# DEFINING THE RELEVANT CONSTRAINTS IN CROP PROGRAMS: DATA REQUIREMENTS TO IMPROVE RESEARCH RESOURCE ALLOCATION



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## SUMMARY



During recent years in International Centers there have been substantial research efforts to describe production systems, measure farm level yield losses, identify consumer preferences, and specify rainfall regimes and soil types. Geographers, economists, climatologists, and soil scientists produce information useful for the plant designers, i.e. breeders and associated disciplines. So far the contribution to research design has been marginal. Research priorities have been set subjectively within the commodity teams without much systematic data processing from the target regions. A better definition of the yield constraints in the target regions should lead to more efficient research programs.

Two different approaches are utilized. First, various types of direct data collection from the target region have been undertaken. This approach is expensive and some of the data are region, season, and variety specific. However, the data do not involve subjective estimates. The second type of approach involves a more theoretical statement of research objective problems. The data requirements here are more difficult to obtain and often require subjective estimates of the breeders. Both approaches should be useful to improve research resource allocation within commodity programs.

## INTRODUCTION

Crop research in the International Centers is predominantly organized into commodity divisions with the principal output being high yielding varieties. Within the commodity division the specific crop programs revolve around breeding. The breeding itself is a probability game with the following steps:

a. A world wide collection of germplasm is made to obtain sufficient genetic variability so that some interesting characteristics can be combined from different parental sources.

b. The identification of the desired characters to overcome specific constraints to yield increase is made. The "relevant constraints" on the production side are some combination of disease and insect pests, soil and water conditions, and plant characteristics. For example, rice breeding at the International Rice Research Institute (IRRI) was principally concerned with building shorter, sturdier varieties to respond to higher fertilizer levels without lodging and with complete water control. Breeding research was later directed at four diseases and three insect pests. Finally, non-photoperiod sensitivity was desired[8,9].

   These "relevant constraints" can be imposed by consumer conditions, such as taste preferences, as well as production factors. Consumers may not eat or may offer a lower price for a bean of a specific color or size. Cassava consumers would be expected to prefer a lower HCN content for fresh consumption, a longer shelf life, and a high starch content.

c. The germplasm is screened for the characteristics identified in (b). The best potential parents are identified. At this stage of the selection process cultivars may be identified with a sufficient number of characteristics to be released into regional variety or farm trials.

d. These parents then enter into a series of crossing and selection trials until materials emerge with the maximum of the desired characteristics.

e. The varieties, lines, or segregants are released to National Institutions for either dissemination, trials in different agro-climatic conditions, or further crossing for desired region specific characteristics. A critical component here is the feedback by the National Institutions into a better definition of the future "relevant constraints" and the entry of their new material, either their selections or new crosses, into the germplasm pool (a) thereby making the process circular.

The comparative advantage of International Centers is that there are apparently economies of scale to germplasm collection, screening, and crossing. Part of the comparative advantage is physical. A larger breeding team can specialize more and thereby produce a much larger number of crosses. Similarly, the interaction between agricultural disciplines should be useful for problem definition and solution. The most important advantage of International Centers may result from the "minimum critical investment". Breeding requres highly trained personnel and specialization in a specific crop, is expensive, and is a long term investment. National governments in developing countries often have few trained agricultural scientists and have to be concerned with many crops. Moreover, in developing countries research is generally given a low priority in public expenditures as decision makers appear to prefer investments with a short payoff period. The potential disadvantage of International Centers in relation to National Institutions is in the restricted ability of the former to diagnose desired varietal characteristics for a series of specific regions in a large number of developing countries.

The crucial research decisions are in the definition of the "relevant constraints" and thus the breeding strategy. The rest is a more mechanical process of collecting germplasm (a), screening and crossing (c) and (d), and dissemination (e). International Centers are continually in a process of gathering, refining and digesting information about the "relevant constraints" for the critical breeding decisions. In the next sections different approaches for data collection to define the relevant constraints are critically reviewed.

## APPROACHES FOR DEFINING THE "RELEVANT CONSTRAINTS"

The rapid increase in the number and budgets of the International Centers has focused attention upon the setting of priorities and the allocation of research resources between commodities[12]. At the individual center, where crop research mandates are already defined, the most important questions are on priority setting for research within the individual crops, and particularly upon the definition of "relevant constraints" for setting breeding priorities. Historically, these priorities have been set with an interdisciplinary problem solving approach supplemented with outside consulting and experiments. Each of the scientific disciplines within the crop team reviews the literature to identify yield constraints. Further experiments are then defined to fill in the gaps. Pathogen and insect pests are catalogued. The response to nutrients and stress of various types are evaluated and optimum plant type characteristics are identified. The breeder must then make subjective priority assessments on the basis of the data presented by the other team scientists and his estimates of the probability for success in any activity.

What are the limitations to this methodology? One basic problem is the size and geographic diversity of the target area for International Centers. For example, a pathogen or yield characteristic may be a critical factor influencing yields in one region but not very important in the entire target area. Moreover, experiment station yield losses may have little correspondence to farmers' yield losses where the input levels, rainfall regimes, soil quality and water control are substantially different.

There have been four basic responses to the above criticisms, agro-climatical surveys, agro-economic surveys, regional variety trials, and farm trials. In the first method an overall data gathering approach in the target region combines data on soils, rainfall distribution, temperature and radiation with the basic crop production statistics. With better quantification of factors such as water balance, plant stress and yields, and probabilities of disease incidence related to climatic conditions simmulation models could be constructed. However, there will be a long time lag before much useful input reaches the plant designers due to the large data requirements of such a system, refined data management and analytical skills required, the poor quality of secondary production data in many crops, and inadequate quantification of the interaction between the plant and its environment. However, even the raw data will be useful.

Another approach has been agro-economic farm surveys. In these surveys a team of economists and agronomists collect farm data on resource use, yields, cultivation practices, pathogen incidence, soil and economic parameters. The principal constraints can be identified through multiple regression of yield limiting factors and the yield losses weighted by the distribution of the factor. This quantification of "relevant constraints" has stimulated more systematic definition of priorities; however, the specific model results have been criticized for being region and season specific and for measurement problems in variables especially disease incidence. Nevertheless, of the various yield constraints identified in one production season in four regions of Colombia three were identified as research priorities by the Bean Program of CIAT.[13,16,17] These surveys identified farm level yield constraints of present varieties. However, the plant designers' question is: What would be the yield constraints for the new genetic material embodying some of the characteristics constraining yields?

Another approach has been the testing of new genetic material in regional or international trials. Differential responses to temperature, soil variability, rainfall distribution, day length, and pathogen/insect incidence can be evaluated. Unfortunately, it has been difficult to separate these and other factors determining yield and focus has been on yield stability across locations, which has been shown in rice not to correspond to yield stability over time in the same location[6]. Differentiating yield reduction into its component parts combined with the agro-climatical weighting of these various factors across the target region would resolve the priorities definition problem for that season and those varieties. However, this resolution will still take a substantial investment in scientific personnel, money, time, and requires further development of methodology. Moreover, the regional variety trials are principally carried out under experimental rather than farm level conditions.

Recently, several International Centers have been putting a major effort into farm trials of new technology. These trials combine agronomic and economic evaluation. IRRI has gone the farthest on these trials taking advantage of the widespread National Center interest resulting from the dissemination of the new IRRI rice varieties into regions with good water control and favorable nitrogen - rice price ratios. These IRRI trials have identified the requirement for more cost effective insect control in rice production[5,7]. At CIAT the farm trials have indicated for Colombia the profitability of improved, region specific, agronomic practices, the inability of improved seed quality in field beans to substitute for new disease resistant varieties, and a series of variety characteristics for future breeding selection including high starch content in cassava and stability of starch content with varying times of harvest[2,18]. The principal limitation on farm trials is their site, time, and variety specific results; hence, it will be necessary to set up networks with national programs to institutionalize this type of data flow.

All four approaches are complementary and are gradually building up data bases to ultimately define the relevant constraints over large target areas. All four are expensive, long run processes of data accumulation. Another type of approach is to analyze some of the present crop program strategy choices and to define data requirements to resolve some of the dilemmas or unanswered questions in these debates. This is undertaken in the next section.

# CRITICAL ISSUES IN CROP RESEARCH DEFINITION

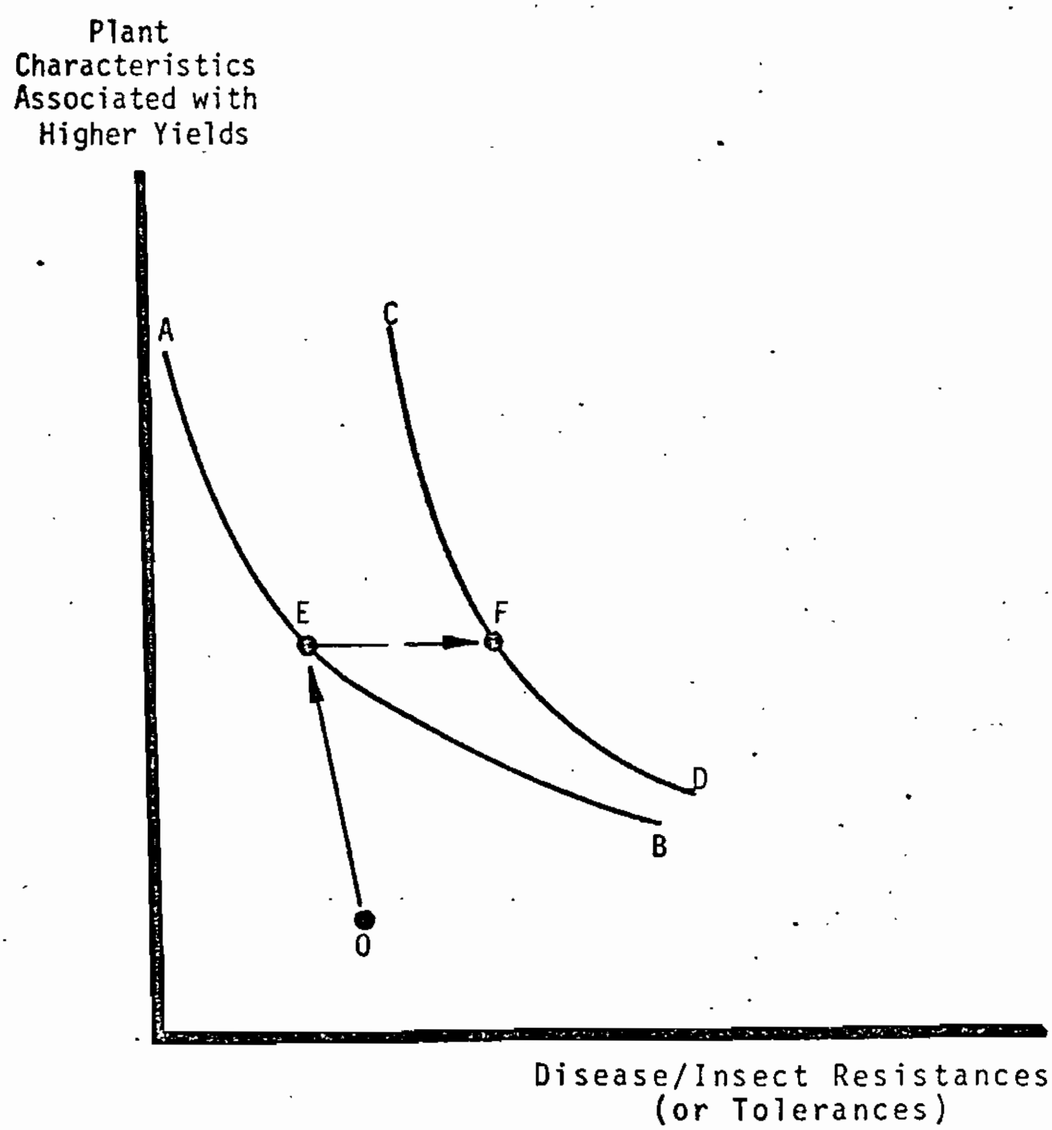
## 1. Yield or Resistance Breeding:

Breeding strategy often involves a choice between physiological plant characteristics such as dwarf varieties or increased harvest index associated with high yields and resistance/tolerance to the major disease/insect complex(es). This decision can be conceptualized graphically with the point, 0, marking the low level of yields before breeding work (Figure 1). AB was the potential yield frontier obtainable from various strategies. All points on this frontier would give the same yields. The curve would be discrete rather than continuous; however, the combination of strategies could make it almost continuous. The breeder's decision would then depend upon his estimates of the shape of the curve and the costs and probabilities of success of various breeding alternatives. The initial assessment was that the principal "relevant constraint" was the lodging when fertilization levels were increased. In some cases the new varieties, IR-5 and IR-8, had even less resistance to disease/insect pests than local varieties as shown in the diagram. These varieties were very successful where there was good water control and high nitrogen levels were utilized. The feedback after their introduction helped define the second generation frontier (CD). The second generation varieties, such as IR-20 and 26, maintained the dwarf characteristics and concentrated on resistance/tolerances and on consumer requirements.

All commodity programs have to implicitly conceptualize this potential yield curve. For some commodities such as beans the largest initial gains are believed to be along the horizontal axis with plant characteristics as a second generation constraint. Would it have been more efficient for the output path in IRRI to have been OF or was it necessary to move OEF to obtain the feedback on insect and disease problems after obtaining the initial credibility in their target region with IR-5 and IR-8? Can other commodity programs move along the output path OF or does this over-complicate breeders' objectives? Without substantially more information from the breeders, it is not possible to compare the efficiency of these two paths. The first generation assessment of the frontier was a more subjective decision whereas the second generation varieties had the benefit of the evaluation of the performance of the first generation varieties in farmers' fields in the target area.

FIGURE 1

YIELDS FROM OVERCOMING SPECIFIC CONSTRAINTS



In summary, if the initial principal constraints are pathogens and yield breeding appears to have a low probability of increasing genetic yield potential, then the breeding strategy will be oriented towards resistance. Similarly, a physiological approach of improving plant type requires the successful identification of characteristics associated with high yields. In both cases the identification of the "relevant constraints" and eco-system stratification are essential to developing the breeding strategy. A final footnote is a response to the naive argument that resistance breeding will only stabilize yields around some low level equilibrium. By reducing the yield variance at the lower tail of the distribution, mean yields increase over time. Similarly, those breeding exclusively for yield characteristics have to take diseases and insects into account at some point in their selection and evaluation program if these pathogens or pests reduce yields in the target areas and can not be economically controlled chemically or with cultural practices.

2. Vertical vs. Horizontal Resistances:

When breeders decide that diseases or insects are priority constraints, the stability of the resistance source often becomes an important concern. Many pathogens have multiple races or strains and vertical resistance can rapidly break down. Vertical resistance utilizing the definition of major gene(s) has been unstable with rice blast, late blight in potatoes, wheat rusts, and the brown planthopper in rice[19]. Several approaches to the problem have been proposed, ranging from the continual development and turnover of varieties resistant to the dominant race or biotype as with the brown planthopper in rice to multilines as the International Maize and Wheat Improvement Center (CIMMYT) has done for wheat rusts[6,19].

Some pathologists have recommended breeding for horizontal resistance, which usually involves the accumulation of minor genes. The development of vertical vs. horizontal resistance as a general theory of plant resistance is relatively new and there are substantial debates on the generality of the theory, the nomenclature used, and the implications for a breeding program. As opposed to a pedigree breeding methodology using gene transfer techniques and individual plant selection, horizontal resistance is usually associated with bulk breeding to move the population distribution towards greater tolerance levels to the local disease/insect complex[15]. Among International Centers only the International Potato Center (CIP) with potato late blight and the International Institute of Tropical Agriculture (IITA) with cassava bacterial blight and African mosaic have attempted this approach. Within both programs these diseases were identified as the principal constraints on production[1,3,4].

Keeping ahead of pathogen evolution in developed countries relies on good disease monitoring, an effective seed production system, and a timely distribution network. These characteristics do not exist in most developing countries. Nevertheless, in the heat of the discussion of genetic vulnerability and potential epidemics such as the maize epidemic in the U. S. in 1970, which reduced U. S. corn yields by 15 percent[14], two important points are forgotten. First, the diffusion of the most genetically uniform food crops is limited by differences in taste preferences and production requirements to fit into specific eco and cropping systems. Secondly, a resistance breeding choice is an investment decision. Even if a vertical resistance breaks down, a shorter development time may give it a substantially higher return than the more time consuming horizontal resistance process. Returns at the social level would be the discounted value of the increased yields over time minus the development and diffusion costs. Even some crude estimates of development and diffusion costs and time till breakdown would enable some economic comparisons of the different resistance strategies. If the sources of genetic resistance are limited, a divergence between the private and public costs may be necessary to reflect the risk of depletion of the resource.

### 3. Major vs. Minor Constraints:

A resistance breeding emphasis requires a ranking of pathogen/insect pests. This is more easily accomplished when the target area is reasonably homogenous as in a U. S. experiment station in a state with a limited number of eco-systems producing the commodity. In an International Center even the conceptualization of this problem produces a headache. Not only is there an extremely large number of eco-systems but also the articulation of production problems by farmers to researchers is very inadequate.

One response has therefore been the supermarket approach. All pests are documented and described and a maximum number are worked on. The argument is made that a present minor pathogen could become a major pathogen once resistance is obtained for those pathogens presently in the latter category. This approach is often inefficient since many pathogens are only associated with particular environments and thus many resistances are not needed in certain eco-systems. Also, the suitability of other control measures must be weighed against the costs of resistance breeding. Moreover, gene linkages between desired and undesired characteristics can result in further delays for local adaptation unless trials in multiple eco-systems are undertaken early in the evaluation process.

This brings the discussion back to the conceptual problems of identifying the future relevant constraints. Certainly, more basic data is necessary on the target regions. Even in the necessarily vague area of predicting the future performance of a variety with some resistances an improvement over the supermarket approach must be possible. To the present only the direct farm level testing and international trials have produced data on new variety performance. Simmulation is a future possibility when more of the basic data are available for the modeling.

## 4. Tastes Over Time:

Consumer tastes are known to have changed historically since not only new varieties but also new crops have moved between regions of the world. Urbanization and increased incomes modify consumption patterns. Tastes are expected to be a function of relative prices; however, the time lags are unknown. Anticipating or precipitating future taste charges would be extremely useful for a commodity program. However, until the factors changing taste preferences are understood, plant designers will have to assume that the present price differentials by variety characteristics will continue into the future. The trade-offs between price differentials and the cost of the breeding search for different crop characteristics can be estimated by combining the market price differentials with the subjective judgement of the breeder. A sixty percent price differential for black beans in Colombia implies that black bean yields have to be very high to compete with the preferred Colombian large reds.

## CONCLUSIONS

To define the relevant constraints two general approaches have been utilized, data gathering exercises and a slightly more theoretical specification of the required information. The former are often expensive, site, season, and variety specific but will gradually give increasingly exact information on the requirements in the target region. The latter approach directly addresses some critical problems in research design but largely depends upon subjective estimates by plant designers for the strategy choices and on future data collection for ranking of diseases and insects and for the responsiveness of tastes to changes in prices over time.

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