultural Extension Service (Dhaka: BARI, 1982), p. 65.

Table 7--Wheat yield variation in different floodplains at various fertilizer doses

Soil Type/ Location	NPK Applied in Kilograms/Hectare								Least Significant Difference 1 percent
	0-0-0	40-40-0	60-40-0	60-60-0	80-40-0	80-60-0	80-60-20	80-60-40	
						(yield in tons/hectare)			
Gray floodplain									
Raipura	1.57	3.63	3.71	3.83	3.92	4.04	4.12	4.22	0.67
Pakundia	1.69	3.26	3.45	3.57	3.66	3.74	3.84	3.95	1.05
Polashbari	0.89	2.00	2.08	2.28	2.28	2.40	2.52	2.50	0.83
Gabtoli	1.51	2.05	2.27	2.46	2.58	2.76	2.98	3.40	1.39
Bhola	1.06	2.36	2.36	2.62	3.48	3.68	3.19	3.64	0.45
Barguna	1.22	2.21	2.56	2.48	2.52	2.08	2.14	2.87	0.96
Mean	1.32	2.58	2.74	2.87	3.08	3.12	3.13	3.41	...
Calcareous brown floodplain									
Sadarpur	1.08	1.80	1.94	2.13	2.17	2.17	2.95	3.22	0.30
Puthia	1.82	2.18	2.30	2.91	2.87	2.56	2.65	2.56	0.59
Khulna	1.39	2.57	3.00	2.81	3.03	2.96	3.06	3.30	0.51
Bagherpara	0.62	0.70	0.75	1.52	1.16	1.14	1.69	2.48	0.38
Mean	1.23	1.81	2.00	2.34	2.31	2.21	2.59	2.89	...
General mean	1.29	2.27	2.44	2.66	2.77	2.75	2.91	3.20	...

Source: Field trials, Bangladesh Agricultural Research Institute, Agronomy Division, 1983.

Phosphate (P) is the second major plant nutrient in the NPK fertilizer grade. The quality and early maturity of grain crops and healthy rooting systems has for many years been associated with adequate phosphate levels in the soil.

In general, application of phosphatic fertilizer is done at the final stage of land preparation in Bangladesh. In a study of 1,867 T. Aman farmers, triple superphosphate was found to be the most widely used fertilizer applied to their fields before transplanting.[1] Bangladesh Rice Research Institute (BRRI) varieties received less. Approximately 10-15 percent of the soil phosphorus is available to the crop. The residual P becomes fixed, particularly in lateritic soils, and it is released slowly over time.

Fertilizer demonstrations were conducted in 1981-82 and yield responses of rice to different nutrients including phosphorus were classified into low, medium, and high on the basis of their value-cost ratio (VCR) (see Figure 1).[2] This was estimated by dividing the value of the increase in yield attributed to fertilizers by the cost of fertilizer used. Yield response of rice to phosphorus is considered low when the VCR is less than 2, medium when it is between 2 and 4, and high when it is more than 4. For instance, VCR = 4 means a return of 4 taka for each taka invested in fertilizer.

The response of rice to a balanced dose of plant nutrients has been quite high. In fact, in the presence of added nitrogen, the uptake of phosphorus is increased. The improved availability of phosphorus may be due in part to the lowering of soil pH in the vicinity of the P fertilizer due to nitrification and root exudates. Table 8 shows some of the favorable effects of applying a balanced dose of NPK. For various socioeconomic reasons, Bangladesh farmers usually cannot apply the recommended balanced doses.

Potassium (K) is the third nutrient needed to complete the balance. K usually increases lodging and disease resistance, as well as photosynthesis rates, and it improves the taste and texture of grains and fruits.

Although potassium is usually available in sufficient amounts, it is suggested that minimal doses of muriate of potash (KCl) be

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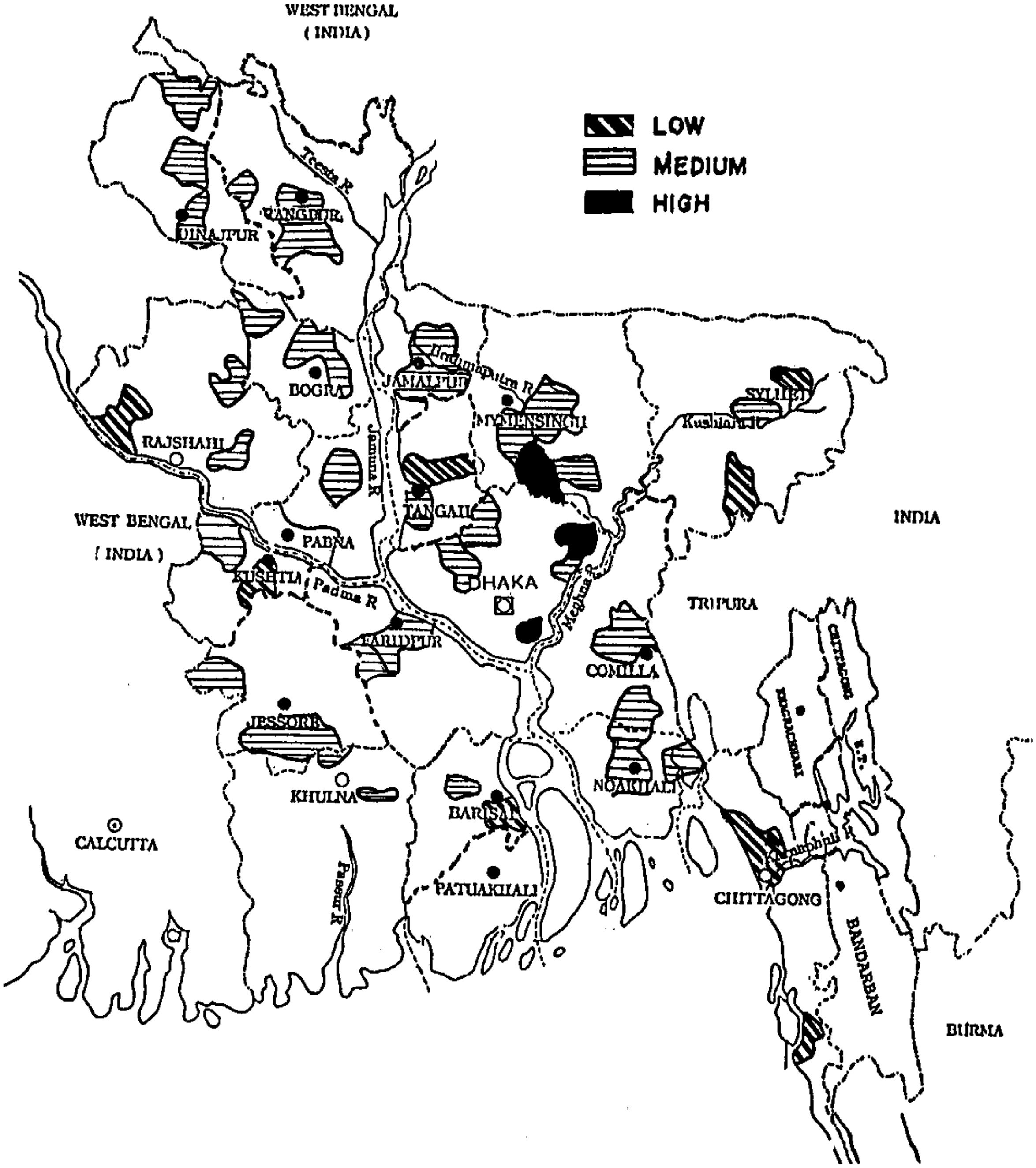
[1] M. S. Ahmad, <u>Studies on Methodology for Forecasting the Yield of Transplanted Aman Rice Based on Dates of Seeding and Transplanting in Bangladesh, 1983-84</u> (Joydebpur Gazipuri, Bangladesh: Bangladesh Rice Research Institute, June 1984).

[2] Bangladesh, Department of Agricultural Extension, Field Services Division, "Results of Fertilizer Demonstrations, 1981-82," report of the Fertilizer Demonstration and Distribution Project, BGD/80/002, Dhaka, 1984.

Figure 1--Yield response of rice to phosphorus



Source: Bangladesh Department of Agricultural Extension, Field Services Division, "Results of Fertilizer Demonstrations, 1981-82," Report of the Fertilizer Demonstration and Distribution Project, BGD/80/002 (Dhaka, 1984).

Table 8--Nutrients removed from soil by rice crops

NPK Applied				Nutrient Removed		
N	P_2O_5	K_2O	Rice Yield[a]	N	P_2O_5	K_2O
			(kilograms/hectare)			
0	0	0	3,029	45.13	11.42	65.43
60	0	0	3,994	59.51	15.06	86.27
0	40	0	3,381	50.38	12.75	73.03
0	0	40	3,264	48.63	12.31	70.50
60	40	0	4,119	61.37	15.53	88.97
0	40	40	3,652	54.41	13.77	78.88
60	0	40	3,981	59.32	15.01	85.99
60	40	40	4,142	61.72	15.62	89.47

Source: Bangladesh Rice Research Institute, Soil Chemistry Division.

[a] Average of 9 experiments.

applied as a preventive measure in maintaining present levels in parts of Khulna's gray calcareous floodplains and in Jessore, Kushtia, and Barisal's nonsaline tidal floodplains. In other areas, K deficiency can pose a problem, especially in the acidic and lateritic soils of Barind, Madhupur, the Lalmai hills, and other hilly areas. The light-textured soils of nonsaline and noncalcareous floodplains, such as those found in the Teesta floodplain around Thakurgaon, Debiganj, Domar, and Nilphamari all require potash applications. Usually K is added as basal application, but in light-textured soils, K is applied as a topdressing at the panicle initiation or heading stage (where the ripening stage is longer than 30 days) to give better results. A topdressing of K on T. Aman rice in the Domar-Debiganj area at the late tillering or panicle initiation stages will eliminate black spots on the grain and increase the quality of paddy.

Although K is subject to greater leaching in sandy soils than in clay soils, higher application rates are usually required on clay soils. For example, given 150 kilograms of applied K_2O per hectare, the exchangeable K level will increase to 10-15 milligrams K_2O per 100 grams in the rhizosphere (the root area) with an increase of K concentration in the soil solution of sandy soil of 0.5 milliequivalents per liter, in contrast to an increase in soil concentration in a clay soil of only 0.05 milliequivalents per liter.

The yield response to potash is affected by soil types, as can be seen by data on rice yields in Table 9. There is significant variation from locality to locality in the response of Aman to K fertilizer, but in general a higher response is found in gray terrace valley soils and gray floodplain soils than in calcareous brown floodplain soils. Significant response is found in Rangpur, Sujanagar, Fakirhat, Madhupur, Nachol, Sherpur (Bogra), Chirirbandar, and Phulbari. One unexpected finding was the inclusion of Sujanagar as a high-response area, although there seem to be high levels of available K (100 parts per million) there in comparison to other localities. It may be assumed that K uptake has been blocked in this area by factors such as K being fixed by certain types of clay or K+ ions in competition with NH_4^+ ions.

Yield response of irrigated wheat to K is, in general, moderate and soil type does not seem to explain much of the variability (Table 10). However, a significantly higher response to K can be seen in Madhupur, Fulbaria, Sujanagar, and Fakirhat. The above explanation for Sujanagar may explain this anomaly as well.

In Bangladesh, KCl is the most commonly used K fertilizer, especially on rice and wheat. Potassium sulfate is a much better fertilizer, supplying both K and S, but this more expensive product is rarely used. However, it is recommended where sulfur deficiency is a particular problem.

In summary, it would be useful to know annual loss rates of NPK under various agroecological conditions, cultural practices, and cropping systems. Unfortunately, this kind of information is not available. Present knowledge of how to reduce loss rates on N-fertilized fields is limited to the following points.

1. Split applications instead of a single application are recommended. In fertile soil, there is no need for basal application. The required N can be applied in appropriate stages of plant growth for maximum utilization.

2. Deep placement of N fertilizers in the rhizosphere normally improves N efficiency. The broadcast method without incorporation into the soil increases N loss.

3. Slow-release N fertilizers decrease N losses. Sulfur-coated urea and "super granules" are also better than normal pelleted or granulated urea for deep placement and slow release.

4. Soils with high pH will always accelerate N loss from all manufactured fertilizers applied, including urea, ammonium sulfate, diammonium phosphate (DAP), and similar products.

Table 9--Response of T. Aman rice yields to potash application

Soil Type	Location	Control Group 0-0-0	Pounds of Potash (K_2O) Applied					Least Significant Difference	
			0	20	40	60	80	5 Percent	1 Percent
					(maunds/acre)				
Gray floodplain	Rangpur (44.0)	27.67	30.50	32.67	34.42	35.50	36.83	1.36	1.93
	Kaunia (17.0)	18.83	26.00	29.67	29.67	32.42	31.83	2.56	5.65
	Mean (30.5)	23.25	28.25	31.17	32.05	33.96	34.33	...	...
Calcareous brown floodplain	Sujanagar (100.0)	29.66	51.30	54.85	57.96	59.71	59.94	1.17	1.62
	Fakirhat (20.0)	20.17	20.00	27.08	33.17	24.33	29.83	3.26	4.63
	Jessore (38.0)	14.50	22.00	24.50	26.67	24.00	23.67	3.43	4.88
	Mirpur (20.0)	27.92	56.92	56.58	60.00	58.17	57.33	2.92	4.15
	Mean (44.5)	23.06	37.56	40.75	44.45	41.55	42.69	...	...
Shallow red-brown terrace soil	Madhupur (24.0)	16.88	26.88	29.50	30.75	32.63	33.50	0.98	1.36
Gray terrace and valley soil	Nachol (16.0)	39.38	47.49	52.25	54.56	56.38	59.88	1.64	2.27
	Patnitola (27.0)	25.61	32.82	33.23	34.79	35.93	36.37	0.79	1.09
	Sherpur (28.0)	19.04	28.18	32.00	33.70	35.54	36.48	2.07	2.95
	Adamdighi (34.0)	25.86	40.67	42.57	44.73	46.57	47.74	0.21	0.30
	Chirir Bandar (38.0)	23.67	42.00	46.33	49.50	49.83	56.17	0.36	0.51
	Phulbari (20.0)	22.66	36.58	37.41	37.83	37.41	37.66	0.58	0.88
	Mean (36.4)	25.48	37.96	40.80	42.72	43.91	44.50	...	...
General mean (37.0)		23.85	35.66	38.59	40.83	41.01	42.46	...	...
Percent increase over 0 pounds of K_2O		...	...	8.22	14.50	15.00	19.10	...	...
Mean K_2O response		...	...	12.01	10.60	7.32	6.97	...	...

Source: Bangladesh Agricultural Research Institute, On-Farm Research Division, in Bangladesh Agricultural Research Council, Second Annual Report: Coordinated Soil Test Crop Response Correlation Studies, 1981-82, Soils and Irrigation Publication No. 13 (Dhaka: BARC, 1983).

Notes: N application rate = 80 pounds/acre; P_2O_5 rate = 60 pounds/acre.
Figures in parentheses indicate potassium (K) level in parts per million.
1 maund = approximately 37 kilograms.

Table 10--Response of irrigated wheat yields to potash in 50 trials

Soil Type	Location	Control Group	Kilograms of Potash (K_2O) Applied per Hectare				Least Significant Difference	
			0	20	40	60	5 Percent	1 Percent
			(tons/hectare)					
Gray floodplain	Narsingdi (50.0)	1.16	2.33	2.38	2.42	2.46	0.008	0.012
	Fulbaria (36.0)	1.33	3.58	3.77	3.97	4.07	0.055	0.082
	Tangail (38.0)	1.20	2.05	2.25	2.35	2.53	0.162	0.236
	Barguna (109.0)	0.92	1.75	1.93	2.05	1.93	0.558	0.813
	Rangpur (44.0)	2.33	3.17	3.42	3.42	3.33	0.494	0.719
	Mean (55.0)	1.18	2.15	2.30	2.39	2.41	...	...
Calcareous brown floodplain	Sujanagar (190.0)	1.53	2.40	3.11	3.78	4.43	0.382	0.537
	Fakirhat (86.0)	1.26	2.47	3.04	3.28	3.17	0.205	0.298
	Jessore (121.0)	1.09	2.65	2.76	2.76	2.85	0.053	0.077
	Bheramara (96.0)	0.52	1.96	2.18	2.55	2.99	0.197	0.027
	Chuadanga (154.0)	1.12	2.00	1.91	2.17	1.82	0.568	0.827
	Mean (129.0)	1.10	2.30	2.60	2.91	3.05	...	...
Shallow red-brown terrace soil	Madhupur (33.0)	1.36	2.55	2.95	3.31	3.97	0.102	0.144
Gray terrace and valley soils	Adamdighi (24.0)	1.04	2.82	2.98	3.00	2.92	0.020	0.029
	Kahaloo (52.0)	0.96	2.73	2.83	2.94	2.85	0.047	0.069
	Parbatipur (60.0)	0.89	1.52	1.60	2.42	2.56	0.465	0.670
	Mean (42.0)	0.96	2.36	2.44	2.78	2.78	...	...
General mean (75.0)		1.20	2.41	2.62	2.86	2.95	...	...
Percent increase over 0 kilograms of K_2O		...	...	8.90	18.90	22.50	...	...
Mean K-response of kilograms of grain/kilograms K		...	...	10.75	11.38	9.05	...	...

Source: Bangladesh Agricultural Research Institute, On-Farm Research Division, in Bangladesh Agricultural Research Council, Second Annual Report: Coordinated Soil Test Crop Response Correlation Studies, 1981-82, Soils and Irrigation Publication No. 13 (Dhaka: BARC, 1983).

Notes: N application rate = 100 kilograms/hectare; P_2O_5 rate = 60 kilograms/hectare.
Figures in parentheses indicate potassium (K) level in parts per million.

5. Use of urea, ammonium sulfate, and DAP in upland conditions enhances nitrate formation and thus N loss through leaching. Band placement or plow sole application at planting time are not practiced in Bangladesh. The usual method of broadcasting urea is only about 50 percent efficient. In fact, the mean efficiency of urea N is about 30 percent under upland rainfed conditions. Under transplanting conditions with good water management, the N loss can be reduced and the efficiency of N uptake can be increased to about 50 percent.

6. A low content of organic matter in the soil also accelerates N loss.

7. Low sulfur and zinc levels decrease N uptake.

8. Continuous waterlogging seriously affects N uptake.

9. Loss of organic P exacerbates the problems of deficiency from P fertilizer fixation. Organic P loss could be decreased by recycling human and animal bones in crop fields. Instead, Moslems and Christians bury their dead in graveyards and Hindus burn their dead, throwing the ashes in rivers where they ultimately find their way to the sea. Animal bones are mostly exported. Conscious efforts to replace phosphates can help to build up reserves in the soil.

At present, quantitative information about NPK utilization from BRRI's Soil Chemistry Division has been used to develop a balance sheet for rice (Tables 11 to 13) and wheat (Table 14). For example, column 3 of Table 13 indicates that the opening balance of N, P, and K for the next crop will be 57, 79, and 61 percent, respectively, of the native nutrient stock originally present in the soil. If depletion continues at this rate, N and K will be in deficit after one more crop is harvested, and P would last for three more crops. This is only a rough estimate, and because NPK uptake is a complex process, recommendations should be based upon other factors as well.

Sulfur and Zinc Deficient Soils

Sulfur is now considered to be the fourth major element vitally needed for crop production. Unfortunately, the stress on single element fertilizers, disregarding ammonium sulfate, single and double superphosphates, and potassium sulfate has led to problems of S deficiency. Commonly used higher analysis fertilizers such as urea, triple superphosphate (TSP), and DAP, and cheap but lower analysis KCl are all devoid of sulfur. Further consideration should be given to the possibility of using sulfuric acid in phosphate fertilizer manufacturing processes to provide an adequate amount of S to soils at recommended phosphate application rates.

Table 11--Nutrients removed by rice crops, 1981/82

Rice Crop	Area	Nutrients Removed N	Nutrients Removed P_2O_5	Nutrients Removed K_2O
	(1,000 hectares)	(1,000 metric tons)		
Aus				
Local	2,674	219.27	61.50	328.90
HYV	472	39.65	11.80	69.38
Subtotal	3,146	258.92	73.30	398.28
B. Aman				
Local	1,586	130.05	36.48	195.08
T. Aman				
Local	3,460	283.72	79.85	425.58
HYV	956	80.30	23.90	140.53
Subtotal	6,002	494.07	139.96	760.19
Boro				
Local	405	33.21	9.32	49.82
HYV	898	75.43	22.45	132.01
Subtotal	1,303	108.64	31.77	181.83
Total	10,451	861.63	245.03	1,340.30

Source: Bangladesh Rice Research Institute.

Table 12--Nutrients supplied to all crops, 1981/82

Fertilizer		Nutrient		
Type	Amount Applied	N	P_2O_5	K_2O
		(metric tons)		
Urea	527,000	237,193	...	...
Diammonium phosphate	80,000	14,400	33,600	...
Triple superphosphate	211,830	...	88,969	...
Muriate of potash	45,560	...	...	27,336
Total		251,595	122,569	27,336
Ratio, $N:P_2O_5:K_2O$		9.20	4.48	1.00
75 percent of nutrients		188,696	91,927	20,502

Source: Bangladesh Rice Research Institute.

Note: The fertilizer application data in this table refer to application on all crops, most but not all of which is actually applied to paddy soils. In this table, 75 percent of fertilizers are assumed to have been applied to paddy in 1981/82. In Mahabub Hossain's paper in this volume (Table 9), estimates of 79.3 percent (1977/78) and 81.3 percent (1983/84) were made.

Table 13--NPK balance sheet for rice crops

Nutrients	Removed by the Rice Crop (1)	Native Nutrient Content in the Soil[a] (2)	Nutrients Added[b] (3)	Total Soil Stock (2+3)	Balance in the Soil (2+3)-1
			(1,000 metric tons)		
N	861.63	1,575.3	188.70	1,764.00	902.37
P_2O_5	245.03	869.5	91.93	961.43	716.40
K_2O	1,340.30	3,414.0	20.51	3,434.51	2,094.21

Source: Data obtained from Bangladesh Rice Research Institute, Soil Chemistry Division.

[a] The native nutrient content in the soil has been taken from the mean of control and others where those respective nutrients were added. The totals of N, P_2O_5, and K_2O used under such conditions without addition of N, P_2O_5, K_2O are respectively 45.22, 24.96, and 98.00. These figures represent about 30 percent of the total soil stock, as shown in Column 3.

[b] Total chemical fertilizer application (for all crops) is used for the computation; however, organic manure application has not been estimated.

Table 14--NPK balance sheet for a wheat area of 513,200 hectares

Nutrients	Nutrients Removed from the Soil	Native Nutrients in the Soil	Nutrients Added	Total	Balance
			(1,000 metric tons)		
N	48.75	52.35	56.57	108.92	60.17
P_2O_5	12.32	32.84	49.60	82.44	70.12
K_2O	70.82	92.38	91.88	184.26	113.44

Source: Data obtained from S. M. Elias and M. S. Hussain, Wheat Production in Bangladesh - Socio-economic Assessment of Improved Technology and Identification of Constraints to Higher Production (Dhaka: Bangladesh Agricultural Research Institute, Division of Agricultural Economics, 1983).

Notes: Mean fertilizer used per hectare: urea, 127 kilograms; TSP, 129 kilograms; MP, 33 kilograms; organic manure, 5,448 kilograms. These figures exceeded estimated application in all recent years.

S is a component of plant protein, and most crops need as much sulfur as phosphorus. In general, a constant proportion of N to S (15:1) is found in plant protein. The S content in field crops varies from 13 to 96 kilograms per hectare, and the percent of S removed when the crop is harvested also varies from 23 to 56 percent of S available per hectare.

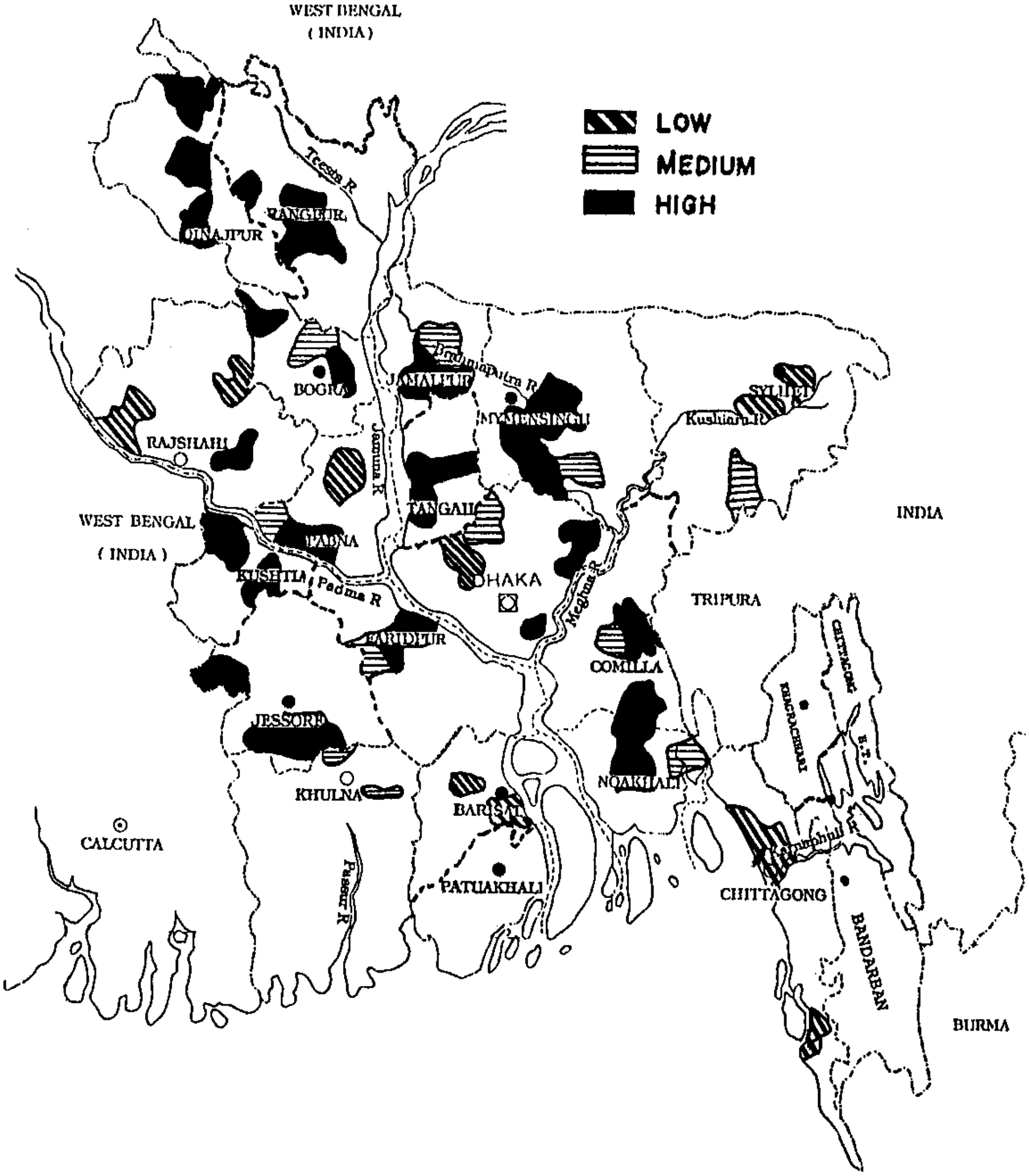
The main forms of S in the soil are the inorganic sulfates and the S in organic compounds. Sulfate in the soil solution available to plants is the product of the interaction of adsorption and leaching losses. S availability is similar to that of N. Organic S acts as a reserve. It undergoes transformation to the sulfate form by microbial action, which depends on a temperature of 40°C, soil moisture at 60 percent of field capacity, pH, numbers and types of soil organisms, and oxygen. Mineralization of S from its organic form occurs when the S content is close to 0.15 percent.

Although S deficiencies are difficult to detect with soil tests, it seems that approximately 3 million acres exhibit S deficiency (Figure 2). The heavier clay soils of the northern districts, Madhupur and Lalmai hill soils, tend to be S deficient. S deficiency is the ultimate result of improper agricultural practices and soil exploitation, such as constant removal of crops with residue where cropping intensity is high, constant loss of soil organic matter, S loss from leaching and erosion, and use of higher analysis fertilizers.

The S requirement for a crop can be estimated on the basis of either its N or P requirement. One unit of S for 5-7 units of N may be used. The standard formula is one unit of S for every three units of P_2O_5. An N:S ratio of 10 is a more reliable index when both N and P are essential. This rule of thumb would underestimate the S requirement where low rates of N and P are applied. Additional experimental trials would have to be conducted to determine the correct dosage. For crops with very high yields, the S requirement increases and the proportion of S to N may be as high as 1:5 or 1:7.

Cultural practices can be modified to deal with problems of S deficiency. In order to get the best response from S applications, especially in rice cultivation, a waterlogged soil must be avoided, particularly in the Boro season. Where a Boro crop must be grown, the date of transplanting must be shifted to late February or March so that the soil is thoroughly dried by the sun after the T. Aman harvest. In some cases such a practice improves the availability of soil S. The practice of drying the soil prior to panicle initiation is also desirable in increasing S uptake efficiency. On the other hand, when the soil is waterlogged for about 115-125 days, the S availability will decrease to an almost critical level.

Figure 2--Yield response of rice to sulfur



Source: Bangladesh Department of Agricultural Extension, Field Services Division, <u>Results of Fertilizer Demonstrations, 1981-82</u>, report of the Fertilizer Demonstration and Distribution Project, BGD/80/002 (Dhaka, 1984).

Note: Data were obtained from 1,182 demonstration sites in 31 thanas. The unmarked areas were not tested. Rice data were aggregated over the Aus, T. Aman, and Boro seasons on the map, but disaggregated results are presented in the report tables. Sulfur was applied in the form of gypsum.

Standard sulfate fertilizers and their S content are listed below.

Fertilizer	S Content (percent)	S (kilograms per ton)
Ammonium sulfate	23.7	243.0
Ammonium nitrate sulfate	5.0	50.0
Ammonium phosphate sulfate	15.4	155.0
Ammonium sulfate nitrate	15.1	121.0
Superphosphate	12-14	140.0
Potassium sulfate	17-18	176.0
Gypsum, $CaSO_4$ $2H_2O$	18-19	186.0
Ferrous sulfate	18-19	186.0
Poultry droppings	1.1	11.0
Zinc sulfate, 36.4 percent Zn	17.8	178.0
Urea - gypsum, $CaSO_4 + 4CO(NH_2)_2$	14.8	148.0
Urea sulfur, $CO(NH_2)_2 + S$	10.0	100.0

The last two compounds can be prepared by adding gypsum to urea or S to urea. Possible sources of S supply will be discussed at the end of this section. Oilcakes also contain S and can be used safely where the S requirement is low. They also make good organic manure for almost all crops.

The response of wheat yields to S application is shown in Tables 15 and 16. Table 15 indicates a slight response to S at an NPKS dose

Table 15--Wheat yield response to NPK, S, and Zn

Treatment	Yields With Irrigation Rajbari	Yields With Irrigation Jessore	Yields Without Irrigation Rajbari	Yields Without Irrigation Jessore
	(tons/hectare)			
Control	1.86	1.39	1.92	1.09
N_1 (60)	3.20	2.50	2.73	1.26
N_2 (120)	3.56	2.38	3.34	1.76
N_2P (120-80)	3.71	2.50	3.40	2.05
N_2PK (120-80-60)	3.70	2.59	3.42	2.16
N_2PKS (120-80-60-30)	4.16	3.74	3.52	2.29
N_2PKSZn (120-80-60-30-4)	4.27	2.97	3.57	2.31
N_3PKSZn (180-80-60-30-4)	4.40	2.15	3.63	2.48
LSD 5%	0.93	0.43	1.02	0.25

Source: Bangladesh Agricultural Research Institute, Annual Report, 1980-81 (Joydebpur: BARI, 1982).

Notes: N_1 = 60 kilograms/hectare, N_2 = 120 kilograms/hectare, and N_3 = 180 kilograms/hectare; P = 80 kilograms/hectare; K = 60 kilograms/hectare; S = 30 kilograms/hectare; and Zn = 4 kilograms/hectare. LSD = least significant difference.

Table 16--Wheat yield response to NPKS

Floodplain Soil Type	Location	NPKS Application Rates									Least Significant Difference	
		0-0-0	60-40-0	80-40-0	100-40-0	80-60-0	100-60-0	120-60-0	100-60-0	100-60-40-30S[a]	5 Percent	1 Percent
		(yield in tons/hectare)										
Gray	Kaliganj	1.60	2.85	3.12	3.22	3.37	3.58	3.55	3.70	4.08	0.140	0.193
	Bhairab	1.97	3.49	3.53	3.59	3.53	3.60	3.61	3.65	3.70	0.035	0.048
	Chowddagram	1.42	2.21	2.32	2.43	2.63	2.71	2.78	2.89	2.97	0.130	0.180
	Mean	1.66	2.85	2.99	3.08	3.18	3.30	3.31	3.41	3.58		
Non-calcareous brown	Dinajpur (Kotwali)	1.91	3.43	3.78	5.00	3.96	3.99	3.78	4.31	3.97	0.250	0.240
	Boda	1.37	2.50	3.04	3.30	3.37	3.63	3.76	3.67	3.86	0.407	0.561
	Mean	1.64	2.97	3.41	4.15	3.67	3.81	3.77	3.99	3.92		
Calcareous brown	Kaliganj	1.56	2.44	2.97	3.07	3.67	4.00	4.12	3.94	4.50	0.157	0.216
General mean		1.64	2.82	3.13	3.43	3.42	3.59	3.60	3.69	3.85	...	...

Source: Results from Bangladesh Agricultural Research Institute, On-Farm Research Division, 1982/83.

Note: NPK application rates are given in kilograms per hectare.

[a] 30 S = 30 kilograms of sulfur per hectare.

of 120-80-60-30 kilograms per hectare (with low statistical significance) at both locations under both rainfed and irrigated conditions. Where N is high, S uptake from soil usually increases. This may satisfactorily meet a plant's requirements. A similar situation is revealed by the data in Table 16.

At 80 kilograms of N per hectare, the rice yields increase to 6.04 tons per hectare for the variety BR3 but not for BR11 (Table 17). The addition of P, K, S, or Zn did not affect the yield significantly, except for BR11 where yield increased by about 0.65 tons per hectare with the application of 200 kilograms of gypsum (36-38 kilograms of S per hectare). Table 18 provides data on the effects of NPKS and Zn on rice at various locations. There was a significant yield increase with the application of S and Zn on T. Aus and Boro rice at Narsingdi and Godagari, and on T. Aus and T. Aman rice in Jessore. Research conducted by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) with the cooperation of BRRI and Bangladesh Agricultural Research Institute (BARI) shows a significant yield response to S on rice at different locations. Based on this research, Figure 3 identifies the location of thanas in which low, medium, and high response rates to S in rice production were recorded, with results aggregated across seasons and test sites within each thana.

Table 17--Rice yield response to NPK with and without Zn, S, and manure

Fertilizer Rate						Yield	
N	P_2O_5	K_2O	Gypsum	$ZnSO_4$	Cow Dung	BR3 (Boro)	BR11 (T. Aman)
(kilograms/hectare)						(tons/hectare)	
0	0	0	0	0	0	3.42	2.99
80	0	0	0	0	0	6.04	4.43
0	60	40	0	0	0	4.03	2.95
80	60	40	0	0	0	6.08	4.56
80	60	40	200	0	0	6.17	5.21
80	60	40	0	20	0	6.48	4.71
80	60	40	200	20	0	6.12	4.71
0	0	0	0	0	20	4.46	3.40

Source: Bangladesh Rice Research Institute, "Internal Review, Section XV," Dhaka, 1982.

Table 18--Yield response on transplanted Aus, Boro, and transplanted Aman rice crops to NPKS and Zn

Treatment	Narsingdi			Kishoreganj			Godagari			Jessore and Kotwali		
	T. Aus	Boro	T. Aman	T. Aus	Boro	T. Aman	T. Aus	Boro	T. Aman	T. Aus	Boro	T. Aman
	(tons/hectare)											
0-0-0	3.16	4.04	2.32	3.74	3.05	2.68	2.64	3.90	2.53	3.52	6.02	3.36
N_1	3.92	5.70	2.44	5.73	4.07	3.12	2.93	4.40	2.83	3.78	6.54	3.99
N_2	4.29	6.86	2.51	6.19	4.10	3.31	2.69	4.83	3.02	3.98	7.33	4.16
N_2P	4.73	7.15	2.64	6.60	4.32	3.33	2.95	5.59	3.23	4.10	7.50	4.27
N_2PK	5.14	6.98	2.75	6.81	4.76	3.69	3.41	5.91	3.52	4.24	7.77	4.46
N_2PKS	5.62	7.19	3.31	6.95	4.18	4.19	3.40	6.69	3.84	4.40	8.10	5.05
N_2PKSZn	6.28	8.08	3.15	7.08	5.12	4.34	3.58	6.86	3.70	5.39	8.39	5.48
N_3PKSZn	5.73	7.96	3.36	6.62	5.09	4.72	3.44	5.80	3.33	5.45	8.66	5.89
LSD, 5 percent[a]	0.25	1.00	0.19	0.17	0.51	0.42	0.10	0.13	0.13	0.10	0.34	0.22

Source: Results of tests conducted by Bangladesh Agricultural Research Institute, On-Farm Research Division, 1981.

Notes: The yield responses above were obtained with the following applications of chemicals. (These are weights of active ingredients, not of the fertilizer mixture itself.) Phosphorus was applied in the form of P_2O_5 and potassium in the form of K_2O.

Chemical	On T. Aus	On Boro	On T. Aman
	(kilograms/hectare)		
N_1	60	60	45
N_2	120	120	90
N_3	135	180	135
P	80	80	80
K	60	60	60
S	30	30	30
Zn	8	8	8

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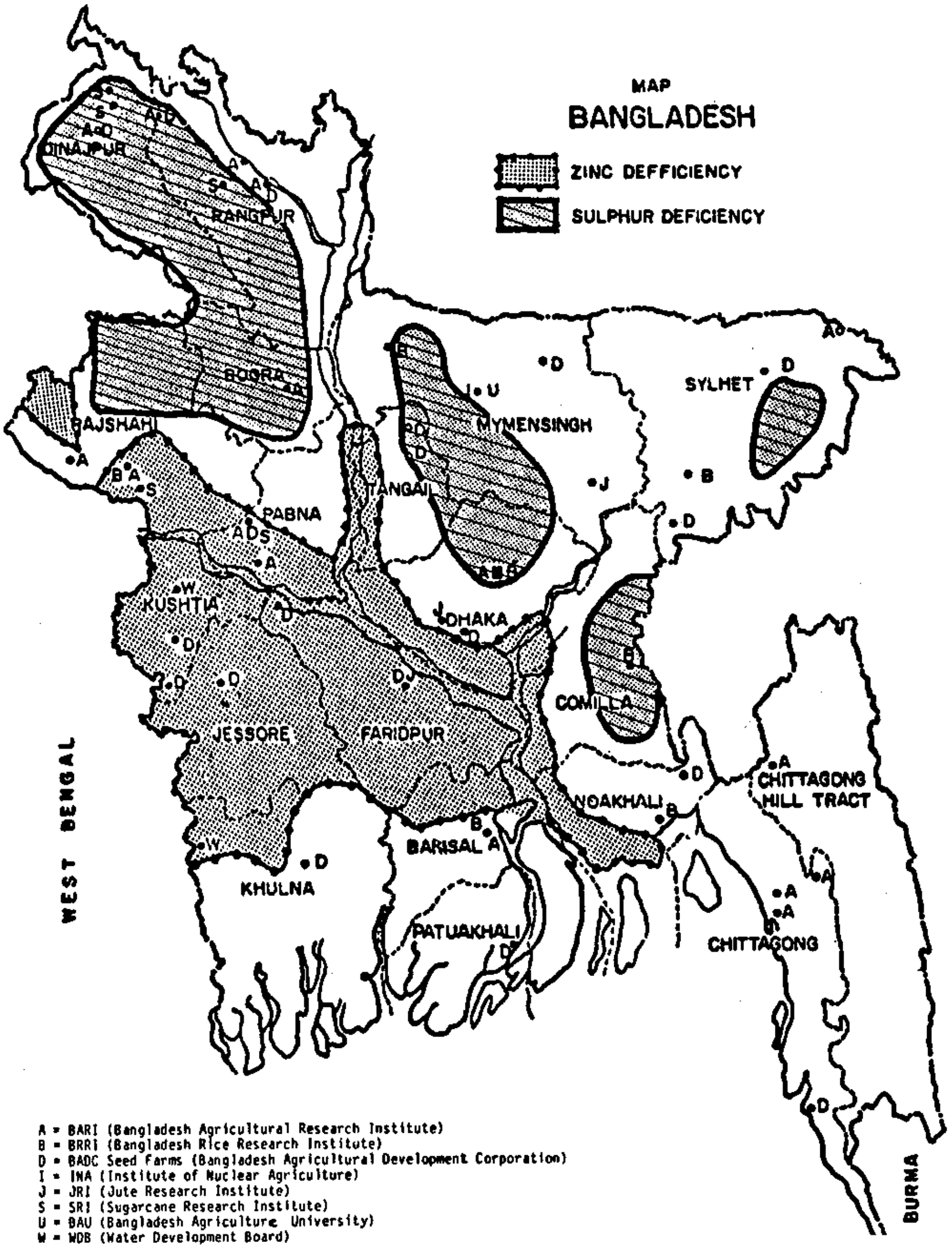
[a] LSD refers to a least significant difference.

Figure 3--Zinc and sulfur deficiencies in Bangladesh



Note: Some overlap of sulfur- and zinc-deficient areas may occur and response tests prove to be positive in areas not accounted for as being deficient, as outlined on this map. This map is more general in that it shows sulfur-deficient soils in the northern and central districts rather than in the coastal areas, and zinc-deficient soils in the deeply flooded areas rather than in well-drained areas.

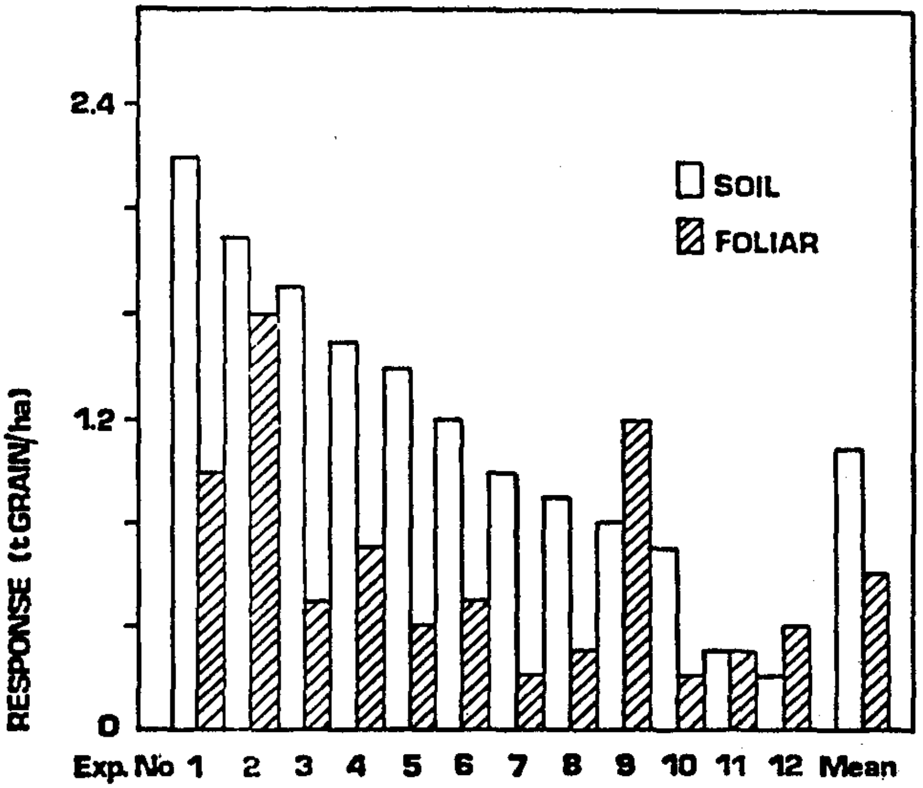
Among the micronutrients, Zn, iron (Fe), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), and cobalt (Co) play a vital role. Under certain conditions, sodium (Na), silicon (Si), and vanadium (V) have been found to be important for some plant species. However, at present in Bangladesh, adequate survey work has only been done on Zn. Approximately 4 million acres are thought to be deficient in Zn, as shown in Figure 2. The soils of the Gangetic alluvium and those near the banks of other major rivers exhibit Zn deficiency.

Zn is not required in large amounts to meet a plant's needs, but it can become the limiting factor affecting yields. In a 10-ton rice crop (5 tons of grain and 5 tons of straw), the nitrogen content may be 105-110 kilograms whereas the Zn content may be limited to a maximum of 250 grams. This is just 0.25 percent of the nitrogen requirement. Nevertheless, if the Zn content in the soil is low (less than 20 parts per million) the plant cannot meet its Zn requirement and the yield is drastically reduced. In the case of severe Zn deficiency, the yield may be as low as zero.

Zinc availability decreases with increasing soil pH. Thus, Zn toxicity, although not common in plants, can be treated with adequate applications of lime. Other factors that affect availability include soil texture, soil moisture status, temperature, organic matter, and the interaction of other nutrients. Zn deficiency is commonly found in calcareous, alkaline, and saline soils where the pH may be greater than 6.0. Liming can retard Zn availability if it increases the soil pH above 6.0. High levels of organic matter in the soil usually increase Zn availability. Also, light-textured soils with low organic matter usually are prone to Zn deficiency. Low soil temperatures and high levels of P applications may also induce Zn deficiency, especially on calcareous soils.

The effect of Zn on wheat yields is shown in Table 15. A combination of NPKS and Zn increased wheat yields to a level of approximately 4 tons per hectare, and yet even in these Zn deficient areas the profitability of applying Zn is not totally convincing given the results shown. Large experimental error may be the cause for such results. The response of wheat to soil and foliar application of Zn (10 kilograms of Zn per hectare and 1.5 kilograms of Zn per hectare respectively) are evident in India (Figure 4). The response of rice to Zn fertilization is shown in Tables 19 and 20. Approximately 6.9 tons per hectare of BR3 could be obtained by the application of 20 kilograms of Zn per hectare. It seems that BR11 gave a lower yield for other reasons. At a high level of N (80 kilograms per hectare) rice can use Zn more efficiently. At Tebunia, Zn applications to the soil and in foliar form produced higher yields than at Gournadi (Table 19). About a 100 percent yield increase was

Figure 4--Response of wheat to soil and foliar application of zinc in India



Notes: Soil application = 10 kilograms Zn per hectare; foliar application = 1.5 kilograms Zn per hectare.

Table 19--Rice yield response to zinc

Treatment	Grain Yield: Tebunia Seed Multiplication Farm Pabna (BR3)	Grain Yield: Gournadi Barisal (IR8)
	(tons/hectare)	
Control	5.51	2.96
Root dipped in 2 percent ZnO suspension	5.93	3.29
$ZnSO_4$ 10 kilograms/ hectare	7.06	3.38
$ZnSO_4$ 20 kilograms/ hectare	6.89	3.48
$ZnSO_4$ 0.5 percent foliar spray	5.60	3.21
1 gallon/hectare zinc chelate spray	6.20	3.42
Coefficient of variation	9.00	10.00

Source: Bangladesh Rice Research Institute, "Internal Review, Section XV," Dhaka, 1982.

Note: BR3 and IR8 designate specific rice varieties planted for the experiment.

Table 20--Mean rice yields with and without NPK or zinc

Treatment: Zn	Treatment: NPK	Grain Yield
		(tons/hectare)
No	No	2.2
No	Yes	2.4
Yes	No	4.5
Yes	Yes	4.7

Source: J. C. Katyal and N. S. Randhawa, "Micronutrients," _FAO Fertilizer and Plant Nutrition Bulletin No. 7_ (Rome: FAO, 1983).

Note: This table is based on data from eight farmers' fields.

obtained for rice through Zn applications by Katyal and Randhawa (Table 20). Figure 5 shows three levels (low, medium, and high) of yield response of T. Aman rice to Zn applications among various thana in Bangladesh where tests were conducted. The economics of Zn fertilization of wheat and rice crops in India are impressive, as shown in Figure 6. The data upon which this figure is based imply an input-output ratio of 1:6. Assuming similar input prices and higher output prices in Bangladesh, the input-output ratio is expected to be even greater.

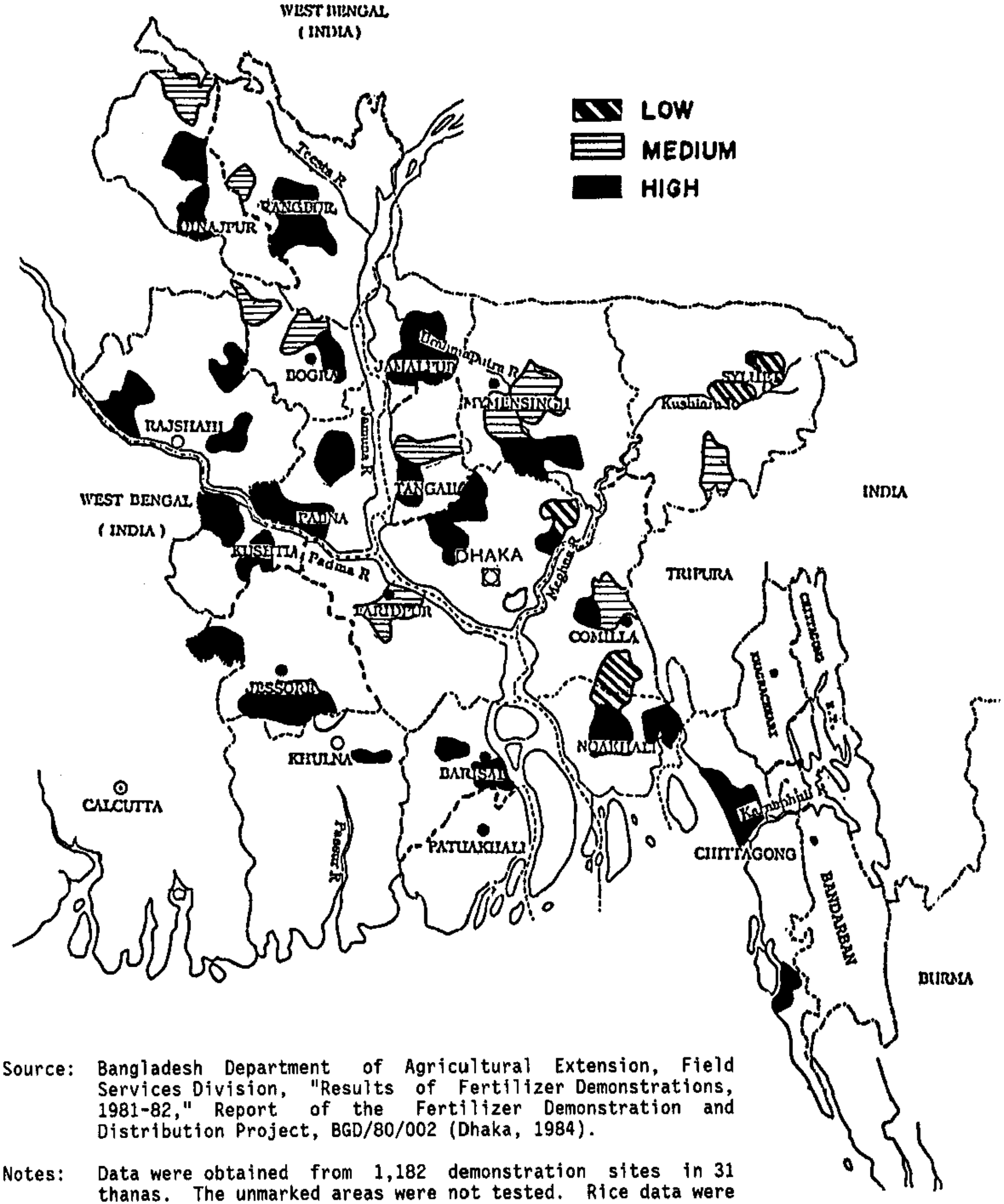
Typical Zn-containing fertilizers are listed in Table 21. Zinc sulfate may be the most effective Zn compound because it combines high analysis (36 percent Zn) with water solubility and therefore may be broadcast with reasonable effectiveness. The roots of rice seedlings can be dipped in Zn oxide. Zn oxide and Zn metallic powder can be broadcast as basal fertilizers. Because these Zn compounds are not water soluble, their effects are slower than those of water soluble ones. Foliar sprays are effective, especially synthetic chelates. The current application levels of S and Zn are not up to standard because extension and field demonstration work is inadequate. The Bangladesh Agricultural Development Corporation (BADC) needs to take a bold step to supply adequate quantities of gypsum ($CaSO_4$) and Zn compounds. The following are tentative requirements for solving the Zn-S deficiency problem.

Element	Approximate Affected Area (million acres)	(million hectares)	Total Requirement Based on Total Area (tons)
S	3.0	1.2	180,000 gypsum
Zn	4.0	1.6	20,000 commercial $ZnSO_4$

The gypsum will be required every third year, as the residual effect of S lasts about two years.

The total gypsum estimated requirement is available at the TSP factory in Chittagong as a by-product of TSP manufacturing. Because gypsum often damages jute bags, its acid content can be reduced by subjecting it to normal rainfall, dehydrating it during winter, and then bagging it. At distribution points, the fertilizer can be stacked in heaps under an ordinary shed. Farmers can pick up the gypsum using their own containers. Used urea bags or any plastic bags will do. Gypsum, when properly used, can supply S for about two years. Therefore, every third year gypsum should be used at the rate of about 60 kilograms per acre (150 kilograms per hectare). Based on this rate, the total gypsum requirement would be about 180,000 tons every three years. At least 10 percent of this requirement should be

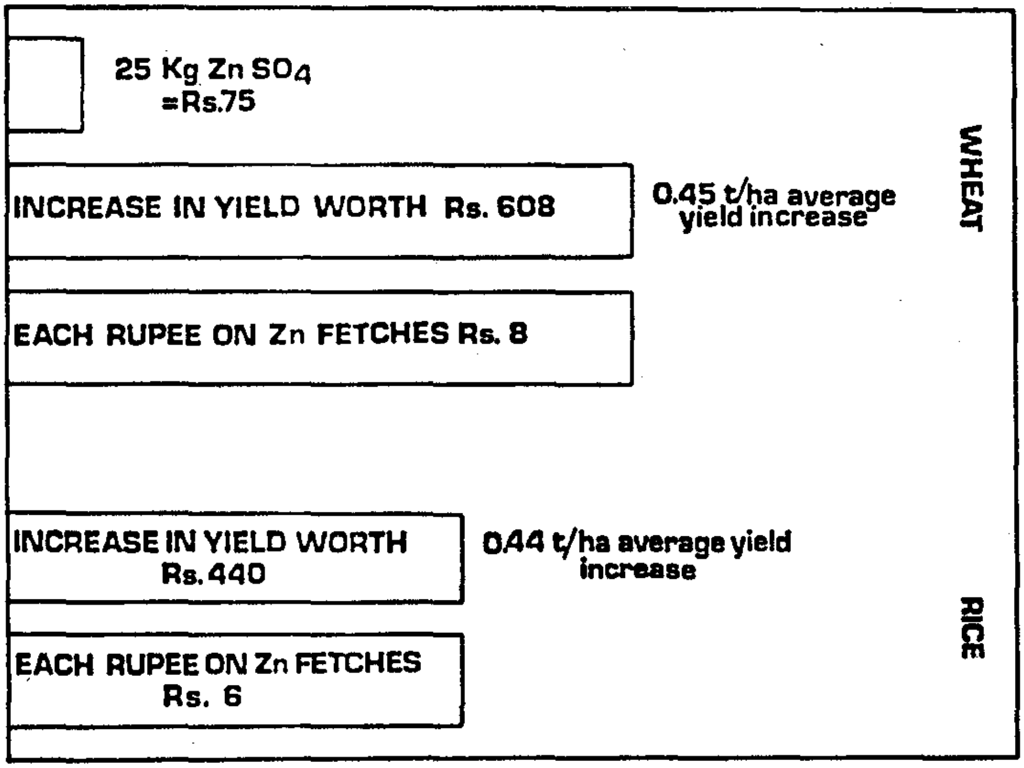
Figure 5--Yield response of rice to zinc



Source: Bangladesh Department of Agricultural Extension, Field Services Division, "Results of Fertilizer Demonstrations, 1981-82," Report of the Fertilizer Demonstration and Distribution Project, BGD/80/002 (Dhaka, 1984).

Notes: Data were obtained from 1,182 demonstration sites in 31 thanas. The unmarked areas were not tested. Rice data were aggregated over the Aus, T. Aman, and Boro season on this map, but disaggregated results are presented in the report tables. The Zn response is not totally clear because Zn was applied in the form of zinc sulfate on the T. Aman crops, which accounted for 56 percent of the demonstration sites, and thus sulfur response could have biased the results. The remaining sites applied Zn in the form of zinc oxide.

Figure 6--Economics of zinc fertilization in India, 1981



Note: U.S. $ = Rs 10.

Table 21--Fertilizers and other usable materials containing zinc

Common/Trade Name	Chemical Formula	Zinc Percentage
Zinc sulfate	$ZnSO_4 \cdot 7H_2O$	23.0
Zinc sulfate	$ZnSO_4 \cdot H_2O$	36.0
Zinc oxide	ZnO	60-80
Zinc chloride	$ZnCl_2$	45-52
Zinc carbonate	$ZnCO_3$	56.0
Zinc oxide sulfate	$ZnO \cdot ZnSO_4$	55.0
Zinc ammonium phosphate	$Zn(NH_4)PO_4$	37.0
Sphalerite	ZnS	60.0
Zinc dust	Zn	99.8
Zinc fritse	Zn	4 (variable)
Synthetic	Chelated sources	
	Na_2-Zn EDTA	14.0
	Na-Zn HEDTA	8.0
	NaZn NTA	13.0
Natural	Zn-lignin sulfonate	5.0
	Zn polyflavonoid	10.0

Source: J. C. Katyal and N. S. Randhawa, "Micronutrients," FAO Fertilizer and Plant Nutrition Bulletin No. 7 (Rome: FAO, 1983).

applied annually to severely affected areas. Based on the same assumption, the annual zinc sulfate requirement will be about 2,000 tons if only the severely affected areas are treated. The total annual Zn requirement based on total area is 20,000 tons of commercial $ZnSO_4$.

Organic Matter in the Soil

Given the low levels of organic matter in the soil in Bangladesh, it is necessary to reconsider crop production using inorganic fertilizers alone, while ignoring the role of organic matter as a source of plant nutrients and soil conditioners. Approximately 60 percent of the soils in Bangladesh have an organic matter content of less than 2 percent, which is the threshold level. In some parts of Joydebpur, Madhupur, and Barind, the organic matter content is as low as 0.8 to 1.0 percent. The organic matter content of 16 soil types and series is given in Table 22. These soils suffer from physical problems that exacerbate the ill-effects of drought and flooding. These include poor aggregation, low water-holding capacity, and increased plasticity. In addition to its physical effects, an ample supply of organic matter enhances plant growth by providing a source of slow-release nutrients, a healthy microbial population, and an increased capacity of soil to hold onto nutrients and to buffer against changes in soil pH. All these factors also lead to higher efficiency of NPK fertilizers as well as higher efficiency of S and Zn.

Use of inorganic fertilizers along with organic manure has consistently given better economic results. Experimentation, especially in the 1930s, proved this to be true, but the practice of using organic matter was not encouraged as it was considered uneconomical. This way of thinking has left soils in such poor condition that incorporation of organic matter is required in Bangladesh even at a cost much higher than would have been needed if recycling of organic matter were common practice.

A report by N. I. Bhuiyan presents the results of a BRRI study to evaluate the effectiveness of various organic materials relative to chemical fertilizer for wetland rice culture.[3] The yield response of BR4 rice to different sources and rates of organic matter are given in Figure 7. These responses are compared with yields obtained from recommended applications of fertilizers (80-60-40 N, P_2O_5, K_2O kilograms per hectare). The study clearly demonstrates that cowpea is the best source of organic matter for wetland rice, followed by Dhaincha. Adding compost, on the other hand, failed to cause an appreciable increase in grain yields.

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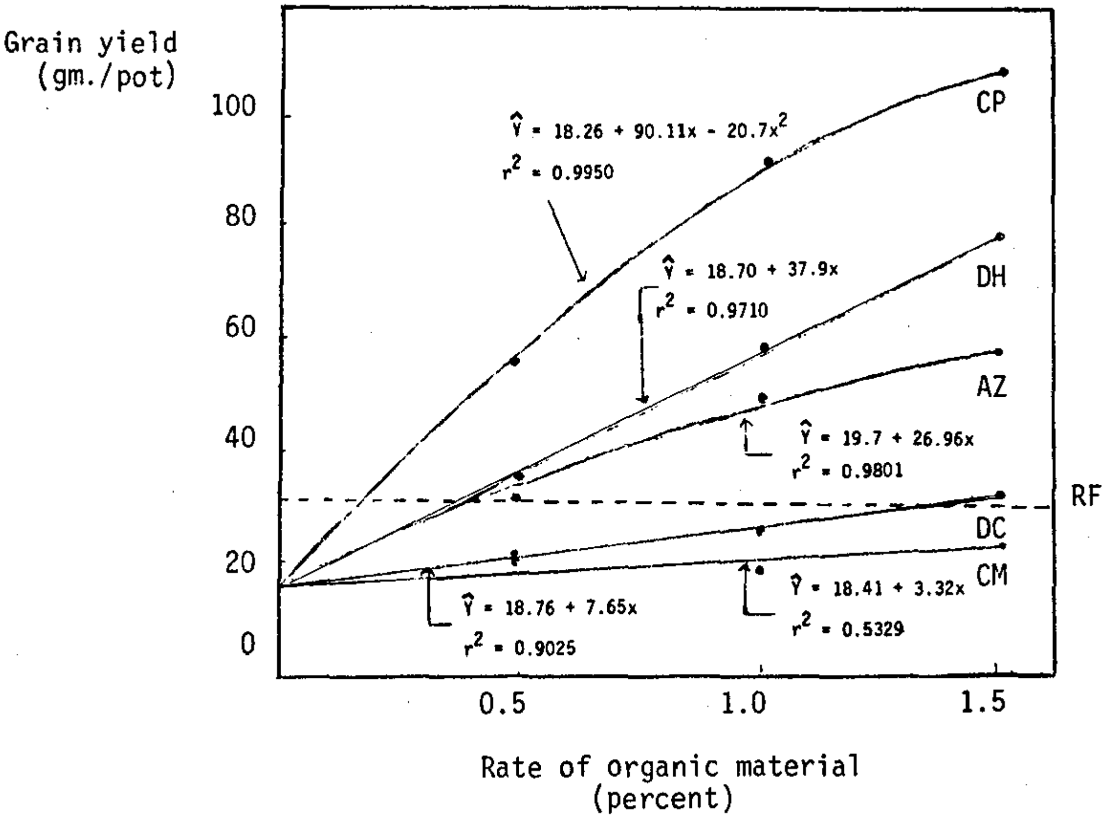
[3] N. I. Bhuiyan, "Use of Organic Materials in Crop Production," paper prepared for the Bangladesh Rice Research Institute, Dhaka, 1984.

Table 22--Percent of organic matter among different soil types and series in Bangladesh

General Soil Type	Soil Series	Organic Matter Content in Surface Soil
		(percent)
Noncalcareous alluvium	...	0.86
Calcareous alluvium	Ramgati	1.46
Gray floodplain	Sabhar Bazar	2.09
Gray piedmont	Prilimpasa	0.96
Acid basin clay	Chakla	4.00
Noncalcareous dark brown floodplain	Lokdeo	1.90
Calcareous dark gray floodplain	Ghior	6.84
Calcareous brown floodplain	Gopalpur	1.10
Noncalcareous brown floodplain	Pirgacha	1.00
Black terai	Lakhipur	2.43
Brown hill	Kulaura	1.25
Shallow red-brown terrace	Gerua	1.62
Deep red-brown	Tejgaon	2.12
Brown mottled terrace	Noadda	1.58
Gray terrace	Chhiata	1.28
Peat	Satla	30.66

Source: Z. H. Bhuiya, "Organic Matter Status of Bangladesh Soils," paper prepared for Bangladesh Agricultural University and presented to the Bangladesh Rice Research Institute, Dhaka, 1983.

Figure 7--Relationships between rice yields and application rates of organic materials



Source: Bangladesh Rice Research Institute.

Notes: Points are the experimental observations. Curves and lines are based on the adjacent regression equations. The dotted line represents grain yield with added chemical fertilizers.

CP = Cow pea
AZ = Azolla
CM = Compost

DH = Dhaincha
DC = Decomposed cow dung
RF = Recommended chemical fertilizer application

In summary, the use of organic materials of various kinds should be popularized. Use of green manures, particularly cowpeas and Dhaincha, has an immediate positive effect on crop production. Other sources such as fresh crop residues, compost, and farmyard manure do not substitute for chemical fertilizers, even when applied in large quantities. However, continuous application of reasonable quantities (say, 10 tons per hectare per year of dry matter) will surely improve the soil tilth and fertility, as well as the efficiency of added chemical fertilizers.

NON-NUTRIENT CONSTRAINTS ON FERTILIZER EFFECTIVENESS AND USE

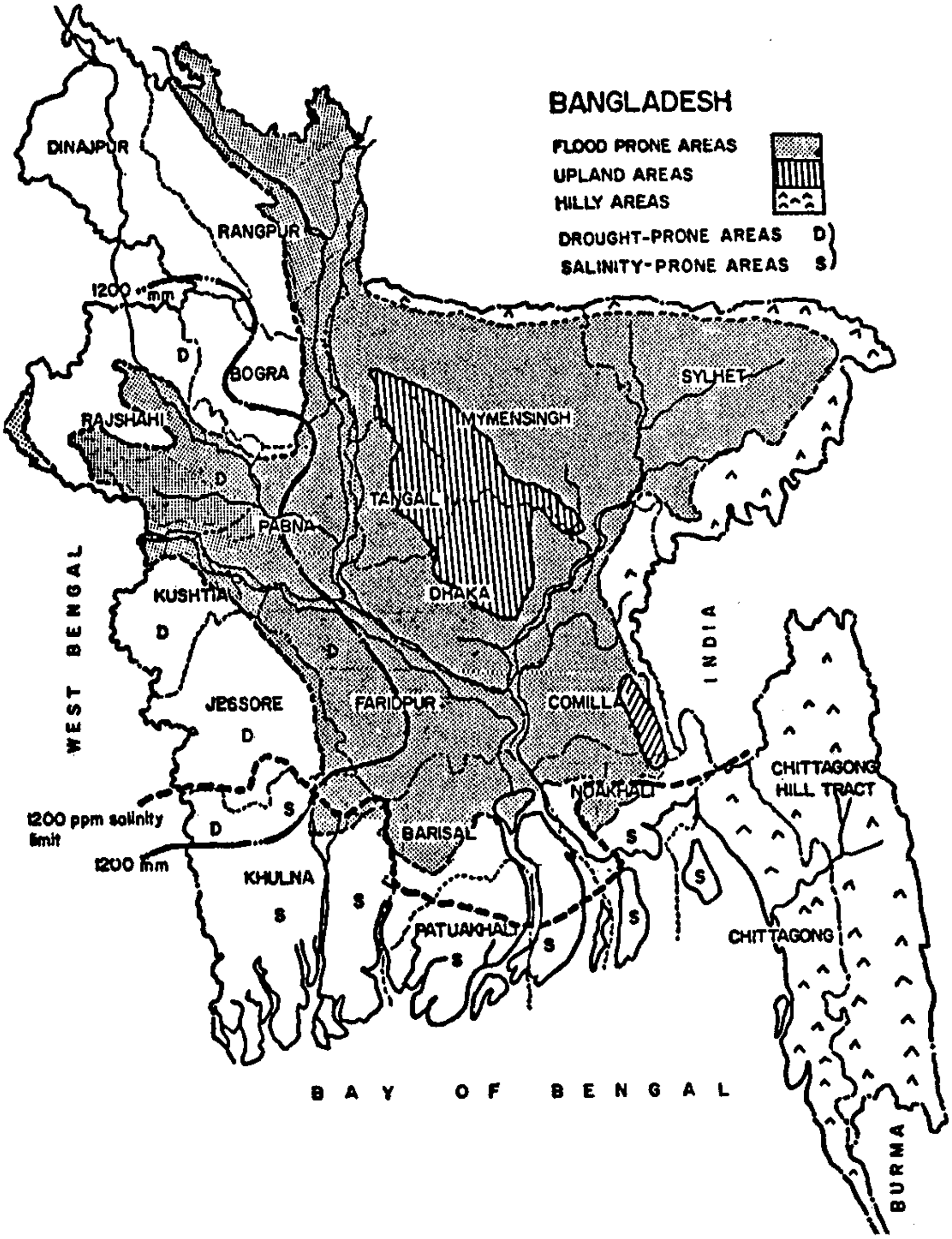
Problem Soils, Drought, and Flooding

By nature, peat soils, acid sulfate soils, fine-textured alluvial soils, and saline and sodic soils are difficult to cultivate and pose problems of water management, soil fertility, and soil conservation. In Bangladesh, the peat soils near Shahjibazar (Sylhet), Gopalganj, and some areas of Khulna may exhibit severe acidity and thus contain only low quantities of plant nutrients per unit volume. Tropical peat soils require high and recurrent inputs for their marginal use.

Acid sulfate soils have been the subject of much research mainly because of their potential suitability for growing rice and their close association with good agricultural land. In Bangladesh, acid sulfate soils are found in southern Khulna and in Cox's Bazaar areas. Cultivation of dryland crops is hampered by toxic levels of aluminum and low availability of P. Wetland rice cultivation on these soils is hampered by toxic levels of dissolved iron as well as low phosphorus availability. A main disadvantage is the risk of strong acidification during droughts when pyrite may oxidize to sulfuric acid. However, with sound agronomic practices, such as growing adapted cultivars and applying P, some acid sulfate soils are particularly suitable for rice cultivation.

Saline soil can be detrimental to the normal growth of crops, and improper usage of chemical fertilizers can compound the problem. In humid climates, such as that in Bangladesh, saline soils commonly occur in coastal areas. Figure 8 shows the salinity belt of Bangladesh delineated at 1,200 parts per million of salt. In these areas rainfall does not exceed evapotranspiration for much of the year and salts are not adequately leached from the surface soil. The salinity-prone areas of selected districts are

Figure 8--Agroecological zones of Bangladesh



District	Hectares
Khulna	192,620
Barisal	124,675
Patuakhali	128,610
Noakhali	109,503
Chittagong	8,490
Total	563,898

In the Rabi season, under rainfed conditions, <u>khesari</u>, chilies, wheat, barley, spinach, beets, <u>basella</u>, watermelons, groundnuts, and <u>cheena-kaon</u> are somewhat salt-tolerant and can be grown in these saline areas. The depth of the salty horizon is crucial here and because these crops have deeper rooting systems, they can escape salinity by deriving soil water from lower strata.

Drought can be harmful in itself, and it may also accentuate the problems caused by saline soil. Figure 8 delineates the drought-prone areas that receive less than 1,200 millimeters of rainfall per year. Drought that does not kill a crop can delay its life cycle. Under drought conditions IR8 rice simply "sits in" and flowers 30-40 days later than a crop not subjected to such stress. In some other crops, drought may force early reproduction, causing severe yield reductions. Drought stress at the critical early reproductive stage will do more damage than if it occurs from panicle initiation to the end of the milk stage. Moreover, the occurrence of drought during the effective nutrient utilization period (ENUP) of any field crop will adversely affect its yield by limiting nutrient uptake. In Aus crops, the ENUP for a 90-100 day variety is only 25-35 days; thus a drought that lasts for 15 days will reduce the yield by about 50 percent. Drought in September/October is dangerous for all T. Aman crops and in April for high-yielding varieties of Boro. Table 23 shows yield reductions under these conditions. One solution is to plant more drought-tolerant plants such as sorghum, smaller millets, gram, barley, and buckwheat. Under mild drought conditions fertilizer effectiveness could be affected. Assuming N fertilizer is properly placed within the anaerobic zone of the soil, mild drought can increase the zone of aeration and thus increase the losses of applied N by denitrification. Salinity problems are also worsened by drought stress.

At 1,230 parts per million of salt, rice grain becomes chalky. Beyond 2,000 parts per million of salt, rice exhibits signs of salinity injury, especially if it occurs at booting (sheath formation) and later stages. However, increased salinity after the milk stage causes negligible damage. Rice seedlings are especially susceptible even when submerged in saline water for only 10-12 hours. Tissue damage to stem and leaf sheath cells is caused by trapped saline water. Mild salinization is usually associated with increasing soil pH. At high pH levels, calcium deficiency is usually the

Table 23--Effect of drought on the yield of T. Aman and Boro HYV rice (drought in October or April)

Soil Moisture Status	Percent of Yield Loss in Crop Stages: Ripe	Milk	Flower	Boot	Panicle Initiation	High Tiller
Standing water, 6 cm	0	0	0	0	0	0
Saturated	0	0	0	0	20	50
Moist	0	0	10	50	80	100
Hairline crack	0	0	50	80	100	100
Open crack, soil dry	0	30	80	100	100	100
Desiccated soil	0	50	100	100	100	100

Note: It is assumed that there is no rain and no irrigation. In the event of rain and/or irrigation at any of these six stages, the score can be revised based on the moisture and growth stages.

first to occur with other micronutrient deficiencies following. It is also important to realize that soluble fertilizer salts can result in damage from toxic compounds, if placed too close to the seed. If direct contact of seed with nutrients is planned, special care must be taken to use low-salt index materials or to keep rates of nutrients low.[4]

Figure 8 also shows extensive tracts of land subjected to flooding. For lowland Aus, flooding usually occurs at its reproductive stage, when the Aus crop will fail completely if the total flood depth exceeds 1.0 meter. Mild flooding of 0.5 meter will not be detrimental and the crop will normally perform well, provided other ecological conditions remain satisfactory, including pressure from pests and parasites.

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[4] L. S. Murphy, "Plant-Soil-Fertilizer Relationships," in The Fertilizer Handbook (Washington, D.C.: The Fertilizer Institute, 1982), pp. 134-35.

T. Aman is normally not grown in flood-prone areas. However, in abnormal years such as 1954, 1955, 1974, and 1984, lower areas were affected either by flash flooding or accumulated rainwater. Lodging, especially at the booting and prebooting stage, is especially injurious to the crop.

Shallow flooding (less than 15 centimeters and close to a meter) is found in the tidal basin. Here, fertilizer placement is extremely important, especially since fertilizer application response rates were shown to be low due to leaching. Mild flood conditions should make little difference to fertilizer effectiveness if the fertilizer is applied properly. Low response rates are primarily responsible for low fertilizer consumption in southern tide-affected districts. Drainage problems and long rainy spells, producing prolonged waterlogging, contribute to the poor nutrient status of these soils. Under reduced soil conditions, soil microorganisms are forced to reduce and successfully compete for necessary plant nutrients. After oxygen and NO^3 nitrogen have been exhausted, phytotoxic concentrations of Fe^{2+} and Mn^{2+} in the soil solution become appreciable. Sulfur also follows, and in its reduced state (H_2S) it is unavailable and more toxic than in its oxidized one (SO_4^{2-}). This sulfide state may also block the uptake of calcium, magnesium, iron, zinc, and so forth, creating nutrient imbalances that disturb the normal physiological state of the rice plant.

Diseases, Pests, and Parasites

Crop losses due to diseases, pests, and parasites are substantial, and much more research needs to be done in this area. Large crop losses pose an added constraint on the economical use of fertilizers. Even if farmers were convinced of its profitability, they still might not want to invest in fertilizers given the high probability that diseases, pests, or parasites will cause severe crop losses.

Diseases.

In Bangladesh one can find almost all rice crop diseases. The most important are blast, tungro, bacterial leaf blight, sheath blight, and ufra. Of less importance are sheath and stem rot, brown spot, and physiological defects due to S and Zn deficiencies. In spite of significant crop losses from these diseases, there has not been any attempt to record them.

Almost all Aus varieties, Pajam, Purbachi, and IR5 are highly susceptible to rice tungro disease. In 1970, there was a severe epidemic of rice tungro virus infecting T. Aman crops in the northern districts. The area under local Aman varieties dropped from 14,812,000 acres in 1969/70 to 12,984,500 acres (a reduction of 5.58 percent). Consequent production was 5,700,000 tons instead of 6,912,400 tons in 1969/70 (a 17.54 percent reduction loss). Another outbreak of tungro disease infected Pajam in Chittagong, Noakhali, and the Comilla regions in 1976/77. There was a reduction of 330,000 acres sown in HYV where Pajam was included, with a production loss of 310,000 tons.

Localized yield reductions due to blast and ufra diseases in Aman crops are no less significant than drought and flood losses and yet are taken for granted. The endemic areas of ufra disease are from Goalando to the Matlab-Chandpur sectors and the Dhaka Narayanganj Drainage Project area. Ufra infestations are also prevalent in Zn deficient areas of deepwater rice. In the Demra area, incidence of this disease is increasing and may reach a serious level within the next five years if adequate protective measures are not taken. The injurious effects of blast on the scented Polao rice varieties such as Kalizeera, Chiniguri, Badshabhog, and Sakkorkhora have escaped the notice of statisticians. These varieties are highly susceptible to blast and at least 10 percent of the total crop is lost to neckblast.

Wheat in Bangladesh, especially that planted with seeds imported from India, Pakistan, or Nepal will normally contract loose smut disease, which damages 4 to 5 percent of the crop. However, the seeds of the infected crop, when planted the following year, show much less infestation, and in later generations damage eventually disappears. Leaf and stem rust diseases of wheat are less of a problem in most areas. Seedling blight, foot, and root rot diseases are common but remain below the economic threshold level.

Root-knot nematodes are on the increase and are affecting all crops. Virus diseases of tomatoes, okra, pulses, and papaya have become quite serious but as yet no losses have been assessed. The same is true of red rot in sugarcane, late blight in potatoes, stem rot in jute and sesame, and wilting and black spot in groundnuts.

Measures are being taken to control these diseases. Some of the rice diseases are being controlled by fungicides. Copper compounds are effective in controlling the Tikka disease of groundnut. Furadon, along with Zn and K fertilizers, is effective in controlling ufra and root-knot nematodes of rice.

Chemical control must be practiced at the appropriate stage of the disease in order for it to be effective. The most vulnerable stage of rice to tungro infection is the seedling stage. Sheath blight occurs from panicle initiation to booting, bacterial leaf blight at booting, stem rot at maximum tillering, and leaf scald at the flag leaf stage. Control measures should be taken at these stages. Seed treatment is effective for certain seed-borne diseases. However, toxic mercury compounds are no longer used in treating seed in Bangladesh because of the risk of accidents.

The following list includes effective cultural practices in rice disease management. Some of these are effective for crops in general. It should be mentioned that one of the main drawbacks of a list such as this is the lack of discussion of adverse consequences that may accompany these practices.

Management of water:

- Flooding the field minimizes the incidence of seedling blight in Boro seedbeds and leaf blast in the field.
- Draining water from the field may control sheath blight, bacterial blight, stem rot, and damping off in the Boro season.

Removal and destruction of stubble and weeds:

- Removal and burning of stubble in the field can control ufra, root knot, sheath blight, and stem rot.
- Alternate weed hosts of different pathogens may be removed for control of diseases such as tungro, bacterial leaf blight (BLB), blast, and brown spot.

Management of fertilizer:

- Judicious use of urea in proportion to P and K minimizes diseases such as blast, leaf scald, sheath rot, sheath blight, stem rot, BLB, and grain spotting.
- Sufficient use of potash can minimize leaf diseases such as brown spot, ufra, blast, leaf scald, sheath blight, bacterial leaf spotting, and blight.
- Nitrogen applications should be split, preferably with higher doses at later stages if the soil N content is high enough to ensure seedling survival. Otherwise basal application should be considered.
- Higher doses of N should be applied only when wider spacing is used.
- Treating Zn deficiency can reduce the intensity of diseases like ufra and root knot.

Planting practices:

- Planting dates may be delayed to avoid disease. For example, Boro seedbed sowing should be later than November to avoid tungro outbreak, and delayed sowing or transplanting of deep-water rice may help avoid ufra disease.
- Crops that are not hosts to the majority of the pathogens should be integrated judiciously into cropping patterns.
- Crops should be rotated.

Sanitation:

- Stubble should be collected and burned.
- Seeds from healthy fields should be collected and used.
- Seeds should be dried in the sun to a lower moisture content to help eliminate seed-borne diseases.

In the long run, perhaps the most important approach to pest and disease control will be the development and use of resistant varieties. Plant breeders are constantly at work improving crop varieties as new mutations of a particular disease appear and resistance breaks down. Use of resistant varieties along with prophylactic measures, balanced doses of NPK, use of organic manures, crop rotation, and water management are important aspects of an integrated system of disease control.

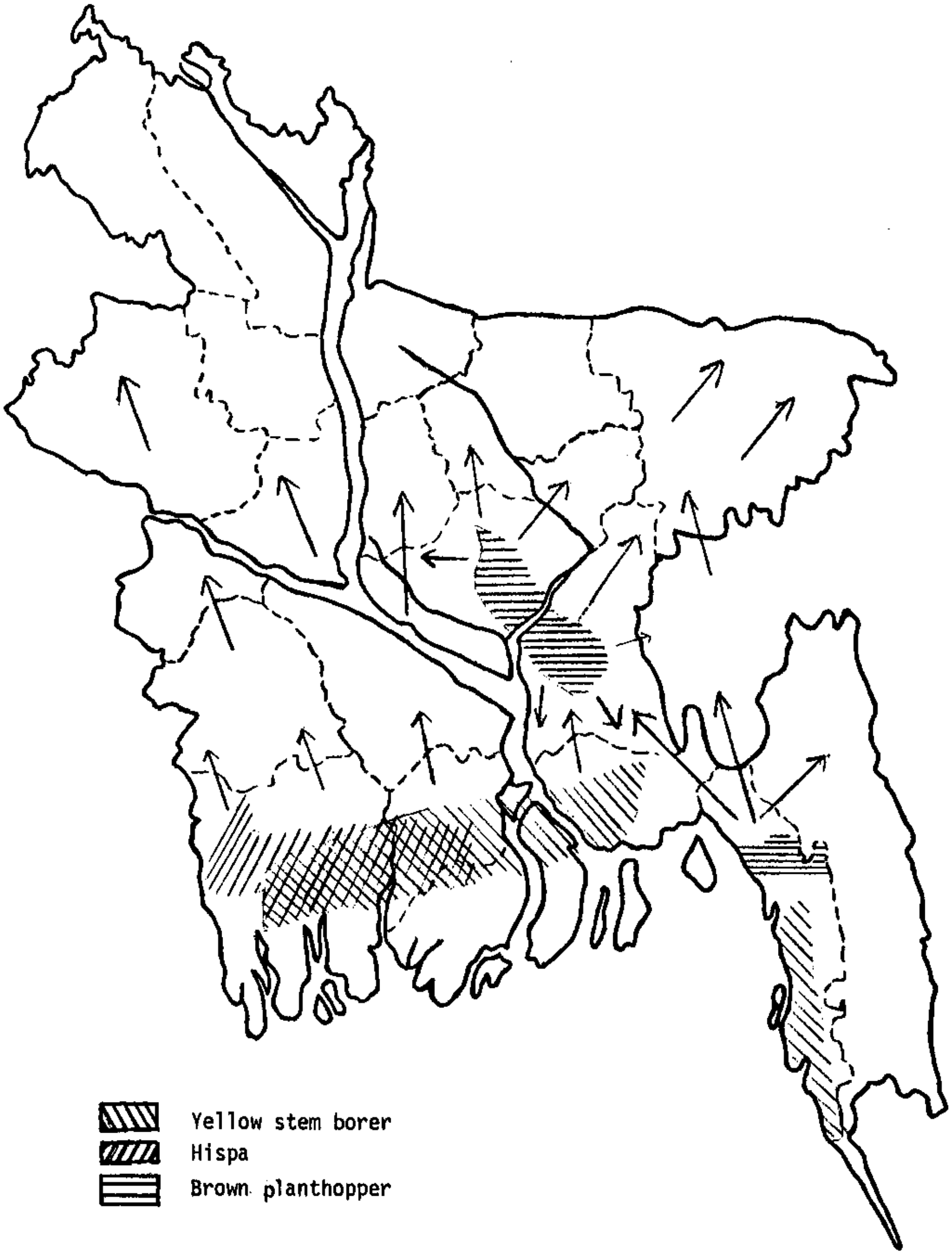
Insect Pests. Climatic conditions in Bangladesh are ideal for the breeding of insect pests. Almost all known species of rice pests are found there. The most important insect pests are stem borers, green leafhoppers, hispas, caseworms, Gandhi bugs, leafrollers and folders, army worms and ear-cutting caterpillars, brown planthoppers, gall midges, thrips, and mealy bugs. There is a higher incidence of pests in the Aus and T. Aman seasons and a lower incidence in the Boro season due to cooler temperatures.

Perhaps the most pernicious of these at present is the hispa. No rice varieties are resistant to it, and in recent years it has caused severe crop damage in Boro, Aus, and Aman crops. Deep-water and T. Aman rice can recover somewhat from an attack because of their longer life cycles. The initial population buildup of hispa occurs in the Khulna-Barisal-Patuakhali zones with the Boro crop. The population multiplies and migrates north as temperature and rainfall increase along with the planting of Aus and B. Aman (Figure 9). In some years T. Aman has been so heavily infested by hispa that farmers have simply allowed the crop to be completely destroyed: they thought control would not be economical because this late-planted crop yields only 450-550 kilograms per hectare.

The brown planthopper (BPH) is also becoming a menacing insect pest. The endemic areas are Dhaka-Comilla and the northern Chittagong zone. The population buildup starts in the Boro season, reaches a peak in March/April, and then spreads in all directions (Figure 9). During T. Aman's preflowering and flowering seasons, it is increasingly found in almost all districts.

Rice's yellow stem borer has its starting point in the Khulna, Barisal-Noakhali, and Chittagong areas during the Boro preflowering stage. It eventually spreads in a generally northerly direction (Figure 9).

Figure 9--Initial infestation areas of yellow stem borer, rice hispa, and brown planthopper



Source: S. A. Miah and A. N. M. Rezaul Karim, "Rice Pest Management Technology, A Workshop of Experience with HYV," Bangladesh Rice Research Institute, Dhaka, March 20-23, 1983.

It is interesting to note that deep-water rice (B. Aman) harbors a stem borer infestation of about 40 percent on average, but damage is still below the economic threshold level. By September, the floods begin to recede and there is a mass migration of stem borers north to the transplanted rice crop. Thus, B. Aman acts as a host for the stem borer. In winter, as temperatures drop, stem borer larvae and pupae remain in the rice crop stubble, especially in Aman, thus providing an alternate host.

Mealy bugs and thrips are associated with drought conditions. Mealy bug damage can amount to nearly 100 percent of the infested plant leaving no chance of recovery. Clearing the field of infested plants has been effective in dealing with mealy bugs. Thrips cause severe sterility if they attack rice during its flowering stage.

Ear-cutting caterpillars are prevalent in deep-water rice. The late harvest of T. Aman is an important factor in allowing this pest to do damage to the rice crop. Late planting of rice, particularly HYV, causes heavy infestation by gall midges and caseworms.

Wheat has a lower incidence of pest damage. The common pests are pink and dark-headed borers and, to a lesser extent, aphids, wireworms, and white ants. Birds also cause damage at seeding and, along with rats, cause significant damage to ripening wheat. They also cause damage during grain storage.

Aphids cause severe damage to mustard and beans, particularly late-planted mustard; the yield loss may be on the order of 50-60 percent. Semiloopers, apion beetles, and mites damage jute, and hairy caterpillars attack pulses and jute. Red ants sometimes cause severe potato damage.

Alam, Karim, and Nurullah have attempted to estimate rice crop losses due to insect pests by conducting 41 experiments in 20 crop seasons from 1970 to 1979.[5] Experimental results show that yields were reduced to 3.68 tons per hectare in untreated plots compared with 4.16 tons per hectare in protected plots. Use of insecticides increased yields by 19.04 percent in T. Aman and 18.03 percent in Boro seasons. Yield losses in T. Aman and Aus seasons were

Rice Variety/Pest	Yield Loss (tons per hectare)
T. Aman	
Stem borer	0.9 - 1.9
Gall midge	1.0
Aus	
Green leafhopper	0.52 -1.9

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[5] Shamsul Alam, A. N. M. R. Karim, and C. M. Nurullah, "Insecticide Use on Rice in Bangladesh," Bangladesh Journal of Agricultural Research 6 (No. 2, 1981): 37-50.

In another study they estimated crop loss from insect pests at BRRI during 1978-79 and found it amounted to 13 percent in Boro rice, 24 percent in Aus rice, and 18 percent in T. Aman.[6] The economic aspects of insecticide use were also studied and some results are presented in Tables 24 and 25. In general the effects were beneficial, particularly in the Aus season and when applied as a curative spray.

Table 24--Effect of timing and frequency of insecticide applications on rice yield

Treatments	Number of Sprays	Yield Increase Boro	Yield Increase Aus	Yield Increase T. Aman	Cost-Benefit Ratio Boro	Cost-Benefit Ratio Aus	Cost-Benefit Ratio T. Aman
		(tons/hectare)					
Regular application at an interval of 2 weeks	5	0.40	0.50	...	1:1	1:0.48	...
At 20, 40, and 60 days after transplanting	3	0.25	0.80	0.30	1:0.40	1:1.3	1:0.48
At mid- and maximum tillering and flowering stages	3	0.40	...	0.80	1:0.64	...	1:1.8
At mid- and maximum tillering	2	0.40	0.50	0.10	1:0.97	1:1.2	1:0.24
At mid-tillering	1	...	...	0.30	...	...	1:1.45
At maximum tillering	1	0.20	0.40	0.00	1:0.97	1:1.94	1:0

Source: Shamsul Alam, A. N. M. R. Karim, and C. M. Nurullah, "Insecticide Use on Rice," Bangladesh Journal of Agricultural Research 6 (No. 2, 1981): 37-50.

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[6] Shamsul Alam, A. N. M. R. Karim, and C. M. Nurullah, "Important Rice Insect Control Technologies," 8th Bangladesh Rice Research Institute Extension Workshop on Experience with HYV Rice, March 22-25, 1982.

Table 25--Effect of preventive and curative sprays on rice yield

Rice Seasons	Yield Increase		Value of Increased Yield		Cost of Insecticide		Cost-Benefit Ratio	
	P	C	P	C	P	C	P	C
	(tons/hectare)		(taka)					
Boro	0.95	0.67	2,629	1,841	3,603(6)	1,331(3)	1:0.60	1:1.38
	0.80	0.30	2,200	825	5,409(9)	195(1)	1:0.41	1:4.23
Aus	0.90	0.58	2,558	1,595	3,230(7)	1,331(3)	1:0.66	1:1.20
	1.91	1.40	5,253	3,823	2,340(6)	741(2)	1:2.20	1:5.16
	0.30	0.00	825	0	3,230(8)	425(1)	1:0.19	0
T. Aman	0.80	0.68	2,200	1,705	3,203(7)	763(2)	1:0.60	1:2.23
	0.21	0.00	573	0	2,351(6)	858(2)	1:0.24	1:0
	1.10	0.10	3,025	273	4,544(8)	852(2)	1:0.55	1:0.32

Source: Shamsul Alam, A. N. M. R. Karim, and C. M. Nurullah, "Insecticide Use on Rice," Bangladesh Journal of Agricultural Research 6 (No. 2, 1981): 37-50.

Notes: Figures in parentheses indicate number of insecticide applications. P represents preventive; C represents curative.

Twenty-five major commercial insecticides were found to be effective against the pests. The types include 17 organophosphates, 4 carbonates, and 4 others of mixed groups. They also found that Sevidol 4:4G, Ofunack 10G, and Ekalux 5G were promoting an increased population of brown planthopper and thus must not be used.

As with disease control, an integrated management program to control pests is currently being promoted, using these cultural practices.

- Infestation of green leafhoppers and subsequent tungro outbreak can be avoided by seeding the Boro crop in late December instead of November.
- Water removal from the field is effective in controlling caseworms and brown planthoppers.
- Avoiding high density and narrow spacing is recommended to ward off brown planthoppers.
- Seedbed management with thinly sown seeds can reduce green leafhopper and other hopper infestation of rice seedlings.
- Forced lodging of ripe rice crops can prevent an attack by ear-cutting caterpillars, and irrigation can destroy them.
- Clearing the field of infested plants has been successful in controlling the top shoot borer on sugarcane, smut-infested spikes of wheat, and hispa-infested sheaths of rice.

Kerosene emulsion, tobacco infusion, ashes, and light traps are also in use to temporarily ward off pests. Pyrethrum, a plant substance, is also being used because of its low toxicity. However, toxic insecticides are recommended because they are economical and effective.

Pest control in the field must be supplemented by pest control in storage. Storage losses sometimes exceed 10-15 percent for rice, wheat, and potatoes. For effective storage, the godown must be insect- and rat-proof and kept at minimum moisture levels. High humidity in storage along with more than 14 percent moisture content of stored grain results in high infestation. Clean, dry storage is essential. Storage treatments with nontoxic fumigants and grain or tuber irradiation before storage have also helped to reduce losses.

Weeds. It is very unfortunate that biologists and economists have frequently ignored the role of weeds in crop production. They rob the soil of necessary crop nutrients, necessitate one of the most labor-demanding chores in crop production, and have other deleterious effects.

Weeds, by virtue of their higher shoot and root growth, can deprive sluggish crop seedlings of sunlight, space, moisture, and nutrients, and they may act as an alternate host for many diseases and insect pests. Weeds grow faster under rainfed or residual moisture levels than the seedlings of most crops, particularly the dwarf, semidwarf, and intermediate plant types of the HYVs. This is why HYV direct-seeded rice cannot grow well in upland conditions. If weeded efficiently, HYV rice can compete, but the cost of weeding is high and farmers are reluctant to do it. Jute farmers, however, spend lots of time and money weeding their fields; without such efforts, the jute yield would be reduced by 50 percent. Agronomists usually think that if the cost of weeding exceeds 20 percent of the other costs of production, it is uneconomical to control weeds.

Tables 26 and 27 provide data on per hectare labor requirements for seeding and weeding of upland rice.[7] Because line seeding and dibbling were done by hand, more man-days per hectare were needed for these tasks than for weeding. But when seed was broadcast, man-days per hectare for weeding reached 95 percent of the total for seeding and weeding combined. Table 27 shows that 16-25 percent of total man-days per hectare are needed for weeding: thus it is very

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[7] Studies done at the Bangladesh Rice Research Institute show that dibbling--planting the seeds in small holes--was the most efficient method of seeding as compared with broadcasting and line sowing; they concluded that multirow, animal-drawn seed and fertilizer drills should be given priority in Bangladesh.

Table 26--Variation in labor needed for weeding using three rice seeding methods

Seeding Methods	Man-Days Used for Seeding Joydebpur	Man-Days Used for Seeding Rajshahi	Man-Days Used for Seeding Mean	Man-Days Used for Weeding Joydebpur	Man-Days Used for Weeding Rajshahi	Man-Days Used for Weeding Mean	Total Man-Days	Man-Days for Weeding as Share of Total Man-Days
	(man-days/hectare)							(percent)
Broadcast	1.74	2.05	1.89	38.67	41.67	40.17	42.06	95.51
Line seeding	40.88	43.44	42.16	33.33	35.89	34.11	76.27	44.72
Dibbling	51.88	64.58	58.23	31.25	40.52	35.89	94.18	38.11

Source: Bangladesh Rice Research Institute, Agronomy Division, "Internal Review," Dhaka, 1982.

Table 27--Comparative labor inputs for different operations of direct seeded upland rice

Operations	Man-Days Used for Seeding Broadcast	Man-Days Used for Seeding Line Seeding	Man-Days Used for Seeding Dibbling	Man-Days Used as a Share of Total Broadcast	Man-Days Used as a Share of Total Line Seeding	Man-Days Used as a Share of Total Dibbling
	(man-days/hectare)			(percent)		
Land preparation	22.73	21.43	22.62	14.60	11.78	11.67
Seeding	1.74	40.88	51.88	1.12	22.48	26.76
Fertilizing	5.21	5.21	5.21	3.35	2.86	2.69
Weeding and mulching	38.67	33.33	31.25	24.83	18.33	16.12
Plant protection	2.34	3.21	3.65	1.50	1.77	1.88
Harvesting and carrying	30.90	27.52	26.04	19.84	15.13	13.43
Threshing	34.72	32.62	34.72	22.30	17.94	17.91
Winnowing, sunning, storing	19.40	17.65	18.49	12.46	9.71	9.54
Total labor	155.71	181.85	193.86	...	...	...

Source: Bangladesh Rice Research Institute, Agronomy Division, "Internal Review," Dhaka, 1982.

expensive. The benefit-cost ratio for weed control during rice cultivation is attractive, however, as shown in Table 28. The ratio generally appears to increase with increased weeding, but tends to decline in (even efficient) weeding operations that result in more than 75 percent weed removal.

Good land preparation (usually four plowings and two ladderings) decreases the weed population. Usually a smart farmer will wait five or six days after the first spring shower to allow weed seeds to germinate. He then prepares the land, destroying about 75 percent of the weeds. Hand weeding after one raking is always an effective weed control for upland direct-seeded rice and jute.

Table 28--Costs and returns associated with weeding during rice cultivation

Number of Weedings	Labor Needed for Weeding	Cost	Gross Returns	Gross Returns Minus Weeding Costs	Benefits from Weeding	Benefit-Cost Ratio from Weeding
	(man-days/ hectare)			(taka/hectare)		
1	66.71	1,334	4,800	3,466	1,964	1.47
2	87.96	1,759	5,595	3,836	2,759	1.57
3	93.24	1,865	6,867	5,002	4,031	2.16
0 (control)	...	...	2,837	2,837	...	...
100 percent weed removal	94.48	1,890	5,955	4,065	2,363	1.25
75 percent	81.36	1,627	5,726	4,098	2,134	1.31
0 percent	...	...	3,591	3,591	...	...

Source: Bangladesh Rice Research Institute, Agronomy Division, "Internal Review," Dhaka, 1982. The benefit-cost ratios appearing in the source have been recalculated for inclusion in this table.

Note: Benefits from weeding were calculated by subtracting gross returns without weeding (control) from gross returns with weeding.

Weeds pose a constraint on the profitability of using fertilizers. Crop response to fertilizer application depends on the competition between the crop and weeds for the added nutrients. If weeds have a competitive advantage, then yield losses of 50-60 percent can be expected, as seen in direct-seeded Aus. Interesting studies on weed control have been conducted at the International Rice Research Institute (IRRI). The effect of N fertilizers on crop yields as influenced by different methods of weed control received special attention. They found that the yield response to hand weeding increases with N application and that application of more than 75 kilograms of N per hectare will decrease yields unless hand weeding is done. In summary, both the intensity of weeding and N levels must be balanced in order to get optimum yields from both inputs.[8]

In Bangladesh, where hand weeding is the most common method of weed control, the results of these studies could support Bangladesh's effort to cope with the problem of weeding and its interaction with fertilizer usage. However, it is difficult to obtain favorable conditions for both growth and weed control, which would lead to more efficient use of chemical fertilizers.

Fertilizer Storage Loss

In general, fertilizer storage losses seem to be low for Bangladesh farmers. This is because farmers in Bangladesh do not purchase fertilizer with the thought of storage in mind. They usually purchase the amount needed and use it as quickly as possible.

BADC is aware of safe storage practices, and information is available from them. The following storage problems are typical of the fertilizers used in Bangladesh.

Urea is fairly stable and has good storage life. However, under hot, humid conditions, urea may absorb moisture and become wet. Although the urea is hard and lumpy when it dries, the N content is not reduced provided bags are sealed well.

DAP is even more hygroscopic and may form a slurry-like mass in the rainy season. At that point, farmers often refuse to use it because it is difficult to handle and causes skin burns.

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[8] For more specific results, see D. T. O'Brien and E. C. Price, Interaction Between Fertilizer and Weed Control Methods in Philippine Upland Rice: Estimates from Farmers' Fields, Research Paper Series No. 97 (Los Baños, Philippines: International Rice Research Institute, 1983).

TSP also absorbs moisture and can become lumpy. The phosphoric acid used to treat the phosphate rock may undergo unfavorable changes in chemical composition. Under such conditions TSP is not a good fertilizer and can cause chlorosis in a plant. Several years ago, BADC had to discard a quantity of TSP that had become hard and lumpy.

KCl is a stable product and under normal storage conditions has the least chance of storage loss.

Ammonium sulfate is also hygroscopic and may suffer severe loss of N under hot, humid conditions due to gaseous ammonium losses to the atmosphere.

Scope for Further Expansion of HYV Areas

HYVs of rice (excluding deep-water rice), wheat, potatoes, and mustard have made a significant contribution in Bangladesh. Starting in the early 1960s with a few hectares sown with Taipei 177/1, Yabani and 36 Norin varieties in Taiwan, area sown in HYVs expanded to approximately 500 hectares of IR8 in 1966/67. Thereafter, area sown with HYVs of Aus, T. Aman, and Boro crops expanded.

With improved irrigation facilities, good climatic conditions, and a low incidence of pests and disease in the Boro season, HYV sown area increased to about 70 percent of the total Boro rice area. Further expansion in Haor areas, home of the endemic species of Boro rice, should be controlled in order to prevent genetic erosion. This locality should remain planted with the local germplasm to maintain a biological balance. Nonendemic Boro areas may be sown with additional HYVs without worry about genetic deterioration. Further expansion is possible in the Boro season, given planned improvement in irrigation and drainage facilities, bringing the estimated potential for modern Boro area to 2.4 million hectares.

Areas of expansion under Aus are limited to areas that are not flood-prone. Approximately 37 percent of all Aus areas (2.8 - 3.0 million hectares) lie in lowlands subject to flooding and are risky for even the local tall Aus varieties. Hence there is no current scope for expansion of HYVs of rice in these areas (1.04 - 1.11 million hectares). Of the remainder (1.76 - 1.89 million hectares), approximately 0.8 million hectares are now sown with transplanted Aus HYVs. Future expansion may bring the total Aus acreage under HYVs to 1.2 million hectares.

In parts of Noakhali and the offshore islands, HYVs of rice are dibbled. When seedlings reach 10-15 centimeters in height, rainwater is ponded to effect a transplanted field condition. In the uplands of Madhupur, Barind, Lalmai, and other hilly areas, HYVs cannot be cultivated as there are no suitable direct-seeded HYVs of rice. However, attempts are being made to accelerate research for development of faster growing varieties that have a life span of 90-100 days, appreciable drought tolerance, and high seed dormancy. It is expected that a prototype may be available by the end of the third five-year plan. Once this is available, about 50 percent of Aus area could be under HYVs by 1995.

It is possible that the Boro rice area could expand to 2.4 million hectares at the cost of Aus or jute. As modern Boro rice and wheat areas increase, there is a corresponding decrease in Aman and Aus deep-water rice areas. Because growing Aus rice is risky in its seedling and early growth stages and jute is a low cash crop, farmers are likely to make the change. Farmers may even be more reluctant to plant their traditional low-yielding Aus crop once wheat has been planted, because rice following wheat requires much larger amounts of fertilizer.

Within the next five years there will be practically no change in the B. Aman rice area. One new medium yield variety of B. Aman, with a yield range of 3-4 tons per hectare) is in the field-testing stage. Its impact will probably be limited unless it is suitable at a flood level of 1-3 meters, which is typical in the floodplains.

There is great scope for expansion of HYVs in the T. Aman season with 2.0 - 2.4 million hectares of land suitable for modern varieties. The areas of T. Aman under different agroecological zones are given in Table 29. The entire drought-prone areas of Khulna and Rajshahi may be brought under HYVs. This amounts to 20-22 percent of the drought area. At least 50 percent of the total nondrought/flooded areas may also be brought under HYVs for a total of 56-58 percent of total T. Aman areas suitable for expansion.

The optimum period for transplanting will be July 15 - August 15 in order to avoid an October drought. However, one supplemental irrigation (5 - 7.5 centimeters) will be essential to compensate for the severe October drought. A large part of the T. Aman crop will be planted in saline areas and therefore the necessity for planting saline-tolerant varieties is increased. At the moment BR10 seems to be performing well under normal rainfall conditions.

The areas suitable for HYVs with and without irrigation amount to 5.6 - 6.0 million hectares. Of this total, 75 percent is expected to be irrigated and 25 percent rainfed. Aus and T. Aman will be approximately 75 percent rainfed and 25 percent supplemented with irrigation. Overall, judicious management of inputs and services including credit, water, marketing, processing, and storage will be needed--horizontal expansion is not enough.

Despite rapid expansion to a peak of 0.58 million hectares in 1981, wheat area never reached the expected level of 1.6 million hectares. Several surveys were conducted to find reasons for this plateau. About a dozen constraints have been identified, including low market prices, nonavailability of seeds and their high cost,

Table 29--Area sown with T. Aman rice in different agroecological zones

Location/ Types of Rice	DP	FP	DP and FP	Not DP or FP	Total
		(1,000 hectares)			
Dhaka					
Local varieties	...	83.57	14.42	426.23	524.22
Modern	...	...	2.66	215.56	218.22
Local and modern total	...	83.57	17.08	641.79	742.44
Chittagong					
Local varieties	...	...	...	662.30	662.30
Modern	...	...	...	269.19	269.19
Local and modern total	...	...	...	931.49	931.49
Khulna					
Local varieties	413.83	...	...	512.25	926.08
Modern	51.31	...	...	37.26	88.57
Local and modern total	465.14	...	...	549.51	1,014.65
Rajshahi					
Local varieties	435.26	...	80.44	770.79	1,286.49
Modern	10.76	...	9.41	81.99	102.16
Local and modern total	446.02	...	89.85	852.78	1,388.65
Bangladesh					
Local varieties	849.09	83.57	94.86	2,371.57	3,399.09
Modern	62.07	...	12.07	604.00	678.14
Local and modern total	911.16	83.57	106.93	2,975.57	4,077.23
Local and modern total as a percent of total area sown with T. Aman rice	22.35	2.05	2.62	72.98	100.00

Source: S. M. H. Zaman, "Current Status and Prospects for Rainfed Foodgrain Production in Bangladesh," a paper prepared for FAO's Expert Group Consultation, Bangkok, November 28-December 2, 1983.

Note: DP = drought-prone; FP = flood-prone.

threshing difficulty, and lack of irrigation facilities. These reasons, along with a higher preference for rice and loss of soil fertility due to wheat, are likely causes. With time, these constraints can be solved, and wheat area and production will ultimately expand to the estimated level.

Other crops have their own sets of constraints. The area under sugarcane seems to have reached a saturation point because of faulty policy on the part of the Sugar Corporation. There is also no improved variety for gur production. Extension work is nonexistent outside the sugarmill zones. Until recently, no attempt was made to manufacture khandeswari sugar (semiwhite powdered sugar) in the nonmill areas. Manufacture of this product, which now only takes place in the Kishoreganj area, should be expanded. Instead Bangladesh is importing sugar at high prices.

Area planted with pulses is unlikely to expand due to a lack of improved varieties and, particularly, of technology for the production of Rhizobium-inoculated seed. Wheat and potato acreage is also affecting pulse production. Mustard yields average 2 tons per hectare with irrigation, high doses of NPK, and pest management. Mustard area is not increasing at this time because soybean oil is being imported liberally at low prices. Groundnuts, another popular crop, has not received appropriate state support for its processing.

So far, no attempt has been made to investigate farmers' work schedules after a long, busy period of cultivating jute/Aus and T. Aman crops. About 40 percent of all arable land is under various Rabi crops, and thus lack of irrigation may not be a limiting factor. Expansion and improvement of irrigation and drainage facilities would promote the production of Boro rice, wheat, potatoes, onions, chilies, other vegetables, and oilseeds, and it would also minimize the risk for B. Aman, Aus, and jute seedlings.

Limited Availability of HYV Seed

The problem of limited HYV seed supply has improved to some extent for rice, wheat, jute, sugarcane (in mill areas), and vegetables, along with the shift toward greater reliance on domestic sources.

The total seed requirements for rice by type are given here.

Rice Type	Seed Requirements (tons)
Aus	
A. Broadcast	185,190
B. Transplanted	18,520
B. Aman	148,150
T. Aman	97,220
Boro Transplanted	32,410
Total	481,490

To fill this need, BADC supplied only 8,253 tons of rice seeds in 1974, and by 1977, the amount supplied had decreased to 1,028 tons (Table 30). By 1982 the amount supplied by BADC increased to only 1,935 tons--about 0.4 percent of the net requirement for rice seed. The remainder has been provided by local seed merchants and farmer-to-farmer exchange. However, the multiplier effect of BADC's seemingly inadequate contribution is great. An injection of approximately 1 percent of new varieties of rice seeds should enable the entire system to supply sufficient improved seed.

Because wheat requires more seed and seed storage is more difficult, wheat seed requirements are higher than those for rice. BADC supplements its own seed supply with imports, raising the total supply to 40-50 percent of the market. Farmer-to-farmer exchange and farmers selling seed in the local market also contribute to the seed supply.

Both rice and wheat are self-pollinated crops; thus genetic degeneration does not occur with subsequent plantings. Nonetheless, varietal mixtures as the result of carelessness, diseased grain from poor handling, and lower germination rates for seeds all contribute to yield reductions. Varietal degeneration occurs in the case of mustard and other cross-pollinated crops, however. When hybrid status is uncontrolled, yields may vary from year to year. In potatoes, yield declines from year to year because seed tubers become contaminated with virus and other diseases when grown in such a warm

Table 30--Quantity of improved seeds supplied by the Bangladesh Agricultural Development Corporation, 1974-82

Year	Seeds		
	Total Rice	Wheat	Potato
		(tons)	
1974	8,253	1,439	2,727
1975	3,429	675	3,278
1976	2,002	4,777	4,321
1977	1,028	1,782	1,942
1978	1,576	3,490	2,411
1979	1,324	4,867	2,775
1980	2,039	14,024	3,711
1981	1,260	14,146	3,322
1982	1,935	11,075	3,466

Source: Bangladesh Agricultural Development Corporation.

country. Farmers will not hesitate to buy expensive freshly imported seed potatoes from Europe knowing yields will be about 50 percent greater.

Improved jute seed is produced by the Jute Research Institute, but there is not enough to meet total requirements. Supply sources of pure sugarcane seed are also limited. Most seed for "English" vegetables, such as cauliflower, cabbage, and carrots, are imported, and hence of higher quality.

In the short run, BADC should look to producing more locally grown wheat seed rather than importing about 50 percent of supply as it is doing presently. Work should also be done to improve mustard, potato, and pulses seed. And finally, research should be undertaken to promote new rice varieties and to incorporate them along with some older varieties. In the long run the private sector should be brought into other areas of seed marketing, especially processing, grading, and storage.

CURRENT PROGRAMS AND RESEARCH PRIORITIES

In Bangladesh the problem of food deficiency required immediate action, which took the form of promoting HYV varieties, improving fertilizer and cultural practices, and managing water and pest problems. Research of this nature, when done hurriedly, may ignore other factors that can have destabilizing or adverse effects on crop production. Some of the consequences of increased use of HYVs and increased cropping intensity with irrigation are summarized here.

First, soil fertility may be lost as the result of improper use of HYVs and related technology. Only about 10 percent of the farmers use the correct dosage of fertilizer, which is roughly in the ratio of 2:2:1 (N, P_2O_5, K_2O), and apply good cultural practices and water management. Failure to apply fertilizers at the right time in appropriate doses and with proper placement leads to unbalanced uptake of nutrients and fertility problems.

Most of these problems are being addressed at the country's research institutes. Research has been undertaken to increase and stabilize soil fertility through proper application of nutrients such as NPK, S, and Zn, along with organic recycling and attention to a cropping systems approach. More emphasis is now given to increased fertilizer efficiency, appropriate cultural practices, and water management, so that reductions in yields are not inevitable. Research is incorporating more and more yield stabilizing factors into the projects.

Second, HYV technology, when not properly applied, greatly exacerbates pest hazards. Evolution of new mutants of fungi and new insect biotypes, both with increased resistance, are the result of misuse of pesticides, thus complicating the research effort. Increased use of N without appropriate P and K balances is responsible for the creation of predisposing factors that lead the way to higher incidence of pests and diseases. Research on the interrelationships among varieties, fertilizer, cultural practices, cropping patterns, and pest and disease infestation now receives special attention. New varieties have a wider spectrum of resistance, but these are problems that require long-term research efforts. Research on the use of biological and other nontoxic pesticides is also in progress.

Third, research to reduce loss from drought, salinity, flooding, cold injury, and soil toxicity and deficiency is going on. These are difficult multidisciplinary areas, and more time is needed for the development of appropriate technology.

Fourth, research on economical aspects of crop production vis-à-vis farmers' conditions is being pursued. Some problems have been identified but, in most cases, the present administrative infrastructures and local institutions are not capable of handling their resolution.

Fifth, the problems associated with subsidies on inputs, price supports, and credit are still being debated and have not been resolved.

Finally, manpower improvement and creation of leadership for the coming century, when tougher and more complicated production problems may develop, need immediate attention. Without a strong program, critical future research will be inadequately addressed.

Both short- and long-term research priorities have been identified and recorded in a recent publication, "National Agricultural Research Plan, 1984-1989," by the Bangladesh Agricultural Research Council. The government is now preparing a third five-year plan to incorporate these research priorities.