Bangladesh. J. Agric. Econs.;. XXI, 1& 2 (1998): 21-38

FARMERS' PERCEPTIONS ON YIELD GAPS, PRODUCTION LOSSES AND PRIORITY RESEARCH PROBLEM AREAS IN BANGLADESH

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ABSTRACT

Perceptions of knowledgeable Bangladeshi farmers regarding rice yield losses due to various technical constraints were studied to quantify the magnitude of yield losses and yield gaps. Two model farmers were chosen from each of the selected 120 thanas of the country. These 240 sample farmers were interviewed to solicit their perceptions on probability of occurence of different biotic and abiotic constraints, the proportion of area affected by these constraints and the corresponding yield losses. The result on normalized yield loss estimation shows that abiotic factors are much more severe than the biotic ones in constraining rice yields irrespective of production ecosystems. Yield loss from all biotic and abiotic constraints is estimated at 0.8 tons ha-1 which is about 28% of the current farm level yields. The volume of rice production lost from these constraints is estimated at 7.8 million tons of paddy valued at US $ 1558 million at the existing international prices. Ex-ante analysis shows that the research investment on the priority problem areas would pay fairly lucrative returns to the government.

I. INTRODUCTION

Rice production is vital to the Bangladesh economy, because rice contributes about 50 percent of the total agricultural value added and it engages over 65 percent of the total agricultural labor force. Besides, rice production continues to be one of the important sources of livelihood accounting for an estimated 76% of the people's average calorie intake and 66% of protein intake (BBS, 1996). The experience of technological change led by varietal improvement in Bangladesh has significantly contributed to the growth of rice production during the last two decades. Gains in the, food grain sector that Bangladesh has achieved since its independence are mostly due to technological progress in the rice cultivation.

The experience of 1990s however suggests that the technological progress is getting out of steam. Adoption of modern varieties is already complete on the irrigated land. Further expansion of irrigation will also be difficult. Given the existing land constraints, further growth in rice production will depend on (a) the development of modern varieties for the unfavorable production environments, (b) the success in reducing yield losses from biotic, water stress and soil related constraints, and (c) increasing efficiency in the use of inputs.

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However, It is widely perceived that there is wide gap between the potential and farm level vield and the major part of the gap is due to the yield loss caused by several biotic and abiotic factors. The magnitude of these losses have not yet been systematically quantified. In Bangladesh, rice scientists initiated crop loss assessment as early as in 1973, but estimates were made through measurement of losses in controlled experiments in a few plots in research stations. It has been reported that the broad spread of modern rice varieties during the green revolution period has been associated with outbreaks of several viral, fungal, bacterial and nematode diseases along 'with numerous insect pests. The losses were often reported to vary from 30 to 90 percent of the yield ~Miah, 1988, BRRI 1979, Dey *et al,* 1996). The way crop yield loss (caused by biotic factors) -,vere evaluated so far, could hardly be used for the estimation of aggregate loss at the country level, because a) crop losses are often calculated using empirical damage functions derived from plot experiments on research stations. Extrapolating their use to farmers' fields requires that proper accounting be done for scale-depending phenomena (Teng 1990) and (b) the estimates are often not available over a large, representative area to enable national or regional estimates of the area affected. Furthermore some pests only cause localized damage, which although may amount to 100% loss becomes relatively unimportant when extrapolated at the national scale. Any excercise on research prioritization needs to recognize that there are pests which cause damage over large areas at low levels and there are pests which occur infrequently in small areas but causing devastating losses in the affected area.

It is therefore, imperative that, in order to derive policy implications, crop loss estimations need to be made on the basis of normalized yield loss i.e, loss at the national level for a normal year. Planners and policy makers need information on the relative importance of various problems so that they can allocate and redistribute the available resources among various researchable issues. To satisfy this national need, the factors associated with the existing yield losses must be clearly identified. This study therefore, presents an overview of the magnitude of production losses due to the technical constraints using data on farmers' perception of yield losses. In particular the study aimed to: a) identify the existing rice yield gaps across the production environments and associated production constraints, b) estimate the contribution of various biotic and abiotic constraints to the yield gap in different rice ecosystem and, c) generate a list of priority problem areas for rice research based on their corresponding yield loss estimates and potential research pay-offs.

The rest of the study is organized as follows: In the second section, we explained the methodology employed in the study: while the empirical results are discussed in the third section. The last section deals with the summary and concluding remarks.

II. METHODOLOGY

Sampling and Data

For this study a nationwide field level survey on the estimation of rice yield gaps and yield losses was undertaken during 1995-96. A sample survey was carried out to study extenstion workers' and farmers' perceptions of yield gaps and yield losses. Thana level Agricultural Extension Officers and model farmers were the sampling units.To draw the sample for the survey, a two stage sampling procedure was adopted. The country was classified into 10 major agroecological zones according to the FAO study. Each agroecological zone was further subdivided into four land types according to flooding depth (MPO, 1992). All thanas in Bangladesh were grouped into these (10 x 4) 40 sub-ecosystems. A sample of 120 thanas (25% from each group) were then drawn randomly to proportionately represent the subecosystems. Two model farmers knowledgeable about rice production practices were purposively selected from each Thana with the advice of extension staff. A structured questionnaire was used for the survey. The research team consisting of agronomists, economists and extension specialists visited each region and held a workshop with extension officials to discuss the objective of the study and to solicit information on major insects and diseases in the region, the coverage of area under different rice ecosystems and soil related stresses. Assistance was solicited to identify model farmers in the selected thana and to conduct the survey.

Farmers were interviewed by crop production specialists in presence of the local extension officer. Information were generated on crop varieties, input use, major yield reducing stresses, frequency of their occurrence over the last 10 years, area affected and corresponding yield losses in the affected area. Extension personnel helped farmers to identify the contrainsts/symptoms but corresponding estimate of losses were obtained from the farmers themselves. A final workshop was held at BRRI to review the findings by the rice researchers and the extension specialists.

Yield loss estimation

The estimates of yield loss were made based on three variables:

Frequency of occurrence of the problem in the last ten years

Percent of area affected by the constraint when it occurs

The amount of yield loss in the affected area

The area affected by each constraint in a normal year was estimated by multiplying the first two variables. The normalized yield losses were estimated by multiplying the yield losses in affected area with the percent of area affected by the constraint. The normalized yield losses per unit area were then multiplied by the total rice area to estimate the production losses from these constraints at the national level.

It may be noted that scientists usually estimate yield loss using the last variable i.e the yield loss in the affected area by inflicting full injuries on the crop and comparing it with a control situation where the crop is fully protected. It is obvious that the magnitude of yield loss would be substantially higher in the affected area because of its intensity of damages . But this does not provide a picture of the loss at the national level. In order to determine the yield loss at the macro level, working out of the normalized loss is the most appropriate one which takes into account the level of injury from a specific constraint that farmers face in a normal year, as well as the percentage of land affected by the constraint.

III. RESULTS AND DISCUSSIONS

Yield Gaps and Yield Stability

The concept of yield gaps comes from the constraints studies carried out by IRRI in 1970s which make a quantitative differences between the potential yields and actual rice yield (Gomez et. al., 1979). Since the purpose of the present study is to identify major production constraints and estimate the contribution of different biotic and abiotic factors to the yield gap, we focus on the gap between actual yields and the potential yield obtained at the research stations. The estimates of rice yield obtained in experimental station and farmers' fields for different ecosystem are presented in Table 1. In this study, the yield difference between research station and the average actual farm level yield is considered as the gap due to the technical constraints. The yield gap is higher in irrigated conditions for all types of rice, as in the average yield. This gap reflects biological, soil

Table 1. Estimates of yield gap in Bangladesh, 1994-95.

Ecosystem/ varieties	Share of the ecosystem of total cropped area (%)	Research station yield (Kg/ha)	Ave. farm level yield (kg/ha)	Yield gaps due to technical constraints (kg/ha)
Irrigated ecosystem	49.0	5867	4093	1774
Dry season (boro)	22.1	6513	4585	1928
Early monsoon (aus)	5.1	3992	3191	801
Rainfed ecosystem	51.0	4276	2107	2169
Upland (Direct seeded aus)	15.3	2402	1664	738
Monsoon season (HYV Aman)[a]	21.8	5012	3806	1206
Lowland (Transplanted aman)	18.9	4080	2193	1887
Deepwater (Direct seeded aman)	6.9	2404	1836	568
Very deepwater (Local boro)	9.9	b	2816	
Total	100.0		2880	877

a = In many cases supplementary irrigation is provided during times of inadequate rainfall.
b = No HYV has been developed for this ecosystem.

and water, physiological and socio-economic constraints. The contribution of the technical factors to the yield gaps both in aus and MV aman rice is substantial (Table 1). There exists a gap of 1928 kg. ha-1 between the research station yield and farm level average yield in case of irrigated boro rice where one expects to find modern varieties, high inputs with assured water management.

Rainfed rice accounts for 51% of the cropped rice area and rainfed lowlands make up the greatest portion of rice land in Bangladesh. There appears high yield gap also (1887 kg/ha) in case of T. aman crop grown under lowland situation. The important factor behind this gap could be that, poor farmers may forgo for sub-optimum investment on agricultural inputs because of the high risk in rice cultivation under lowland condition. It thus implies that there is ample scope for increasing yield through crop management practices under such environments.

Farmers' Experience with Yield Fluctuations

The yield variations experienced by farmers can be reviewed from Table 2. In years of favourable production environment farmers achieve a yield of 3.56 t/ha (maximum yield) on average for all seasonal varieties of rice, while with biotic and abiotic stress that they experience in a normal year an average yield of 2.82 t/ha. Thus, the biotic and abiotic stresses reduces the yield by nearly 21 percent (740 kg/ha).

Table 2. Farmers' experience with rice yields by ecosystem and by season (kg/ha).

Ecosystem	Normal yield	Maximum yield	Minimum Yield	The gap between	
				Max. & normal yield	Max. & minimum yield
Rainfed ecosystem	1968	2468	1426	500	1042
Aus direct seeded	1664	2161	1204	497	957
Aman direct seeded	1836	2323	1409	487	914
Aman transplanted	2252	2758	1609	506	1149
Irrigated ecosystem	4095	5193	3158	1097	2032
Aus, transplanted	3191	4116	2388	925	1728
Aman, transplanted	3806	4797	2899	993	1899
Boro, transplanted	4585	5832	3591	1247	2241
Average	2818	3558	2119	740	1439

Source: Farm household survey.

The minimum yield shows the yield that farmers' achieve in years of severe stresses. These are usually on account of floods and droughts. The gap between maximum and minimum yield for all seasonal varieties taken together, is estimated at 1.44 t/ha, or about 40 percent of the maximum yield. Thus, the water related stresses could reduce the yield by a substantial amount.

The maximum yield under irrigated conditions is estimated at 5.19 t/ha, compared to 2.47 tons under rainfed conditions. This large difference arises due to the availability of irrigation facilities and the adoption of modern varieties. This gap could be reduced substantially, if appropriate modern varieties could be developed for rainfed conditions.

Under the irrigated conditions the maximum yield achieved by farmers is 4.79 t/ha for the wet season (aman) and 5.83 t/ha for the dry season. The one ton difference in yield is due to the favorable environmental factors such as less cloud cover, higher sunshine, and larger difference between the day and night temperature.

The best environmental situation for rice production is exemplified by the boro crop under the irrigated ecosystem. For this crop farmers achieve a yield of 5.83 t/ha, if there is no biotic and abiotic stresses. Yield obtained in the research station and on-farm experiment for the popular Boro varieties (e.g. BR14, BR3 etc) is reported as between 6.0 & 6.5 t/ha (BRRI,1998).

This shows limited possibility of increasing the yield through improved crop management practices.

Biotic Constraints to Rice Production

Insect pests : The major destructive rice insect pests as reported by the survey farmers are stemborers, rice hispa, rice bugs, brown planthopper, leaffolder, ear cutting caterpillar, case worm, gall midge, mealy bugs, thrips and storage insects . In terms of intensity of damages in the affected area with respect the insects, the yield loss varies from 236 kg to 772 kg ha-1 Table 3. The highest intensity of loss in the affected area was reported for Brown plant hopper and ear cutting catterpiller with an yield loss *of* about 40 % of the farm level yield. while the lowest was reported at only about 12% for caseworm. In terms of frequency of occurrence leaf folder was reported as the most serious insect followed by stemborer. Farmers reported that they faced these problems usually once in three years. In terms of area affected when the problem ocurs, most important insects are stemborer and rice hispa. Farmers reported that in the seasons when it occurs, stemborers affect 32% of the area for the irrigated ecosystem., and 27% of the land for the rainfed ecosystem. The estimate for rice hispa is 12 and 21 percent respectively. The brown plant hopper however appears to be a localized problem. According to the respondents, it affects only 4.4% and *?.1~Ic* of the area in the irrigated and rainfed ecosystems respectively when it occurs. The ear catterpiller and case worm also affects only a small fraction *of* area. If those three variables are taken into account to estimate normalized yield loss we find only stem borer, rice hispa and rice bug as the major damaging insects in Bangladesh. With expansion of irrigation however the brown

Table 3. Probability of occurence, area affected and yield losses from different constraints in rice production in Bangladesh.

Constraints	Rainfed area				Irrigated area			
	Frequency of occurence (%)	Percent of area affected	Yield loss in affected area (kg/ha)	Yield loss as percent of yield[a]	Frequency of occurence (%)	Percent of area affected	Yield loss in affected area (kg/ha)	Yield loss as percent of yield[a]
Insects :								
Stemborer	0.496	27.4	383	19.2	0.517	32.3	555	13.5
Rice-Hispa	0.312	20.6	538	27.0	0.291	12.3	911	22.2
Rice bugs	0.347	10.5	420	21.1	0.490	12.6	212	5.1
Brown planthopper	0.330	2.0	772	38.7	0.343	4.4	1229	30.0
Leaffolder	0.493	6.3	323	16.2	0.464	8.1	128	3.1
Ear Caterpilar	0.218	2.1	765	38.9	0.318	2.5	202	4.9
Case Worm	0.291	3.7	236	11.8	0.328	3.6	94	2.2
Others	0.356	7.0	448	22.5	0.343	5.0	566	13.8
Diseases :								
Bacterial blight	0.360	14.1	527	26.4	0.328	19.7	531	12.9
Blast	0.295	10.5	498	25.0	0.296	8.0	773	18.8
Brown spot	0.379	4.3	430	21.6	0.291	4.4	353	8.6
Sheath blight	0.255	1.8	500	25.1	0.271	3.9	395	9.6
Leaf scald	0.345	3.5	568	28.5	0.348	1.0	553	13.5
Tungro	0.253	3.5	743	37.3	0.213	2.0	900	21.9
Ufra	0.231	2.8	1098	55.1	0.500	0.9	924	22.5
Others	0.200	3.0	738	37.0	0.283	3.3	337	8.2
Weeds	0.546	7.5	1737	87.2	0.435	7.2	1640	40.0
Drought:								
Seedling	0.173	12.7	1760	88.4	0.295	1.2	3679	89.8
Vegetation	0.229	10.7	1623	81.5	0.208	6.2	2126	51.9
Anthesis	0.239	16.6	2381	100.0	0.194	11.6	1970	48.1
Submergence :								
Seedling	0.213	6.3	3133	100.0	0.232	1.5	5475	100.0
Vegetation	0.220	11.7	2780	100.0	0.264	7.1	4188	100.0
Anthesis	0.278	8.1	4698	100.0	0.279	6.8	4389	100.0
Heat	0.196	1.3	400	20.1	0.290	1.3	1451	35.4
Cold at seedling	0.100	0.0	1151	57.8	0.133	1.2	1103	26.9
Cold at anthesis	0.170	1.5	1169	58.7	0.170	2.0	2270	55.4

Source: Farm survey.

[a]The average farm level yield estimated from the survey was 1.99 ton ha^{-1} for the rainfed areas and 4.10 ton ha^{-1} for the irrigated areas.

plant hopper may emerge as a major problem as the normalized loss is about three times higher for the irrigated ecosystem compared to the rainfed ecosystem. The calculated normalized yield loss for different insects pests are presented in Table 4.

Table 4. Normalized yield losses from different constraints in rice production in Bangladesh.

	Normalized yield loss					
	Rainfed land		Irrigated land		Bangladesh	
	Kg/ha	% of ave. farm yield	Kg/ha	% of ave. farm yield	Kg/ha	% of ave farm yield
Insects						
Stemborer	52.1	2.62	92.8	2.27	68.4	2.42
Rice hispa	34.6	1.74	32.8	0.81	33.9	1.20
Rice bugs	15.4	0.78	13.1	0.32	14.5	0.51
Brown plant hopper	6.1	0.31	18.9	0.46	10.9	0.38
Leaffolder	10.0	0.50	4.8	0.12	7.9	0.28
Ear caterpillar	3.5	0.18	1.6	0.04	2.7	0.10
Case worm	2.6	0.13	1.1	0.03	2.0	0.07
Others	11.2	0.56	9.8	0.24	10.6	0.37
Diseases						
Bacterial blight	26.9	1.35	34.2	0.84	29.8	1.05
Blast	15.5	0.78	18.4	0.45	16.7	0.59
Brown spot	7.0	0.35	4.6	0.11	6.0	0.21
Sheath blight	2.3	0.12	4.2	0.10	3.1	0.11
Leaf scald	6.2	0.31	2.0	0.05	4.5	0.16
Tungro	6.6	0.33	3.9	0.10	5.5	0.19
Ufra	7.7	0.36	4.4	0.10	6.1	0.21
Others	4.5	0.23	3.5	0.9	4.1	0.14
Weeds	71.4	3.59	52.0	1.27	63.6	2.25
Drought						
Seeding	38.7	1.94	13.2	0.32	28.5	1.01
Vegetation	39.6	1.99	27.5	0.67	34.8	1.23
Anthesis	94.6	4.76	44.5	1.09	74.6	2.63
Submergence						
Seedling	42.4	2.13	19.8	0.48	33.4	1.18
Vegetation	71.6	3.60	78.5	1.91	74.4	2.63
Anthesis	105.8	5.32	83.6	2.04	96.9	3.42
Heat	1.0	0.05	5.7	0.14	2.9	0.10
Cold at seeding	0.0	0.16	7.8	1.90	3.1	0.11
Cold at anthesis	3.1	0.16	7.8	1.90	3.1	0.11

Source : Farm survey

The pattern of variation in the incidence behavior of the major insects according to production environments were also worked out and the corresponding results are presented in Tables 5 to 8. It is interesting that the rate of incidence of the major insects varied substantially as influenced by seasonal differences as well as intensity of rainfall and cropping pattern.

Table 5. Yield losses due to stemborer by production environment

Production envrinment	Frequence of occurrence	Percent of area affected when occurs	Yield loss in affected area (kg/ha)	Normalized yield loss (kg/ha)
Season				
Aus	0.453	28.53	769	99
Aman	0.532	29.88	354	57
Boro	0.506	32.59	585	96
Rainfall				
Low rainfall	0.396	29.2	850	99
Medium rainfall	0.556	33.18	471	87
High rainfall	0.521	16.34	330	28
Cropping System				
Rice-fallow	0.502	28.71	400	58
Rice-nonrice	0.524	27.58	442	64
Rice-rice	0.515	28.27	538	78
Rice-rice-nonrice	0.474	47.27	354	79

Source : Farm survey

The infestation of stemborer was much alarming in aus season as indicated by the higher normalized yield loss (99 kg ha-1) compared to that for aman (57 kg only) in monsoon season rice. The incidence is high in the low rainfall areas compared to the high rainfall areas. The incidence of stemborer is alarming in the areas with high intensity of rice cultivation. Yield loss due to hispa is higher for the winter crop (boro) compared to that in aus and aman seasons. Yield loss caused by hispa is higher in low rainfall areas and for lands which are deeply flooded.

Diseases : The diseases as reported by the farmers are bacterial leaf blight, blast, brown spot, leaf scald, sheath blight, sheath rot, tungro virus, ufra nematode and bakane With respect to loss in affected area , the most serious diseases are ufra nematode, follwed by tungro virus which reduce the yield by 30 to 40 percent. But they occur very infrequently and affect a very small portion of the area, so at the national level they cause very insignififant damage. With respect to the area covered the most important diseases are bacterial leaf blight and blast. The bacterial blight reportedly occurs once in three years and affects 20 and 14 percent of the land in the irrigated and

Table 6. Yield losses due to Rice Hispa by production Environment

Production Environments	Frequency of occurence	Percent of area affected	Yield loss in affected area (kg/ha)	Normalized yield loss (kg/ha)
Season				
Aus	0.278	18.08	583	29.3
Aman	0.318	16.76	555	29.6
Boro	0.302	14.80	989	44.2
Rainfall				
Low rainfall	0.305	17.31	974	51.4
Medium rainfall	0.305	16.01	629	30.7
High rainfall	0.297	16.34	469	22.8
Cropping system				
Rice-fallow	0.363	23.68	582	50.0
Rice-rice	0.284	12.00	762	26.0
Rice-non rice	0.346	13.12	686	31.1
Rice-rice-non rice	0.294	36.76	445	48.2

Source : Farm survey

rainfed ecosystems respectively. An emerging major disease is sheath blight as the extent of loss and area covered is substantially higher for the irrigated compared to the rainfed ecosystems. With respect to normalized yield loss, the major diseases are bacterial leaf blight and blast causing 1.1

Table 7. Yield losses from bacterial leaf blight by production environments.

Production environment	Frequency of occurence	Percent of area affected when occurs	Yield loss in affected area(kg/ha)	Normalized yield loss (kg/ha)
Season				
Aus	0.366	13.55	373	18.5
Aman	0.341	18.34	555	34.7
Boro	0.321	17.03	618	33.8
Rainfall				
Low rainfall	0.292	21.37	705	44.0
Medium rainfall	0.361	13.77	470	23.3
High rainfall	0.356	16.47	518	30.4
Cropping System				
Rice-fallow	0.263	19.25	676	34.2
Rice-rice	0.346	15.00	504	26.2
Rice-nonrice	0.441	14.51	728	46.6
Rice-rice-non rice	0.294	24.57	458	33.1

Source : Farm survey

and 0.6 percent yield loss at the national level for a normal year. The incidence of yield loss from these two diseases under different production environments can be seen from tables 7 and 8. The loss from BLB are higher in low rainfall and medium and upland conditions and also inflict more damages under rice fallow and rice- nonrice cropping pattern. The incidence of blast was reported higher in the high rainfall areas causing more damages in less intensively cropped areas.

Table 8. Yield loss from blast by production environments.

Production Environments	Frequency of occurence	Percent of area affected	Yield loss in affected area (kg/ha)	Normalized yield loss (kg/ha)
Season				
Aus	0.264	9.03	382	9.1
Aman	0.292	11.30	629	20.8
Boro	0.338	5.71	962	18.7
Rainfall				
Low rainfall	0.305	7.00	738	15.8
Medium rainfall	0.280	6.46	622	11.2
High rainfall	0.316	14.86	662	31.1
Cropping system				
Rice-fallow	0.306	13.91	529	22.5
Rice-rice	0.309	7.10	725	15.9
Rice-non rice	0.483	2.97	474	6.8
Rice-rice-non rice	0.211	4.78	524	5.3

Source : Farm survey

Abiotic Stresses

Drought : The damage intensity of drought is substantial under both rainfed and irrigated ecosystem in Bangladesh. It hampers the growth of rice plant almost in all stages. In Bangladesh, the drought is most damaging if it occurs during late September to end of October, i.e, during the anthesis stage of the Aman crop. It could lead to complete failure of the crop. The farmers reproted that this problem occurs once in four years and nearly 17 percent of the land is affected when the problem occurs causing complete loss of yield. The Boro crop could also be affected by drought at the anthesis stage, if there is too much evapotranspiration during late March and April, and the irrigation equipments get dry. The normalized yield loss due to drought at anthesis was estimated at about 95 kg ha-1 and 45 kg ha-1 in rainfed and irrigated ecosystems respectively. The average normalized yield loss due to drought at all stages is about 5 percent of the farm level yield.

Submergence : In Bangladesh nearly 40 percent of the land goes under water during the monsson season. Submergence is a major problem for the rainfed low lands. In southern part of the country the incidence of tidal submergence is often common during the monsoon season and it occurs mostly at vegetative stages of the Aman crop. Sudden heavy rains cause submergence of the rice plants in the poorly drained land in the depressed basin of the country in the north-east (Sylhet basin), south central areas (Faridpur) and part of north-west (Pabna, Sirajganj and Natore area). In terms of the intensity of affected area and yield loss, submergence at anthesis caused the highest normalized yield loss (106 kg ha-1) in the rainfed area and the average normalized national yield loss due to anthesis submergence is 97 kg ha-1 followed by vegetative submergence (74 kg ha-1).

Soil related probelms : According to farmers' report the soils that are severely deficient in zinc and sulphur may cause an yield loss of about 1200 kg ha-1 or nearly 40% of the yield. Many farmers now apply chemicals to avert the losses. In our survey, the areas from which this problem was reproted constituted only about three percent of the total area. The total area facing the problem would probably be much higher. The estimate probably shows losses after farmers managing the problem with chemical controls. The other major soil related stresses reported was infertile soil due to organic matter deficiency, which reportedly affect 3.3 percent of the area with a reported yield loss of 800 kg ha-1 in the affected area. Rice yield losses due to soil related stresses are presented in Table 9.

Table 9. Yield losses due to soil related stresses in Bangladesh.

Soil Stresses	Percent of area affected	Yield loss in affected area (kg/ha)	Normalized yield loss (kg/ha)
Organic matter deficiency	3.33	807	26.9
Phosphorous deficiency	0.56	1543	8.6
Potasium deficiency	0.60	524	3.1
Sulphur deficiency	2.97	1355	40.2
Zinc deficiency	3.12	1135	35.4
Gypsum deficiency	0.76	2074	15.8
Soil salinity	0.58	941	5.5
Total	11.92	1137	135.5

Source : Farm survey

In terms of yield loss in the affected area, among different soil related stresses, sulphur deficiency tops the list but the area coverage by sulphur deficiency is much lower than organic matter deficiency. The normalized yield loss for sulphur deficiency ranks top (40 kg ha-1) followed by zinc deficiency (35.4 kg ha-1).

Relative importance of biotic and abiotic constraints

The summary information on the yield loss estimation exercises are presented in Table 10. It is evident from the table that the yield loss from all the biotic and abiotic constraints is estimated at 0.8 tons ha-1 is about 28 percent of the current farm level yields in Bangladesh. This essentially implies that, if these losses (from concerned biotic and abiotic stresses) could be eliminated, rice production in Bangladesh could be increased by another 28 percent with existing technologies. The volume of rice production lost from these constraints is estimated at 7.8 million tons of paddy valued at US dollars 1558 million at the existing international prices. Nearly about 20 percent of the losses are on account of insect-pests, more than 26 percent are on account of submergence, almost 18 percent are on account of soil-related problem. The yield losses from the biotic constraints are estimated at 8 percent of the farm level yield accounting for about 29 percent of the total losses (Table 6).

Table 10. Yield gaps and yield losses from various constraints, estimates from farmers' perceptions.

Constraints	Normalized yield loss		Estimates of production losses in Bangladesh		Percent share of the constraint to total loss
	Kg/ha	As % of farm level yield	Million tons	Million US $	
Insect pests	151	5.4	1.52	304	19.5
Diseases	76	2.7	0.76	152	9.8
Weeds	64	2.3	0.64	128	8.2
Drought	138	4.9	1.38	276	17.7
Submergence	205	7.3	2.06	412	26.4
Heat and cold	7	0.2	0.07	14	0.9
Soil related stress	136	4.8	1.36	2.72	17.5
Total	777	27.5	7.79	1558	100.0

Source : Farm survey

Priority Problem Areas

Based on the magnitudes of crop losses due to the biotic and abiotic constraints, it is possible to identify research agenda related to field-oriented problems. According to Herdt and Riely (1987) setting priorities for research involve the following steps: (a) identifying production constraints and potential production gains by overcoming these constraints and other likely sources of yield increase; (b) estimating the likelihood, possible time length and the cost of solving these constraints; (c) determining equity weight associated with each problem and its potential solutions; and (d) determining the net present value of expected costs and benefits for all possible problems. The constraints or factors to which research should be directed for a program in Bangladesh are presented below.

Priority research problem areas under different ecosystems in Bangladesh :

Ecosystem/ season	Major constraints in order of priority
Irrigated	Stemborer (93) submergence at anthesis (89) submergence at vegetation (79), weeds (52) Drought at anthesis (44), Bacterial blight (34) Rice hispa (33) Drought at vegetation (28), Submergence at seedling (28) Blast (18)
Rainfed	Submergence at anthesis (106), Drought at anthesis (95), Submergence at vegetation (72), Weeds (71), Stemborer (52), Submergence at seedling (42), Drought at vegetation (40), Drought at seedling (39) Rice hispa (35), Bacterial blight (27).
Bangladesh Average	Submergence at anthesis (97) Drought at anthesis (75) Submergence at vegetation (74) Stemborer (68) Weeds (64) Sulfur deficiency (40) Zinc deficiency (35) Drought at vegetation (35) Rice hispa (34) Submergence at seedling (33) Bacterial blight (30) Drought at seedling (29) Organic matter deficiency (27)

Note: The figures within parentheses are yield losses in kg/ha. The soil related stresses have not been estimated separately for the irrigated and rainfed ecosystems.

Ex-ante assessment of returns from research investment

In this section we apply the cost-benefit approach to estimate the pay-offs of investment to address the problem areas mentioned in the previous section. The cost of addressing the problem through research is the investment on scientist's salaried, operational expenses and laboratory equipments for developing the technology. It usually takes a long time of cooperation between national and international scientists to develop technologies or management options to address the problem. We have assumed here that Bangladesh scientists will be engaged basically on applied and adaptive research with knowledge and information already available from basic and strategic research in international centres and advanced research institutions in other countries. We assume that a team composed of two senior scientists, four junior scientists and a number of technicians will address each problem which will need a research investment of US$ 3752 thousands for a period of 5 years. It was further assumed that it will take atleast two years for the extension system to take the technology to the farmers. It may be noted here that, the cost of extension services was not included in the present exercise due to the time and resource constraint. So, it remains as one of the limitations of this piece of research. However, under the present form of hypothesis, the investment is expected to yield benefit to farmers beginning the 8th year according to the following extension path.

Time stream of benefit : In this study we assumed that,

farmers start adopting the technology from the 8th year according to the following rate:

1st year, only 10 percent farmers adopt the technology,
2nd year, only 20 percent farmers accept it,
3rd year, about 30 percent farmers adopt it,
4th year, about 45 percent farmers adopt it,
5th year, 60 percent farmers adopt it.

The time horizons for the benefit has been taken as 20 years since the beginning of the research. The estimates of net present value (NPV) and benefit cost ratio (BCR) are presented in Table 11.

At full development the technology will be adopted at most on 60 percent of the land. The benefit is the value of the production that is currently being lost by the problem. We estimate the cost and benefit stream for 20 years beginning the initiation of the project.

Since the costs are spread over time and benefit accrue at a later time, it is necessary to convert the costs and benefits in terms of present value. The present worth of the net benefit (NPV) of a research project is obtained by deducting the present worth of research costs from the present worth of research benefits. Thus NPV is calculated by multiplying the annual production loss due to each constraint in the zone by price of rice in years t. It is a proxy measure for the productivity gain. Research costs are incurred for the first 5-6 years. During that period, benefits are assumed to be zero. Benefits starts accruing to farmers after seeds are multiplied and extended to farmers. Benefits may accrue for an infinite number of years after the research accomplishment, but it is limited to 12-13 here, as this is a reasonable period of time. After that time, the period value of benefits becomes insignificant because of the high rate of discounts and in this case the opportunity cost of capital is taken into consideration. The discount rate chosen for this economic analysis is 15%.

The BCR is the ratio obtained when the present worth of a benefit stream of a project is divided by the present value of the research cost stream. If BCR worked out to be greater than one, then the present worth of research would have exceeded present worth of research costs. The constraints which have BCR greater than one could be identified and prioritized. A given production constraint can be addressed by many research alternatives with different NPVs. In situations where resources are scarce and projects are mutually exclusive, the NPV is a more appropriate measure than the BCR (Ramasamy et al., 1996). For the present exercise, the estimates of net present value (NPV) and benefit cost ratio (BCR) are presented in Table 11. It is evident from the analysis that research investment for the abiotic stress submergence both at vegetative and anthesis stage would pay high benefit to the government as indicated by the corresponding calculated BCR and NPV. Almost similar level of economic return could be accrued through the research investment for developing technologies on antithesis drought. Ex-ante analysis also shows that, the eventual benefit from the investment on different biotic constraints, research for developing stemborer resistance would pay the highest return to the government (Table 11).

Tabel 11. Estimated benefit-cost ratio and net present value for the control of selected biotic and abiotic constraints.

Problem	BCR	NPV ('000 US$)
Biotic :		
Stemborer	36.83	137752
Rice hispa	18.26	68044
Rice bug	7.78	28759
Brown plant hopper	4.24	15462
Bacterial blight	16.05	59785
Leaf blast	8.97	33191
Brown spot	3.22	11635
Ufra	3.28	11838
Tungro virus	3.01	11078
Weeds	34.24	128046
Leaf folder	4.24	15459
Sheath blight	1.66	5793
Leaf scald	2.41	8614
Abiotic :		
Vegetative drought	18.73	6986
Anthesis drought	40.20	150382
Vegetative submergence	40.05	149844
Anthesis submergence	52.19	195373

Note : In deriving the BCR, research cost has been assumed at the international standard. While the NPV has been calculated using the research cost at the National (Bangladesh) level.

IV. SUMMARY AND CONCLUSIONS

In Bangladesh, rice yields in the recent years in all production environments have come to a halt despite adoption of improved package of practices. It is mainly due to yield losses for both biotic and abiotic stresses. It is therefore, necessary to take steps to reduce such wide gap between the highest and normal yield at farm level. It is evident from the present study that abiotic constraints are much more severe than the biotic ones irrespective of production ecosystems in Bangladesh.

Considering the farm level maximum and minimum yield, the gap is estimated at 1.44 tons ha-1 or about 40% of the maximum yield. There exists a yield difference of 2.7 tons ha-1 between the maximum yield achieved in irrigated and rainfed situations respectively. This gap could be reduced substantailly if appropriate MVs could be developed for rainfed conditions. Among the biotic constraints the most important ones are stemborer, rice hispa, rice bug, brown plant hopper, bacterial leaf blight, blast, sheath blight, tungro virus and ufra. In abiotic stresses both drought and submergence at different growth stages of rice plant are causing catastrophic yield losses under all ecosystems. Rice yield losses due to weed infestation was also estimated at substantially higher level. The priority research problem areas are, therefore, set in order of importance: submergence at anthesis, drought at anthesis, submergence at vegetation, stemborer, weeds, sulphur deficiency, zinc deficiency, rice hispa, bacterial blight, blast, and organic matter deficiency. Future research programme should be directed to address these issues.

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