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The Indian Sorghum Improvement Program has aimed to develop short duration, high yielding and widely adapted hybrids and varieties from temperate x tropical varietal crosses. Such hybrids and varieties are expected to withstand location specific environmental fluctuations and still give high yield at a given location since genotype x year interaction was observed to be smaller than genotype x location interaction (Rao, 1970).

The question is pursued here more formally. The concept of stability is used exclusively in its temporal connotationand is the converse of low levels of risk. Adaptability is restricted to its location dimension and is defined as low fluctuations of (average over years) yields across location. This distinction is due to Evenson et. al. (1978). Stability (or conversely risk) and adaptability are measured by using a simple analysis of variance technique. The decision-theoretic concept of risk aversion is then used to establish a genotype ranking which is based on farmers preferences and takes account of both average yield and stability. The following questions are then pursued:

i) Do hybrids outperform varieties when the preference based ranking is used rather than a simple yield ranking?

ii) Do yield and preference based rankings deviate strongly from each other?

iii) Are measured adaptability and (temporal) stability highly related?

iv) How well can single year data predict stability or adaptability?

Materials and Methods

A balanced set of five hybrids (CSH.1, CSH.2, CSH.4, CSH.5 and CSH.6) and six varieties (Swarna, 148, 302, 555, 604 and local) tested over 18 common locations from 1971 to 1974 in the All India Coordinated Trials was chosen out of total 103 varieties/hybrids tested in a total of 82 locations. The trials were conducted during the monsoon season and virtually all under rainfed condition. A uniform fertilizer dose of 80 Kg N + 40 Kg P_2O_5 and 40 Kg K_2O per ha was adopted with minor variations at some locations. The soil type was dissimilar from region to region but deep black soils were prevalent in the major sorghum growing belt. Trials were conducted in a complete randomized block design, entries replicated three times with a net plot size of 22.5 sq. metres. The plantings were done at a spacing of 45 cm between rows and 15 cm between the plants to get a plant population of 180,000 per ha. Early sowing and other plant protection measures were used.

The average across station rainfall for the different years was as follows:

1.1 Measures of risk and adaptability

The stability relevant and adaptability relevant components of variability are measured based on the following random effects make:

$$Y_{i\ell t} = \mu_i + \lambda_{i\ell} + \tau_{i\ell t}$$

$Y_{i\ell t}$ is the yield of genotype i (i=1,...,V) at location $\ell(\ell=1,\ldots,L)$ and in year t (t=1,...,T). The genotype mean is μ_i, $\lambda_{i\ell}$ is the effect of location ℓ on genotype i and $\tau_{i\ell t}$ is the location by year interaction. For analysis of variance purposes $\tau_{i\ell t}$ has to be further split up into $\tau_{i\ell t} = \nu_{it} + \eta_{i\ell t}$ where ν_{it} is the average year effect on genotype i and $\eta_{i\ell t}$ is the residual location by year interaction. The following two subsections are a sharply condensed version of portions of Binswanger and Barah (1980) to which the reader is referred for fuller details.

Replications are neglected in the analysis, although an extension to include their effect is straight-forward. The variance of genotype i yield then is

$$\sigma_i^2 = \sigma_{i\lambda}^2 + \sigma_{i\tau}^2 \qquad (2)$$

The "adaptability component" of the variance is $\sigma_{i\lambda}^2$ (estimated by S_λ^2) while the "stability component" is $\sigma_{i\tau}^2$, measured by $S_{i\tau}^2$. (Formally this component is again broken up as $\sigma_{i\tau}^2 = \sigma_{i\nu}^2 + \sigma_{i\eta}^2$). A farmer at any given location only experiences the stability component $\sigma_{i\tau}^2$ as his level of risk. Unlike the breeder, he is not interested in the (average) performance of the genotype at other locations, i.e. the adaptability component σ_λ^2 is irrelevant for him.

From the mean squares (MS) of analysis of variance tables of each genotype yield across years and locations (and neglecting replications) these components are measured as

$$S^2_{i\gamma} = S^2_{i\nu} + S^2_{i} = \frac{MS_{years} - MS_{residual}}{L} + MS_{residual}$$

$$= \frac{MS_{years} + (L-1)MS_{residual}}{L} \qquad (3)$$

$$S^2_{i\lambda} = \frac{MS_{location} - MS_{residual}}{T} \qquad (4)$$

For reasons explained in the next section and because of the one-to-one relationship of rankings based on variance and standard deviation, square roots of these components are used as estimates of stability- and adaptability-relevant standard deviations.

1.2 Decisions under risk and a measure of risk aversion

Ranking of genotypes by average yield and risk, as measured here by the stability-relevant standard deviation will usually not coincide. A unique ranking for choosing among these genotypes can only be established by using decision theory under risk as developed by statistician and economists. For an exposition of these theories see Anderson, Dillon and Hardaker 1977. The simplest such framework is Expected Returns-Variance analysis (E-V analysis). Before proceeding, however, note the following about this choice-theoretic framework : One can neglect the issues of subjective probabilities or perceptions of farmers because the analysis here is prescriptive i.e. it addresses the question of

what should be recommended to farmers. E-V analysis also assume that yields are normally distributed over time (which cannot be tested with only 4 years of data); if there are sharp divergences from normality, more complex models are required.[1] Furthermore, E-V analysis is usually performed done with profits rather than yields. Since in the trial considered the cost of production is the same for all genotypes and we have no information about their output price differences profit or yield leads to identical rankings. Where data sets have different characteristics the same analysis can be done by letting $Y_{i\ell t}$ stand for profits rather than yield.

In E-V analysis the farmer is assumed to have a utility function which measures his level of satisfaction taking into account both average yield and stability, i.e.

$$U = f\ (\mu_i\ ,\ \sigma^2_{i\tau}\ ) \qquad (4)$$

Problems associated with measuring such functions have occupied economists and experimental psychologists for the past 150 years and need not concern us here. What is important is that different combinations of expected return and stability can lead to the same level of satisfaction, i.e. one can solve equation (4) for <u>Iso-Utility curves</u>.

$$\mu_i\Big|_U = g\ (\sigma^2_{i\tau}) \qquad (5)$$

Because of the one to one correspondence of σ and σ^2 we can write this in the expected return - standard deviation space as

$$\mu_i\Big|_U = h\ (\sigma_{i\tau}).$$

Such iso-utility curves are given in fig.1 below as lines AB, BD or CD.

The steeper the lines, the less risk-averse is an individual. The slope of the line $\Delta S/\Delta \bar{Y}$ is the tradeoff an individual is willing to accept between expected yield and standard deviation. Individuals with a given slope of these lines will choose the genotype which lies on the line farthest to the right in the graph because lower standard deviation and higher yield lead to higher utility.

Binswanger (forthcoming) has measured the slope $\Delta S/\Delta E$ of these isoutility curves for semi-arid tropical farmers in the Indian sorghum growing belt. He finds that it lies in the fairly narrow range of 1.5 to 3.0 with a mean value of 2.0. This mean value will be used for the preference based ranking.

2. RESULTS

The stability relevant standard deviation S_τ plotted (vertical axis) against the mean yield of each genotype across all location and over years (horizantal axis) shows that the genotypes fall into two distinct groups (fig.1). The hybrid groups have average yields ranging from 29.5 to 46.8 quintals per hectare while the local check and the varieties have yields from 19 to 28.1 quintals per hectare. Hybrids thus dominate all varieties from the yield point of view. However, the hybrids as a group tend to have slightly higher stability-relevant standard deviations than the varieties-cum-local groups. The most popular hybrid such as CSH.5 and CSH.6, therefore, are highest yielder as well as higher in S_τ. By and large higher yields must be "paid for" by higher stability-relevant standard deviations.[2]

Five genotypes 555, 604, 148, CSH.4 and CSH.5 are stability- or risk-efficient since no other genotype exists which has both higher (or equal) yield and lower (or equal) standard deviation. No risk-averse decisions maker, regardless of his level of risk aversion, would choose a genotype which is not stability-efficient in this sense.[3] But to choose the "preferred" genotype from the risk-efficient set requires knowledge of the extent of risk aversion.

For this particular data set and for all three levels of risk aversion (1.5, 2, 3) the preferred genotype is also the highest yielding one, CSH.5. In fact the ranking based on risk-preference divides the genotypes into the same two groups as a yield-based ranking, namely the hybrid and the varieties groups (Table 1). This answers question (1)

Table 1. Ranking of sorghum genotypes according to different device criteria and in different years

Genotype	4 years average yield Q/ha	RANKING		Stability efficient set	Stability standard deviation	Adaptability standard deviation	Adaptability efficient set	Individual year ranking			
		Yield	Risk preference					1971	1972	1973	1974
1	2	3	4	5	6	7	8	9	10	11	12
CSH-5	46.80	1	1	*	17.65	10.90	*	1*	1*	1*	1*
CSH-4	35.18	2	2	*	13.07	7.88	*	3	4	3*	2*
CSH-6	35.16	3	3		14.64	11.27		2	2	2*	4
CSH-1	30.29	4	4		14.95	9.96		4	3	4	10
CSH-2	29.54	5	5		15.34	11.93		5	6	5	5
SWARNA	28.12	6	6		13.90	7.00	*	7	5*	6	3
302	24.18	7	9		14.27	7.34		9	7	7	9
148	23.77	8	7	*	11.40	6.08	*	6	9	8	7
604	23.09	9	8	*	10.83	5.90	*	8*	8*	9	6
555	21.51	10	10	*	9.48	6.52		11	10*	10*	8
LOCAL	18.52	11	11		11.74	4.95		10	11	11	11

* The genotype is in the respective stability-efficient, adaptability-efficient or variability -efficient set

Table 2. Annual yields, their standard deviations, and variability efficient sets

Genotype	1971	1972	1973	1974
CSH-5	57.76* (25.92)	40.57* (16.47)	45.15* (19.35)	43.71* (15.38)
CSH-4	35.30 (18.18)	32.15 (16.44)	37.17* (15.51)	36.12* (9.36)
CSH-6	38.18 (19.99)	36.76 (20.57)	40.22* (16.57)	25.48 (11.52)
CSH-1	31.39 (17.92)	33.22 (19.15)	35.91 (18.20)	20.66 (11.63)
CSH-2	30.28 (19.19)	30.15 (18.86)	32.34 (22.25)	25.41 (17.58)
Swarna	24.81 (18.24)	31.16* (13.90)	24.48 (14.13)	32.02 (14.85)
302	22.34 (17.16)	29.26 (18.58)	20.56 (10.-2)	24.59 (16.16)
148	26.40 (15.19)	24.48 (11.65)	19.h1 (12.00)	25.09 (12.02)
604	23.35* (12.48)	24.74* (10.48)	18.95 (12.79)	25.34 (13.10)
555	21.29 (12.96)	22.10* (8.66)	17.94* (8.65)	24.74 (14.11)
Local	21.95 (13.43)	18.33 (10.22)	17.16 (16.20)	16.68 (10.5)

* Genotype is in variability-efficient set i.e. there exists no other genotypes which has equal or high yield and equal or lower standard deviation.

in the introduction in the affirmative. Furthermore the yield based ranking and the preference based ranking not only coincide across these groups but are very close within each group as well. The only rank reversal is the one between 302, 148 and 604. These genotypes have very similar yields but substantially different standard deviations causing reversal in rankings. Where yields differ widely such reveraals do not happen. For this data set the second question of the introduction is also answered affirmatively.

The adaptability-relevant standard deviation is plotted against average yield in Fig.2. In absence of a choice-theoretic criterion for trading off yield against adaptability variance (Binswanger and Barah, 1980) one can only make the inference that a genotype dominates another in the adaptability sense if it has equal or higher yields and equal or lower adaptability variance (standard deviation) . CSH-5 dominates CSH-2 and CSH-6 ; and CSH-4 dominates CSH-1, CSH-2 and CSH-6. Variety 148 dominates only 555. This dominance criterion can be used to define an adaptability-efficient set of genotypes as that set genotypes which are not dominated by any other genotype in the adaptability sense. The adaptability-efficient set consists of 604, 143, SWARNA, CSH-4 and CSH-5. The local check is also adaptability-efficient. Since the local check differs from location to location, interpreting its adaptability-relevant standard deviation is not very meaningful.

However, the adaptability-efficient set contains largely the same genotypes as the stability efficient set (Table 2). Swarna is contained in the adaptability-efficient set but not in the stability-efficient one while the reverse is true for 555. In particular CSH-5 and CSH-4 rank highest by yield and by risk preference and are also adaptability-efficient.

Varieties 148 and 604 are among the lowest yielding but highest in their stability and adaptability.

The correlation coefficient between stability relevant and adaptability relevant standard deviation is also high at r = 0.80 which is significant at the 0.01 level of probability. Thus the third question in the introduction is also answered affirmatively.

In a single year multilocation data, the total SD confounds stability and adaptability variance components and is thus neither a measure of stability nor of adaptability. It is larger than either one individually. However one can define variability-efficient sets just as before for stability and adaptability. A genotype is variability-efficient if no other genotype has both higher (or equal) yield as well as lower (or equal) total standard deviation.

Comparing single year yield rankings with the yield rankings over all four years and with the risk-preference rankings the individual year rankings coincide fairly well with the overall yield and preference rankings where ultimate yield differences are large. CSH-5 always occupies first rank and local is last in 3 out of 4 years. On the other hand, Swarna does better than some of the hybrids in 2 out of 4 years. This leads to the conclusion that large yield differences in single year are good predictors of yield differences over several years and of risk preference based rankings but smaller differences must be confirmed in several years of trials. The fourth question of the introduction therefore receives only a qualified yes.

3. DISCUSSION

It is our contention that the use of the joint regression technique of stability analysis is an inappropriate technique for analyzing stability in its risk connotation, although we do not dispute its usefulness in other contexts (see Yates and Cochran 1938, Findlay and Wilkinson 1963, Eberhardt and Russel 1966, Perkins and Jinks 1968, and Freeman 1973). First the concept of stability used there coincides with stability as absence of risk only if it is used in a (usually non-existent) data set for a single location over many years. It does not properly distinguish between a location and temporal dimension of variability, except in its extension by Evenson et. al. (1978). Second its measures of stability (regression coefficients and sometimes the residual variances around regression lines) has not been related to any choice theoretic criteria for choice under risk . The neglect of a proper choice-theoretic framework is in our view the major reason for the continuing confusion about what are proper measures of "stability" of genotypes, whether the discussion revolves around risk or adaptability as defined here.

The technique proposed here overcomes these shortcomings in the risk dimension. (But further work is required to develop a choice-theoretic framework of the adaptability issue). It is simple and can be easily used with multilocation yield trials. It does require corresponding measures of risk aversion but such measures will increasingly become available for other farmer populations than the one studied here.

One limitation of the techniques is that the results are fairly specific to the agroclimatic region within which the experiments have been conducted, a problem shared by the joint regression approach as well. The preference based rankings of these eleven genotypes may not be the same

if tested in a similar way in Africa, for example. As discussed in Binswanger and Barah (1980) or Hardwick and Wood (1972) such region-specificity can only be overcome by using regression techniques on plant independent variables.

The results of the specific application are comforting to Sorghum breeders in India, and may be elsewhere. Yield and risk-preference based rankings are very closely related, although further analysis is required to see whether this is also the case at lower fertilizer or plant protection levels. Furthermore adaptability and stability are highly related, supporting a multilocation breeding and testing approach in the pursuit of both low risk and high yields.

FOOTNOTES

1. Measuring risk by variance or standard deviation is only appropriate for normal distribution (See Roumasset 1979 on the problems of appropriate measures of risk.) The use of the measure of risk aversion used below, (the tradeoff between yield and standard deviation) has a similar requirement.

2. They may, however, have lower coefficients of variation (CV) of yields. But CV cannot be used in this type of analysis because (a) no decision theoretic framework exists relating CV to yield or profits and (b) unlike for S_T, rankings by CVs of profits will not be identical to rankings by CVs of yields, even if output price and input levels do not differ by genotypes.

3. Even without knowledge of the level of risk aversion of a decision maker one can thus classify genotypes into two sets. This type of analysis can be extended to non-normally distributed yields where the concept of stochastic dominance is used (Anderson 1974). But such efficiency or stochastic dominance analysis does not lead to unique rankings.

REFERENCES

Anderson, J. R. (1974), "Risk efficiency in the interpretation of agricultural production research", Review of Marketing & Agricultural Economics, Vol.42(3), pp 131-183

Anderson, J. R., J. L. Dillon and J. B. Hardaker (1977). "Agricultural Decision Analysis", Ames, Iowa State University Press

Eberhart S. A. and W. A. Russel (1966), "Stability Parameters for comparing Varieties", Crop Science, Vol.6, p 36-40

Evenson, R. E. et al (1978), "Risk and Uncertainty as Factors in Crop Improvement Research," IRRI paper series No.15, Manila Philippines

Finlay, K. W. and G. N. Wilkinson (1963), "The Analysis of Adaptation in a Plant Breeding Programme", Aust. Jour. Agri. Res., Vol.14, pp 742-54

Freeman, G. H. (1973), "Statistical Methods for the Analysis of Genotype-Environment Interaction", Heredity, Vol.31, pp 339-54

Hardwick, R. C. and Wood, J. T. (1972), "Regression Methods for Studying Genotype-Environment Interaction", Heredity, Vol.28, pp 209-22

Laing, D. R. and R. A. Fisher (1973), "Preliminary Study of Adaptation of Entries in 6th ISWN to non-irrigated Conditions", CIMMYT, Mexico

Perkins, J. M. and Jinks, J. L. (1968), "Environmental and Genotype Environmental Components of Variability", Heredity, Vol.23, pp 339-56 pp 525-35

Yates F. and W. G. Cochran (1938), "The Analysis of Groups of Experiments," Journal of Agri. Sci., Vol.28, pp 556-580

FIG 2: ADAPTABILITY EFFICIENCY

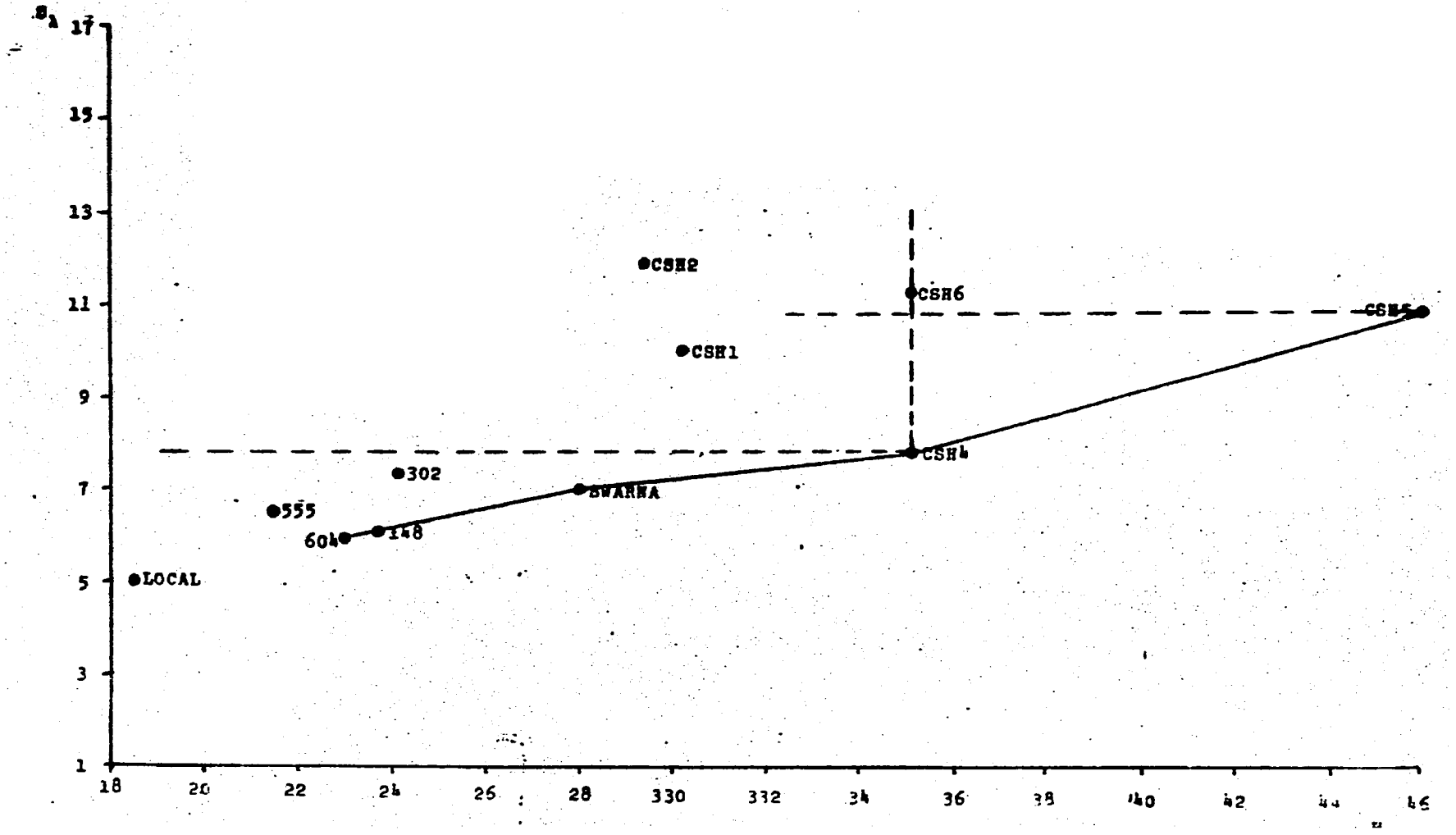
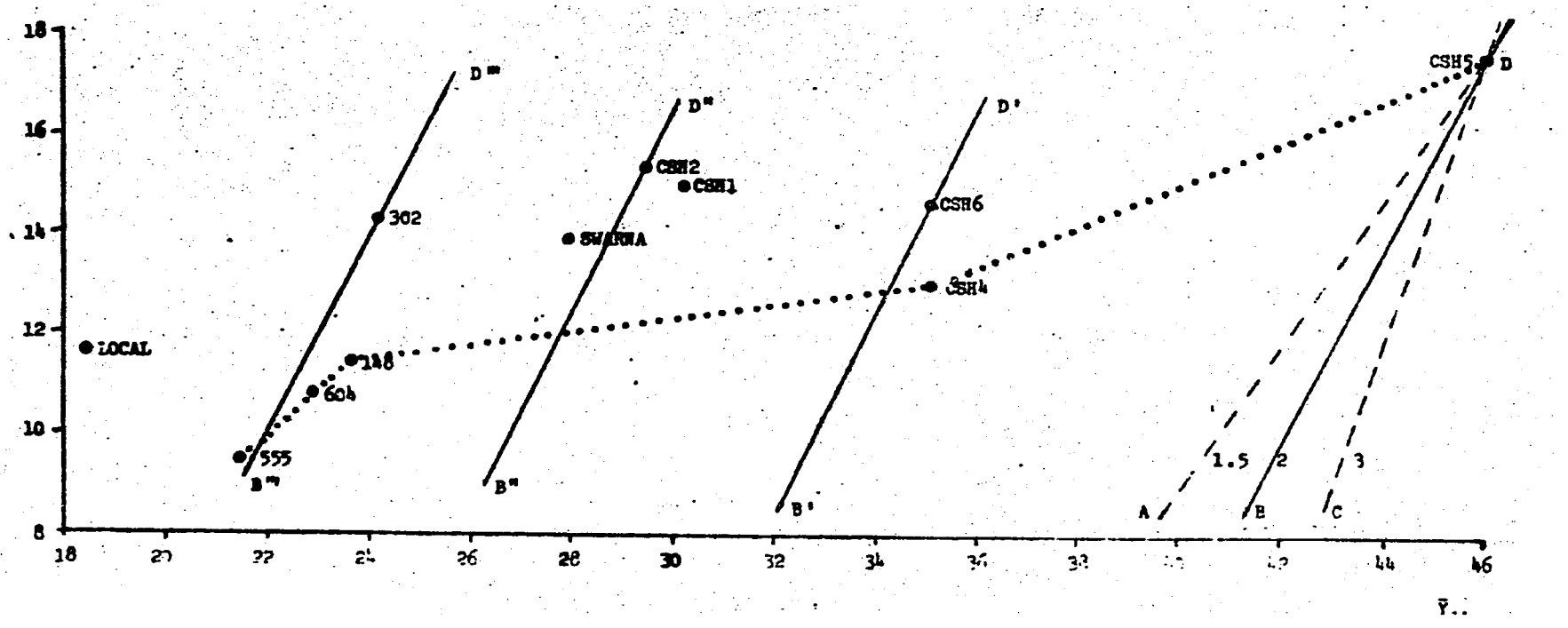
FIG 1: 'RANKING ACCORDING TO RISK PREFERENCE'