Equity considerations in setting priorities for Third World rice biotechnology research

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Agricultural biotechnology promises to accelerate the rate of technical change in agriculture through more rapid invention of genetically improved microbes, plants and animals. The organisms changed and the way they are changed will determine the payoff of biotechnology, as a result, much interest is focussed on the priorities for biotechnology research. Private biotechnology firms have an additional concern in setting research priorities. They need to be able to capture enough of the payoff to provide a reasonable return on their investment.

The Rockefeller Foundation has committed significant resources to biotechnology reseach designed to improve tropical rice. Rice was chosen because 90 percent or more of the world's rice is produced and consumed in the developing world, largely by low income people, and as a result, gains from technical change in rice will largely accrue there. And because rice is a less important crop than wheat, maize and many other crops in the developed world, it is unlikely that either public agencies or private firms in developed countries will invest heavily in rice biotechnology.

In addition to direct technology development, a second objective of the Foundation's program is to provide a forum where researchers from developing countries can interact with some of the world's leading plant biotechnologists and exchange information on the latest plant genetic development tools, thereby reducing the "science knowledge gap" between developing and developed countries.

Within the broad scope of tropical rice improvement, the Foundation intends to give priority in the application of biotechnology to those rice characteristics that would be beneficial for improving the well-being of the mass of low income rice producers and consumers and in combating environmental degradation. This article describes briefly how priorities are being determined and what they are.

Benefits to low income producers and consumers

Increased agricultural productivity generates income gains that are ultimately distributed among individuals in society. The literature on distribution include two themes: one on the distribution of gains between producers and consumers and a second on the distribution of assets among individuals in the society.

The theory on distribution between producers and consumers shows rather clearly that when technical change occurs in a commodity for which demand is highly inelastic (like rice and other basic food crops) and whose price is determined in the domestic market or where the technical change also affects the international market, (conditions which hold for rice in most Asian countries) most gains will go to consumers (Norton and Davis 1981). Also, producers who consume a large fraction of what they produce reap gains in their roles as consumers, and, somewhat counter-intuitively, their gains are larger the smaller the proportion of their output they sell (Hayami and Herdt 1977).

These types of analyses are based on a narrow view of the short-run effects of technical change, while those that focus on changes in control over asset are more clearly long run (Deere and de Janvry 1979). Both themes recognize that those who control productive resources receive the earnings from those resources. The per unit resource earnings (wage rate, rental rate, etc.) obviously have an effect on the total earnings of a resource, but per unit earnings are determined in the market for each factor of production, which is affected by technology in all farm enterprises and in the non-farm sector. As a result, the link between technical change in the production of one commodity and income distribution is rather complex and cannot be accurately summarized in a simple phrase. Thus, statements like "the Green Revolution required increased purchases of fertilizer and therefore reduced farm income" ignore not only the increased output produced, but also the increased use of other inputs, total payments to all inputs, and the lower cost of an important consumption good, food.

A complicating dimension is the question of whether equity should be measured in absolute or relative terms — as gains in the income of the poor or as gains in the relative income of the poor compared to the wealthy. The most widely used measure of income distribution, the Gini coefficient, is a relative income concept. However, one may argue that in extreme low income situations the most useful indicator of equity is what happens to the absolute incomes of the poor, for several reasons. At the very low income levels that prevail in a number of developing countries, any gain in absolute incomes for the poor is extremely important. Focus on relative distribution can be misleading — relative incomes can improve without any gain in the absolute income of the poorest, if for example, incomes of the non-poor decline. Also, given any but the simplest two group classification, the idea of relative incomes is so complex that measures of it are not unambiguous.

Research that differentially increases the efficiency of production in one agro-ecology compared to another may lead to income benefits to producers who control land for which a new technology is suitable. Thus, semi-dwarf rice cannot be used in deep water conditions, so farmers with deep-water land get no reduction in production costs from successful research on short straw rice. However, if the technological change is pervasive enough to have downward impact on rice prices, then consumers who purchase rice gain from the lower cost, including those deep water rice producers who must purchase some of their needs, i.e. producers who are net buyers.

To stretch the theory of income distribution and technological change which is formulated for producers and consumers to reflect equity between the poor and the non-poor, a four-part grouping is constructed consisting of: poor consumers, non-poor consumers, poor producers and non-poor producers. This neat set of categories is upset by the recognition that technology is differentially applicable to various agro-ecologies. Thus, among producers one must distinguish those in ecologies for which a technology is suitable from those ecologies for which a technology is not suitable. Furthermore, many rice producers are net buyers of rice using income generated from non-rice sources, and those who are non-poor because of income earned from non-rice enterprises are less affected by rice technical change than are those entirely dependent on the rice sector. Recognition of these differences leads to defining the classes listed in Table 1.

The table shows the direction of impact that a technological change pervasive enough to reduce product price has on price, rice production costs, rice consumption costs, and the net effect of those three factors on welfare. It is assumed in the example that farmers with land in agro-ecology 1 can adopt the new technology while farmers with land in agro-ecology 2 cannot, there is no differential adoption effect of wealth (i.e. being poor or non-poor) on adoption, and the technical change reduces market price and hence aggregate revenue (because demand is inelastic). The result is that production costs of adopters in the affected agro-ecology are reduced (indicate by –), while the production costs of non-adopters and those in the non-affected agro-ecology are not changed (indicated as no change by 0). All consumers benefit, but those producers who are net sellers do not benefit through any reduction in rice consumption costs because they obtain their needs directly from their own production.

Table 1 - Impact of a technological change in rice production applicable in agro-ecology 1 but not 2, which leads to a fall in market price

Group	Impact on price received	Impact on rice prod. costs of group	Impact on rice cons. costs of group	Net impact on welfare
Consumers, non-producers				
1. Poor	0	0	–	+
2. Non-poor	0	0	–	+
Producers				
In agro-ecology 1 (technology suitable)				
3. Poor net buyers who adopt	–	–	–	?
4. Poor net buyers, non-adopters	–	0	–	?
5. Non-poor net buyers who adopt	–	–	–	?
6. Non-poor net buyers, non-adopters	–	0	–	?
7. Poor net sellers who adopt	–	–	0	?
8. Poor net sellers, non-adopters	–	0	0	–
9. Non-poor net sellers who adopt	–	–	0	?
10. Non-poor net sellers, non-adopters	–	0	0	–
In agro-ecology 2 (technology not suitable)				
11. Poor net buyers	–	0	–	?
12. Non-poor net buyers	–	0	–	?
13. Poor net sellers	–	0	0	–
14. Non-poor net sellers	–	0	0	–

Quantification of the effects indicated in the table would permit one to determine the net impact on well-being of each group identified. In the absence of quantification one can determine that consumers who are not also producers (groups 1, 2) gain from the technical change because the price they pay for rice falls and the quantity available increases. The impacts on the individual producer groups may be positive or negative even though the effect on producers as a group is negative. Producers in the agro-ecology where the technology is suitable are likely to gain if they are net buyers of rice and adopt the technology (groups 3, 5) and the fall in price received is more than offset by gains from falling costs and via consumed rice. Non-adopters who are net buyers (group 4, 6) are unlikely to gain unless their gains as consumers exceed their losses from lower prices of rice sold. Adopters who are net sellers (groups 7, 9) may gain if their costs fall more than their revenues, while non-adopting net sellers (groups 8, 10) lose. Producers in the agro-ecology where the technology is unsuited will not gain unless their gains as net buyers exceed the losses caused by the lower price (groups 11, 12). Net sellers among producers where technology is not suitable lose unambiguously (groups 13, 14).

Thus, for the most part, it is an empirical question as to whether producers in any particular groups gain or lose. Even with empirical answers on the direction of changes, determining the overall equity effect is a matter of judging "trade-offs" across groups to determine whether "the poor" gain overall. That is, one must ask whether the gains to groups 1 and 2 and the possible gains to groups 3, 4, 7 and 11 offset the losses to groups 8 and 13 possible gains to groups 3, 4, 7 and 11.

If it is clear that producers in agro-ecology 2 are all poorer than producers in agro-ecology 1, then one might make the argument that a technology applicable only in agro-ecology 1 would be anti-equity despite its benefits to consumers, or one might argue that it would have to have large benefits to consumers before they were sufficient to offset the possible negative effects on groups 3, 4, 7, 8, 11 and 13. However, these kinds of statements are inherently value-driven and illustrate the complexity of ensuring that a given technical change has positive effects on a broad group of individuals, such as "the poor", or "poor producers". It is clear that a significant fraction of benefits from technical change flow to consumers throughout the market affected by the technical change, those on farms and elsewhere. It is also clear that producers benefit as producers only from technology suitable for the agro-ecology in which they farm. In summary, all consumers of a product for which there is technical change gain while only producers who adopt the technical change gain as producers, but all producing individuals gain who also consume the product.

Methods for setting priorities

Economy theory can be used to show that among the alternatives for new technology, the economically optimal allocation of research funds would be that one in which each alternative is exploited to the point where it produces a sustainable expected marginal increase in the well-being of poor rice producers and consumers that is equal. This is a highly technical criterion parallel to the criterion by which a multi-product firm maximizes profit but our criterion maximizes social well being of the poor and considers long run environmental dimensions while a firm maximizes private profit. Assembling the data and relationships necessary to evaluate the criterion is extremely demanding, so an approximation to the criterion is used to set priorities for rice biotechnology. It entails the following steps:

1. Identify the alternative genetic improvements relevant for each rice production ecology in each developing country region (i.e. identify the research problems),
2. Determine the expected increase in productivity associated with solving each problem,
3. Determine the effect of the productivity gain of solving each problem on the expected well-being of poor producers and consumers in each region (i.e. the private benefits),
4. Determine the expected private costs associated with solving each problem by alternate methods,
5. Determine whether environmental externalities are associated with alternative problem solutions, if so, adjust private costs and benefits to approximate social costs and benefits,
6. Determine whether alternatives differentially affect various groups of producers and consumers, if they do, assign equity weights to alternatives,
7. Determine the net present value (NPV) of equity weighted, environmentally adjusted costs and gains in well-being for all possible problems, rank problems by NPV,
8. Estimate the relative success the application of conventional approaches have had and the potential for successful application of biotechnology.

A complete discussion of each step is beyond the scope of this brief article (see Herdt and Riely 1987), but some indication of how each was accomplished is useful.

A list of the alternative rice biotechnology problems or options for improvement was assembled by surveying scientists with many years of experience in tropical rice research. Twenty-four insect pests, sixteen plant diseases, eight soil problems, eight water and temperature problems, and twelve other problems were identified. The experts were also asked the extent of areas affected by each problem and the effect each problem had on yield per hectare. The same experts were asked to estimate how long it would take to "substantially solve" each research problem using conventional (not biotechnology) rice genetic improvement methods, assuming that in addition to present work an additional $0.2 million per year were expended. Problem solutions that offered environmental benefits over alternatives were given positive environmental weights, those with environmental costs were given negative environmental weights. It was determined that some problems were specific to certain agro-ecologies, and equity weights intended to reflect the relative value to poor producers and consumers of solving problems in each agro-ecology were arbitrarily set. Technologies addressing problems in upland conditions were given weights of 3, those for deep water and rainfed lowland weights of 2, and irrigated weights of 1. A social rate of time preference was used to discount the expected weighted costs and benefits of solving each problem from the year of expected solution to the present. Then judgements were made of the likely effectiveness of applying biotechnology as compared to other approaches, and a final ranking of problems was made. The remainder of this article concentrates on this final step.

The guiding principle followed in arriving at judgements on the use of biotechnology for rice improvement is that given equal social benefits, traits which are easy to introduce using "conventional" approaches probably should not have high priority for biotechnology because the conventional methods are easier and cheaper. Conversely, those traits that have been difficult to manipulate would seem to be better candidates for attention using biotechnology, including genetic engineering.

Past efforts to address various research problems can be grouped into four categories (see Table 2). Some problems have been controlled quite effectively with results that have been sustained over a significant period of time (abbreviated ES); an example is the semi-dwarf trait. Other problems have been effectively addressed with genes conferring strong resistance but the results have not been sustained over time and a series of new strong genes for resistance have been sequentially identified (abbreviated EU); an example is the brown planthopper. Research efforts to solve some other problems have been ineffective, even though they have been substantial (IS); an example is blast. A fourth category is made of problems or opportunities for which there are no solutions because there have been no significant efforts expended (abbreviated IN); apomixis is an example.

In a similar way, judgements were made as to the likely effectiveness of the application of biotechnology approaches to each problem. These were categorized as likely to be highly effective (HE), likely to be not effective (NE) or unknown (U).

A score for aggregate biotechnology appropriateness was developed by combining weights for the effectiveness of conventional and biotechnological approaches. The weights reflect the judgement that it would be less appropriate to undertake biotechnology on problems for which conventional approaches have been effective and sustainable, or for problems for which there is an indication that biotechnological approaches are likely to be ineffective than on problems for which conventional approaches have been effective but not sustainable, or ineffective because no significant effort has been devoted to the effort. Problems effectively addressed by conventional approaches were assigned weights of 0.5. Problems for which the likely effectiveness of biotechnology is unknown were given weights of 1. Problems for which conventional approaches have been ineffective even with heavy investments were given weights

Table 2 - Possible effectiveness of conventional and biotechnology approaches to possibly rice trait improvements

	control with conventional				potential w/ biotechnology			Aggregate BT potential	Wted NPV *BT potential
	ES	EU	IS	IN	HE	U	NE		
Bacterial blight	1					1		0.5	137
Blast			1			1		2	135
Brown spot				1		1		1	–3
Grain discoloration			1			1		2	104
Grassy stunt virus	1				1			1	26
Hoja blanca			1		1			4	29
Leaf scald				1		1		1	21
Leaf streak				1		1		1	–3
Ragged stunt virus			1		1			4	621
Root nematode				1		1		1	–3
Sheath blight			1			1		2	336
Sheat rot				1		1		1	28
Tungro virus			1		1			4	6905
Udbatta				1		1		1	3
Ufra				1		1		1	3
Yellow mottle virus			1		1			4	–9
Ants				1		1		1	–1
Armyworm				1	1			2	17
Black bug				1		1		1	–3
Brown planthopper		1				1		1	1944
Caseworm			1		1			4	–8
Diopsis				1		1		1	0
Gall midge			1			1		2	2583
Grain sucking (rice) bugs			1			1		2	21
Grasshopper				1		1		1	–4
Green leafhopper		1				1		1	9
Hispa				1		1		1	57
Leaffolder			1		1			4	400
Mealy bug				1		1		1	15
Mole cricket				1		1		1	–4
Naranga				1		1		1	–4
Root aphid				1		1		1	–4
Seedling maggot				1	1			2	–6
Striped stemborer	1				1			1	132
Storage insects				1		1		1	158
Thrips				1		1		1	10
White grubs				1		1		1	–3
Whitebacked planthopper		1				1		1	121
Whorl maggot			1		1			4	9
Yellow stemborer			1		1			4	3781
Acid soils				1		1		1	–3
Acid sulphate soils				1		1		1	–4
Alkaline soils				1		1		1	63
Alumin toxicity				1		1		1	0
Coastal saline/acid sulphate				1		1		1	256
Iron deficiency				1		1		1	16
Iron/mang toxicity				1		1		1	11
Peat soils				1		1		1	–3
Drought at seedling			1			1		2	75
Drought at anthesis			1			1		2	575
Cold at seedling				1		1		1	310
Cold at anthesis				1		1		1	–3
High temperature				1		1		1	–4
Submergence (flash flood)			1			1		2	1685
Upland drought/blast/iron			1			1		2	1962
Waterlogged (elongation)			1			1		2	524
Birds				1			1	0.5	206
Crabs				1			1	0.5	71
Grain quality	1				1			1	–2
Grain processing				1		1		1	–2
Rodents				1			1	0.5	75
Vitamin A				1		1		1	–3
Weeds				1			1	0.5	359
Apomixis				1		1		1	275
Cytoplasmic male sterility			1			1		2	2322
Shorter growth dur	1					1		0.5	–2
Greater lodging resist		1				1		1	1228
Seedling vigor			1			1		2	1080
Total									28618
Weights for aggregate BT potential	0.5	1	2	1	2	1	0.5		

BT potential = conventional effectiveness * biotechnology effectiveness

ES = effective and sustainable
EU = effective but not sustainable
IS = ineffective even with substantial research
IN = ineffective because no substantial research conducted

HE = effectiveness of biotechnology approach likely to be high
U = effectiveness of biotechnology approach unknown
NE = biotechnology approach likely not effective

AGGTAB

of 2, as were problems for which there are indications that biotechnology may offer especially effective approaches. An aggregate biotechnology potential weights was derived by multiplying the weight of conventional approaches by the weight for biotechnological approaches.

Table 2 shows initial judgements about the extent to which conventional approaches have been successful, the traits for which biotechnological approaches might be promising, and the aggregate potential for biotechnology approaches. Given these weights, an aggregate rating of 4 or 2 would indicate highest potential for a biotechnological approach and a rating of 1 indicate moderate potential. Among those with the highest biotechnology potential are tungro virus, submergence, cytoplasmic male sterility, gall midge, and seedling vigor.

Implications for biotechnology applications

Table 3 shows four alternative priority listings for the 68 problems included in the analysis, ranked according to: (1) current value of rice lost to each problem or not produced because of each unmet opportunity for raising potential productivity, (2) the same current value of output lost, adjusted by equity and environmental weights, (3) the equity and environmentally weighted value of output lost, discounted to its Net Present Value, (4) the equity weighted NPV multiplied by the biotechnology potential for each (i.e. the last column of Table 2).

Data in the table are in million dollars, representing increases in productivity that are distributed among classes of producers and consumers in the complex patterns suggested in the opening section of the paper. Zero values at the bottom of the first ranking mean that those problems each were estimated to result in less than $0.5 million worth of lost rice annually in the developing world.

Comparing the ranking between the first two columns gives an idea of the effect that applying the specified equity and environmental weights has on the rankings. The weighting process results in very large increases in the absolute values reported, but little change in the rankings of problems. Nine of the problems are ranked in the top ten by both criteria, and 19 of the top 20 are common, although the exact rank of each is slightly changed. This happens because most problems occur in all agro-ecologies so the equity weights have little differential effect.

Comparing the second and third sets of rankings show the effect of discounting future gains to the present, where the time required for success differs for various problems. Again, 9 of the top 10 are the same as are 19 of the top 20. This happens because the differences in the time expected until success and the costs of research on each problem are small relative to one another, except for a few problems like weeds and upland/drought/blast/iron toxicity, for which the "time to success" is very long. The rankings for those problems change, but because they are so important, they remain in the "top ten."

The final column shows the result of applying the biotechnology potential score to the data generated by the third criterion. Again, the problems that are ranked highly by the first three criteria tend to be ranked highly by this, even though the absolute values attached to each problem are considerably affected by the judgements about their biotechnology potential.

Table 3 - Rank ordering of research problems by alternative criteria

Value of output foregone (mil $)		Equity weighted value of output foregone (mil $)		Equity weighted NPV (mil $)		Equity weighted NPV * BT potential	
Weeds	1699	Upland drought/blast/iron d	8537	Brown planthopper	1944	Tungro virus	6905
Tungro virus	1534	Tungro virus	7907	Tungro virus	1726	Yellow stemborer	3781
Upland drought/blast/iron d	1423	Weeds	7103	Gall midge	1292	Gall midge	2583
Greater lodging resistance	1092	Brown planthopper	5361	Greater lodging resistance	1228	Cytoplasmic male sterility	2322
Brown planthopper	1059	Gall midge	4216	Cytoplasmic male sterility	1161	Upland drought/blast/iron d	1962
Cytoplasmic male sterility	1032	Cytoplasmic male sterility	335	Upland drought/blast/iron d	981	Brown planthopper	1944
Submergence (flash flood)	750	Greater lodging resistance	3106	Yellow stemborer	945	Submergence (flash flood)	1685
Gall midge	704	Yellow stemborer	2918	Submergence (flash flood)	842	Greater lodging resistance	1228
Birds	601	Submergence (flash flood)	2608	Weeds	718	Seedling vigor	1080
Yellow stemborer	516	Drought at anthesis	2156	Seedling vigor	540	Ragged stunt virus	621
Seedling vigor	481	Birds	2050	Birds	412	Drought at anthesis	575
Drought at anthesis	421	Apomixis	1775	Cold at seedling	310	Waterlogged (elongation)	524
Apomixis	402	Seedling vigor	1753	Drought at anthesis	288	Leaffolder	400
Cold at seedling	278	Bacterial blight	1261	Apomixis	275	Weeds	359
Bacterial blight	246	Cold at seedling	1018	Bacterial blight	274	Sheath blight	336
Waterlogged (elongation)	235	Rodents	982	Waterlogged (elongation)	262	Cold at seedling	310
Coastal saline/acid sulphat	230	Waterlogged (elongation)	885	Coastal saline/acid sulphat	256	Apomixis	275
Rodents	223	Coastal saline/acid sulphat	783	Sheath blight	168	Coastal saline/acid sulphat	256
Crabs	209	Storage insects	770	Storage insects	158	Birds	206
Sheath blight	152	Sheath blight	767	Ragged stunt virus	155	Storage insects	158
Storage insects	143	Ragged stunt virus	703	Rodents	151	Bacterial blight	137
Ragged stunt virus	141	Crabs	682	Crabs	141	Blast	135
Leaffolder	92	Hispa	508	Striped stemborer	132	Striped stemborer	132
Hispa	88	Grain discoloration	495	Whitebacked planthopper	121	Whitebacked planthopper	121
Grain discoloration	80	Leaffolder	479	Leaffolder	100	Grain discoloration	104
Striped stemborer	73	Striped stemborer	416	Blast	68	Rodents	75
Whitebacked planthopper	67	Blast	392	Alkaline soils	63	Drought at seedling	75
Blast	63	Whitebacked planthopper	338	Hispa	57	Crabs	71
Drought at seedling	60	Drought at seedling	308	Grain discoloration	52	Alkaline soils	63
Alkaline soils	59	Alkaline soils	221	Drought at seedling	38	Hispa	57
Sheath rot	28	Mealy bug	152	Sheath rot	28	Hoja blanca	29
Mealy bug	26	Sheath rot	138	Grassy stunt virus	26	Sheath rot	28
Grassy stunt virus	26	Grassy stunt virus	129	Leaf scald	21	Grassy stunt virus	26
Leaf scald	21	Grain sucking (rice) bugs	123	Iron deficiency	16	Leaf scald	21
Grain sucking (rice) bugs	21	Leaf scald	112	Mealy bug	15	Grain sucking (rice) bugs)	21
Iron deficiency	17	Iron deficiency	83	Iron/mang toxicity	11	Armyworm	17
Iron/mang toxicity	13	Thrips	68	Grain sucking (rice) bugs	10	Iron deficiency	16
Thrips	12	Armyworm	66	Thrips	10	Mealy bug	15
Armyworm	11	Hoja blanca	60	Green leafhopper	9	Iron/mang toxicity	11
Hoja blanca	9	Iron/mang toxicity	51	Armyworm	9	Thrips	10
Green leafhopper	6	Odbatta	34	Hoja blanca	7	Whorl maggot	9
Ufra	6	Ufra	34	Ubdatta	3	Green leafhopper	9
Ubdatta	6	Green leafhopper	31	Ufra	3	Ufra	3
Ants	4	Ants	27	Whorl maggot	2	Ubdatta	3
Aluminum toxicity	3	Diopsis	17	Diopsis	0	Aluminum toxicity	0
Diopsis	3	Aluminum toxicity	12	Aluminum toxicity	0	Diopsis	0
Whorl maggot	2	Whorl maggot	12	Ants	–1	Ants	–1
Caseworm	2	Root nematode	5	Grain processing	–2	Shorter growth duration	–2
Yellow nottle virus	1	Yellow nottle virus	5	Grain quality	–2	Grain quality	–2
Root nematode	1	Caseworm	5	Caseworm	–2	Grain processing	–2
Black bug	0	Black bug	3	Yellow nottle virus	–2	Black bug	–3
Mole cricket	0	Mole cricket	1	Black bug	–3	Brown spot	–3
High temperature	0	High temperature	0	Seedling maggot	–3	Cold at anthesis	–3
Grain processing	0	Grain processing	0	Peat soils	–3	Vitamin A	–3
Grasshopper	0	Grasshopper	0	Leaf streak	–3	White grubs	–3
Acid sulphate soils	0	Acid soils	0	Cold at anthesis	–3	Leaf streak	–3
White grubs	0	White grubs	0	Vitamin A	–3	Acid soils	–3
Vitamin A	0	Vitamin A	0	Brown spot	–3	Peat soils	–3
Peat soils	0	Peat soils	0	White grubs	–3	Root nematode	–3
Acid soils	0	Seedling maggot	0	Acid soils	–3	Mole cricket	–4
Brown spot	0	Root aphid	0	Shorter growth duration	–3	Root aphid	–4
Naranga	0	Naranga	0	Root nematode	–3	High temperature	–4
Root aphid	0	Acid sulphate soils	0	Mole cricket	–4	Naranga	–4
Seedling maggot	0	Shorter growth duration	0	High temperature	–4	Acid sulphate soils	–4
Cold at anthesis	0	Cold at anthesis	0	Grasshopper	–4	Grasshopper	–4
Grain quality	0	Grain quality	0	Acid sulphate soils	–4	Seedling maggot	–6
Leaf streak	0	Brown spot	0	Naranga	–4	Caseworm	–8
Shorter growth duration	0	Leaf streak	0	Root aphid	–4	Yellow nottle virus	–9

The results of this analysis indicate the problems that are widespread and highly yield-limiting in any of the agroecologies and for which there is a reasonable chance that biotechnology can provide a solution or raise production potential should be addressed using biotechnology. Among the insect pests these include: gall midge, brown planthopper, yellow stemborer, leaf folder, storage insects, striped stemborer and rice hispa. Among the diseases they include: tungro virus, ragged stunt virus, blast (if at the same time a greater degree of upland drought tolerance can be introduced), sheath blight and bacterial blight. Among the physical environmental conditions are: submergence tolerance to flash floods, tolerance to waterlogged conditions or chronic floods, upland drought tolerance, lowland drought at anthesis and cold temperature at the seedling stage. Among the opportunities for raising potential productivity are: greater lodging resistance, cytoplasmic male sterility, greater seedling vigor and apomixis. Additional problems that are highly ranked despite the lack of any apparent genetically determined means of control are weeds and birds. Both are especially important in Africa, as well as in other areas where upland rice is important.

The results of this analysis will be used as a general guide to allocation of the Rockefeller Foundation's resources addressed to rice improvement, but those decisions will be tempered by other considerations because of the following weaknesses in the analysis:

— the estimates of area and yield lost to each problem for Latin America and Middle East and North Africa are purely nominal; estimates of experts familiar with those areas must be obtained, as well as better data for the other regions,

— the estimates of success with conventional approaches and the potential for biotechnological solutions need further improvement, and in fact the latter will change as researchers discover new ways to use the evolving tools,

— the use of arbitrary weights to reflect environmental and equity considerations leaves much to be desired — at the least, additional experiments on the model to discover the effect of alternative sets of weights will be conducted, and

— alternative approaches to incorporating the equity and environmental dimensions will be sought, as well as practical alternative ways to reflect the fact of diminishing returns to research on individual problems.

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