Diversification and Stability Implications of New Crop Varieties: Theoretical and Empirical Evidence[+]

Clem Tisdell and Mohammad Alauddin[*]

Abstract

High yielding varieties of crops are reputed on the basis of empirical evidence [Hazell (1982,1985); Mehra (1981)] and on ecological grounds [Conway (1986)] to increase variability of agricultural production and yield. However, Alauddin and Tisdell (1988a,1988b) have found empirical evidence for Bangladesh suggesting that 'Green Revolution' technologies have reduced variability of yields and risks of low yields.

This paper examines how through diversification of crops, increased incidence of multiple cropping, greater environmental control over the growing of crops and other factors, risks of low crop yields can be reduced when HYVs are adopted. In doing this, use is made of portfolio diversification theory, Cherbychev's inequality and variations of it [Markowitz (1959)].

In order to indicate patterns of change in diversity of crops and varieties and provide further evidence of factors influencing variations in the risk of low yields from crops, evidence is presented from secondary data and from field surveys conducted in two areas of Bangladesh about changes in the extent of diversification of crops and varieties grown since the introduction of HYVs.

In conclusion, this paper discusses risks to yields such as the possibility that the genetic base and diversity of varieties of crops is shrinking. This may have potential to cause catastrophe at some time in the future. Thus while risks to yields are, it seems, being presently reduced by 'Green Revolution' technologies, this may be at the expense of a secular problem: a reduction in available crop varieties which could make it difficult to sustain yields in the more distant future.

[+] A Contributed Paper Prepared for the Thirty Second Annual Conference of the Australian Agricultural Economics Society, La Trobe University, Bundoora, Victoria 3083, February 9-11, 1988.

---

[*] The authors are respectively Professor and Research Scholar, Department of Economics, University of Newcastle, Newcastle, NSW 2308, Australia.

1. INTRODUCTION

It is frequently argued both on ecological grounds and empirical evidence that high yielding varieties (HYVs) of crops create greater uncertainty about and instability of farm yields and production. But this may not be so in practice. This is because the occurrence of HYVs in many cases:

(1) makes multiple cropping possible;
(2) permits greater diversification of varieties of crops grown; and
(3) has associated with it techniques that mean greater control over the environment and therefore, over agricultural production.

While earlier empirical evidence pointed towards greater relative instability of crop yields as a result of the introduction of HYVs, more recent research indicates the opposite tendency.

Let us consider the available evidence, suggest reasons for a decrease in relative variability of crop yields and farm incomes, and then examine some Bangladeshi farm-level evidence on diversification of crop varieties. This will be followed by the discussion of a secular problem: the likelihood that HYVs may lead to the disappearance of traditional varieties and loss of genetic diversity.

2. REVIEW OF THE EMPIRICAL EVIDENCE ON CROP YIELD AND PRODUCTION INSTABILITY

The question of stability and adaptability of crops has been discussed at theoretical and empirical levels [Tisdell (1983)]. For instance, Evenson et al. (1979) point to the need to draw a distinction between (a) stability of a genotype, that is, its changing performance with respect to environmental factors over time, and (b) adaptability, that is, its performance with respect to environmental factors that change across locations. Evenson et al. (1979) express concern that new HYVs of crops could increase yield variability in developing countries and recommend more research into crops with a view to reducing such variability.

Recent in-depth studies of Indian agriculture [Mehra (1981); Hazell (1982,1985)] found evidence of increased instability in agricultural production following the introduction of modern agricultural technology. Parthasarathy (1984:A74) indicates that greater yield instability is positively associated with districts experiencing higher agricultural growth rates in the Indian state of Andhra Pradesh. Hazell (1982:10) goes so far as to conclude that "production instability is an inevitable consequence of rapid agricultural growth and there is little that can be effectively done about it". One needs to reminded of course that despite apparent similarity in conclusions, Mehra (1981) and Hazell (1982) differ in an important respect. Mehra (1981) hypothesizes a causal link between the new technology and increased production and greater yield instability. Thus while Mehra (1981) attributes most of the production variation to yield instability, Hazell (1982,1985) attributes rising production variability to greater yield variability as well as a reduction in the offsetting patterns of yield variation (a rise in covariation of yields) between crops and regions.

While the studies by Hazell (1982) and Mehra (1981) are substantial, in our view, they are subject to two methodological limitations. These have been discussed in greater detail by Alauddin and Tisdell (1988a,1988b). However, it is worth reporting some of the shortcomings here.

First, Hazell (1982,1985) and Mehra (1981) measure production stability or lack of it around a line of 'best fit'. As Ray (1983:462-463) points out, "any inference regarding changes in the pattern of growth and instability in production will be greatly influenced by the choice of mathematical function, the selection of which cannot be left alone to the statistical criteria of best fit" [Rudara (1970)]. Furthermore, while their studies compare the variability of one period with that of another, they do not consider whether variability itself shows any tendency to increase or decrease within a period of specified duration.

Secondly, both Hazell (1982) and Mehra (1981) assume arbitrary cutoff points. Furthermore, they do not seem to follow a consistent rule for dropping observations for 'unusual' years. Probably both Mehra (1981) and Hazell (1982) were justified in dropping observations relating to 1965-66 and 1966-67 because of severe drought during those years. As Hazell (1982:13) points out, "catastrophes of this kind are sufficiently rare and severe that they can be considered as separate phenomena from year to year fluctuations". Mehra (1981:10) argues that, " ... the mid-1960s witnessed two drought years 1965-66 and 1966-67 of such unusual severity as to significantly alter the variance of any period in which they are included, thus casting doubts about the validity of their conclusions".

On closer examination of the foodgrain production data presented by Savant (1983:476) one can identify two worst years during the period 1967-68 to 1977-78 which corresponds to the second period designated by

Mehra (1981) and Hazell (1982). In 1972-73 Indian foodgrain production dropped by over 8 million metric tons (8 per cent) from the previous year's production. It was even worse in 1976-77 when the decline was 10 million metric tons (over 8 per cent) from the production of 1975-76. Apart from 1965-66 and 1966-67 no other year between 1950-51 and 1977-78 saw such an absolute decline in foodgrain production in India. To be consistent one would have expected these two years to be dropped from the analysis of the second period. In that case, one would perhaps end up with a different picture to those emerging from the studies by Mehra (1981) and Hazell (1982).

It seems likely that the findings of both Mehra (1981) and Hazell (1982) are sensitive to changes in cutoff points and to their decisions to delete certain observations. This gains some support from a more recent study by Hazell (1985). In that study, Hazell (1985) compares instability in world cereal production between two periods viz., 1960-61 to 1970-71 and 1971-72 to 1982-83 and also examines instability in cereal production in different regions of the world e.g., in South Asia. When comparing the instability of cereal production between the two periods for India, he does not drop observations for 1965-66 and 1966-67. Nor does he drop the observations for 1972-73, 1976-77 or 1979-80 when total foodgrain production fell by a huge 22 million tonnes i.e., about 17 per cent [Savant (1983:476)]. When no observations are dropped from either period, one finds that the coefficient of variation of cereal production in India decreases by 29 percent [Hazell (1985:150)] during the second period (1971-72 to 1982-83) as compared to the first (1960-61 to 1970-71) whereas the earlier studies by Mehra and Hazell indicated a rise in the coefficient of variation. Thus the assumption of arbitrary cutoff points and inconsistency in deletion of observations, can lead to conflicting results.

At this stage it is pertinent to mention that while Hazell (1982) and Mehra (1981) found increased variability in foodgrain production and yield following the introduction of the 'Green Revolution' technologies, some studies also provide evidence to the contrary. In an earlier study, Sarma and Roy (1979) found that the coefficient of variation of Indian foodgrain production declined from 14 per cent in the pre-'Green Revolution' (1949-50 to 1964-65) to 8 per cent in the period following it (1967-68 to 1976-77) [Dantwala (1985:112,123); see also Government of India (1982)].

A recent study [Jain et al. (1986)] extends the Hazell (1982) analysis for India to 1983-84. Without dropping any observations from either period, they find that the period of new technology (1967-68 to 1983-84) is associated with a lower production and yield variability compared to the earlier period (1949-50 to 1966-67). One further point that emerges from recent studies is that while Hazell (1986:16) shows that the probability of a 5 per cent fall below the trend in world cereal production may have doubled in recent years, there are wide variations between regions and commodities. For instance, the coefficients of variation of both rice and wheat production have declined in recent years [Hazell (1986:18); Evans (1986:2)]. Hazell (1986:18) also claims that "the least risky countries are those that predominantly grow rice, presumably because much of the crop is irrigated. These countries include Indonesia, Thailand, Bangladesh and Japan". Thus more recent evidence seems to cast some doubt on the validity of the earlier Hazell contention of instability being an inescapable consequence of increased agricultural growth.

Alauddin and Tisdell (1988a) measured the degree of foodgrain (rice and wheat) production and yield variability for in terms of deviations from a moving average of a five-year period. The variance of a variable for any year was estimated as its observed variance for the five-year period up to and including the year under consideration. So the variance itself was a moving value. Using this approach and applying it to Bangladeshi time series data for the period 1947-48 to 1984-85 the changing behaviour of absolute and relative measures of variability (standard deviation and coefficient of variation) in production and yield was examined. The evidence suggested no increase in production and yield variability in the period of new agricultural technology. It was suggested on the basis of an analysis of aggregate time series data that the 'Green Revolution' might have had a stabilising impact on the relative variability of production and yield rather than a destabilising one.

In addition, Alauddin and Tisdell (1988b) employed the Hazell (1982) approach of fitting trend lines to time series data and measured foodgrain production and yield variability in terms of deviations from the trend values for Bangladeshi national and district level data both before and after the introduction of the new agricultural technology. The results indicated that the 'Green Revolution' may (in contrast to Hazell's findings for India) have reduced relative variability of foodgrain production and yield. Districts experiencing greater penetration of HYVs and associated techniques seemed to have lower relative variability.

Furthermore, the probability of production and yield falling 5 per cent below the trend [Hazell (1985:149)] was found by Alauddin and Tisdell (1988b) to be lower for high HYV adoption districts than those with lower adoption rates. For Bangladesh as a whole, intertemporal analysis indicated falling relative variability of foodgrain production and yield, and this is also true for most districts in Bangladesh.

Neither of the two sets of results emerging from the employment of the alternative methodology [Alauddin and Tisdell (1988a)] and Hazell's own method [Alauddin and Tisdell (1988b)] provide any evidence to support Hazell's findings for India of rising relative instability of foodgrain production and yields in Bangladesh following the introduction of the 'Green Revolution' technologies. If anything the evidence points towards a decline in such instability. It is useful to consider in some detail ways in which the 'Green Revolution' technologies can reduce yield instability.

3. REASONS: DIVERSIFICATION AND MULTIPLE CROPPING

The 'Green Revolution' has had a strong effect in raising average or expected yields of crops [Herdt and Capule (1983); Alauddin and Tisdell (1986b)]. This is because in some cases HYVs raise within season yields when they replace traditional varieties as well as increasing the scope for multiple cropping and so on an annual basis also add to expected yields. If a single crop of a HYV has a lower yield than a single crop of a traditional variety and if the former permits multiple cropping but the latter does not, annual expected yield may be much higher with HYV introduction. To the extent also that yields between seasons are not perfectly correlated, this will tend to reduce risks by, for example, lowering the coefficient of variation of annual yields, although as we have discussed elsewhere [Alauddin and Tisdell (1987); see also Boyce (1987)] sustainability problems may emerge in the long term. Multiple cropping is likely to reduce the probability of annual farm income falling below a disaster level, if we leave secular problem to one side [Anderson et al. (1977:211)].

While HYVs may have a higher expected yield and greater risk or yield variability than traditional varieties, in some cases HYVs may involve higher yields and less risks to individual farmers than traditional varieties. In the latter case, they dominate traditional varieties and can be expected to replace them in due course. As explained in the next section, techniques associated with HYVs by ensuring greater environmental control may help to establish this dominance.

As is well known, there is no simple shorthand way of measuring uncertainty and instability. But for the purpose of this exercise let us take the variance or the standard deviation as an indicator. In Figure 1, the mean income for a farm and its standard deviation are shown. The combination at A may indicate the situation of the farm using a traditional variety. The advent of an HYV may if it replaces the traditional variety make B or even C possible. Aggregate evidence from Bangladesh indicates a rise in absolute variability but a reduction in relative variability following the 'Green Revolution' as well as a rise in mean yields [Alauddin and Tisdell (1988a,1988b)]. So the overall situation is depicted by a point to the right of A located above line OA. The slope of OA is determined by the mean yield of the traditional variety divided by its standard deviation. In the case illustrated, the yield characteristics of HYV at B lie above the line OA and reduce the coefficient of variation even though the HYV has a much greater variance than the traditional variety.

INSERT FIGURE 1

Where the variability of yields from HYVs are greater than that for traditional varieties, diversification of varieties grown can be used as a strategy to reduce the risk of growing some HYV provided yields of varieties are not perfectly correlated. If the yields of the varieties are perfectly correlated, and if A and B and the unmixed crop variety possibilities, the efficiency locus [Markowitz (1959)] is indicated by the line AB in Figure 2 [Anderson et al. (1977:193)]. Lack of perfect correlation between returns from the different crop varieties results in the efficiency locus or curve joining A and B to bulge to the left so that a curve like AKB in Figure 2 may result [for details on the nature of this curve see Anderson et al. (1977:193)]. Thus when returns are not perfectly correlated, variety diversification can reduce risk and lower the coefficient of variation.

INSERT FIGURE 2

Cherbychev's inequality and variations on it can be used to explore this matter further [Anderson et al. (1977:211)]. According to this inequality the probability that a random variable, x, deviates from its expected value by more than an amount k is equal to or less than its variance divided by k, that is

$$\Pr\left[|x-\mu| \geq k\right] \leq \sigma^2/k \qquad (1)$$

According to the inequality, if an income of x_1 or less than x_1 is to be avoided (would be a disaster), the probability of not avoiding this is given by the following inequality

$$\Pr[x \leq x_1] \leq \sigma^2/(\mu - x_1)^2 \qquad (2)$$

A farmer may require the probability to be less than a particular value, say k. This will be satisfied if

$$\sigma^2/(\mu - x_1)^2 \leq k \qquad (3)$$

Thus if σ^2 is assumed to be the dependent variable, all combinations of (μ, σ^2) on or below the parabola

$$\sigma^2 = k(\mu - x_1)^2 \qquad (4)$$

satisfy this constraint, except for all combinations involving a value of $\mu < x_1$, x_1 being assumed to be less than μ. Thus for the case illustrated in Figure 3 combinations to the left of the DEF, the positive branch of relevant parabola may not satisfy the safety first constraint whereas those to the right of this branch or on it do satisfy the constraint.

INSERT FIGURE 3

Several points may be noted:

(1) Where returns from different varieties are not correlated and on the basis of the argument illustrated in Figure 2, it may be possible to meet the safety first constraint by diversification of varieties grown.

(2) If the variance and mean level of income increase in the same proportion, the likelihood of the safety first constraint being satisfied rises. For example, if in Figure 3, A is the combination of (μ, σ^2) for the traditional variety and B corresponds to that for a HYV, the HYV meets the constraint but the traditional variety does not. As one moves out further along the line OA, the likelihood of the constraint being satisfied rises and the probability declines of incomes falling below x_1. This can even happen, up to a point, when μ rises and σ^2 increases more than proportionately.

It should be noted Cherbychev's inequality is not very powerful. Because of this, there <u>may</u> be combinations to the left of curve DEF in Figure 3 which also satisfy the probability constraint. In that respect a modification of this inequality so that it is based on the lower semi-variance is more powerful [Tisdell (1962)]. If the probability distribution of income is symmetric about its mean the lower semi-variance is $0.5\sigma^2$ and it follows that

$$\Pr\ [x \leq x_1]\ \leq 0.5\sigma^2/(\mu - x_1)^2 \qquad (5)$$

The relevant safety first parabola now is

$$\sigma^2 = 2k(\mu - x_1)^2 \qquad (6)$$

and the relevant branch might be as indicated by curve DGJ in Figure 3. Clearly similar consequences follow to those mentioned earlier. It is useful to consider some estimates of the semi-variance and men value of foodgrain yields in Bangladesh.

4. EMPIRICAL ESTIMATES OF PARAMETERS

Let us now consider empirical estimates using Bangladeshi foodgrain yield data. First of all annual indices of overall foodgrain yield were derived using the average of the triennium ending 1977-78 as the base. The degree of variability can be measured in terms of deviations from a moving average of a specified period (say 5 years) of the relevant variables. The variance of a variable for any year is estimated as its observed variance for the five year period up to and including the year under consideration. So the variance itself is a moving value. This enables one to get a series of values of absolute and relative measures of variation and identify particular phases during which variability tends to increase, decrease or remains more or less stationary.

As the primary concern of this paper lies in the deviations below the mean, we choose a period of longer duration (than five years). This is because a five yearly period is likely to significantly reduce the number of observations for negative deviations. This is unlikely to provide a robust basis of analysis. Using this approach and applying it to Bangladesh, we considered time-series data for the period 1947-48 to

1984-85 to specify the changing behaviour of yield variability over time. We tried moving values for 9 and 11 years and the results were similar. We have in this paper presented results based on the 11 year period. The relevant data are set out in Table 1.

INSERT TABLE 1

A few observations seem pertinent. First, there is a steady increase in foodgrain yields. Secondly, there seems to be little overall time trend in lower semi-variance, (lower) coefficient of semi-variation and probability of yield falling 50 per cent or more below the initial 11 year average yield. However, these measures of variability seem to increase initially and then decline before showing a rising tendency once again at a slowly rate than initially. Indeed at about the mid-1960s these appear to be a fundamental change in relative variability of yields. A large and significant downward shift occurs in the trend of relative variability and it increases at a slower rate than prior to the mid-1960s.

These aspects come into sharper focus when one plots the relevant observations against time. Figure 4 plots semi-variance (**SEMVAR**). One can visually identify two distinct phases (the first phase 1952-63, that is 1952-53 to 1963-64 and the second phase 1964-79, that is, 1964-65 to 1979-80). Up to the early 1960s semi-variance of yield shows a strong tendency to increase. In order to make quantitative comparison of change in its behaviour three regression lines with time (T) as the explanatory variable were estimated. These are presented as Equations (13), (14) and (15) for the corresponding periods. Figure 4 illustrates Equations (13) and (14) for the first and second phases respectively. Equation (13) clearly indicates a strong time trend in semi-variance in terms of both explanatory power and statistical significance. Equation (14) shows a similar trend in the later period. However, the relative rate of change is much lower in the second phase compared to the one in the first as indicated by their respective slopes. More importantly, there is a change in trend apparent with the relative variability indicated by Equation (14) being much lower than that for (13) as a function of time.

Phase 1: $\text{SEMVAR} = 1.4045 + 3.1080T, \quad R^2=0.7529, \quad \text{t-value}=5.52 \qquad (13)$

Phase 2: $\text{SEMVAR} = -13.1311 + 1.5031T, \quad R^2=0.5443, \quad \text{t-value}=4.09 \qquad (14)$

Entire : $\text{SEMVAR} = 11.7585 +0.4011T, \quad R^2=0.0895, \quad \text{t-value}=1.60 \qquad (15)$

INSERT FIGURE 4

Figure 5 plots coefficients of semi-variation (SEMCOV) against time. One can identify two similar phases in its behaviour to those for semi-variance. To facilitate quantitative comparisons, Equations (10), (11) and (12) were estimated by least squares linear regression. Equations (10) and (11) have been illustrated in Figure 5. Equation (10) corresponds to the first phase and shows that the coefficient of semi-variation had a strong tendency to increase during Phase 1. The strong explanatory power and high t-value lend clear support to this claim. However, there is an important change in its behaviour when one considers Equation (11) which relates to the second phase and Equation (12) which relates to the entire period. A comparison of Equations (10) and (11) clearly shows a much slower rate of increase in the coefficient of semi variation in the second phase. Once again a strong downward shift in relative variability is suggested by the comparison of Equations (10) and (11) and their lines shown in Figure 5.

Phase 1: SEMCOV = 3.0193 + 0.4502T, R^2=0.7787, t-value=5.93 (10)
Phase 2: SEMCOV = 1.0681 + 0.1669T, R^2=0.4380, t-value=3.30 (11)
Entire : SEMCOV = 4.7619 + 0.0047T, R^2=0.0006, t-value=0.12 (12)

INSERT FIGURE 5

Figure 6 depicts the behaviour of probability of yield falling 50 or more below the average of the initial 11 year period (PROB50). Overall no time trend can be established. But two distinct phases can be identified. It increases during the period up to the early 1960s (Phase 1) and falls to lower values on average in the subsequent period (Phase 2). The behaviour of PROB50 can be placed into a pattern by considering the estimated regression equations in Figure 3 and Equations (13), (14) and (15) which relate respectively to the first and second phases and the entire period. A comparison between Equations (13) and (14) and the corresponding lines shown in Figure 7 suggests that the trend in probability of a disaster level of yield underwent a significant downward shift around the mid-1960s.

Phase 1: PROB50 = 0.00320 + 0.00115T, R^2=0.6236, t-value=4.07 (13)
Phase 2: PROB50 =-0.00075 + 0.00028T, R^2=0.3491, t-value=2.74 (14)
Entire : PROB50 = 0.00824 - 0.00011T, R^2=0.0420, t-value=1.07 (15)

INSERT FIGURE 6

Figure 7 plots relative semi-variance against mean yield (MEANYLD). It follows a similar pattern to those in Figures (4)-(6).

INSERT FIGURE 7

Note that the scatter falls into two distinct clusters and sets, with observations centred on 1963 or earlier being well to the left of those for the later period. If a linear least squares approximation is made to the two clusters, the following equations are obtained:

CLUSTER 1: $SEMVAR = -166.2208+2.2395MEANYLD, \quad R^2=0.7750, \quad t\text{-value}=5.87 \qquad (16)$

CLUSTER 2: $SEMVAR = -109.8443+1.3425MEANYLD, \quad R^2=0.5364, \quad t\text{-value}=4.03 \qquad (17)$

These indicate significant shift downward in the lower semi-variance in relation to mean foodgrain yield about the mid-1960s and that the semi-variance is increasing at a slower rate in relation to the mean level of foodgrain yield in the second phase than in the first. In addition, if it is assumed that Cluster 1 is drawn from a distinct population, the efficiency locus in Phase 1 is as indicated by the heavy line segments passing through the points such as ABC whereas in Phase 2 it is indicated by heavy line segments passing through the points such as DEF. This would imply that there has been a considerable outward shift (shift to the right) in the efficiency locus. All the available evidence strongly points towards this conclusion. Note, however, the efficiency loci as shown are rough approximations and more than two loci are likely to have applied in the period under consideration. Also such loci, unlike Locus 1, should be non reentrant. But the order of change is such as to override such considerations.

From the available data, it seems that relative variability of Bangladeshi foodgrain production shifted downwards significantly around the mid-1960s. While the relative variability below the mean is still continuing to rise it appears to be doing so at a much slower rate than prior to the early 1960s. Similar shifts have occurred in relation to the probability of a 'disaster' level of yield, meaning the shift was downward around the mid-1960s.

Why does the apparent break occur in trends in variability? The second period, 1964-79 corresponds to the commencement of the introduction of the new technology to control agricultural production. Increased irrigation and fertilizer use followed later by the introduction of HYVs occurred during the second phase, as distinguished here.

In an earlier study Alauddin and Tisdell (1988a) reported relative yield variability (coefficient of variation rather than semi variation) showing a declining tendency in the period following the 'Green Revolution'. This contrasts somewhat with an increasing tendency of the (lower) coefficient of semi variation reported above. Why this contrast? It is probably because the declining trend in overall relative yield variability has resulted in a greater decline in the (upper) coefficient of semi-variation than the lower coefficient of semi-variation. Nevertheless, both the earlier study and the present study suggest a significant downward shift around the mid-1960s in trends in relative variability of yields.

It should, however, be pointed out that this whole analysis depends on mathematically expected values (averaging procedures) even when it takes account of higher moments. While there may be a reduction in the relative frequency or probability of disaster, disaster when 'disaster' comes it may be more catastrophic. This is not captured by averaging procedures. Thus while use of HYVs may reduce the probability of a disaster level of income (or less) occurring, a catastrophically lower income may occur when disaster strikes. More research into the probability of this is needed.

5. OTHER REASONS FOR REDUCED INSTABILITY

It was demonstrated in Section 3 that an increase in the incidence of multiple cropping can reduce the overall (annual) variability of production and yield and a fortiori reduce their coefficients of variation. In the last section, it was demonstrated that there has been what appears to be a significant downward shift in the trend of relative yield variabilities following the introduction of the 'Green Revolution' technologies. This gains further support from the cross-sectional evidence provided by Alauddin and Tisdell (1988b). However, we do not wish to give the impression that it is the increase in incidence of multiple cropping alone that has reduced relative variability of yields, nor that irrigation alone is the only factor involved in this effect. The combined package of new technology has contributed to it and the use of many elements in the package are highly correlated. Thus variables such as the index of multiple cropping and the extent of irrigation, might best be regarded as proxies for the introduction of a whole bundle of new technologies [Alauddin and Tisdell (1988a)].

To illustrate the correlation issue: The incidence of multiple cropping in Bangladesh is, for instance, closely associated with the availability of and expansion of irrigation enabling greater human control to be exerted over the growing conditions of crops. Consequently both elements may add to stability. It is also conceivable that the more ready availability of supplementary inputs such as fertilizers and pesticides with the expansion in the market for these due to the 'Green Revolution' has made it easier for growers to stabilise their production. Variations in the use of such inputs can be more finely tuned to changing environmental conditions and add stability, although we are that aware fine-tuning does not always lead to greater stability in agricultural production. Also as pointed out earlier, experimental factors may also make for a decline in relative variability of yields following the introduction of HYVs, namely by the rejection of risky varieties after early use, through determination of appropriate locational-use of varieties by trial-and-error and by progress in the development of and learning about appropriate cultural practices for the varieties adopted. Much more research is required to apportion the role of each of these factors in reducing yield instability.

To elaborate on the above: In the beginning, experiment stations often test and release a wide range of varieties. Some of these prove to have higher variability under field conditions than is apparent under experimental conditions and are discontinued. Others may initially be applied outside the regions ecologically most suited for them. Thus general learning about the ecological suitability and appropriateness of introduced varieties to particular areas takes place over time. In addition, individual farmers become more familiar with the environmental and husbandry requirements of new varieties so they can improve their cultural practices. This is an individual learning by experience phenomenon. Both of these experimental factors will tend to reduce yield variability with the efflux of time.

6. EVIDENCE FROM BANGLADESH ABOUT THE EXTENT OF CROP DIVERSIFICATION

Let us now consider the nature of crop diversification that has taken place in Bangladesh since the introduction of the new technology. The 'Green Revolution' is confined to cereals (rice and wheat) and partly to jute and sugarcane. Even though some success in research in other crops like potato, summer pulses and oilseeds is believed to have been achieved [Alauddin and Tisdell (1986a); Gill (1983); Pray and Anderson (1985)] it is yet to take-off in any real sense.

Recent evidence [e.g., Alauddin and Hujeri (1986)] indicates that the area under rice and wheat has expanded at the expense of non-cereals. This substitution of cereals for non-cereals has resulted from, among other things, the improvement in the technology specific to the former relative to the latter. The output of non-cereals as a whole has declined as a result of decline in yield and hectareage. Thus there is trend away from non-cereals to cereal production in the period of the new technology. On the other hand, the intensity of cropping has increased in recent years. Cultivated land that was once left fallow for a significant part of each year (for example, during the dry season) is now used for crops such as wheat and dry season rice varieties. Thus the 'Green Revolution' has induced greater monocultural multiple cropping.

Let us now consider some farm-level evidence relating to crop diversification in Bangladesh. We recently conducted a field survey on the 1985-86 crop year in two Bangladeshi villages: Ekdala in the north-western district of (greater) Rajshahi and South Rampur in the south-eastern district of Comilla. Both villages have a relatively long history of HYV technology adoption. South Rampur being in the laboratory area of the Bangladesh Academy of Rural Development (BARD), was one of the earliest to adopt HYVs. Ekdala was also one of the early adopters of the new technology in the region. However, the villages differ ecologically. Ekdala is located in the low rainfall area and is considered druought-prone while South Rampuri is in the high rainfall area and is flood-prone. The two villages differ in respect of access to irrigation. While South Rampur is completely irrigated Ekadal is only partially irrigated [Alauddin and Tisdell (1988a)].

In all 58 landowning farmers were interviewed from each of the two villages on the basis of stratified random sampling with each category of farmers (small, medium and large) have approximately the same proportionate representation as their respective total numbers in the aggregate number of farming households in the villages.

An analysis of the farm-level data indicates that the two villages exhibit very different cropping patterns. Ekdala has a more traditional cropping pattern. Apart from growing cereals (rice and wheat), a number of other crops are also grown. Prominent among these are sugarcane, pulses, jute and oilseeds. The category designated others, include such crops as banana and watermelon. Cereals occupy 65 per cent of gross cropped area. Overall cropping intensity is quite high (over 178 per cent) and is considerably in excess of the national figure of 150 per cent in recent years [Alauddin and Tisdell (1987)]. South Rampur on the other hand has a much more specialised cropping pattern in that rice is the only crop grown. Almost every plot of land is double cropped with rice. Intensity of cropping is significantly higher (nearly 200 per cent) than that in Ekdala. Furthermore, it is observed from the Ekdala data that farmers with access to irrigation allocate a significantly higher percentage of gross cropped area to rice and wheat than those without access to irrigation. The latter category of farmers allocate a significantly higher percentage of gross cropped area to non-cereals like sugarcane, pulses, oilseeds, watermelon. Irrigated farms cultivate land much more intensively than non-irrigated farms where cropping intensity is much lower (about 116 per cent) than the overall intensity of cropping for Bangladesh.

Thus the availability of irrigation has considerable impact on cropping pattern and intensity of cropping. A plot of land under irrigation is normally double cropped with rice (boro HYV rice followed by local or HYV aman rice). This, however, involves (rice) monoculture multiple cropping. This seems to be consistent with the the changes in cropping pattern for Bangladesh as whole. This trend is likely to have two harmful effects as noted by Hamid et al. (1978:40). First, it may affect soil fertility in future in that crop rotation required for maintaining soil fertility cannot be practised. Secondly, mere production of increased quantities of rice at the expense of other non-cereal food crops e.g., pulses, vegetables is unlikely to solve food deficit. The need to produce non-cereal food and vegetables with high protein content in order to overcome the general protein and nutrient deficiencies can hardly be overemphasized.

It would be useful to have data for Bangladesh indicating whether the number of strains or varieties for crops such as rice grown on farms is increasing or decreasing and have some information about trends in the total number of varieties available. It is possible that with the introduction of HYVs the number of available varieties at first increase and then decline. At the same time, the fundamental gene bank may be declining while the number of available strains or varieties is at first increasing. So a difficult measurement problem in relation to genetic diversity exists.

Only limited evidence is available from our survey areas of Ekdala and South Rampur. The farm-level data from Ekdala indicate that farmers primarily rely on two or three varieties of HYV rice. During the 1985-86 crop year, BR11 and China varieties constituted 82 per cent of the gross area planted to HYV rice. In South Rampur, farmers were found to allocate over 70 per cent of HYV rice area to four rice varieties: BR3 (21 per cent), BR11 (26 per cent), Paijam (13 per cent) and Taipei (10 per cent). Furthermore, the South Rampur Survey indicated that the number of rice varieties in use has fallen from about 12-15 in the pre-'Green Revolution' period to 7-10 in the post-'Green Revolution' phase. This seems to be supported by the Ekdala evidence.

7. PROBLEMS OF REDUCED GENETIC DIVERSITY OF CROPS: A SECULAR DECLINE IN AVAILABLE VARIETIES AND STRAINS

The discussion in Section 2, suggesting that the introduction of HYVs of crops permits individual farmers to increase their diversification of varieties of a crop grown, is based upon the premise that varieties in existence prior to the introduction of HYVs and the development of other improved varieties continue to be available. But in practice this assumption is likely to be violated in other than a short period of time. Improved varieties quite frequently drive existing varieties out of existence so that in the long-term, less choice of varieties may be available than prior to the introduction of HYVs [Cf. Plucknett et al. (1986) esp. pp.8-12]. Furthermore, the varieties which disappear may be those which provide the most valuable genetic building blocks for development of new varieties. Thus crop productivity may become dependent on limited number of varieties and the risk of production being unsustainable may rise considerably [Cf. Plucknett et al. (1986)].

It seems that new varieties of crops have a limited life on average. The World Conservation Strategy (WCS) document [IUCN (1980)] suggests that wheat and other cereal varieties in Europe and North America have a life-time of only 5-15 years. "This is because pests and diseases evolve new strains and overcome resistance; climates alter, soils vary; consumer demand change. Farmers and other crop-producers, therefore, cannot do without the reservoir of still-evolving possibilities available in the range of varieties of crops, domesticated animals, and their wild relations. The continued existence of wild and primitive varieties of the world's crop plants humanity's chief insurance against their destruction by the equivalents for those crops of chestnut blight and Dutch elm disease" [IUCN (1980), sec 3.3].

The WCS document goes on to point out how the bulk of Canadian wheat production now depends on four varieties and so does most of US potato production and provides other examples of growing agricultural dependence on narrower range of varieties. Furthermore, there appears to have been a rapid disappearance of primitive cultivars , for instance, the percentage of primitive cultivars in the Greek wheat crop fell from over 80 per cent in the 1930s to under 10 per cent by the 1970s and the absolute number of these declined quite considerably. [IUCN (1980:sec 3.4); Allen (1980:41)]. Such declines are claimed to be "typical of most crops in most countries" [IUCN (1980: sec 3.4)]. Thus while in the shorter-term new varieties may become available and increase the scope for reducing instability of production and income, for instance via diversification, in the long-term the opposite tendency may be present.

This raises a number of questions for economists. For instance, if varieties disappear is some market failure present and will the disappearance lead to a socially sub-optimal outcome? Is government intervention required to correct the situation? If so, what guidelines should be adopted in determining which crop varieties to preserve? What social mechanisms should be adopted to bring about the range of conservation of varieties required?

These are very difficult questions to answer, especially for an economist. As Alan Randall (1986:95) points out "the economic analyst lives rather high on the information food chain. He/she functions by using information about base line conditions and the consequences of change developed by practitioners of many other disciplines, and metabolizing it according to economic principles. When information about consequences is highly speculative (as it often is in preservation cases) the economist can do little to fill the information gap".

Nevertheless, economists can help identify possible sources of market failure (as well as political and administrative failure) and consider ways to analyse the problem of choosing which varieties to preserve. Basically the market failure problem appears to revolve around the inability of those preserving a species to capture all or a substantial amount of potential economic benefits from their action and the uncertainty of benefits and the length of time that may have to elapse before the variety preserved once again becomes of value. Failure to appropriate benefits is linked to externalities and lack of property rights in genetic material preserved. However, even if property rights happened to be granted, the transactions costs involved in enforcing those could be expected to be very high so it is likely that the owner of the rights would not find it worthwhile to preserve these. As Arrow (1965), and Arrow and Lind (1970) point out it may also be that individuals make an excessive private allowance for risk and uncertainty compared to a socially optimal allowance. In addition, private discounting of future returns may be excessive [Brown and Jackson (1986)].

Given uncertainty and irreversibility of variety loss or the considerable costs of re-establishing varieties once lost, then it is likely to be economic to try to maintain flexibility to some extent and preserve a wider range of varieties than otherwise [Krutilla (1967)]. To the extent, however, that genetic engineering is possible and becomes less costly, the reversibility question may become less relevant. Yet genetic engineering is still in its infancy and presumably the options for engineering depend upon the nature and diversity of the available gene bank. So for the time being, problems of reversibility remain relevant.

Despite the above, it is unlikely to be economic to conserve all varieties of crops. How then should one determine which varieties to conserve? Economists have most commonly suggested the following approaches to the problem of genetic diversity: (1) cost-benefit analysis (CBA) and (2) safe minimum standard (SMS). The first is most closely associated with Resources for the Future (RFF) [Smith and Krutilla (1979)] whereas the latter is associated with Ciriacy-Wantrap (1968) and with Bishop (1978). Basically, the difference between these two approaches revolves around how to deal with decision-making under uncertainty. The RFF approach is fundamentally an expected gain or utility approach whereas the SMS approach is minimax loss approach. But some other general approaches [e.g., Quiggan (1982)] have been proposed and have been reviewed by Chisholm (1988). Randall (1986) proposes that priorities be set using a combination of CBA and SMS criteria - a middle-ground position as he calls it. For those species (varieties) for which there is sufficient information to undertake CBA it should be applied, and SMS should be applied to those for which information is not sufficient for CBA. Basically the latter involves choosing the set of species or varieties to preserve which have the lowest costs associated with preservation. It is not possible to go into the benefits and drawbacks of the different approaches here. The intention is to bring attention to the issue generally.

8. CONCLUDING COMMENTS

The available evidence from Bangladesh points to a major decline in the relative variability of foodgrain yields following the introduction of new crop technology associated with the 'Green Revolution'. An analysis of mean yields and semi-variance data for Bangladesh indicates a strong shift downwards in the trend line of relative instability of crop yields about the mid-1960s. and a major alteration in trends with rates of increase in yield instability being lower after the mid-1960s. Factors which may be responsible for this phenomenon were discussed and particular attention was given to the diversification of crops and varieties of particular crops grown as a possible contributor. Our data from Bangladesh are inadequate at present to determine whether there is a more (or less) crop diversification following the 'Green Revolution'. While initially the advent of the new varieties would seem to expand the available choice of varieties and possibilities for crop diversification for farmers, this may not be so in the long-term. Some traditional varieties may be dominated <u>initially</u> by some favourable characteristics of new varieties. Consequently, these traditional varieties may disappear thereby reducing available genetic diversity and raising risks in the long run [Cf. Plucknett et al. (1986:Ch. 1)]. This raises a possible dilemma and a basic issue for policy - namely, what is the responsibility of governments to preserve genetic diversity and how should governments decide which varieties to preserve. Economists are divided in their advice to governments about the appropriate decision-making model to apply to such choice problems [cf. Randall (1986)].

REFERENCES

Alauddin, M. and Mujeri, M.K. (1986) "Growth and Changes in the Crop Sector of Bangladesh: A Review of Performance and Implications for Policies", **Scandinavian Journal of Development Alternatives**, 5(4), pp.109-125.

Alauddin, M. and Tisdell, C.A. (1986a) "Bangladeshi and International Agricultural Research: Administrative and Economic Issues", **Agricultural Administration**, 21(1), pp.1-20.

Alauddin, M. and Tisdell, C.A. (1986b) "Decomposition Methods, Agricultural Productivity Growth and Technological Change: A Critique Supported by Bangladeshi Data", **Oxford Bulletin of Economics and Statistics**, 48(4), pp.353-372.

Alauddin, M. and Tisdell, C.A. (1987) "Trends and Projections for Bangladeshi Food Production: An Alternative Viewpoint", **Food Policy**, 12(4), pp.318-331.

Alauddin, M. and Tisdell, C.A. (1988a) "Has the 'Green Revolution' Destabilized Food Production? Some Evidence from Bangladesh", **Developing Economies**, 26(3) [forthcoming].

Alauddin, M. and Tisdell, C.A. (1988b) "Impact of New Agricultural Technology: Data Analysis for Bangladesh and Its Districts", **Journal of Development Economics** [forthcoming].

Alauddin, M. and Tisdell, C.A. (1988c) "Patterns and Determinants of Adoption of High Yielding Varieties: Farm-Level Evidence from Bangladesh", **Pakistan Development Review** [forthcoming].

Allen, R. (1980) **How to Save the World**, London: Kogan Page.

Anderson, J.R., Dillon, J.L. and Hardakar, J.B. (1977) **Agricultural Decison Analysis**, Ames, Iowa: Iowa University Press.

Arrow, K.J. (1965) **Aspects of the Theory of Risk-Bearing**, Helsinki: The Academic Bookstore.

Arrow, K.J. and Lind, R.C. (1970) "Uncertainty and Evaluation of Public Investment Decision," **American Economic Review**, 60, pp.364-378.

Bishop, R. (1978) "Endangered Species Uncertainty: The Economics of a Safe Minimum Standard", **American Journal of Agricultural Economics**, 60(1), pp.10-18.

Boyce, J.K. (1987) "Trends and Projections for Bangladeshi Food Production: Rejoinder to M. Alauddin and C. Tisdell", **Food Policy**, 12(4), pp.332-336.

Brown, C.V. and Jackson, P.M. (1986) **Public Sector Economics**, Third Edition, Oxford: Basil Blackwell.

Chisholm, A.H. (1988) "Uncertainty, Irreversibility and Rational Choice", in C.A. Tisdell and P. Maitra (eds.) **Technological Change, Development and the Environment: Socio-Economic Perspectives**, London: Croom Helm, pp.173-216 [forthcoming].

Ciriacy-Wantrup, S.V. (1968) **Resource Conservation: Economics and Politics**, Division of Agricultural Services, Berkeley and Los Angeles: University of California.

Conway, G. (1986) **Agroecosystem Analysis for Research and Development**, Bangkok: Winrock International.

Dantwala, M.L. (1985) "Technology, Growth and Equity in Agriculture" in J.W. Mellor and G.M. Desai (eds.) **Agricultural Change and Rural Poverty: Variations of a Theme by Dharm Narain**, Baltimore, Md.: Johns and Hopkins University, pp.110-123.

Evans, L.T. (1986) "Yield Variability in Cereals: Concluding Assessment", in P.B.R. Hazell (ed.) **Summary Proceedings of a Workshop on Cereal Yield Variability**, Washington, D.C.: International Food Policy Research Institute, pp.1-12.

Evenson, R.E., O'Toole, J.C., Herdt, R.W., Coffman, W.R., and Kaufman, H.E. (1979) "Risk and Uncertainty as Factors of Crop Improvement Research", in J.A. Roumasset, J.M. Boussard and I. Singh (eds.) **Risk, Uncertainty and Agricultural Development**, Laguna, Philippines: Southeast Asian Regional Center for Graduate Study and Research in Agriculture and the Agricultural Development Council, pp.249-264.

Gill, G.J. (1983) "Agricultural Research in Bangladesh: Costs and Returns", Dhaka: Bangladesh Agricultural Research Council (mimeo.)

Government of India (1982) **Economic Survey 1981-82**, New Delhi: Government of India, Ministry of Finance.

Hamid, M.A., Saha, S.K., Rahman, M.A. and Khan, A.J. (1978) **Irrigation Technologies in Bangladesh: A Study in Some Selected Areas**, Department of Economics: Rajshahi University, Bangladesh.

Hazell, P.B.R. (1982) **Instability in Indian Foodgrain Production**, Research Report No. 30, Washington, D.C.: International Food Policy Research Institute.

Hazell, P.B.R. (1985) "Sources of Increased Variability in World Cereal Production Since the 1960s", **Journal of Agricultural Economics**, 36(2), pp.145-159.

Hazell, P.B.R. (1986) "Introduction", P.B.R. Hazell (ed.) **Summary Proceedings of a Workshop on Cereal Yield Variability**, Washington, D.C.: International Food Policy Research Institute, pp.15-46.

Herdt, R.W. and Capule, C. (1983) **Adoption, Spread and Production Impact of Modern Rice Varieties in Asia**, Los Baños, Philippines: International Rice Research Institute.

IUCN (1980) **World Conservation Strategy: Living Resources Conservation for Sustainable Development**, Glands, Switzerland: International Union for the Conservation of Nature and Natural Resources.

Jain, H.K., Dagg, M. and Taylor, T.A. (1986) "Yield Variability and the Transition of the New Technology" in P.B.R. Hazell (ed.) **Summary Proceedings of a Workshop on Cereal Yield Variability**, Washington, D.C.: International Food Policy Research Institute, pp.77-85.

Krutilla, J.V. (1967) "Conservation Reconsidered", **American Economic Review**, 57, pp.777-786.

Markowitz, H.M. (1959) **Portfolio Selection - Efficient Diversification of Investments**, Cowles Foundation Monograph No. 16, New York: John Wiley and Sons Inc.

Mehra, S. (1981) **Instability in the Indian Agriculture in the Context of the New Technology**, Research Report No. 25, Washington, D.C.: International Food Policy Research Institute.

Parthasarathy, G. (1984) "Growth Rates and Fluctuations of Agricultural Production: A District-Wise Analysis in Andhra Pradesh", **Economic and Political Weekly** 19(26), pp.A74-A84.

Pray, C.E. and Anderson, J.R. (1985) **Bangladesh and the CGIAR Centers: A Study of their Collaboration in Agricultural Research**, CGIAR Study Paper No. 8, Washington, D.C.: World Bank.

Plucknett, D.P., Smith, N.J.H, Williams, J.J. and Anishety, N.M. (1986) **Gene Bank and the World's Food Supply**, Princeton, N.J.: Princeton University Press.

Quiggan, J. (1982) "A Theory of Anticipated Utility", **Journal of Economic Behaviour and Organization**, 3, pp.323-343.

Randall, A. (1986) "Human Preferences, Economics and Preferences and the Preservation of Species", in B.G. Norton (ed.) **The Preservation of Species: The Value of Biological Diversity**, Priceton, N.J.: Princeton University Press.

Ray, S.K. (1983) "An Empirical Investigation into the Nature and Causes for Growth and Instability in Indian Agriculture: 1950-1980", **Indian Journal of Agricultural Economics** 38(4), pp.459-474.

Sarma, J.S. and Roy, S. (1979) **Two Analyses of Indian Foodgrain Production and Consumption Data**", Research Report No. 12, Washington, D.C.: International Food Policy Research Institute.

Savant, S.D. (1983) "Investigation of the Hypothesis of Deceleration in Indian Agriculture", **Indian Journal of Agricultural Economics** 38(4), pp.475-496.

Smith, V.K and Krutilla, J.V. (1979) "Endangered Species, Irreversibility and Uncertainty: A Comment", **American Journal of Agricultural Economics**, 61, pp. 371-375.

Tisdell, C.A. (1962) "Decision Making and the Probability of Loss", **Australian Economic Papers**, 1(1), pp.109-118.

Tisdell, C.A. (1983) "The Optimal Choice of a Variety of a Species for Variable Environmental Conditions", **Journal of Agricultural Economics**, 34(2), pp.175-185.

Table 1

Mean Values, Lower Semi-Variance, Coefficient of Semi Variation of Yield of all Foodgrains, and Probability of Yield Falling below a 'Disaster Level': Bangladesh, 1947-48 to 1984-85

Year	Index	Mean Yield	Lower Semi-Variance	Coefficient of Semivariation	PROB50
1947	70.74				
1948	78.79				
1949	75.44				
1950	73.29				
1951	69.23				
1952	70.50	73.231	5.441	3.362	.00406
1953	74.80	73.195	5.203	3.291	.00389
1954	71.06	73.304	6.807	3.729	.00506
1955	65.40	74.332	6.807	3.729	.00478
1956	81.34	75.853	10.874	4.651	.00706
1957	74.96	76.925	12.396	4.946	.00763
1958	70.34	79.032	15.357	5.495	.00854
1959	79.98	80.452	29.751	7.539	.01550
1960	86.75	82.096	42.678	8.652	.02060
1961	90.02	83.783	22.724	6.149	.01020
1962	81.02	84.761	29.112	6.913	.01260
1963	93.68	86.492	34.836	7.488	.01400
1964	90.42	88.512	9.345	3.686	.00347
1965	89.14	89.374	12.327	4.120	.00443
1966	83.96	89.222	11.317	3.967	.00409
1967	92.09	88.599	2.946	2.060	.00109
1968	94.00	89.939	8.686	3.420	.00305
1969	92.57	89.787	8.686	3.420	.00307
1970	89.46	90.540	8.686	3.420	.00299
1971	85.08	91.098	7.882	3.287	.00266
1972	83.17	93.104	16.185	4.517	.00507
1973	95.75	94.233	19.108	4.891	.00576
1974	92.01	94.958	17.482	4.727	.00514
1975	98.70	96.493	27.217	5.789	.00759
1976	95.28	97.977	33.891	6.450	.00900
1977	106.03	100.230	35.737	6.429	.00883
1978	104.52	102.953	14.167	3.891	.00322
1979	101.97	104.944	25.196	5.096	.00540
1980	109.46				
1981	105.79				
1982	109.85				
1983	113.12				
1984	117.66				

Notes: 1947 means 1947-48 (July 1947 to June 1948) etc. Index numbers are constructed with the average of the triennium ending 1977-78=100. Mean values are 11 yearly moving averages of the index numbers. Coefficeint of semi variation is the ratio of the sqaure root of lower semi-variance to the corresponding mean expressed in percentage terms. PROB50 is probability of yield falling 50 per cent or more below the first 11 yearly average mean yield.

Source: Based on Alauddin and Tisdell (1988a: Table 1).

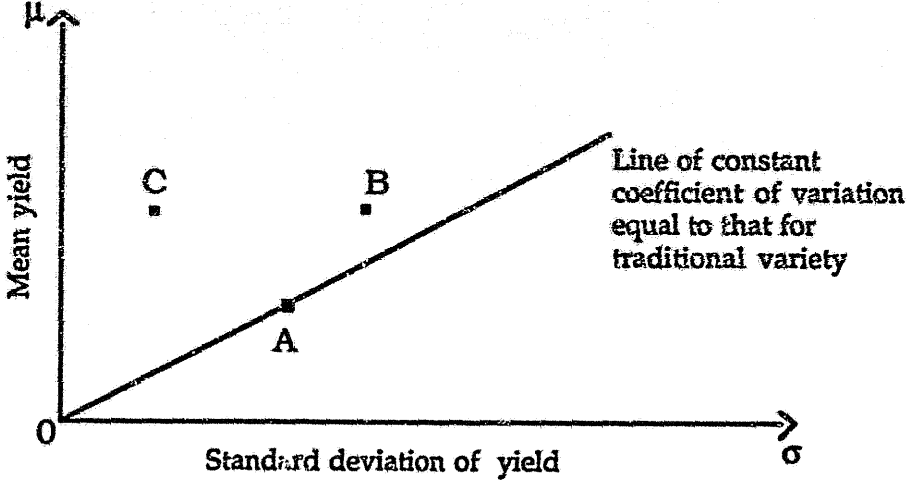

Figure 1: HYVs often appear to have a lower coefficient of variation of yield than traditional varieties and sometimes have a lower standard deviation and a higher mean yield.

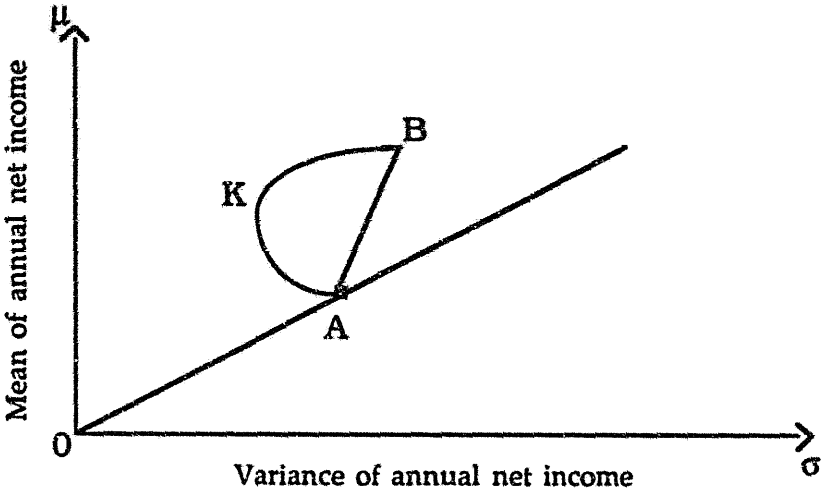

Figure 2

Figure 2: As the efficiency loci indicate, the availability of HYVs may permit diversification of variety of crops grown and reduce relative variability of yields on farms at least in the short run.

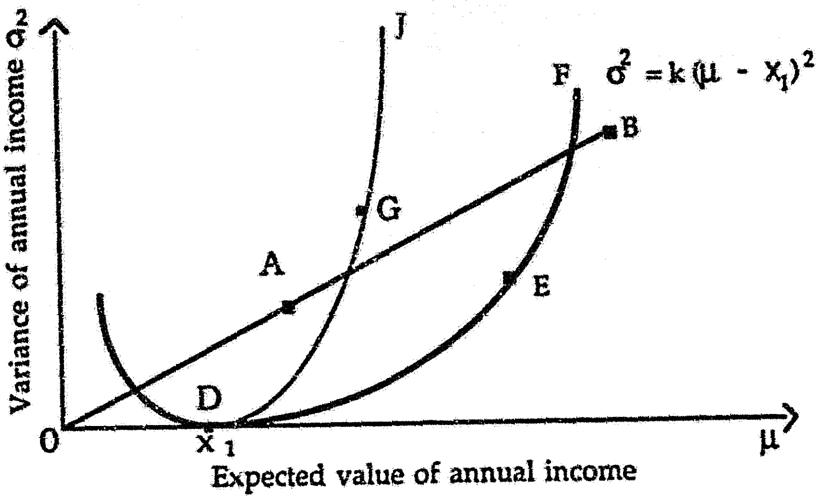

Figure 3: Curves based on Cherbychev's inequality (and a modification to it based on lower semi-variance) indicating combinations which satisfy and which do not satisfy 'safety first' requirements.

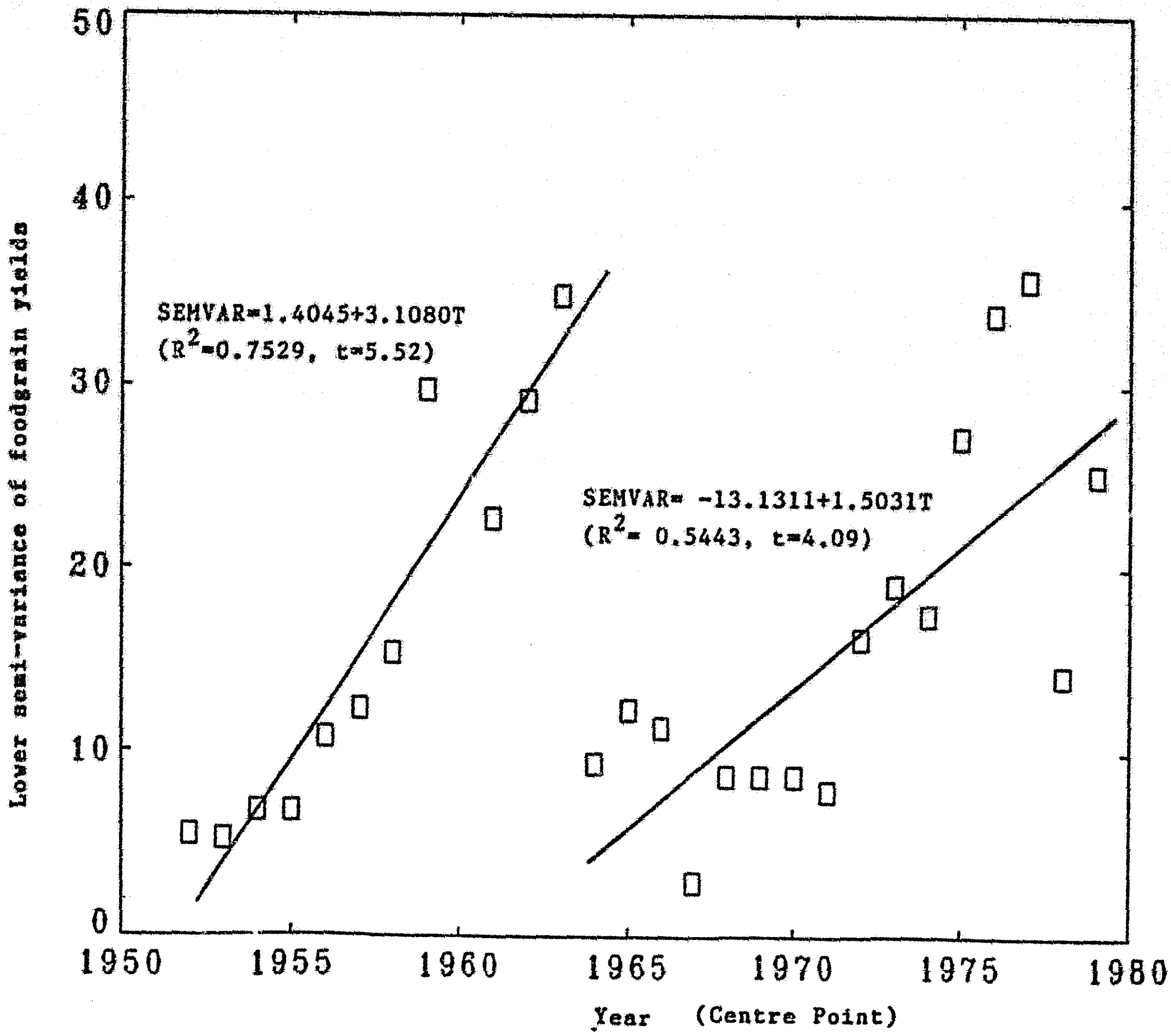

Figure 4: Lower semi-variance of foodgrain yields, Bangladesh based on 11 year moving averages 1947-48 to 1984-85. Notice the shift downward in the apparent trend function about the mid-1960s.

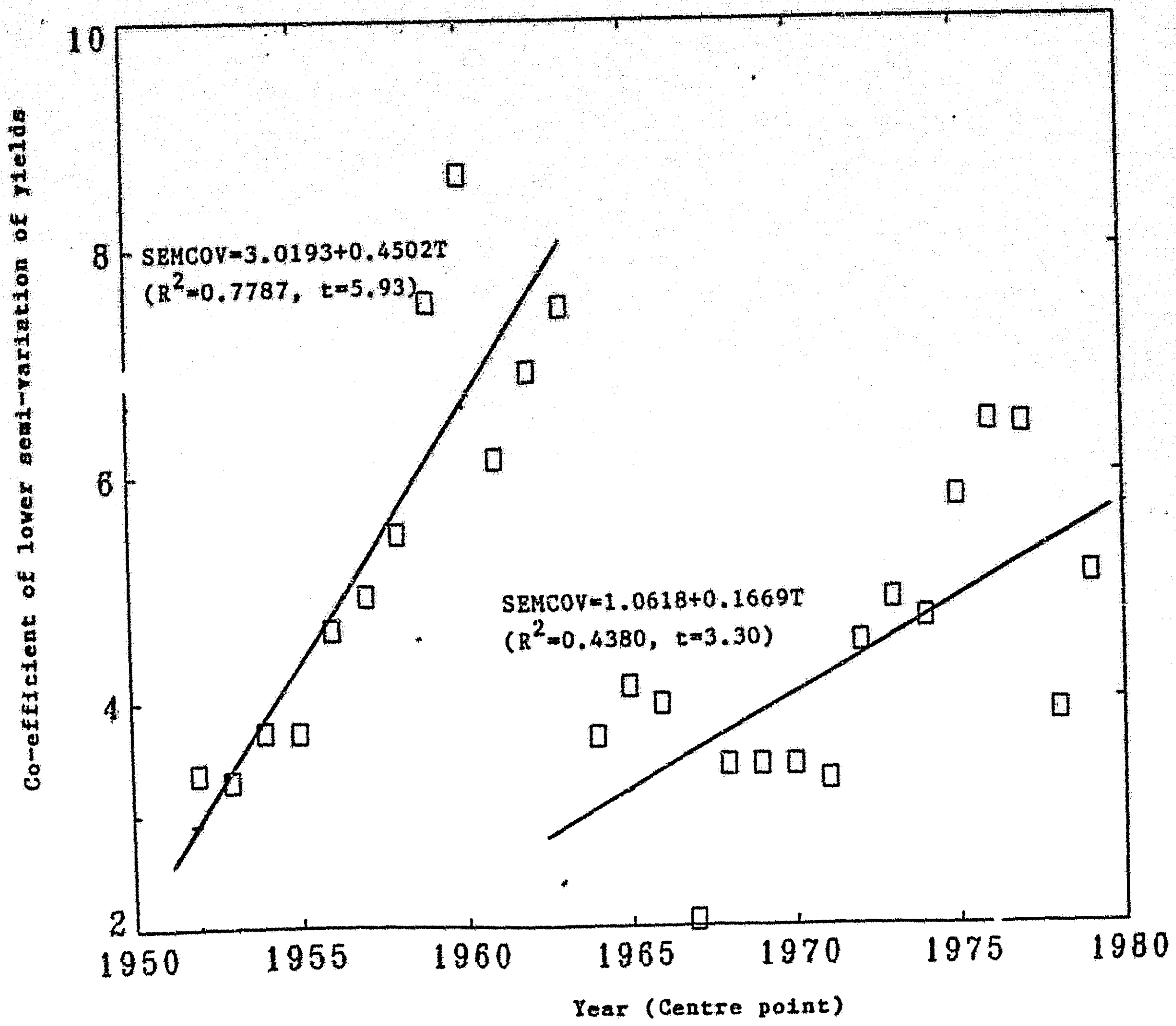

Figure 5: Coefficient of lower semi-variation of foodgrain yields, Bangladesh, based on 11 year moving averages 1947-48 to 1984-85. Notice the strong downward shift in the apparent trend function about the mid-1960s and the much slower rate of increase of the coefficient in the second phase.

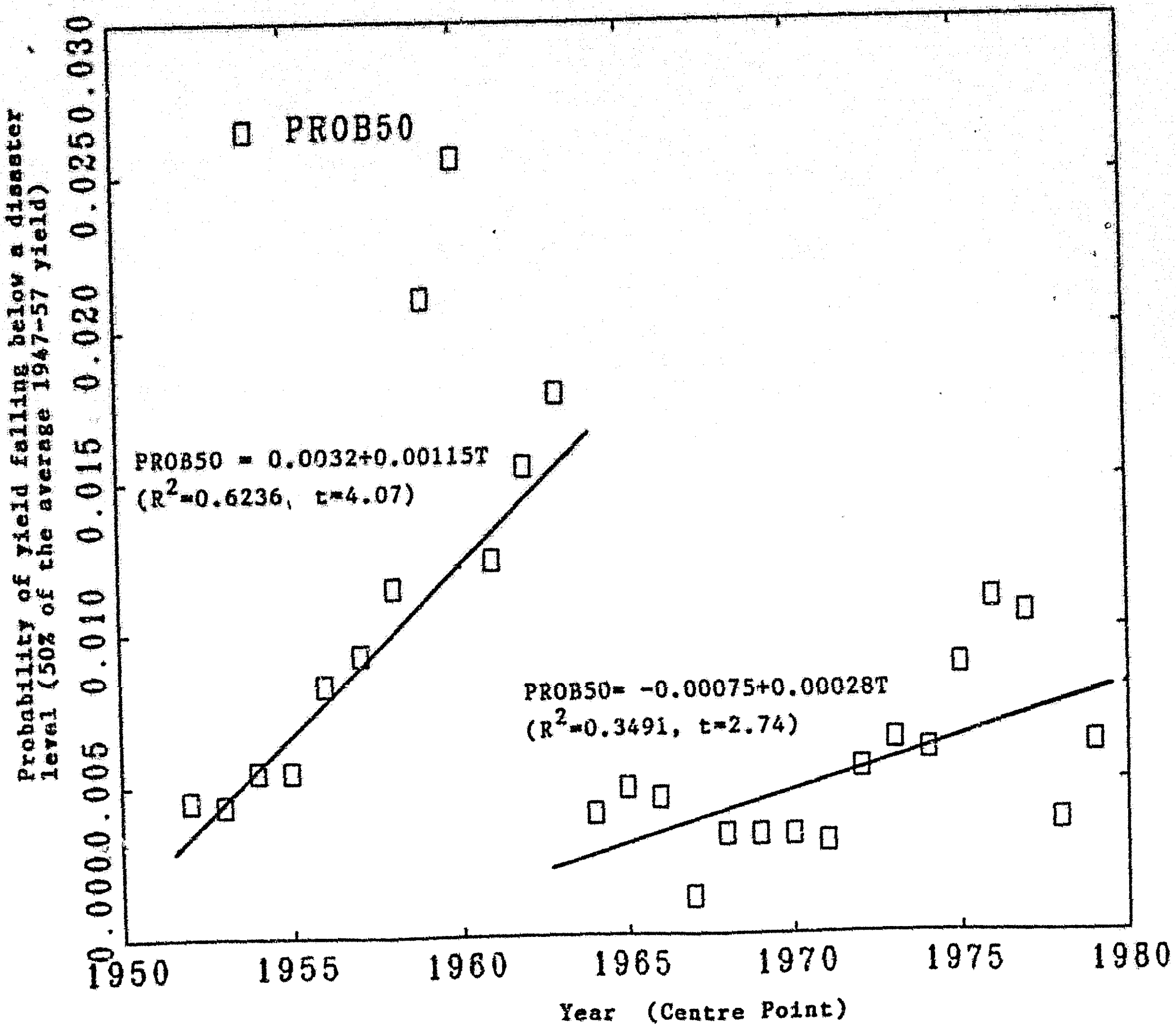

Figure 6: Probability of foodgrain yield, Bangladesh falling below a disaster level (arbitrarily defined as 50 per cent of the average yield 1947-57) for Bangladesh based on 11 year moving averages 1947-48 to 1984-85.

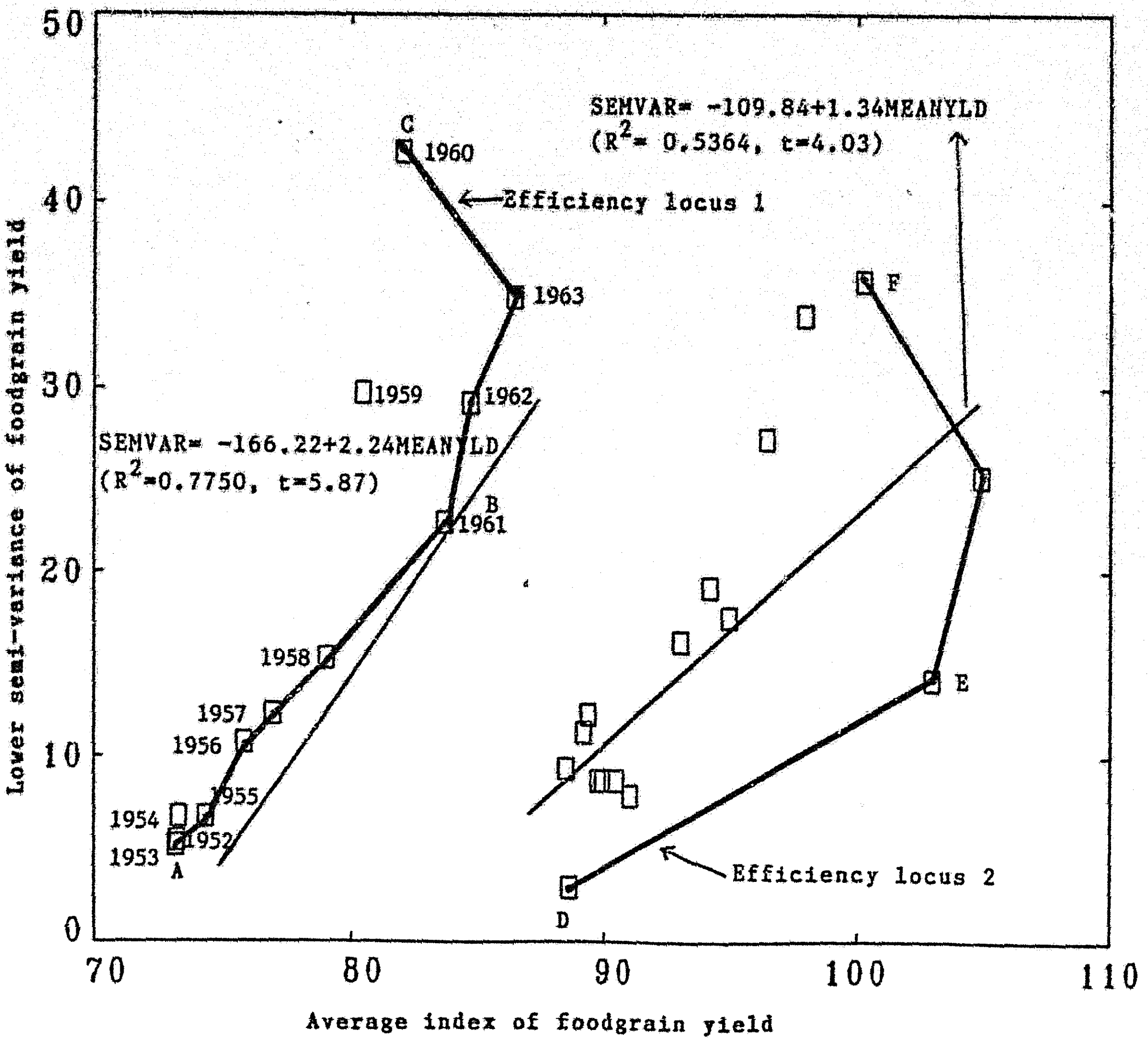

Figure 7: Scatter of lower semi-variance of foodgrain yield and mean value of foodgrain yield based on 11 year moving averages, Bangladesh, 1947-48 to 1984-85. Note the apparent shift in scatter after 1963 (centre point) and, the strong shift rightward in the 'hypothetical' efficiency locus.