crop yields

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Stability, Adaptability and Targeting in Crop Breeding Programs

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The design of an efficient crop improvement research program incorporates a number of complex factors. Most importantly, the environments in which a given crop is produced are generally variable in two important dimensions. Soil type, temperature, humidity, rainfall and the distribution of temperature and rainfall differ between locations. Many of these environmental factors also vary from season to season in the same location. This environmental variability would not be important for research program design, however, if it were not for "genotype-environment interactions".

Genotype-environment interactions describe the sensitivity of biological processes to alternative environments. A plant or a collection of plants of the same or similar genotypes will perform differently in different environments. Its actual performance will depend on the environments and on traits associated with the genotype. Plant breeders can, through genetic manipulation, alter the degree of environmental interaction. In an older literature the concept of <u>tolerance</u> was used to characterize a low degree of genotype interaction with particular environments. Breeding for cold-tolerance, salt-tolerance and aluminum-tolerance for example, has long been part of crop-breeding work.

In this paper we will attempt an analysis of some of the economic questions that emerge because of variable environments, genotype environment interactions and the selection and crossing options open to the crop-breeder. In the first section of the paper we will discuss the concepts of <u>stability</u> and <u>adaptability</u> as they relate to the problem. The second section of the paper then presents a model of optimal targeting of crop-breeding activities. The final section offers some empirical evidence regarding stability and adaptability in wheat genotypes.

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I. Stability, Adaptability, Transferability and Targeting

Stability may be defined in terms of the impact of season to season environmental variation or a variety or set of varieties at a given location. A variety is stable if it displays a low degree of seasonal variation relative to other varieties planted at the same site. A location is stable if yields show low variability relative to yields at other locations.

Adaptability is defined in terms of the impact of different environments on the yield of a variety. Varieties which yield well under different environments are adaptable, displaying little genotype-environment interaction.

Targeting refers to the selection of a specific environment or set of environments toward which a breeding program is directed. A typical research institution has several targets, although they are not always clearly defined. State experiment stations in the U.S. have justified branch stations and testing stations as part of a multiple target breeding strategy. Soybean breeders in Minnesota may, for example, target some of their effort to the short season of Northern Minnesota, some to the Southwest areas of the state and some to intermediate areas.

Transferability between locations depends on the performance of cultivars in two locations. If performances are highly correlated then varieties and research are said to be transferable between the locations. Note that transferability can result either from inherent similarities of the two locations, or from the targeting of research towards both locations.

Stability and adaptability are thus refinements of the term tolerance as used in the older agronomic literature and the term stability as used in more recent agronomic literature. The distinction between stability and adaptability is important because farmers in any given location will value stability in the selection of varieties but will not value adaptability. Public research institutions will value adaptablility because it may lower the total cost of providing improved varieties to a large number of farmers in different locations with different environments. It can lower this cost by reducing the number of targets in a breeding program.

Targeting has its costs. If Minnesota soybean varieties were to be targeted to each county in the state, for example, this would require a crossing and selection program for each county and county stations for testing and selection. It would be quite expensive. Breeders would note that little would be gained from such a program over what say 3 or 4 targets for the state would produce at much lower cost. They would note that Minnesota producing environments are not all that heterogenous and that soybean varieties are fairly adaptable (or that adaptability can be obtained at low cost in terms of yield loss.)

To formalize this process in a model of optimal targeting we require, however, knowledge of the following:

1. The marginal cost of added targets in a given program.

2. The marginal cost of stability in terms of yielding ability sacrificed to obtain stability

3. The marginal cost of adaptability between alternative locations.

4. Environmental variability over time and across locations

II Modeling Research Transferability and Efficient Crop Improvement

This section will analyze the design of crop improvement systems from a more theoretical aspect. We will present and discuss two models of optimal research system design, corresponding to a problem of somewhat different scope and assumptions.

A. A Model of Experiment Station Location

The problem which this model examines is that of efficiently locating the experiment stations, selecting and screening the products of a crop improvement program. The effort is directed at economizing on the expenditures of experiment stations and maximizing the technology transfer between regions.

Let

δ_i = 1 if an experiment station is located in region i

= 0 if not

L_i be the land area of region i

X_i be inputs to research in region i

g_i (X_i) relate yield changes in region i to experiment station station inputs in region i

$\bar{B}$ be the budget for experiment stations

A_i be overhead cost for an experiment station in region i

C_i (X_i) be the function relating region i's total variable costs to its inputs

The set of functions

$$g_i = g_i\ (X_i) \qquad i = 1 \ldots n$$

relates yield (or profit per acre) increases in region i to research inputs in region i. These $g_i\ (X_i)$ functions may be regarded as highly simplified research production functions, the X_i being an index of research inputs.

Many interesting problems would require a vector of research inputs and a set of constraints on the availability of certain inputs in some regions. These complications are more appropriate to the model of part (b) of this section.

There is another set of functions

$$\gamma_i = \gamma_i\ (\delta_1 g_1,\ \delta_2 g_2,\ \ldots,\ \delta_n g_n) \quad i = 1,2 \ldots, n$$

with γ_i being the yield increase in region i which would result from the pattern of experiment station efforts determined by

$$(\delta_1 g_1,\ \delta_2 g_2,\ \ldots,\ \delta_n g_n)$$

The $\gamma_1\ (\delta_1 g_1,\ \ldots,\ \delta_n g_n)$ may be regarded as a set of technology transfer functions, indicating the relevance of the experiment station research efforts to each region. The units in which the γ_i are measured are the same as those of the g_i.

There is a budget constraint

$$\bar{B} = \sum_i \delta_i (A_i + C_i\ (X_i))$$

and an objective function which is simply

$$V = \sum_i L_i \left[\delta_i g_i(X_i) + (1-\delta_i)\ \gamma_i\right]$$

The value of yield increases in region is set proportionate to the land area of the region, although one could permit regional disparities to have some weight in determining regional priorities.

This objective function precludes a region's use of transferred results if an experiment station is located in the region. This assumption could be weakened but it is probably appropriate as a first approximation.

The cost function and transfer functions will induce some centralization of varietal selectional screening at least over some range of parameter values. The fixed cost of running experiment stations will militate against the establishment of many small stations, although rapidly increasing marginal costs could have an opposite effect under some circumstances. As well, if regions are similar and can use each other's results, it would be senseless for them to duplicate each others results. As a generalization it can be said that high fixed costs and relatively homogeneous regions will tend to encourage centralization of research efforts.

Neither the objective function nor the cost functions make explicit assumptions on research factor mobility. The formulation can encompass both perfect markets in factors (i.e. $C_1' = C_2' = \ldots = C_n'$)≥ 0 and immobility of factors (i.e. $C_i' \to \infty$ if $X_i > \bar{X}_i$ where $\bar{X}_i$ is region i's endownment of research resources). These formulations could be made more elaborate and explicit but these are adequate for current purposes. In general, however, one can regard the perfect market case as corresponding to the situation within a country and the second case as being more relevant to relatively limited international mobility.

One can set

$$\psi = \sum_i L_i \left[\delta_i g_i + (1-\delta_i)\ \gamma_i\right]$$

$$+ \lambda\ (\bar{B} - \sum_i \delta_i (A_i + C_i(X_i))$$

and compute

(1) $$\frac{\partial\psi}{\partial X_i} = o \Rightarrow L_i g_i' + \sum_{j\neq i} (1-\delta_j) L_j g_i'\ \partial\gamma_j/\partial g_i = \lambda C_i'$$

(2) $$\frac{\partial\psi}{\partial\delta_i} \geqq o \Rightarrow L_i(g_i - \gamma_i) + \sum_{j\neq i} (1-\delta_j) L_j\ \partial\gamma_j/\partial\delta_i \geqq \lambda\ (A_i + C_i(X_i))$$

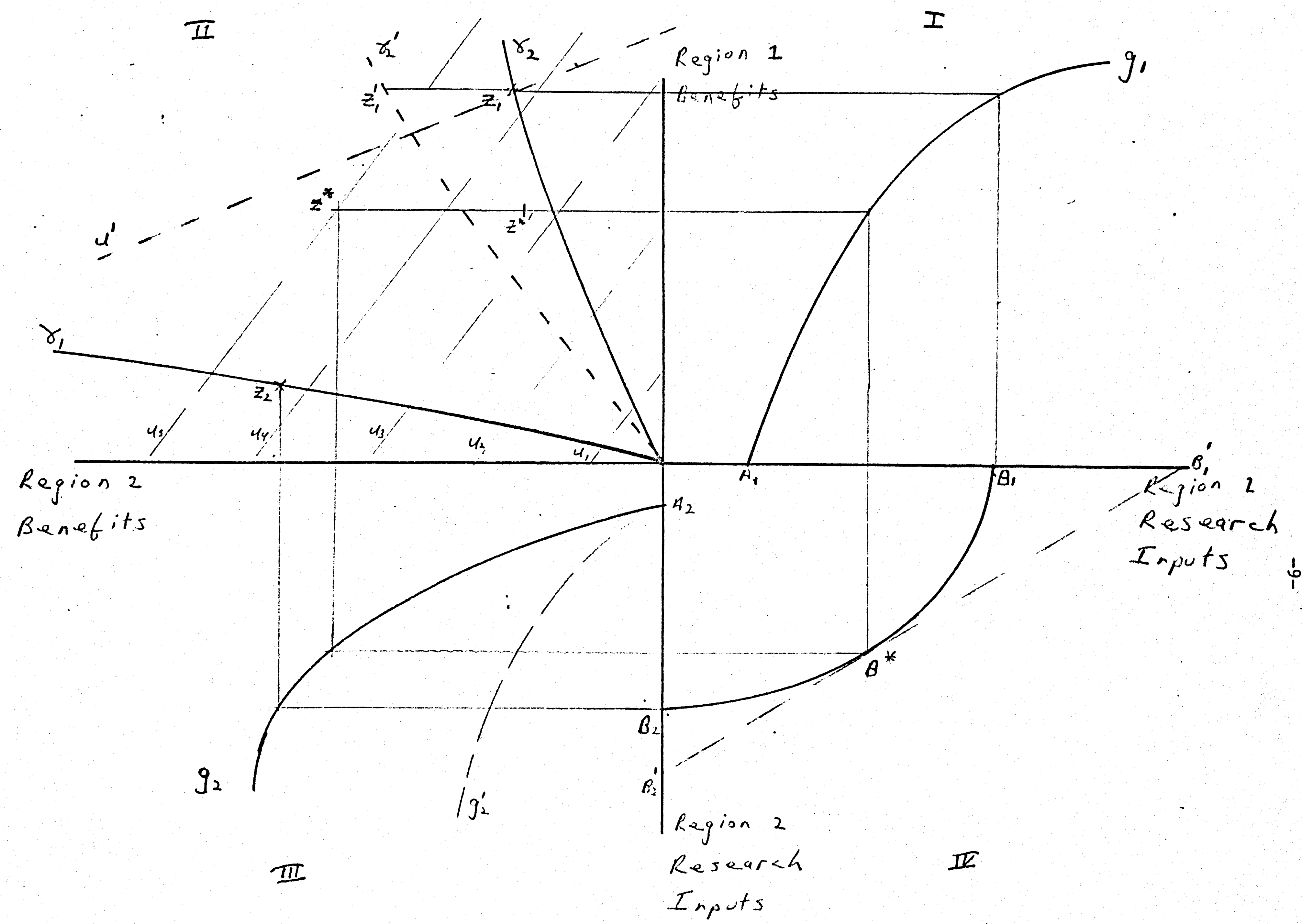
The two equations may be regarded as defining a two stage decision process. Equation (1) establishes the optimal scale of an experiment station in region i, given decisions on the location and scale of experiment stations in other regions. The scale of operation in region i, is determined by equating marginal benefits and marginal costs of an experiment station in region i. The RHS of (1) is the marginal cost of additional testing in region i, evaluated at the scarcity price of research inputs. The first term of the LHS is the product of the land area of region i and the marginal yield increase of additional testing. The second term is a summation of benefits over all other regions with each component of the sum consisting of three parts; (1) $(1-\delta_j)$, the dummy variable indicating whether or not region j is importing research results, (2) L_j, the land area of region j, and (3) $g_i'\ \partial\gamma_j/\partial g_i$, the marginal effect of region i research on region j's yields.

Using the optimal scale of region i research, as determined by equation (1), equation (2) determines whether or not to operate an experiment station in region i. The RHS of (2) is the total cost of the experiment station, evaluated at the scarcity value of research inputs. On the LHS, $(g_i - \gamma_i)$ is simply the difference between yield increases in region i when research is conducted at the level determined by equation (1) and when research is imported from the other regions. The last term on the LHS of (2) is the same as in (1) except that $\partial\gamma_j/\partial\delta_i$ replaces $g_i' \, \partial\gamma_j/\partial g_i$. The former represents the incremental contribution to (subtraction from) region j's yield increase when research at the optimal scale determined by (1) is initiated (stopped). Thus equation (1) determines the optimal scale of operation while equation (2) determines whether research at this scale pays.

Figure (1) below illustrates some features of the model in the two region case. Quadrant IV represents possible allocations of research inputs between region 1 and region 2. The curve is shaped to present a case of increasing marginal costs. Quadrants I and III correspond to the g_i functions above. Final costs are indicated as the distance from the origin of points A_1 and A_2. The relative weights of region 1 and region 2 benefits are determined by the slope of the U isoquants in quadrant II. These could be bowed. The transfer functions are represented by the γ_1 and γ_2 curves. Benefits transferred to region 2 are read as the abscissa of the point on γ_2 corresponding to a given level of region 1 benefits. Benefits transferred to region 1 are read as the ordinate of the point on γ_1 corresponding to a given level of region 2 benefits.

To determine the allocation of resources we examine three possible allocations, B_1, B_2, B^*. As in the algebraic formulation, one assumes that one obtains a point on the γ_1 or γ_2 curves only if the entire allocation of research resources goes to one of the regions. If both regions have experiment stations region 1 benefits are determined by g_1 and region 2 benefits by g_2. Thus, Z_1 corresponds to the B_1 allocation, Z_2 to the B_2 allocation and Z^* to the B^* allocation. In this case it is clear that each region performing its own research is more efficient than transfer.

What factors determine this result? (1) In quadrant IV one finds rapidly increasing costs as inputs to each region were increased. If one had constant



II
I
Region 1
Benefits
Region 2
Benefits
Region 2
Research
Inputs
Region 2
Research
Inputs
III
IV

Figure 1

-9-

marginal costs, say at the B^* ratio and the same resource availability, the resource constraint would be the targent line to B^*, drawn as the dotted straight line. It is clear that one could do better on the γ_1 and γ_2 curves if B_1' and B_2' were attainable resource allocation.

(2) In quadrant II, the γ_2' curve which permits greater transferability would allow Z_1' to be achieved, clearly a superior result.

(3) Again in quadrant II, the U' weighting of region 1 and region 2 benefits would set Z_1 preferred to Z^*. If a region is important it is likely to be allocated more resources and other regions will depend on transferring results.

(4) In quadrants I and III note that, despite fixed costs of A_1 and A_2, the g_1 and g_2 functions rise rapidly. At the allocation B^* both regions can achieve a good deal of research success. If, however, region 2 followed the g_2' curve, only $Z^{*'}$ could be attained with the B^* allocation, a point which Z_1 clearly dominates. In this case region 1 research is so effective relative to region 2 research that even with limited transferability between the regions it is optimal to establish a station only in region 1. If the slope of both g_1 and g_2 were reduced the effect would depend on the magnitude of the change.

(5) If A_1 and A_2 were both increased by some amount there would be an increased efficiency to transferring research between regions. This case is not illustrated but it is easy to show that benefits corresponding to B^* would be reduced by greater amounts then those corresponding to B_1 or B_2.

If there were three regions the shapes of the γ_1 and γ_2 functions would generally depend on the allocation of resources to region 3. In that case γ_1 and γ_2 would have to be interpreted as incremental contribution to transferability and different curves would exist for each value of g_3.

Efficient Allocation of Research Resources

In the model presented above the function determining transferability of research between regions was independent of the research productivity function of a region. The potential for transfer between two regions was fixed and could not be improved by devoting more resources to it. As well it was assumed that neither the parameters of the transfer functions nor those of the research production functions would be affected by the allocation of research resources. These considerations made the model most suitable for examining the location of experiment stations as their locations could be assumed to have no effect on the nature or quantity of the varieties available for testing, and the transfer of research manifested itself as the usefulness of the information contained in the results of testing at other locations to locations without experiment stations.

The model presented below allows a tradeoff between domestic benefits from research and greater adaptability of the research product. While in the earlier model one chose the points on the γ_j and g_j functions which maximized the value of the objective function, in this model there is some choice as well as to the form of these functions. For these reasons the model presented here is appropriate to the general problem of agricultural research transfer.

If there was not any research transfer the research production functions could be represented, as before, by

$$g_1 = g_1 (X_1)$$

$$g_2 = g_2 (X_2)$$

where X_1 and X_2 index research inputs in region 1 and region 2. To allow for the transfer of research two transfer functions are introduced. These functions determine the extent to which research in one region is applicable to research in another. The research production functions can then be rewritten as

$$g_1 = g_1\ (a_1X_1 + t_2\ X_2)$$

$$g_2 = g_2\ (t_1\ X_1 + a_2X_2)$$

where

$$o \leqq a_j \leqq 1 \qquad j = 1,2$$

and

$$t_j = t_j\ (a_j)$$

$$\begin{aligned} t_j' &= o \quad t_j < t_j^* \\ &< o \quad t_j > t_j^* \quad j = 1,2 \end{aligned}$$

The form of the transfer function allows a region to increase the usefulness of its research to a second region at the cost of lowering the benefits from the research to itself. The value of t_2 would indicate the percentage of research in region 2 which is useful to region 1. This usefulness is acquired at the cost of a reduction of a_2 from its potential maximum of one, achieved when region 2 research is solely interested in its own improvement, to some fractional value. The steepness of the decline of a_2 as t_2 is increased, is determined by the ease with which region 2 can incorporate the needs of region 1 into its own research program.

The value of t_2 can be greater than one. An example would be the case of a region in which very unstable climatic conditions required extensive testing before an accurate assessment could be made of the potential of a a new technique or variety. If there was a second region whose average climate was similar but more stable, for certain innovations less testing would be required in the second region than in the first.

Figure 2 below illustrates the relationships described above. The extent of free transfer from region 1 to region 2 is indicated by the horizontal portion of t_1, and the range of free transfer of research from region 2 to region 1 is indicated by the vertical portion of t_2. This range corresponds to the research transfer which is acquired without sacrifice to the region conducting research. It may be regarded as a measure of the extent to which the environments in the two regions are similar, or as the extent to which research goals in the two regions converge fortuitously. The γ_j functions of the previous model are obviously related, as they amounted to the free benefits which could be expected in one region from research in another. Beyond t_1^* and t_2^* every increment of t_1 or t_2 requires a diminishment of a_1 or a_2 respectively.

In the model of the previous section it was assumed that if domestic research existed there would not be any transfer of research from other re-

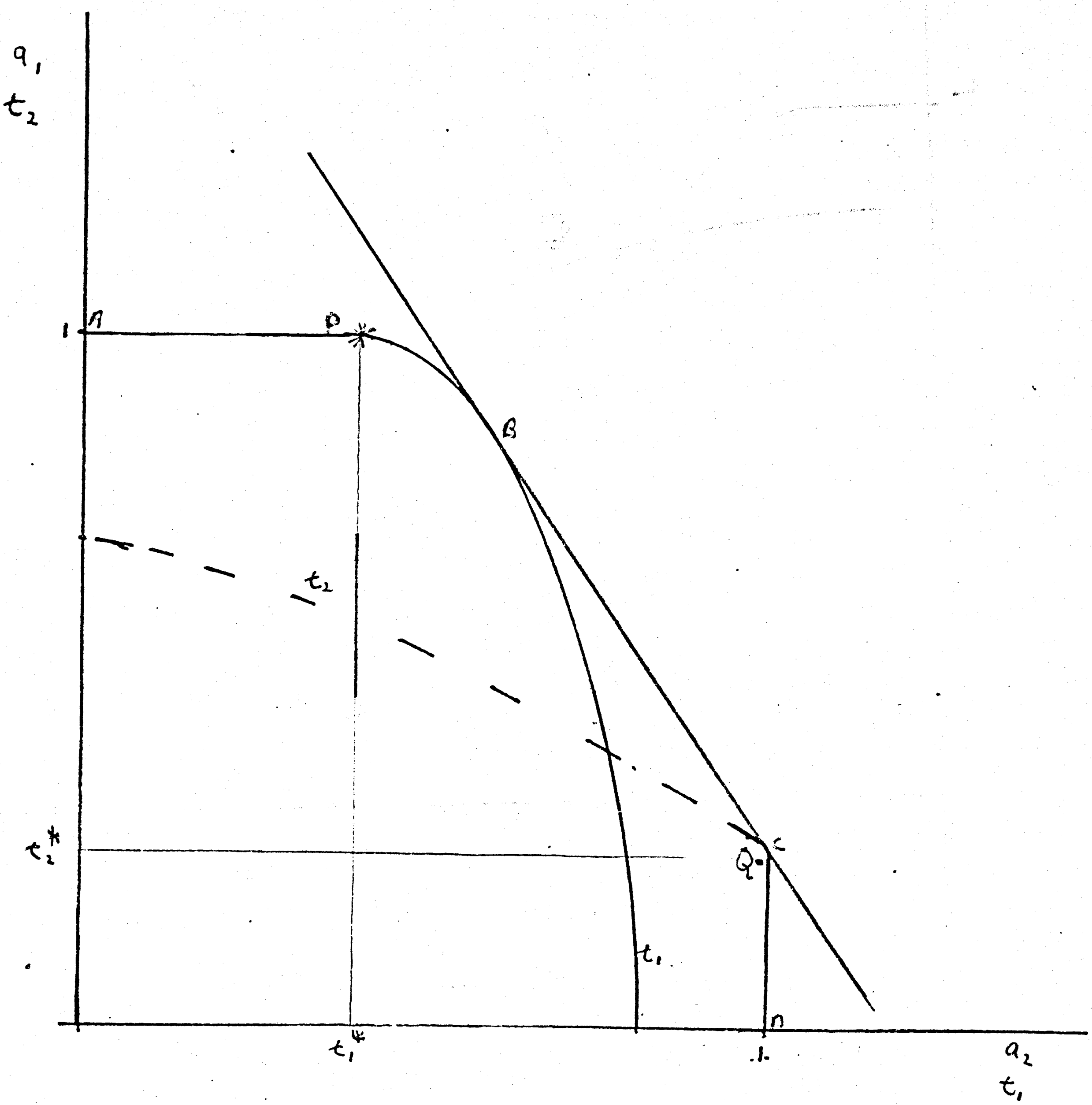


Figure 2. In the diagram the value of a_1 is the ordinate of the corresponding point of the t_1 curve, and the value of a_2 is the abscissa of the corresponding point on the t_2 curve. Once points on the two curves are chosen a_1 and t_2 represent factors by which research in region 1 and region 2, respectively, are transformed into research useful to region 1. A similar interpretation holds for a_2 and t_1.

gions. In this model that is not assumed, Evenson and Kislev have presented evidence that domestic research may enhance transfer potential.

In the problem presented below one is maximizing a welfare function of the form

$$U = U\ (g_1, g_2)$$

which encompasses the objective function of the previous model. Setting up the problem

$$\psi = U\ (g_1, g_2)$$

$$-\lambda_1\ (g_1 - g_1\ (a_1 X_1 + t_2\ (a_2)\ X_2))$$

$$-\lambda_2\ (g_2 - g_2\ (t_1(a_1)X_1 + a_2 X_2))$$

$$-\lambda_B\ (C_1\ (X_1) + C_2(X_2) - \bar{B})$$

where $C_i\ (X_i)$ is the cost function for region i research and

$\bar{B}$ is a budget constraint.

$$\partial\psi/\partial g_1 = 0 \Rightarrow U^1 - \lambda_1 = 0 \tag{1}$$

$$\partial\psi/\partial g_2 = 0 \Rightarrow U^2 - \lambda_2 = 0 \tag{2}$$

$$\partial\psi/\partial X_1 = 0 \Rightarrow \lambda_1 g_1' a_1 + \lambda_2 g_2' t_1 - \lambda_B C_1' = 0 \tag{3}$$

$$\partial\psi/\partial X_2 = 0 \Rightarrow \lambda_2 g_2' a_2 + {}_1 g_1 t_2 - \lambda_B C_2' = 0 \tag{4}$$

$$\partial\psi/\partial a_2 = 0 \Rightarrow \lambda_1 g_1' t_2' X_2 + \lambda_2 g_2' X_2 = 0 \tag{5}$$

$$\partial\psi/\partial a_1 = 0 \Rightarrow \lambda_1 g_1' X_1 + \lambda_2 g_2' t_1' X_1 = 0 \tag{6}$$

where $U^i = \partial U/\partial g_i$

For compactness g_1 and g_2 are written as composite functions of a_2 and a_1.

Primes denote derivatives with respect to the function's argument.

Equations (1) and (2) above set the equilibrium values of research advances in the regions equal to their marginal utility. In equation (3) and (4) the first terms are the marginal values of the component of research which benefits the region conducting the research and the second terms are the marginal values of the research transferred to the other region. These terms are equated in both equations to the marginal cost of research inputs, where inputs are valued at their scarcity price. Equation (5) and (6) sets the marginal rates of transfer equal to the relative marginal values of research advances in the two regions.

From (5) and (6) it is clear that

$$\frac{\lambda_1 g_1'}{\lambda_2 g_2'} = -t_1' = -1/t_2' \tag{7}$$

This is not unreasonable, signifying that the marginal rate at which one is willing to transform effective research in one region into effective research in the other is independent of the location in which the research is conducted. Corner solutions are possible and the equalities of (7) hold strictly only for interior solutions.

Using (5), (6), (7) and substituting into (3) and (4) one obtains

$$\frac{-t_1' a_1 + t_1}{-t_1' t_2 + a_2} = \frac{C_1'}{C_2'} \tag{8}$$

Recalling that (7) set

$$-t_1' = -1/t_2' = \lambda_1 g_1' / \lambda_2 g_2'$$

the interpretation of (8) becomes clear. The numerator and denominator of of the LHS respectively index the values of increasing research benefitting region 1 and region 2. In determining the value of experiment stations above there was a similar term. In this case, however, one has flexibility in choosing the relative proportions of benefits accruing to the region doing the research and to the region to which the research is transferred. The advantage to having this flexibility is that it permits some dissociation of the locus of research from the locus of benefits. It leads as well to a generalization which may not be as optimistic. To obtain the best results from transferring research one required both high transferability <u>and</u> low research costs in the region conducting the research.

The nature of the solution becomes more apparent when one considers the special case of

$$C_1' = C_2' = k$$

which we referred to above as the factor mobility case. In that case

$$\frac{a_2 - t_1}{a_1 - t_2} = - t_1' = - 1/t_2'$$

and points B and C represent the equilibrium points of transferability. Since the scale of either operation will not affect their relative marginal costs any level of X_1 and X_2 can be chosen. Referring back to figure 2, this condition can be seen to imply that any combination along ABCD can be selected, the exact point determined by

$$\lambda_1 g_1' / \lambda_2 g_2' = -t_1'$$

the value of which depends not only on the welfare function and research benefits function, but also on the ease with which research inputs can be transferred from other regions. If there was no transfer potential at all, then, in contrast to (7),

$$\lambda_1 g_1' / \lambda_2 g_2' = 1 \tag{9}$$

would be the equilibrium condition for the allocation of resources. The model of section (A) can easily be reformulated in terms of the current model, and its equilibrium condition shown to be

$$\frac{\lambda_1 g_1'}{\lambda_2 g_2'} \gtreqless 1 \tag{10}$$

as $\qquad \delta_1 - \delta_2 \gtreqless 0$

where δ_j = 1 if research is conducted in region j

0 otherwise

and t_j^* is the potential free transfer available to region j.

It is easily seen that (9) constrains the ratios of the marginal benefits of research to a single value, (10) allows a comparison of three possible values, and (7) allows for any value along a transfer curve.

Referring to the conditions arrived at above some policy questions can be discussed.

(1) When does one region do research for both regions?

As would be expected the factors involved are costs, ease of transferability, and the welfare function. The ability to conduct research at relatively low cost and to transfer research without incurring large losses are important. A welfare function which assigns roughly similar weights to advances in each region or which favors the region more capable of conducting and transferring research will suggest a buildup of the more efficient region's research establishment with appropriate emphasis on transfer. If the welfare function favors the region less capable of conducting and transferring research one is likely to find two research establishments and relatively little transfer.

(2) When do regions conduct research separately?

As noted above it is not only transferability which is important but costs and priorities. If there is little transfer potential and no great cost differences the regions are likely to operate on their own. If there is transfer potential and similar research costs both regions will conduct research but place some emphasis on transfer.

(3) How do fixed overhead costs and/or increasing returns to scale in research affect the results?

Fixed costs discourage small, low productivity research establishments (as they did in section A.) Increasing returns to scale in benefits from research work to focus efforts more closely on a given region if research is directed at it, but may temporarily exclude some regions from enjoying a large portion of benefits. Consider the following example:

Region 1's main problem is drought, while region 2's is disease. In both regions there are a host of common secondary problems whose amelioration will not prove effective if the primary problems are not solved. If there are not the resources to deal with both drought in region 1 and disease in region 2, one region is likely to be neglected and have its research resources directed at the common problems whose solution can be transferred to the other region.

Thus fixed costs and increasing returns tend to discourage small efforts and small establishments.

(4) Must a region engage in research to benefit from transfer?

Not in the model as presented. It would be simple and reasonable to redefine g_1 and g_2 so that

$$g_1 = g_1\ (a_1X_1 + t_2\ (a_2)\ X_2\ (1 - e^{-\rho\ X_1}))$$

$$g_1 = g_2\ (a_2X_2 + t_1(a_1)\ X_1\ (1-e^{-\rho\ X_2}))$$

The interaction of domestic research with the level of transferred research suggest that some domestic capacity is required to take advantage of the available transferable research, and that if a region did not conduct research it may be efficient to curtail efforts of increasing transferability until it can properly use them.

This effect would tend to counteract that of the fixed costs of running research establishments but would not alter the effects of increasing returns to scale in benefits.

Possible Extensions

One important extension would be to disagregate research. There is reason to believe that research which is less applied in nature may be more amenable to transfer. This research would be aimed primarily at designing new techniques for applied research and examining new approaches to problems faced by farmers. In countries or areas of diverse environmental regions it may be efficient to emphasize this type of research, if possible, over the more applied but less transferable research.

It would also be of interest to examine the cost side more carefully. In the long run it may be cheaper for many regions to lower the cost of their research rather than rely on importing other regions' research. More careful consideration of the long-run supply curves of the factors in short supply may prove instructive.

III. Measuring Adaptability and Stability

It was possible to obtain some insights into the relationships of locations and varieties using relatively simple techniques. Our data consisted of observations on the yields of fifteen varieties of wheat planted at seventeen locations across a common period of five years. These were obtained from the published data of CIMMYT on its International Spring Wheat Nursery Yield Trials which are conducted annually. The trials used were trials 3 through trial 7 which were conducted between 1967 and 1971.

Table 1 provides information on the varieties planted and the locations of the trials. As one may have noticed, six of the fifteen varieties are of Mexican origin. These varieties are products of the CIMMYT breeding program.

Table 1 also presents means and standard deviations of the yields of each variety at each location. These data are tabulated by both varieties and locations to facilitate comparisons of relative performance across both dimensions. One can observe fairly loose relationships between mean yields and their standard deviations. The standard deviation of yield at a location is a simple index of stability. The tradeoff should be most apparent in the region for which varieties are targetted, as breeders at other locations may have differing priorities in their programs. Figure 3 displays yields and stabilities for the fifteen varieties at several locations.

As a measure of instability the standard deviation has some limitations. A portion of the variance in yield results from the experimental design at different locations. This will limit the faith which may be placed in comparisons of standard deviations between locations but should not affect com-

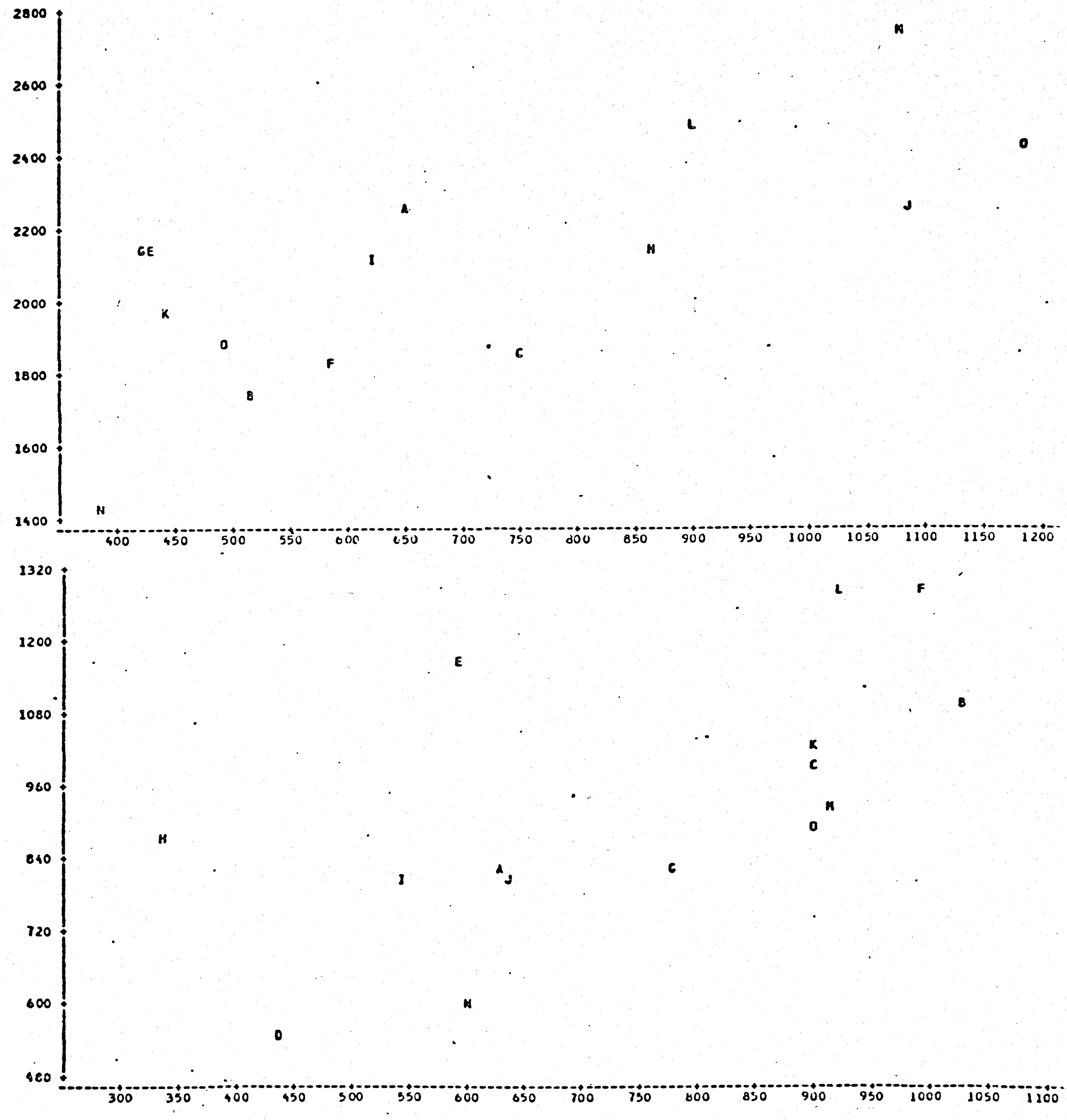


Figure 3: Yields plotted against standard deviations of yields for 15 varieties at two locations.
(a) Eskisehir, Turkey, (b) Pergamino, Argentina
Varieties represented by their letter headings in Table 1

parisons within locations. The coefficient of varation may be a more relevant measure of instability.

There is also a positive correlation in the yields of Mexican varieties across locations and within a few smaller subsets of varieties. In general one would expect this type of relationship between varieties bred for similar conditions.

However as the adaptability of a set of variety increases, perhaps, as in the CIMMYT case, because the breeders aim for this goal, one would expect a breakdown of this relationship. As breeding goals become less location bound and more tied to other characteristics, performance similarity of varieties would depend less on their geographical origin than on breeding priorities.

A simple measure of a variety's performance at a location is the ratio of its yield to the maximum yield at the site.

If one lets

$$Y^*_{ij} = Y_{ij}/Y_{jmax} \qquad i = 1 \ldots 15$$

$$S^*_{ij} = S_{ij}/S_{jmin} \qquad j = 1 \ldots 17$$

where an ij subscript refers to the i'th variety in the j'th location and Y_{ij}, S_{ij}, are respectively its yield and standard deviation, then Y^*_{ij} and S^*_{ij} index variety i's performance relative to the best performance in location j.

One can take these entries and define the following adaptability measures

$$AM_i\ (J,K) = \left| Y^*_{ij} - Y^*_{iK} \right|$$

$$AS_i\ (J,K) = \left| S^*_{ij} - S^*_{ik} \right|$$

These two measures reflect the change in variety i's relative yield and standard deviation between location j and location k. Low values of these two measures reflect similar levels of viability in the two locations, although one notes that zero yields at both sites would suggest high adaptability levels. In general a value greater than .15 would reflect unsuitability to at least one of the locations. We have printed as Table 2 the AS and AM values for all 15 varieties and all combinations of the Sonora location with other locations. Each location would have a similar table, although the symetry between locations would reduce the data burden by somewhat over half.

There is a possibility that one will label as adaptable a variety which shows little variation in relative yield or stability because of similarities in the two locations which are being compared. To reduce this possibility we have also computed

$$BM_i(J,K) = \left| Y_{ij} - Y_{ik} \right| \Big/ \left. \sum_{i=1}^{n} \left| Y_{ij} \quad Y_{ik} \right| \middle/ n \right.$$

Thus BM_i compares the change in variety i's yield between two locations with the average change over all varieties. While, again, zero yields in two locations will indicate high adaptability, it permits some disentanglement of varietal effects from environmental effects. A sample computation of BM_i for one variety Gaboto across all location pairs is provided in Table 5.

This procedure introduces a pitfall in that the preponderance of Mexican varieties may weight the denominator to reflect unduly their changes across the two environments rather than an average change more representative of that shown by varieties of different origin across two environments.

There are several approaches to this problem. One is to define

$$BM_i^* (J,K) = \left| Y_{ij} - Y_{ik} \right| \Big/ \left| Y_{jmax} - Y_{kmax} \right|$$

i.e. to relate variety i's change to that of the maximum yielding varieties. While BM^* is less susceptible to the problem raised above it can be difficult to interpret. It may also be desirable to define BM_i in terms of percentage change rather than absolute changes, as the data indicate that varieties may perform relatively well in two locations, but have a high absolute change in their yield.

A compact method of presenting pairwise comparisons of similarity of varieties and locations is through tables of their correlations or rank correlations. As certain locations and varieties are similar the sample statistics which are computed can be construed as valid only for this set of varieties and locations. The extension to general statements of similarities between the varieties and locations must be tempered by recognition of the lack of independence among many of the observations. Table 4 below provides a sample of correlations between locations. One might guess that quite high correlations are required before one can be confident that the relationships are not artifacts.

Some of these relationships are graphed below as figure 4. The plots highlight another problem. Consider the plot of relative yields in Sonora, Mexico against those of Njoro, Kenya in figure 4. While the fit may be reasonable, of the four highest yielding varieties at Sonora only one is high yielding in Njoro. The same holds for high yielding varieties in Njoro. Even with high sample correlations one would want to give greater weight to the varieties which are high yielding. If the relationship dissolves at those points there is little that can be said about transferability which would not be misleading.

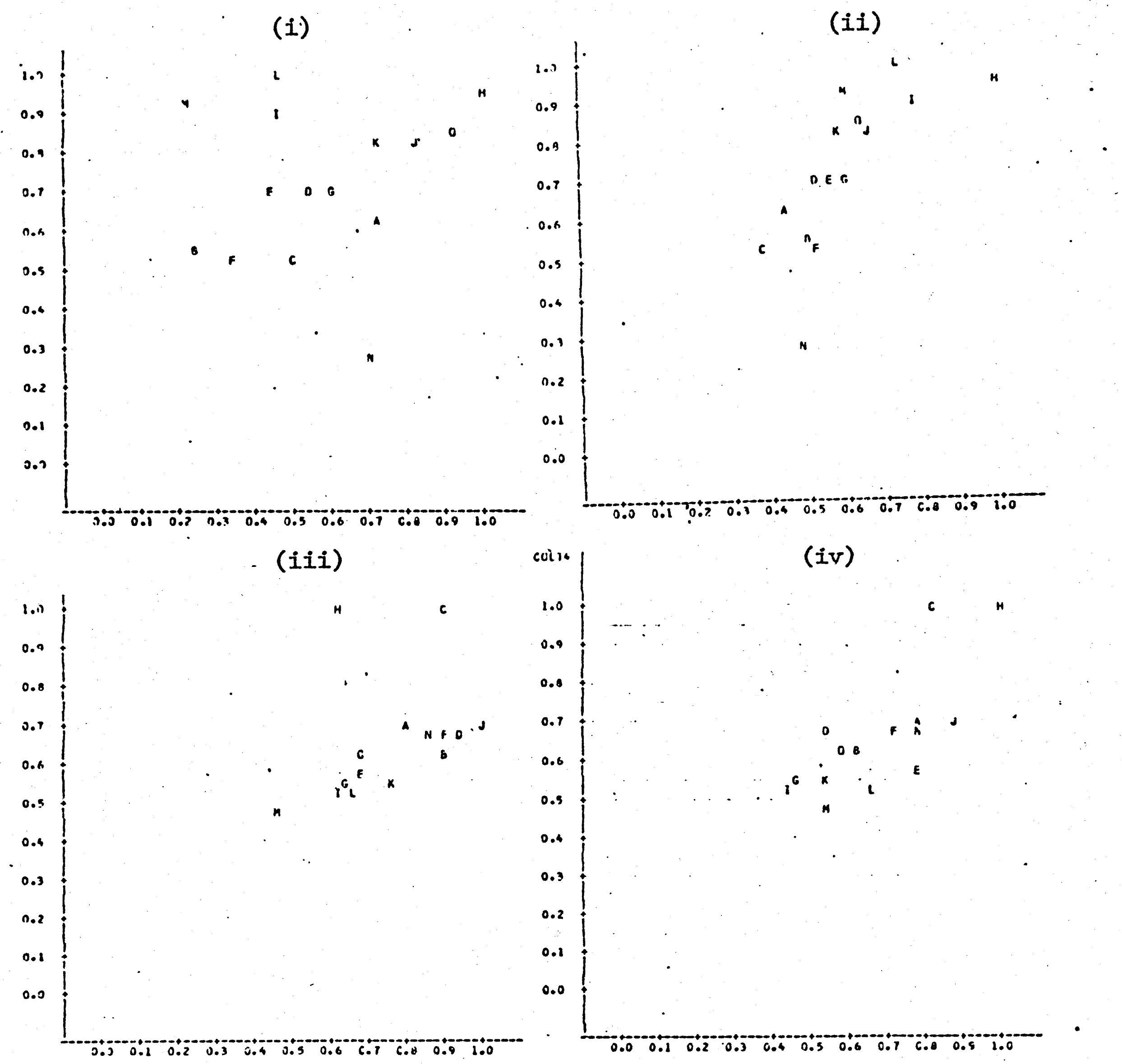


Figure 4: Plots of relative yield and relative stability in Sonora, Mexico against relative yield and relative stability in other regions. Letters correspond to varieties according to the labels in the columns of table 1.

(i) Sonora vs Njoro, relative yields
(ii) Sonora vs Lyallpur, relative yields
(iii) Sonora vs Davis, relative stability
(iv) Sonora vs Ahwaz, relative stability

Figure 5 illustrates some of the relationships between varieties. The absolute yield of each variety was ranked across locations. These ranks were correlated. As was expected, the Mexican varieties tend to be strongly related. It is more surprising to find very strong rank correlations between varieties 1, 3, 7, 11 which come from different countries. It is also surprising to find two Colombia varieties, Crespo and Napo, so strongly related to two Mexican varieties, although the four varieties appear to have some common antecedents, at least in pairwise comparisons.

It is important to know why varietal performance is so highly correlated between locations. The choice of varieties Carazinho, Nainari, Tobari, C-306 and Selkirk would guarantee that no variety excluded would have a lower rank correlation with the selected varieties than .9 over the 17 locations. Of these varieties, Selkirk performs poorly in almost all locations and contributes very little information by its presence. The average median correlation between varieties is .79. It is possible that the 17 locations tested are so similar that little variation in varietal performance is to be expected. It is also possible that the locations differ but that location effects overwhelm the varietal effects because of low genotype-environment interactions. The third possibility is that the varieties do react to different environments but possess roughly similar traits and react in similar ways to the changing environments.

While more study of these possibilities is required, it would seem that there is sufficient variation between locations and that varietal effects are important.

Figure 6 provides a similar illustration of rank correlations between locations. The average median rank correlation is .57. Solid lines connect locations with correlations greater than .85, dotted lines those with rank correlations .80 and .85. Somewhat surprisingly perhaps, locations display much looser relationships. Four locations, Pergamino, Argentina, Saskatoon, Canada, Njoro, Kenya and Tel Amara, Lebanon do not meet even the lower criterion. Among the other locations the degree of correlation is much less pronounced outside of the Sonora, Gorgan, Ahwaz, Davis, Lyallpur, and Sonora, Beirut, Ed Damer groups. At least nine locations are required to guarantee a minimum rank correlation of varietal yeilds between excluded and included locations of .8. The high rank correlation of Sonora Mexico with six other locations is of note, as the International Wheat and Maize Research Center is located there. To some extent this must be attributed to the success of the Mexican varieties in each of these locations. On the other hand it also serves to indicate some limits to the adaptability of the Mexican varieties to the other locations.

#	Variety	Country of Origin
1	Bonza	Colombia
2	Carazinho	Brazil
3	Chris	U.S.A.
4	C-306	India
5	Crespo	Colombia
6	Gaboto	Argentina
7	Huelquer	Chile
8	Inia	Mexico
9	Lerma Rojo	Mexico
10	Napo	Colombia
11	Nainari	Mexico
12	Penjama	Mexico
13	Pitic	Mexico
14	Selkirk	Canada
15	Tobari	Mexico

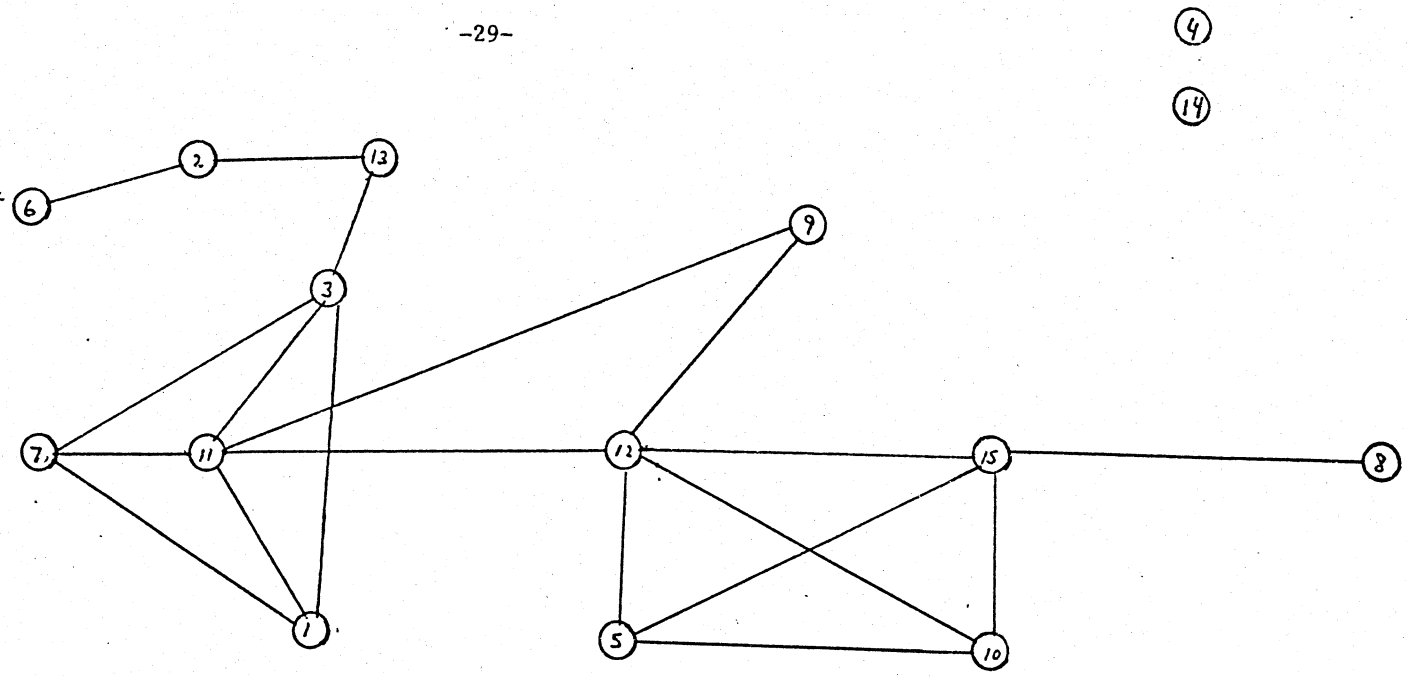


Figure 5: Solid lines correct varieties whose rank correlations of yields across all locations exceed .9.

#	Location
1.	Guatemala
2.	Ahwaz
3.	Gorgan
4.	Beirut
5.	Tel Amara
6.	Saskatoon
7.	Davis
8.	Aberdeen
9.	Eskisehir
10.	Pergamino
11.	Tibaitata
12.	Lyallpur
13.	Ed Damer
14.	El Girba
15.	Njoro
16.	Toluca
17.	Sonora

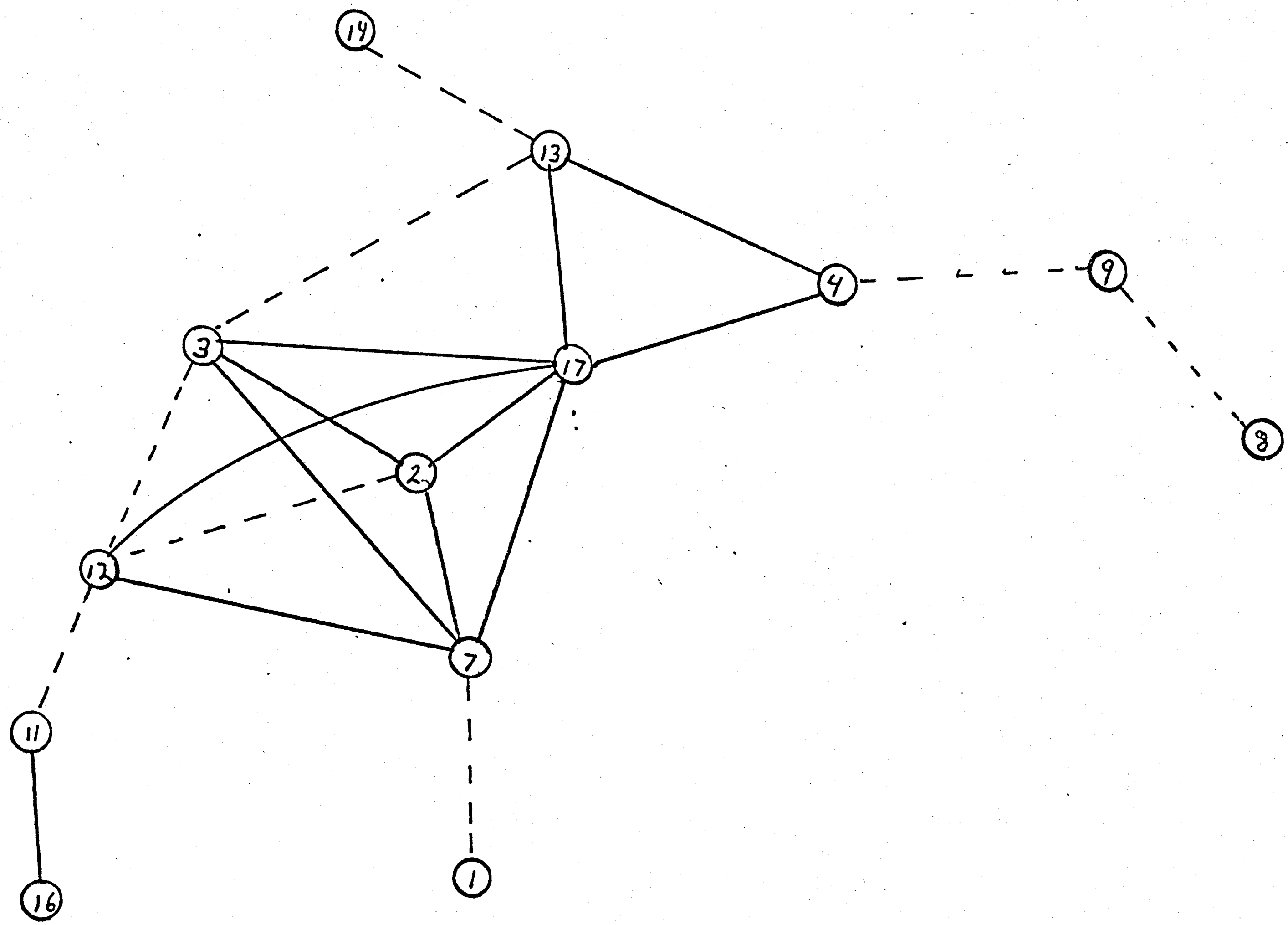


Figure 6: Solid lines connect locations with rank correlations of varietal yields exceeding .85. Dotted lines link locations with varietal yield rank correlations between .80 and .85.

IV. Conclusion

As world food demand increases, the task of augmenting production to meet these demands becomes critical. With relatively few fertile lands to introduce into cultivation, the bulk of effort will be directed at improving yields and conserving scarce resources. The researchers who must provide these improvements are themselves an extremely scarce resource, especially in low income countries. These scarcities make the efficient use of their talents and the distribution of research benefits across a wide area essential.

Even the simple models presented in the first sections would be difficult to solve in real world situations. The data requirements are demanding and few of the models' relationships have been estimated. The empirical section represents the first stage in exploring some of these relationships. While the approach taken may not be definitive, it is one of the few attempts at rendering coherent the mass of largely unexploited yield trial data.

The data used consisted only of yield observations. It would be preferable to have independent measures of the environments of the regions and their fluctuations, but accurate measures of this type will not be constructed in the near future. For this reason it is desireable to extract as much useful information as is possible from the data which is readily available and relatively interpretable. Many of the questions discussed above have persisted in the literature, and the empirical approach which we have adopted, although preliminary, seems capable of contributing to their resolution.

Location \ Variety	(A) Bonza (Col.) M	(A) Bonza (Col.) S.D.	(B) Carazinho (Brazil) M	(B) Carazinho (Brazil) S.D.	(C) Chris (USA) M	(C) Chris (USA) S.D.	(D) C-306 (India) M	(D) C-306 (India) S.D.	(E) Crespo (Col.) M	(E) Crespo (Col.) S.D.	(F) Gaboto (Arg.) M	(F) Gaboto (Arg.) S.D.	(G) Huelquen (Chile) M	(G) Huelquen (Chile) S.D.	(H) Inia (Mex.) M
Guatemala	2438.8	1630.45	2461.4	1331.35	2342.8	1131.46	1602.4	1573.23	3359.0	1140.97	1945.2	877.00	2332.4	1226.98	3320.2
Ahwaz, Iran	2902.0	894.17	2942.0	1102.51	2553.0	845.77	3399.6	1269.65	3620.6	888.87	2944.0	953.24	3428.4	1527.10	3680.8
Gorgan, Iran	3105.2	553.21	3211.6	324.11	3093.0	577.06	3616.0	611.54	3732.8	913.77	3014.0	698.39	3939.4	755.22	4240.4
Beirut, Leb.	2306.0	635.34	1997.8	481.31	1375.2	500.54	2667.4	631.47	2639.4	630.48	2117.2	534.68	2384.8	563.12	2678.2
Tel Amara, Leb.	3247.0	1325.45	3666.6	1019.54	3009.0	1325.11	4002.8	1699.59	4150.2	1335.81	3652.4	1404.71	3651.8	1440.57	3898.8
Saskatoon, Can.	3424.0	723.77	3517.2	618.59	3234.0	734.77	2588.0	449.22	3606.4	824.82	2843.4	659.67	4175.6	458.92	3293.8
Davis, USA	4306.8	1347.74	3792.6	1203.39	3457.8	1188.89	4363.8	1141.64	5228.8	1596.35	3541.4	1203.86	4442.8	1696.07	6041.2
Aberdeen, USA	4047.0	957.88	3608.0	890.56	3483.8	927.06	3450.0	937.96	3861.2	518.31	3599.6	1117.00	4815.0	1103.63	3634.4
Eskisehir, Turk.	2257.6	647.96	1754.0	513.22	1860.8	748.38	1892.0	492.91	2155.6	430.79	1814.4	585.96	2140.8	423.45	2133.8
Pergamino, Arg.	818.8	631.24	1100.0	1027.24	1000.8	898.07	553.6	435.77	1173.8	596.02	1288.2	,995.50	826.0	778.19	867.4
Tibaitata, Col.	2679.6	1178.63	1091.0	792.38	1870.4	811.26	1520.6	683.62	3657.2	2282.94	1089.2	516.30	3130.6	1505.76	4503.8
Lyallpur, Pak.	2268.6	846.32	2633.6	326.81	2022.2	315.75	2776.4	614.33	2936.2	652.72	2692.0	558.80	3148.0	491.04	5272.8
Ed Damer, Sudan	2383.6	807.29	1707.8	702.27	2023.8	661.22	3088.8	1225.68	2541.6	589.60	1688.6	908.01	2674.6	791.96	3139.4
El Girba, Sudan	2033.8	775.02	1655.8	552.71	1664.2	736.66	2654.8	805.84	2006.2	692.39	1418.6	763.24	1951.0	1019.05	2079.0
Njoro, Kenya	2324.4	693.15	785.4	787.51	1625.0	1004.99	1746.2	805.27	1436.0	979.95	1111.0	1066.63	1986.0	985.15	3270.0
Toluca, Mexico	2860.6	1437.57	1379.4	701.06	2848.4	1674.21	1944.0	1523.32	4983.0	1324.08	1906.6	1125.74	3515.2	1579.70	4628.8
Sonora, Mexico	3349.6	1394.63	2997.8	1588.82	2903.6	987.97	3873.6	1480.61	3787.6	1711.39	2807.6	1452.45	3759.8	1784.98	5217.6
Average	2750	969	2371	821	2409	886	2690	964	3228	1006	2322	9017	3077	1067	3641

Location	Inia S.D.	(I) Lerma Rojo (Mex) M	(I) Lerma Rojo (Mex) S.D.	(J) Napo (Col.) M	(J) Napo (Col.) S.D.	(K) Nainari (Mex) M	(K) Nainari (Mex) S.D.	(L) Pemjamo (Mex) M	(L) Pemjamo (Mex) S.D.	(M) Pitic (Mex) M	(M) Pitic (Mex) S.D.	(N) Selkirk (Con) M	(N) Selkirk (Con) S.D.	(O) Tobari (Mex) M	(O) Tobari (Mex) S.D.
Guatemala	958.40	3180.8	1090.11	2880.0	1356.62	2353.2	1073.15	3397.6	824.67	2946.4	1948.60	2124.4	1641.98	3322.8	713.77
Ahwaz, Iran	692.14	3789.4	1574.77	3533.0	787.02	3737.4	1305.14	3959.6	1060.20	3732.8	1271.34	1707.6	898.06	3683.8	1209.94
Gorgan. Iran	965.72	4147.4	805.03	3443.8	425.65	3969.6	893.78	4020.4	660.84	4380.4	1050.53	2062.0	739.07	3693.0	1093.97
Beirut	1169.59	2608.8	768.03	2675.8	517.26	2621.6	893.66	2781.0	868.79	3125.2	816.39	1746.0	483.41	2850.6	1166.37
Tel Amara	1464.51	4150.0	1798.39	4110.4	1366.69	3833.6	1603.76	3987.8	1432.21	4417.0	1450.83	2591.8	1006.85	3638.0	1500.15
Saskatoon	666.19	3752.2	664.94	3207.0	621.61	3886.0	440.90	3591.2	608.38	4546.4	930.45	2910.4	604.77	3314.2	667.71
Davis	1741.62	5387.4	1746.29	4537.2	1076.84	4785.2	1424.38	5216.8	1649.61	5221.0	2295.60	2581.6	1257.96	4869.6	1570.17
Aberdeen	1143.54	3879.0	1131.95	3943.6	1308.85	4400.8	1084.83	4427.2	1100.02	5438.8	1115.09	2954.4	1148.08	4327.2	1053.59
Eskisehir	864.80	2126.0	623.05	2263.0	1038.34	1973.0	446.11	2474.6	899.40	2734.4	1077.76	1420.2	387.20	2420.8	1187.15
Pergamino	334.40	809.0	542.07	811.6	635.14	1033.2	902.26	1277.6	923.27	921.6	913.56	604.8	597.64	894.4	903.06
Tibaitata	2335.77	3296.2	1452.11	4083.6	1941.77	2323.0	1206.86	3993.0	2030.78	2190.2	1359.78	1054.0	613.37	3779.6	1813.10
Lyallpur	595.49	4128.0	855.60	3473.8	844.94	3013.4	1032.82	3944.6	499.82	3173.8	644.42	2500.2	1501.98	3416.6	551.78
Ed Damer	1288.21	3019.4	1013.40	2515.8	508.92	2821.2	849.26	2864.2	1021.05	3635.2	1367.87	1008.0	845.30	3298.6	1203.54
El Girba	1124.15	2333.8	1098.94	1688.2	540.29	2159.4	836.86	2354.8	897.71	2161.4	939.19	879.6	607.07	2094.4	1312.60
Njoro	824.07	1518.8	1589.29	2659.6	946.41	2377.0	784.98	1489.2	1101.57	704.6	1021.41	2311.0	939.59	3021.4	663.89
Toluca	1382.92	4033.8	1457.09	4696.0	1440.11	3240.4	1343.84	4414.8	1877.25	2382.4	2244.76	2152.2	1535.68	4384.6	1661.23
Sonora	981.72	4868.4	1879.49	4527.0	1382.10	4493.8	1802.47	5466.6	1865.04	5062.2	2100.05	1444.4	1480.92	4611.8	1600.34
Average	1090	3355	1177	3238	988	3178	1054	3509	1137	3340	1326	1885	958	3389	1169

Table 1: Mean Yield and Standard Deviation of Yield of 15 spring wheat varieties at 17 locations.
M - mean yield S.D. - standard deviation of yield

Locations \ Varieties	COL1 COL9	COL2 COL10	COL3 COL11	COL4 COL12	COL5 COL13	COL6 COL14	COL7 COL15	COL8
Guatemala	0.105062 0.0456184	0.176068 0.0195373	0.158393 0.0177226	0.236967 1.3878E-16	0.295777 0.0588231	0.0589302 0.361042	0.0012921 0.134352	0.0227685
Ahwaz	0.120163 0.066444	0.19462 0.064142	0.113609 0.121837	0.149978 1.2490E-16	0.221523 0.016698	0.229918 0.167033	0.178068 0.0867143	0.0248618
Gorgan	0.0961459 0.0562367	0.18479 0.0419359	0.174947 0.084172	0.116901 0.0821843	0.159298 0.0739765	0.174473 0.206511	0.211548 0.000558548	0.0135888
Beirut	0.125134 0.0558093	0.0908704 0.0280813	0.0688728 0.0168117	0.144919 0.110137	0.151692 0.0739765	0.163869 0.294462	0.0753105 0.0685014	0.0974815
Tel Amara	0.122375 0.0489799	0.281726 0.102467	0.150079 0.0458728	0.197632 0.09717	0.246735 0.0739765	0.313304 0.322556	0.138984 0.0199963	0.0717701
Saskatoon	0.140384 0.0652595	0.225238 0.122727	0.191177 0.0326956	0.139352 0.2101	0.100381 0.0739765	0.111826 0.375932	0.230664 0.11466	0.229965
Davis	0.100166 0.00120463	0.0794044 0.077077	0.0478381 0.0299523	0.0137459 0.136463	0.172661 0.0617912	0.0726164 0.16311	0.0476401 0.0375672	0.0455493
Aberdeen	0.131359 0.177363	0.114997 0.103033	0.109393 0.0128975	0.0742629 0.185997	0.0170739 0.0739765	0.148246 0.278985	0.197529 0.0480156	0.286215
Eskisehir	0.21289 0.11307	0.0930723 0.00131256	0.149362 0.100499	0.0166689 0.0950117	0.0954644 0.0739765	0.149954 0.25516	0.0951373 0.0416808	0.174097
Pergamino	0.0228764 0.262564	0.30552 0.198093	0.245745 0.0199972	0.278847 0.00822854	0.218332 0.210607	0.486408 0.20527	0.0465719 0.14933	0.281108
Columbia	0.0177749 0.158701	0.306145 0.0796913	0.115859 0.195243	0.370968 0.113415	0.119163 0.439723	0.271751 0.0301981	0.00732523 0.00442979	0.0455493
Lyallpur	0.182493 0.107686	0.0489158 0.169305	0.147637 0.24941	0.182043 0.251897	0.136004 0.324104	0.00304695 0.209947	0.0907504 0.195665	0.0455493
Ed Damer	0.0429606 0.059971	0.0785894 0.136053	0.0255703 0.0459683	0.141098 0.212093	0.00630162 0.0739765	0.049078 0.013066	0.0479738 0.0637731	0.0908393
El Girba	0.153345 0.0114849	0.0753157 0.192215	0.0957117 0.008652	0.291406 0.113003	0.0628257 0.111876	0.0207612 0.0671017	0.0471186 0.0547216	0.171341
Njoro	0.0980865 0.426107	0.308201 0.0175388	0.0342109 0.0951353	0.174588 0.544587	0.253718 0.110549	0.173836 0.442505	0.0804372 0.0803433	0.0455493
Toluca	0.0386673 0.0810595	0.271564 0.114284	0.0404707 0.171756	0.318468 0.114028	0.307138 0.447918	0.130971 0.167686	0.0176618 0.0362795	0.0255323

Table 1(a): Absolute value of change in the yield of varieties relative to maximum yields at each location pairs. The location pairs to which changes are referred are Sonora, Mexico and the row location. The varieties are ordered as in table above. Column 1 - Banza, Col 2 - Carazinho, etc.

e.g. The entry for col. 10 in Ahwaz refers to the difference between Napo's yield relative to the maximum yield in Sonora and Ahwaz

Locations \ Varieties	COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8	COL9	COL10	COL11	COL12	COL13	COL14	COL15
Guatemala	0.863706	0.246842	0.578833	0.695951	0.144717	0.250793	0.0991821	0.342735	0.387208	0.492823	0.332521	0.744378	0.590883	0.791962	0.630135
Alwaz	0.128708	0.0255107	0.215591	0.326202	0.459019	0.102269	0.388127	1.3878E-17	0.360727	0.270766	0.0496309	0.368003	0.302337	0.210977	0.11797
Gorgan	0.28623	0.6184	0.774054	0.378628	1.07603	0.675268	0.512214	1.97957	0.569302	0.0945579	0.921589	0.139147	1.1021	0.771799	1.74514
Beirut	0.100567	0.6184	0.0335991	0.196199	0.433318	0.368613	0.648226	1.43002	0.318765	0.333138	0.0207096	0.0946984	0.442957	0.504127	0.793189
Tel Amara	0.104167	0.605801	0.309729	0.179847	0.416534	0.0843476	0.387442	0.454536	0.128329	0.0504525	0.243183	0.477298	0.698197	0.508488	0.140198
Saskatoon	0.220988	0.215394	0.660156	0.489306	0.127521	0.0167065	0.777342	0.510972	0.406325	0.00202083	0.836022	0.519903	0.0288104	0.13682	0.115705
Davis	0.169025	0.500885	0.0976909	0.448001	0.260816	0.361537	0.243171	0.617338	0.292802	0.407836	0.513281	0.367867	0.00736511	0.340298	0.172014
Aberdeen	0.427496	0.0998182	0.782264	0.30149	0.743246	0.675596	0.311097	1.20631	0.269466	1.11742	0.257015	0.222581	0.0122591	0.706566	0.402621
Eskisehir	0.252867	0.292933	0.926447	0.235152	0.630667	0.0338297	0.724593	1.23347	0.305349	1.40297	0.683872	0.423063	0.644313	0.508488	1.43584
Pergamino	0.467069	1.45345	1.67923	0.205043	0.0390856	1.49747	0.508883	1.3878E-17	0.293458	0.491489	0.862101	0.861176	0.592772	0.278712	1.07039
Columbia	0.862228	0.0836902	0.564931	0.184108	2.67845	0.479491	1.09822	3.52403	0.898037	2.35309	0.501476	2.03355	0.494528	0.320479	1.88156
Lyallpur	1.26131	0.583369	0.00636476	0.437419	0.323928	0.29026	0.263075	0.88595	0.795248	1.26812	1.43497	0.316817	0.0982437	3.24833	0.117382
Ed Damer	0.1657	0.23847	0.292907	0.900239	0.584701	0.304714	0.262039	1.53127	0.076814	0.407836	0.167259	0.106565	0.548661	0.152483	0.734764
El Girba	0.0138612	0.595403	0.357092	0.0166761	0.461729	0.0668417	0.0679135	1.08065	0.0470657	0.407836	0.287119	0.238233	0.40084	0.384891	0.799313
Njoro	0.376517	0.432191	0.507439	0.295207	0.267162	0.127155	0.334295	0.241288	0.47945	0.0177243	0.65362	0.240485	0.600623	0.0932008	0.630135
Toluca	0.62996	0.6184	1.38173	0.664695	0.145428	0.126276	0.435079	0.972604	0.163923	0.64634	0.0808354	0.77796	1.06279	0.682018	0.739444

Table 2 (b): Absolute value of change in standard deviation of varieties relative to the minimum standard deviation at each location pair. As above, the location pairs are Sonora, Mexico and each of the row locations.

Variables / Location	COL1 COL10	COL2 COL11	COL3 COL12	COL4 COL13	COL5 COL14	COL6 COL15	COL7 COL16	COL8 COL17	COL9
1 Guatemala	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
2 Ahwaz	1.50721 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
3 Gorgan	1.20665 0	0.248028 0	0 0	0 0	0 0	0 0	0 0	0 0	0
4 Beirut	0.4051 0	0.983053 0	0.810654 0	0 0	0 0	0 0	0 0	0 0	0
5 Tel Amara	1.65215 0	1.6336 0	2.27361 0	1.21634 0	0 0	0 0	0 0	0 0	0
6 Saskatoon	1.17132 0	0.210991 0	0.4366 0	0.725059 0	1.72868 0	0 0	0 0	0 0	0
7 Davis	0.876821 0	0.492353 0	0.559279 0	0.69498 0	0.138183 0	0.633325 0	0 0	0 0	0
8 Aberdeen	1.28165 0	0.950255 0	1.06064 0	0.975477 0	0.110405 0	1.43035 0	0.0374224 0	0 0	0
9 Eskisehir	0.203093 0	0.931633 0	0.808974 0	0.804036 0	1.12159 0	0.75242 0	0.711911 0	0.941429 0	0
10 Pergamino	0.371514 0	0.697019 0	0.652259 0	0.538447 0	0.843827 0	0.614558 0	0.627828 0	0.755537 0	0.452445
11 Colombia	1.3467 0.109734	2.33047 0	1.93881 0	1.17541 0	2.29625 0	1.53054 0	1.35997 0	1.78196 0	0.740958
12 Lyallpur	1.23375 0.62997	0.493847 2.19449	0.521373 0	0.82856 0	1.26936 0	0.205238 0	0.62432 0	0.838373 0	0.823769
13 Ed Damer	0.539711 0.245847	1.68033 0.808338	1.30295 1.39666	1.34938 0	1.67402 0	1.19209 0	0.945197 0	1.33578 0	0.231449
14 El Girba	0.586101 0.129073	1.11729 0.314938	0.975422 1.04542	1.31977 0.436629	1.2469 0	0.931713 0	0.823237 0	1.06442 0	1.28925
15 Njoro	0.976693 0.168298	1.22335 0.0212073	1.10695 1.23766	1.32274 0.656821	1.37867 0.423754	1.10189 0	0.923933 0	1.18454 0	1.0518
16 Toluca	0.0473349 0.262112	1.33628 1.42517	1.33606 1.02772	0.187082 0.199249	1.97176 0.329587	0.917113 0.559462	1.30705 0	1.52418 0	0.0712982
17 Sonora	0.646025 0.504331	0.197555 1.40053	0.372294 0.12397	0.456219 0.808495	1.30901 0.693658	0.0412595 0.781891	1.20398 0.969123	1.11113 0	0.536954

Table 3 : Absolute values of changes in yield of Gaboto relative to mean absolute value of changes between location pairs. Each column location corresponds to the row location with the same number.

COL6

COL6	COL8	COL3	COL2	COL7	COL1	COL9	COL17	COL13	COL5	COL14	COL12
1.00000	0.79286	0.68929	0.57857	0.53214	0.48214	0.46429	0.40714	0.38929	0.36429	0.34643	0.32857
0.0000	0.0004	0.0045	0.0238	0.0412	0.0687	0.0813	0.1320	0.1515	0.1819	0.2059	0.2318

COL11	COL4	COL16	COL15	COL10
0.28571	0.27857	0.26786	-0.25714	0.25000
0.3019	0.3147	0.3344	0.3549	0.3688

COL7

COL7	COL3	COL17	COL2	COL12	COL1	COL13	COL11	COL4	COL5	COL16	COL14
1.00000	0.90357	0.87500	0.85357	0.85000	0.80714	0.78214	0.77857	0.76429	0.72857	0.70714	0.65714
0.0000	0.0001	0.0001	0.0001	0.0001	0.0003	0.0006	0.0006	0.0009	0.0021	0.0032	0.0078

COL9	COL6	COL8	COL15	COL10
0.62857	0.53214	0.51786	0.09643	0.06071
0.0121	0.0412	0.0480	0.7325	0.8298

COL8

COL8	COL9	COL6	COL2	COL3	COL4	COL17	COL13	COL7	COL11	COL1	COL12
1.00000	0.80357	0.79286	0.66429	0.65357	0.59286	0.59286	0.52857	0.51786	0.51071	0.50714	0.49643
0.0000	0.0003	0.0004	0.0069	0.0082	0.0198	0.0198	0.0428	0.0480	0.0517	0.0537	0.0598

COL14	COL16	COL5	COL10	COL15
0.45000	0.40714	0.31071	0.20714	0.02143
0.0924	0.1320	0.2597	0.4588	0.9396

COL9

COL9	COL4	COL8	COL17	COL11	COL1	COL13	COL7	COL16	COL2	COL3	COL12
1.00000	0.82143	0.80357	0.72857	0.69643	0.67143	0.64286	0.62857	0.62500	0.61786	0.59286	0.56429
0.0000	0.0002	0.0003	0.0021	0.0039	0.0061	0.0097	0.0121	0.0127	0.0141	0.0198	0.0284

COL14	COL6	COL5	COL15	COL10
0.53929	0.46429	0.45000	0.10714	0.07500
0.0380	0.0313	0.0924	0.7039	0.7905

COL10

COL10	COL15	COL1	COL6	COL2	COL8	COL14	COL13	COL9	COL5	COL12	COL7
1.00000	-0.47857	0.32857	0.25000	0.20714	0.20714	-0.15357	-0.15000	0.07500	0.06786	-0.06071	0.06071
0.0000	0.0711	0.2318	0.3688	0.4588	0.4588	0.5848	0.5936	0.7905	0.8101	0.8298	0.8298

COL3	COL4	COL11	COL16	COL17
0.05357	0.04286	0.01786	0.01071	-0.00714
0.8496	0.8795	0.9496	0.9698	0.9798

Table 4 Rank correlations of yields at selected locations for 15 varieties. Correlations are ordered by diminishing absolute value of correlation. Probability that Rho = 0 for 15 d.f. is listed below. Columns correspond to locations as in table 3.

BIBLIOGRAPHY

Abou, El-Fittouh, H.A. Rawlings and P.A. Miller, 1969, Genotype by environment interactions in cotton - their nature and related environmental variables, Crop Science 9 pp 377-381.

Anand, S.C., 1968 - Variety and environment interactions in wheat, Journal of Research of the Punjab Agricultural University, Ludhiana 5(2), pp 63-66.

Binswanger, H.P., 1976, A note on adaptability and stability, mimeographed ICRISAT

CIMMYT - International Spring Wheat Nursery Yield Trials, vol. 3-7

Englander, Alfred S., 1979, Resource allocation in agricultural research programs, chapter 6, unpublished dissertation draft, Yale University

Evenson, R.E., 1978, The organization of research to improve crops and animals in low-income countries in Schultz, T.W. (ed.) Distortions of Agricultural Incentives (Bloomington: Indiana University Press)

_______, J.C. O'Toole, et al - Risk and uncertainty as factors in crop improvement research, in Roumasset, J.A., Boussard, J.M., and Singh, I., (eds), Risk Uncertainty and Agricultural Development (Laguna, New York: SEARCA/ADC)

______, and Kislev, Y. 1975, Agricultural Research and Productivity (New Haven, Yale University Press)

Finlay, K.W. and G.M. Wilkinson, 1963, The analysis of adaptation in a plant breeding program, Australian Journal of Agricultural Research 14(6) pp 742-754

Johnston, J. 1973 Econometric Methods 2nd ed. (New York: McGraw Hill)

Laing, D.R. and R.A. Fischer, 1973, Preliminary Study of Adaptation of entries in 6'th ISWN to non-irrigated conditions, Mimeo, CIMMYT, Mexico

Mungomery, V.E., R. Shorter and P.E. Byth, 1974, Genotype X Environment interactions and environmental adaptation, I. Pattern analysis application to soya bean population. Australian Journal of Agricultural Research 25 pp 59-72.