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TECHNOLOGICAL DIFFUSION : A STUDY BASED ON INDIAN AGRICULTURE

INDRANI GHOSH

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Abstract of the Paper

Since the mid-60s the high-yielding variety (HYV) technology or the 'new technology' has been introduced to the Indian agriculture. This technology involves the use of an input package viz. HYV seeds, fertilizer, pesticide and water. Initially it was introduced to a few regions and then it diffused to other regions of the country. An attempt has been made in this paper to study the pattern and rate of diffusion of this technology.

At the outset, a model has been constructed to analyse the pattern of diffusion of the HYV technology in the context of Indian agriculture. To begin with, the analysis of the behaviour of an individual farmer is considered. Then we analyse the aggregate behaviour of the farmers with respect to the diffusion of the HYV technology. However, from the analyses of both the individual and aggregate behaviour of the farmers we get that the diffusion path followed by the HYV technology can best be described by the logistic function.

Then, to study the pattern of diffusion of HYV technology in the context of Indian agriculture, this model is used. We have estimated both the rate of diffusion and the asymptotic value of the diffusion path i.e. the ceiling of HYV technology. However, we have considered here the case of wheat only. For this purpose relevant data relating to the major

TECHNOLOGICAL DIFFUSION : A STUDY BASED ON INDIAN AGRICULTURE

Indrani Ghosh

I. INTRODUCTION

Appreciation of the importance of agriculture in the process of development has been greatly enhanced by the "Green Revolution", that has begun to transform the economies of various countries of the world. Even for countries with high population densities such as India, the recent advances in agricultural production have raised new hopes. Even with traditional methods, agricultural production is a complex phenomenon, where scarce resources are distributed over time and crops. The farmer's choices involve different activities that represent the performance of various tasks. These choices are expanded by the technological change in the agricultural sector.

From the beginning of the Third Plan, some improvement in the general level of agricultural technology was observed in India. In the context of agriculture, "technological change" refers to the use of modern inputs e.g. high-yielding varieties (HYV) of seeds, chemical fertilisers, tractors, pump-sets etc. in crop production. Since the middle of the decade of 1960's, the high-yielding variety (HYV) technology, which involves an input package viz. HYV seeds, fertilisers, pesticides and irrigation brought a remarkable change in the agricultural situation of India. This technology is expected to play a major role in the achievement of food production target and consequently in the drive for making the country self-sufficient in food supply. But this new technology has not affected the different regions of our country uniformly. A few regions led in their introduction and then it was diffused to other regions of the country at different rates. Since the increase in productivity depends not only on the potential gains in yield from high-yielding varieties under ideal conditions but also on the actual diffusion to farmers' fields, it is important to study the pattern and rate of diffusion of this technology.

Let us now make a review of some of the research work done related to the area of our interest. At first we discuss about those writings which have similar methodological issues like ours.

The pioneering econometric work on technological diffusion has been made by Griliches (1957). This work refers to the agriculture of the United States. His study revealed that the general pattern of diffusion of hybrid seeds in various areas of U.S.A. followed an s-shaped growth curve. Because of this reason, he fitted the logistic growth function to the observed data. By using the estimated parameters of the logistic function, he derived for the different regions of U.S.A., the date of the first introduction of hybrid seeds, the rate of acceptance of hybrid seeds and the extent to which traditional varieties will be replaced by the hybrid seeds.

He assumed that the behaviour of both farmers and hybrid seed producers were based on expectation of profit. The time-lag between the availability and the first introduction of the hybrid seed into a particular region could be explained on the basis of varying profitability of entry, according to him. He argues that, the differences in the rate of acceptance of hybrid seeds and the differences regarding the extent to which hybrid seeds would be adopted in the long run by the various regions of U.S.A., are also due to differences in the profitability of the shift from the traditional to the hybrid varieties. In areas where the profits to be realized from the shift were large and unambiguous, the transition was exceedingly rapid. Later on Robert Dixon (1980) made an attempt to revise Griliches's work by using more recent data and improved estimating techniques. As it was found from Griliches's work that the diffusion curves of hybrid seeds for different regions were s-shaped but skewed rather than symmetrical for many regions, Dixon has used the gompertz function instead of the logistic function. Dixon's analysis, with the help of the gompertz function, also leads to the same conclusion as was reached by Griliches viz. that profitability is the major factor explaining the differences in the rate at which various states of U.S.A. adopted hybrid seeds.

Shetty (1966) carried out an early study on technological diffusion in the context of Indian agriculture. He tried to find out how rapidly the use of an innovation spreads from one farm to another and what factors determine the rate of diffusion of such an innovation. He considered the diffusion of improved seeds along with the diffusion of two other innovations viz. the application of chemical fertilizers and the Japanese method of paddy cultivation.

This study shows that the rate of diffusion tended to be faster for innovations that are more profitable and the two factors viz. larger size of the land holding ownership of the operational land and possession of more liquid assets help to increase the farmer's propensity to innovate. Further, this study also shows that educational level or age of the farmer has no effect on the diffusion process.

Another interesting study on the adoption of the HYV technology by the various classes of farmers was carried out by Rahman (1981). This study was based on Bangladesh agriculture. The major findings of this study were as follows :

(i) The criterion of higher profitability of the new technology did not help much in explaining the differences in the rate of adoption of this new technology. (ii) The new technology is capital-intensive. (iii) This technology requires more of both labour and capital than the traditional technology and (iv) Lack of own resources and inadequate access to cheap sources of credit and inputs by the small farmers act as a constraint on the adoption of the new technology at a higher rate.

There exist a number of other studies which are different from ours with respect to methodological issues but dealt with different aspects of the HYV technology. In this connection we may refer to the study by Raju (1975). He has studied the behaviour of the small farmers in adopting the new technology.

Another study on similar lines was made by Subrahmanyam (1975). In this study the author tried to determine how far credit would help the small farmer in the adoption of new high yielding varieties of paddy. Some authors have studied the effect of different factors on the production of HYV crops viz. Singh and Goel (1976) have studied the impact of increase in the prices of fertilizers on the production and profitability of HYV rice and wheat; Bhagat (1983) analysed the effects of economic, socio-cultural and demographic factors on the adoption of improved agricultural practices in tribal Bihar and Ballabh and Sharma (1987) observed the difference in the rate of adoption of HYV wheat and paddy because of the impact of flood.

There are also studies on the impact of HYV technology. For example, Ghosh (1981) has studied the impact of the HYV technology on land holdings through changes in the lease market.

Apart from these studies, a number of studies have been carried out on the different aspects of the HYV technology in Indian agriculture. We do not mean to present a review of all this literature within the limited scope of this paper. However, all these studies indicate that there is need for further research on the pattern of diffusion of the HYV technology in the field of Indian agriculture.

II. THE MODEL

In this section we describe a model constructed to analyse the pattern of diffusion of the high-yielding variety (HYV) technology in the context of Indian agriculture. We begin with an analysis of the behaviour of an individual farmer. For this purpose, let us make the following assumptions :

(i) The farmer possesses a fixed amount of land which is entirely cultivated in every year and he does not lease in or lease out land;

(ii) the farmer cultivates only one type of crop on his land and

(iii) the farmer is already familiar with the HYV technology. (Hence we assume that some HYV technology is already in use).

To analyse the pattern of diffusion of HYV technology, we take the help of the model constructed by Stoneman (1981) with respect to technological diffusion in the sphere of industry.

The level of use of the HYV technology will be determined by the farmer with a choice between the HYV and traditional technologies. Moreover, the farmer will learn over time about the characteristics of the HYV technology and, therefore, the farmer will change the level of use of the HYV technology accordingly. Finally, the change in the level of use of the HYV technology will involve some adjustment cost. Therefore, the diffusion path for the HYV technology will be the result of the interaction of the choice between the technologies, learning mechanism and the cost of adjustment.

At first let us consider the long-run situation. Suppose that the farmer (i-th farmer) faces a choice between the HYV and the traditional technology and he cultivates his land with the two technologies in the proportion $\alpha_i : (1 - \alpha_i)$. Also, suppose that the proportion of area cultivated by HYV technology when the diffusion is complete be α_i^*. To determine this desired level of use of the HYV technology (α_i^*), the objective of the farmer is profit maximisation subject to minimum risk. Therefore, utility derived from the use of the HYV technology is positively related with the expected profit and negatively with the variance of the profit. Hence the behaviour of the farmer can be described by the mean-variance approach to technique choice. However, to determine the level of use of the HYV technology we are not considering the supply side factors in this exercise.

Let us assume that the yield of the two technologies - HYV and traditional are approximately normally distributed independent of each other as follows :

Yield of HYV : $X_{ni} \sim N(\mu_{ni}^*, \sigma_{ni}^{2*})$

Yield of tradi-nal variety : $X_{oi} \sim N(\mu_{oi}, \sigma_{oi}^2)$

Now, generally market price of any agricultural product remains the same, irrespective of differentiation in the production technologies. Moreover, it is assumed that the market price of the crop remains constant over time. Let us denote this market price of the crop by P. (It may change over time because of factors other than HYV technology, for example, changes in the prices of other commodities etc. Therefore, those factors will remain exogeneous to our model.) Let us define 'C_i' as the cost of cultivation of the crop per unit area for the i-th farmer. The farmer will choose 'α_i' so as to maximise profit per unit of the cropped area, as follows :

$$\pi_i = [\alpha_i X_{ni} + (1 - \alpha_i) X_{oi}] P - C_i; \; 0 \leq \alpha_i \leq 1.$$

Since the absolute values of X_{ni} and X_{oi} are unknown (only their distributions are known) therefore, we can derive only the expected profit. It is easy to see that :

$$E(\pi_i) = [\alpha_i \mu_{ni}^* + (1 - \alpha_i) \mu_{oi}] P - C_i \; ..... \; (1)$$

and Var $(\pi_i) = W_i = P^2 [\alpha_i^2 \sigma_{ni}^{2*} + (1 - \alpha_i)^2 \sigma_{oi}^2]$ ..(2)

We have already assumed that the farmers' utility (U_i) varies positively with $E(\pi_i)$ and negatively with Var (π_i). Specifically let us assume,

$$U_i = aZ_i - \frac{b}{2} W_i \; ...... \; (3); \; a > 0, \; b > 0$$

Let us assume a = 1 (without a loss of generality). Now, the farmer will choose that value of α_i' as optimium which maximises (3).

Substituting Z_i and W_i from (1) and (2) respectively into (3) we obtain :

$$U_i = [\alpha_i \mu_{ni}^* + (1-\alpha_i)\mu_{oi}] P - C_i - \frac{b}{2} p^2 [\alpha_i^2 \sigma_{ni}^{*2} + (1-\alpha_i)^2 \sigma_{oi}^2] \quad \ldots (4)$$

By using the first-order condition of maximisation from (4) we get :

$$P(\mu_{ni}^* - \mu_{oi}) - bp^2 \alpha_i (\sigma_{ni}^{*2} + \sigma_{oi}^2) + bp^2 \sigma_{oi}^2 - \frac{\partial C_i}{\partial \alpha_i} = 0 \quad \ldots (5)$$

If no additional expenditure is required for the HYV technology, then the cost of cultivation per unit of the cropped area will remain the same as before. Therefore, then $\frac{\partial C_i}{\partial \alpha_i} = 0$.

Now eqn. (5) becomes :

$$P(\mu_{ni}^* - \mu_{oi}) - bp^2 \alpha_i (\sigma_{ni}^{*2} + \sigma_{oi}^2) + bp^2 \sigma_{oi}^2 = 0$$

From this we have :

$$\alpha_i = \frac{(\mu_{ni}^* - \mu_{oi}) + bp \sigma_{oi}^2}{bp(\sigma_{ni}^{*2} + \sigma_{oi}^2)} = \alpha_i^*$$

Here, α_i^* is defined as that level of α_i' that would be desired if the HYV technology involves no additional cost of cultivation.

The farmer will not reach the long-run ceiling position instantly. This will be the result of the short-run experiences. In the short-run in each time-point the farmer's decision will be guided by the experience of the past periods. Let us now, describe the short-run situation.

Suppose in time period 't' the farmer cultivates his land with the HYV and traditional technologies in the proportion α_{it} : $(1 - \alpha_{it})$. Anticipated yields of the HYV technology at time period 't' is approximately normally distributed as follows :

$$\text{Yield of HYV : } X_{nit} \sim N(\mu_{nit}, \sigma^2_{nit})$$

Yield of the traditional technology is assumed to be known, since it is used for a long time and the distribution of the yield of this traditional technology remains the same, independent of time. Therefore, the yield of the traditional technology is distributed normally as already stated in the long-run situation i.e.

$$\text{Yield of traditional technology : } X_{oit} \sim N(\mu_{oi}, \sigma^2_{oi})$$

Suppose, cost of cultivation per unit area in period 't' is C_{it}.

$\therefore$ In the short-run profit becomes :

$$\pi_{it} = [\alpha_{it} X_{nit} + (1-\alpha_{it}) X_{oit}] P - C_{it}; \quad 0 \leq \alpha_{it} \leq 1.$$

$$E(\pi_{it}) = [\alpha_{it}\mu_{nit} + (1-\alpha_{it})\mu_{oi}] P - C_{it}$$

and $\operatorname{var}(\pi_{it}) = P^2 [\alpha_{it}^2 \sigma_{nit}^2 + (1-\alpha_{it})^2 \sigma_{oi}^2]$

Therefore the utility fn., in the short-run becomes :

$$U_{it} = [\alpha_{it}\mu_{nit} + (1-\alpha_{it})\mu_{oi}] P - C_{it} - \frac{b}{2} P^2 [\alpha_{it}\sigma_{nit}^2 + (1-\alpha_{it})^2 \sigma_{oi}^2] \quad \ldots\ldots\ldots (7)$$

By using the first-order condition of maximisation and assuming that no additional cost is required for HYV cultivation from (7) we have :

$$\alpha_{it} = \frac{(\mu_{nit} - \mu_{oi}) + bP\sigma_{oi}^2}{bP(\sigma_{nit}^2 + \sigma_{oi}^2)} = \alpha_{it}^*$$

$\therefore$ α_{it}^* represents the desired level of use of HYV technology in the short-run.

We have stated that, the farmer's decision in each time-point will be guided by the experience of the past periods. Therefore, in time-period 't+1', the farmer's anticipation regarding the yield of the HYV technology will depend on the experience of period 't'. The behaviour of the farmer in this respect can be described by the Bayesian way of learning. The farmer will learn over time about the return available from and risk involved in the use of the HYV technology. As time proceeds, the farmer will gain experience and so, he will change his anticipation regarding the yield from the HYV technology. This change in anticipation will lead to changes in both α_{it} and α_{it}^{*}. In this way the farmer will move towards the true estimate of the yield of the HYV technology and then will establish the long-run post-diffusion levels of use of this technology i.e. α_{i}^{*}.

Let us now describe the Bayesian learning mechanism. Suppose that the true yield of the HYV technology is normally distributed as $N(\mu_{ni}^{*}, \sigma_{ni}^{2*})$ and constant over time. But the farmer does not know μ_{ni}^{*}, only σ_{ni}^{2*} is known. The farmer holds a prior distribution on the mean yield of the new technology at time 't', that is also normally distributed as $N(\mu_{nit}, Z_{it})$. Therefore, by using the theorem of compound normal distribution[1] we find the yield of the HYV technology as anticipated by the farmer will be distributed normally as $N(\mu_{nit}, \sigma_{nit}^{2})$ where

$$\sigma_{nit}^{2} = \sigma_{ni}^{2*} + Z_{it} \qquad \text{...... (9)}$$

Now, suppose that in time period 't' actual yield of the HYV technology experienced by the farmer is 'X_{it}'. Therefore, by Bayes Theorem[2], the posterior density of the average yield is $N(\mu_{nit+1}, Z_{it+1})$ where

$$\mu_{nit+1} = \frac{X_{it} Z_{it} + \sigma_{ni}^{2*} \mu_{nit}}{Z_{it} + \sigma_{ni}^{2*}} \qquad \text{...... (10)}$$

and

$$Z_{it+1} = \frac{\sigma_{ni}^{2*} Z_{it}}{\sigma_{ni}^{2*} + Z_{it}} \qquad \text{...... (11)}$$

Now solving (11) we have :

$$Z_{it} = \frac{Z_{oi}\,\sigma^{2*}_{ni}}{\sigma^{2*}_{ni} + tZ_{oi}} \quad \text{where } Z_{it} = Z_{oi} \text{ for } t = 0.$$

(Derivation is presented in appendix - I, A).

$\therefore$ From (9) we get :

$$\sigma^{2}_{nit} = \sigma^{2*}_{ni} + Z_{it}$$

$$= \sigma^{2*}_{ni} + \frac{Z_{oi}\,\sigma^{2*}_{ni}}{\sigma^{2*}_{ni} + tZ_{oi}} \quad \text{.........} \quad (12)$$

$$\therefore \lim_{t \to \infty} \sigma^{2}_{nit} = \sigma^{2*}_{ni} \quad \text{.........} \quad (13)$$

Again, from eqn.(10) we have :

$$\mu_{nit} = \frac{X_{it-1}\,Z_{it-1} + \sigma^{2*}_{ni}\,\mu_{ni\,t-1}}{Z_{it-1} + \sigma^{2*}_{ni}}$$

$$\therefore E(\mu_{nit}) = \frac{E(X_{it-1}) + \dfrac{\sigma^{2*}_{ni}\,\mu_{nit-1}}{Z_{it-1}}}{1 + \dfrac{\sigma^{2*}_{ni}}{Z_{it-1}}}$$

$$= \frac{tZ_{oi}\,\mu^{*}_{ni} + \mu_{noi}\,\sigma^{2*}_{ni}}{tZ_{oi} + \sigma^{2*}_{ni}}$$

$$= \mu_{nit} \quad \text{.........} \quad (14)$$

(Derivation is presented in appendix - I, B).

μ_{nit} is now redefined as the expected value of the anticipated mean yield in time 't'.

From eqn. (14), now we have :

$$\mu_{nit} = \frac{\mu_{ni}^{*}}{1 + t^{-1}_{\sigma^{2*}_{ni}}} \; ; \; \frac{\mu_{noi} \; \sigma^{2*}_{ni}}{t\sigma_{oi} + \sigma^{2*}_{ni}}$$

$$\underset{t \to \infty}{Lt} \mu_{nit} = \mu^{*}_{ni} \qquad \text{.......... (15)}$$

Now from eqn. (8), we have

$$\alpha^{*}_{it} = \frac{(\mu_{nit} - \mu_{oi}) + bP\sigma^{2}_{oi}}{bP(\sigma^{2}_{nit} + \sigma^{2}_{oi})}$$

∴ Substituting from eqns. (13) and (15), we have :

$$\underset{t \to \infty}{Lt} \alpha^{*}_{it} = \frac{(\mu^{*}_{ni} - \mu_{oi}) + bP\sigma^{2}_{oi}}{bP(\sigma^{2*}_{ni} + \sigma^{2}_{oi})} = \alpha^{*}_{i} \; \text{[From eqn.(6)]}$$

Therefore, we find that as the farmer gains experiences over time he moves toward the long-run situation and finally reaches the post-diffusion level of use of the HYV technology at α^{*}_{i}.

Now, let us go back to the short-run situation again. From eqn. (7) we have :

$$\frac{\partial c_{it}}{\partial \alpha_{it}} = P(\mu_{nit} - \mu_{oi}) - bP^{2}\alpha_{it}(\sigma^{2}nit - \sigma^{2}oi) + bP^{2}\sigma^{2}oi \qquad \text{..... (17)}$$

[By using the first-order condition of maximisation]

Again (17) can be written as :

$$\frac{\partial c_{it}}{\partial \alpha_{it}} = [P(\mu_{nit} - \mu_{oi}) + bP^{2}\sigma^{2}oi] \frac{\alpha^{*}_{it} - \alpha_{it}}{\alpha^{*}_{it}} \qquad \text{..... (18)}$$

Now, let us define the cost function. Since 'C_{it}' refers to the cost of cultivation per unit of the cropped area where the HYV and traditional varieties of crops are cultivated in the proportion α_{it} : $(1 - \alpha_{it})$ respectively, therefore we can write -

$$C_{it} = C_{1it}\alpha_{it} + C_{2it}(1 - \alpha_{it}) \qquad \text{...... (9)}$$

where C_{1it} = cost of cultivation of the HYV crop per unit area.

and C_{2it} = cost of cultivation of traditional variety crop per unit area.

We have to make two simplifying assumptions viz., that, the farmer bears no fixed cost and that he enjoys no economics of scale with respect to the traditional technology. Now, since the farmer is cultivating the traditional variety for a long time, we can assume that, he knows the optimum proportion of the factors of production from his experience and hence, the variable cost per unit area remains constant. Therefore, we can write C_{2it} as a constant, say,

$$C_{2it} = K_1 \qquad \text{...... (19)}$$

Now, we have to consider the characteristics of the HYV technology. For the cultivation of HYV crop, it is required to apply a package of inputs viz., irrigation, fertilizer and pesticides along with HYV seeds. The success of this technology depends on two things :

(i) The factor inputs should be applied in optimum proportion and

(ii) Different operations of cultivation e.g. ploughing, sowing, interculture, irrigation etc. should be performed on time and under proper supervision.

However, the farmers will learn about the optimum proportion of the factor inputs required for the HYV cultivation through experience over time. Moreover, the cost per hectare of this new technology will be higher, greater the rate of diffusion of this new technology.* This will happen because of the following reasons :

(i) As soon as the area under HYV crop increases by a large amount, the problem of proper supervision will arise. Therefore, additional hired labour should be employed and hence wage cost per hectare will increase.

(ii) If the area under HYV crop increases at a very high rate then the different operations of cultivation cannot be performed timely with the existing equipment and machinery. For example, the farmer may own a tractor, but this may not be sufficient for the timely performance of all the operations of cultivation of a large area and therefore, the farmer will either hire the service of another tractor or use bullocks. As a result cost per hectare will increase.

(iii) If the rate of diffusion of HYV technology is such that areas under HYV cannot be irrigated by canals, the farmer will depend on either tubewells or wells along with canal water. As a result wage cost per hectare will increase because tubewell and well irrigation are associated with higher labour-hours per hectare than canal irrigation. The study by Bina Agarwal (1983) supports the empirical generalization.

Now, we have to define the cost of cultivation per unit area for the HYV technology by the following function :

$$C_{1it} = K_2 \frac{(\alpha_{it} - \alpha_{it-1})^2}{\alpha_{it-1} \cdot \alpha_{it}} \qquad \ldots\ldots\ldots\ldots (20)$$

This form has the following two properties :

(i) For a given increase in the proportion of area under HYV, the higher is the existing proportion of area under HYV (α_{it-1}), the lower is the cost of cultivation per unit area. This property is logical on the ground that, higher level of α_{it-1} implies that the farmer gained more experience and hence, he will be nearer the optimum factor proportion and thus cost per hectare will be less.

(ii) Given the level of past use (α_{it-1}), cost per hectare increases at an increasing rate as the current level of use (α_{it}) increases. In other words, higher is the rate of diffusion, greater is the increase in cost per hectare. This property is consistant with the characteristics of the HYV technology as discussed above.

Now substituting (19) and (20) into (18) we get the cost function as follows :

$$C_{it} = K_2 \frac{(\alpha_{it} - \alpha_{it-1})^2}{\alpha_{it-1}, \alpha_{it}} \alpha_{it} + K_1 (1 - \alpha_{it}) \quad \ldots. \ (21)$$

Differentiating (21) w.r.t. α_{it} we get the following :

$$\frac{\partial C_{it}}{\partial \alpha_{it}} = \frac{2K_2}{\alpha_{it-1}} (\alpha_{it} - \alpha_{it-1}) - K_1$$

$$= 2K_2 \frac{d\alpha_{it}}{dt} \frac{1}{\alpha_{it}} - K_1 \quad \ldots\ldots. \ (22)$$

Now, substituting (22) into (17) we obtain :

$$2K_2 \frac{d\alpha_{it}}{dt} \frac{1}{\alpha_{it}} - K_1 = [P (\mu_{hit} - \mu_{oi}) + bP^2 \sigma^2_{oi}] \left(\frac{\alpha^*_{it} - \alpha_{it}}{\alpha^*_{it}}\right)$$

$$\therefore \frac{d\alpha_{it}}{dt} \frac{1}{\alpha_{it}} = \frac{1}{2k_2} [P (\mu_{hit} - \mu_{oi}) + bP^2 \sigma^2_{oi}] \left(\frac{\alpha^*_{it} - \alpha_{it}}{\alpha^*_{it}}\right) + \frac{K_1}{2K_2} \quad \ldots (23)$$

In the long-run situation eqn. (23) will take the following form :

$$\frac{d\alpha_i}{dt} \frac{1}{\alpha_i} = \frac{1}{2K_1} \left[P(\mu_{ni}^{*} - \mu_{oi}^{2}) + bP^2 \sigma_{oi}^2 \right] \left(\frac{\alpha_i^{*} - \alpha_i}{\alpha_i^{*}} \right) + \frac{K_1}{2K_2} \qquad \text{........ (24)}$$

Now, eqn. (24) represents nothing but a logistic function. Therefore, we find that, the diffusion path followed by the HYV technology for an individual farmer can be described by the logistic function.

So long we considered the behaviour of an individual farmer with respect to the adoption of the new technology. But different farmers will have different anticipations about the return from the new technology. They will also have different attitudes to risk. Therefore, different farmers will adopt the new technology at different points of time. However, finally we will get a diffusion curve of the HYV technology for the state as a whole. Those who are risk-lovers will be early adopters and those who are risk-averters will be late adopters.

Let us now analyse the aggregate behaviour of the farmers with respect to the diffusion of the HYV technology. Let us suppose that there are 'n' number of farmers and 'A_i' represents the cultivable area owned by the i-th farmer.

Now eqn. (23) which represents the diffusion path w.r.t. an individual farmer originates from eqns.(17) and (21). Therefore, instead of aggregating eqn. (14) over 'n' individuals we have to do the aggregation on eqns. (17) and (21) for the computational simplification.

Eqn. (17) is as follows :

$$\frac{\partial c_{it}}{\partial \alpha_{it}} = P(\mu_{nit}-\mu_{oi}) - bP^2\alpha_{it}\ (\sigma^2_{nit}+\sigma^2_{oi}) + bP^2\sigma^2_{oi}$$

Now if we take the weighted average of the R.H.S. over 'n' individuals, weights being A_i 's, then we have :

$$\frac{\sum_{i=1}^{n} A_i \left\{ P(\mu_{nit}-\mu_{oi}) - bP^2\alpha_{it}\ (\sigma^2_{nit}+\sigma^2_{oi}) + bP^2\sigma^2_{oi} \right\}}{\sum_{i=1}^{n} A_i}$$

$$= \frac{\sum_{i=1}^{n} PA_i\ (\mu_{nit}-\mu_{oi})}{\sum_{i=1}^{n} A_i} - \frac{bP^2 \sum_{i=1}^{n} A_i\alpha_{it}\ (\sigma^2_{nit}+\sigma^2_{oi})}{\sum_{i=-1}^{n} A_i} + \frac{bP^2 \sum_{i=1}^{n} A_i\sigma^2_{oi}}{\sum_{i=1}^{n} A_i}$$

$$= P(\bar{\mu}_{nt}-\bar{\mu}_o) - bP^2\frac{\sum_{i=1}^{n} A_i\alpha_{it}\sigma^2_{nit}}{\sum_{i=1}^{n} A_i} - bP^2\frac{\sum_{i=1}^{n} A_i\alpha_{it}\sigma^2_{oi}}{\sum_{i=1}^{n} Ai} + bP^2\bar{\sigma}^2_o$$

$$= P(\bar{\mu}_{nt}-\bar{\mu}_o) - bP^2\ \frac{\sum_{i=1}^{n} A_i\ \alpha_{it}\ \sigma^2_{nit}}{\sum_{i=1}^{n} A_i\alpha_{it}}\ \frac{\sum_{i=1}^{n} A_i\ \alpha_{it}}{\sum_{i=1}^{n} A_i}$$

$$- \frac{bP^2 \sum_{i=1}^{n} A_i \left[\alpha_{it}\sigma_{oi}^2 + (1-\alpha_{it})\sigma_{oi}^2 - (1-\alpha_{it})\sigma_{oi}^2\right]}{\sum_{i=1}^{n} A_i} + bP^2 \bar{\sigma}_o^2$$

$$= P(\bar{\mu}_{nt}-\bar{\mu}_o) - bP^2 \bar{\sigma}_{nt}^2 \bar{\alpha}_t + \frac{bP^2 \sum_{i=1}^{n} A_i(1-\alpha_{it})\sigma_{oi}^2}{\sum_{i=1}^{n} A_i(1-\alpha_{it})} \cdot \frac{\sum_{i=1}^{n} A_i(1-\alpha_{it})}{\sum_{i=1}^{n} A_i}$$

$$-bP^2 \frac{\sum_{i=1}^{n} A_i \sigma_{oi}^2}{\sum_{i=1}^{n} A_i} + bP^2 \cdot \bar{\sigma}_o^2$$

$$= P(\bar{\mu}_{nt}-\bar{\mu}_o) - bP^2 \bar{\sigma}_{nt}^2 \bar{\alpha}_t + bP^2 \bar{\sigma}_o^2 (1 - \bar{\alpha}_t) - bP^2 \bar{\sigma}_o^2 + bP^2 \bar{\sigma}_o^2$$

$$= P(\bar{\mu}_{nt} - \bar{\mu}_o) - bP^2 \bar{\alpha}_t(\bar{\sigma}_{nt}^2 + \bar{\sigma}_o^2) + bP^2 \bar{\sigma}_o^2 \quad \ldots\ldots\ldots (25)$$

Again eqn. (21) is as follows :

$$C_{it} = K_2 \frac{(\alpha_{it} - \alpha_{it-1})^2}{\alpha_{it-1}\alpha_{it}} \alpha_{it} + K_1 (1-\alpha_{it})$$

$$\therefore \bar{C}_t = \frac{\sum_{i=1}^{n} A_i C_{it}}{\sum_{i=1}^{n} A_i} = K_2 \frac{\sum_{i=1}^{n} A_i \frac{(\alpha_{it}-\alpha_{it-1})^2}{\alpha_{it-1}}}{\sum_{i=1}^{n} A_i} + K_1 \frac{\sum_{i=1}^{n} A_i(1-\alpha_{it})}{\sum_{i=1}^{n} A_i}$$

$$= K_2 \frac{\sum_{i=1}^{n} A_i \left(\frac{\alpha_{it}^2 + \alpha_{it-1}^2 - 2\alpha_{it}\alpha_{it-1}}{\alpha_{it-1}}\right)}{\sum_{i=1}^{n} A_i} + K_1 (1 - \bar{\alpha}_t)$$

$$= K_2 \left[\frac{\sum_{i=1}^{n} A_i \frac{\alpha_{it}^2}{\alpha_{it-1}}}{\sum_{i=1}^{n} A_i} + \frac{\sum_{i=1}^{n} A_i \alpha_{it-1}}{\sum_{i=1}^{n} A_i} - \frac{\sum_{i=1}^{n} 2A_i \alpha_{it}}{\sum_{i=1}^{n} A_i} \right] +$$

$$K_1 (1 - \bar{\alpha}_t) \quad \ldots\ldots (26)$$

Now if in any time period for all individuals the value of $\frac{\alpha_{it}^2}{\alpha_{it-1}}$ is same then eqn. (29) can be written as follows :

$$\bar{C}_t = K_2 \left[\frac{\bar{\alpha}_t^2}{\bar{\alpha}_{t-1}} + \bar{\alpha}_{t-1} - 2\bar{\alpha}_t \right] + K_1 (1 - \bar{\alpha}_t)$$

$$= K_2 \frac{(\bar{\alpha}_t - \bar{\alpha}_{t-1})^2}{\bar{\alpha}_{t-1}} + K_1 (1 - \bar{\alpha}_t)$$

$$\therefore \frac{\partial C_t}{\partial \bar{\alpha}_t} = 2K_2 \frac{d\bar{\alpha}_t}{dt} \frac{1}{\bar{\alpha}_t} - K_1 \quad \ldots\ldots\ldots (27)$$

Now combining eqns. (25) and (27) we have :

$$2K_2 \frac{d\bar{\alpha}_t}{dt} \frac{1}{\bar{\alpha}_t} - K_1 = P(\bar{\mu}_{nt} - \bar{\mu}_o) - bP^2 \bar{\alpha}_t (\bar{\sigma}_{nt}^{-2} + \bar{\sigma}_o^{-2}) + bP^2 \sigma_o^{-2}$$

$$\ldots\ldots (28)$$

Now, since we proved that eqn. (17) holds good for aggregate, therefore eqn. (18) also hold good for aggregate. Hence, aggregating eqn. (18) and then substituting in the R.H.S. of eqn. (28) we have :

$$2K_2 \frac{d\bar{\alpha}_t}{dt} \cdot \frac{1}{\bar{\alpha}_t} - K_1 = \left[P(\bar{\mu}_{nt} - \bar{\mu}_o) + bP^2 \sigma_o^{-2} \right] \left(\frac{\bar{\alpha}_t^* - \bar{\alpha}_t}{\bar{\alpha}_t^*} \right)$$

$$\therefore \frac{d\bar{\alpha}_t}{dt} \cdot \frac{1}{\bar{\alpha}_t} = \frac{1}{2K_2} \left[P(\bar{\mu}_{nt} - \bar{\mu}_o) + bP^2 \bar{\sigma}_o^2 \right] \frac{(\bar{\alpha}_t^* - \bar{\alpha}_t)}{\bar{\alpha}_t^*} + \frac{K_1}{2K_2} \qquad \ldots\ldots (29)$$

Eqn. (29) is nothing but the aggregate form of eqn. (23) and hence it also represents a logistic function. Therefore, the diffusion path followed w.r.t. the HYV technology by taking the individual farmers in aggregate (i.e. at the state-level) can be described by the logistic function subject to the condition that, the value of $\frac{\alpha_{it}^2}{\alpha_{it-1}}$ is same for all individuals in each time period. The implication of this condition is that, at any time-period who are cultivating relatively larger percentage of total area by HYV technology, in the next time period their increment in the percentage of area under HYV will be relatively low. This also means that for the farmers who initially start with relatively larger percentage area under HYV, the rate of growth of percentage area under HYV technology measured from time to time will be relatively low. However, this does not mean that, the overall rate of diffusion of HYV technology for these groups of farmers will be relatively low.

To study the pattern of diffusion of HYV technology in the context of Indian agriculture we have used this model, which is described in the next section.

III. EMPIRICAL STUDY

III.A.

To study the pattern of diffusion of HYV technology, we looked both at the rate of diffusion of HYV technology and the asymptotic value of the diffusion path i.e. ceiling. Since, it was not possible to study the pattern of diffusion of HYV technology for all crops, therefore, we have carried out a crop specific analysis. HYV technology has been applied to the production of a number of crops viz., rice, wheat, jowar, bajra, maize and some oilseeds. However, we have considered here the case of wheat only. To study the pattern of diffusion of HYV wheat we have considered nine states of India viz., Bihar Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab Rajasthan and Uttar Pradesh. It was not possible to consider other states because of data limitations. This study is limited to the period from 1966-67 to 1980-81, since all the relevant data were not available for the period before 1966 and after 1981.

After collecting the time-series data on the area under HYV wheat and the total area under wheat, by applying our model we have fitted a logistic growth function for each of the states separately. (As a cross-check, by plotting the time-series data of the area under HYV wheat as the percentage of the total area under wheat, we find that almost every where the resulting curves are s-shaped as represented in the following graphs). Estimating the parameters of the logistic growth function by "the method of the rate of increase" as suggested by H. Hotelling we obtained the rate of diffusion of HYV wheat and the ceiling i.e. the long-run limit of diffusion of HYV wheat.[3] The estimated parameters of the logistic growth function with respect to HYV wheat are presented in Table 1. The values of 'b' and 'L' stand for the rate of diffusion of HYV wheat and the ceiling respectively. The table shows that the rate of diffusion of HYV wheat is highest in Gujarat (2.43) and lowest in U.P. (0.48) whereas the ceiling value is highest in Haryana (88.88) and lowest in Karnataka (36.39). However, the values of r^2, representing the degree of goodness of fit of the logistic function, vary from 0.15 to 0.63.

III.B.

Now we are going to develop the economic interpretation of the differences in the estimated parameter 'b' i.e. the rate of diffusion of HYV wheat as between the states. Inter-state variation in the rate of diffusion of the HYV wheat results from the inter-state variations in the rate of adoption of the HYV wheat by the farmers, which again depends on different socio-economic factors.

The primary factor governing the adoption of HYV in preference to traditional variety is expected to be the comparative profitability of HYV. Hence, *ceteris paribus*, the rate of diffusion of HYV will be higher in those states where the increase in relative profit from the cultivation of HYV over the traditional variety is greater in comparison to others. Profitability depends on yield, cost of cultivation, risk involved in cultivation etc. Now if irrigation is assured and the required amount of fertilizer is available, different operations of cultivation e.g. ploughing, sowing etc. are performed timely then the risk anticipated by the farmer will diminish. As a first approximation, we have considered only the effect of yield on the profitability, assuming the effect of ri to be neutral as between varieties and farmer. The yield of HY is generally greater than that of the traditional variety. Therefore, income per unit of the cropped area will be higher i the case of HYV and HYV will be considered as superior to the traditional variety. Moreover, this will affect the profit als Therefore, we have to consider the average increase in yield of HYV over the traditional as one of the explanatory variables fo the differences in the rate of diffusion of HYV,

Secondly, the factor that may be advanced to explain th differential rate of adoption of HYV is the statewise variation in the importance of a particular crop. It is expected that, any particular crop is grown in a relatively larger percentages of area of a state depending on the agro-climatic condition of that state which is favourable for that specific crop and as a result, that crop becomes important in the state considered. S we can expect that, the rate of diffusion of HYV will be higher those states where the importance of the crop considered is greater than others. Therefore, as an explanatory variable we have used the percentage of area under a crop to the total cropped area of a state which gives the measure of the importance of a crop to that state.

Thirdly, the adoption of the HYV technology is influenced by the specific factor-intensity of this technology. It is well known that, this new technology tends to be relatively capital - intensive. It demands an input package, the major components of which have to be purchased from the market. Therefore, the adoption of this technology requires liquidity. Now, the large farmers have better access to capital than the smaller ones. Therefore, it is expected that, the rate of diffusion of HYV technology will be higher in those states where average size of farm is comparatively large.

Therefore, the average size of farm is used as one variable to explain the differences in the rate of diffusion of HYV. Apart from the average size of farm, the different level of the development of the credit markets in different states will also affect the rate of diffusion of the HYV technology. In our country most of the farmers are poor and they do not have good access to capital. Therefore, they can adopt this technology only if they get the credit facilities. The poor farmers cannot adopt a new technology, bearing a high risk, by depending on the private moneylenders. Institutional credit can help the farmers to adopt the new technology. It is expected that the state with higher institutional credit facilities will have a high rate of adoption of HYV, comparatively speaking. So, we have considered agricultural credit given by different institutions as an explanatory variable.

The institutional credit for the agricultural sector is mainly provided by the co-operatives and the commercial banks. Of the two, co-operatives provide the major part. It may be noted that the role of co-operatives in providing agricultural credit before the mid-60's was insignificant. Before the mid-60's, cultivators were mainly dependent on the private money-lender for credit. At present, the picture is just the opposite. Now-a-days, the major part of the agricultural credit is provided by the different financial institutions. The share of institutional credit in total agricultural credit has increased to 62.6% in 1981 as against 31.7% in 1971 and 18.6% in 1981.[4] Of the total institutional credit, co-operatives accounted for a very large percentage. During the year 1978-79, co-operatives form 66% of the total agricultural credit provided directly by the institutions.[5]

Because of difficulties experienced in obtaining data for agricultural credit provided by the commercial banks, we have considered only the credit provided by the co-operatives, in our analysis.[6]

Another factor that can be taken into account to explain the differential rate of diffusion of HYV technology is the differential rate of application of the complementary inputs required for the success of this technology. The new technology involves the application of HYV seeds together with the associated package of inputs e.g. irrigation, fertilizers, pesticides and improved implements. However, some of these inputs were already known before the onset of the new technology. But their application was not essential for the traditional technology and hence their use was also limited. On the other hand, to get the maximum level of output, that can be obtained from the HYV seeds, it is essential to use certain packages of inputs as mentioned above. Therefore, it is expected that, in the states where the rate of application of these complementary inputs is higher, the rate of diffusion of HYV technology will also be higher. Hence, we have used the percentage of irrigated area to the total area under the crop as an explanatory variable. It has not been possible to consider the other complementary inputs, because of non-availability of the data.

Success of the HYV technology depends on the assured suppply of water. If irrigation facility is well developed then there would be no problem. But if it is not so then the alternative source would be the sufficient amount of rainfall. Hence, it is expected that, the statewise variation in rainfall will have some effect on the rate of diffusion of HYV crops and it is also expected that, these two are positively related. So, we have used actual annual rainfall as an explanatory variable for the differential rate of adoption of HYV crops.

Literacy of the agricultural population is another factor which may have some indirect influence on the rate of adoption of the HYV technology. The people who are directly concerned with the agricultural activity, are those who live in the rural areas. Literacy among the people of the rural sector increases their consciousness about the things that are happening in the world outside their own surroundings. A new technology inevitably involves some risk and farmers ignorant about the outcome may heavily discount returns from the new technology. Those people who have a traditional way of thinking may prefer lower output with certainty than larger output with uncertainty. The degree of risk-aversion will be higher for these people. As a result, they will hesitate to adopt this new technology. Our hypothesis is that the degree of risk-aversion is inversely related to the degree of literacy. Hence, we have used the percentage of literacy in the rural sector as another explanatory variable.

Lastly, the differential rate of diffusion of HYV technology may also be affected by the differential rate of development of the states, at least to some extent. Because with the development of the states number of credit insitutions will increase, consciousness of the people will rise, state of demand will improve and therefore, the farmers will be interested to adop a new thing. The economic development of a state is generally represented by the per capita state domestic product (SDP). Therefore, we have to use per capita SDP as an explanatory variable.

III.C- METHODOLOGIES

For the estimation of the rate of diffusion of HYV (b), we have considered the period from 1967-68 to 1980-81. Since our objective is to make a cross-section analysis of the variation in the rate of diffusion of HYV, values of the explanatory variables for the different states are used after averaging over the period from 1967-68 to 1980-81.

However, it is to be noted that, the value of 'b' depends strongly on the ceiling (L). Definitionally, 'b' represents the percentage of the ceiling value by which HYV will diffuse over time. For example, the values of 'b' and 'L' in Gujarat are 2.43 and 65.67 respectively and these imply that the area under HYV wheat in Gujarat will increase by 2.43% of the ceiling value (i.e. 65.67) per year. But the ceiling value differ from state to state. Therefore it is required to adjust 'b' so as to make them comparable between the states. For this purpose, we have expressed the value of 'b' as the percentages of the area under the crop considered instead of the percentages of the ceiling value. Hence, instead of 'b' as the dependent variable, we have used 'y' where $y = bx \frac{L}{100}$.

The first explanatory variable we have used is the average difference in the yield of HYV over the traditional (X_1). But the data on the yield of the traditional varieties of the crop (wheat in this case) were not available. Therefore, we have calculated these values by using the formula as follows :

$$\text{Yield of the traditional varieties of wheat} = \frac{\text{Total production of wheat} - \text{Production of HYV wheat}}{\text{Total area under wheat} - \text{Area under HYV wheat}}$$

Production of HYV wheat were, again, calculated by multiplying the area under HYV wheat with the yield of HYV wheat. Then we calculated the difference between the yield of HYV and traditional varieties of wheat for the time period considered and finally averaged these figures.

The variable actual annual rainfall (X_5) has been constructed by summing up the figures for actual rainfall for the months from July to June for each of the agricultural years.

We have already stated that, we used co-operative credit as the proxy of total agricultural credit since it covers 66% of the total agricultural credit (institutional). For our analysis agricultural credit has been constructed by summing up the credit provided to the individuals by different institutions under co-operatives. Therefore, it represents the sum total of the credit given by Primary Agricultural Credit Societies (PACS), Grain Banks (for those states where they exist) and Primary Land Development Banks (PLDB). In Gujarat and U.P. there are no PLDB, and, therefore they have been substituted by the Central Land Development Bank (CLDB), which directly gives loans to the individuals in these two states. Again, in Bihar and Maharashtra PLDB's were functioning till 1971-72 and since 1972-73 loans were provided to the individuals directly by the CLDS's. In Maharashtra, till 1971-72 CLDS's were also giving loans to the individuals but it was only around 0.07% of the total co-operative credit to agriculture and so we ignored these figures. Similarly, in Tamilnadu and Kerala also, CLDS's provided loans to the individuals and it accounted for 0.001% and 0.05% in Tamilnadu and Kerala, respectively. Therefore, these figures are also ignored for these two states.

To make comparable between the states, we have normalized agricultural credit by the total cropped area of the state. Therefore the variable X_6 represents agricultural credit per hectare of the total cropped area of the state.

In our analysis, we have used another variable, viz., per capita state domestic product (SDP), (X_8) as an index of the level of economic development. We have used the average of the per capita net state domestic product at 1970-71 prices for the period from 1970-71 to 1980-81. For the period upto 1969-70 figures were given at the 1960-61 prices, and they could not be converted into 1970-71 prices. Therefore, we did not use them.

IV. FINDINGS AND ANALYSIS

In order to explain the inter-state variation in the rate of diffusion of HYV wheat with the help of our nine explanatory variables, we have carried out multiple regression analysis. The data used for this purpose are presented in Table 2.

The notation used is as follows :

$Y = \frac{bk}{100}$ = Rate of diffusion of HYV x $\frac{\text{Ceiling}}{100}$

X_1 = Average of the incremental yield of HYV over the traditional.

X_2 = Area under wheat (i.e. the specific crop considered) as the percentage of total cropped area of the state.

X_3 = Percentage of area irrigated under the crop (wheat, in this case).

X_4 = Average size of farms.

X_5 = Actual annual rainfall.

X_6 = Agricultural credit per hectare of the total cropped area.

X_7 = Percentage of literacy in rural sector.

X_8 = Per capita net state domestic product.

In our analysis, we used eight (8) explanatory variables, as noted above. On the other hand, in case of wheat, the number of observations is nine, so problem of degrees of freedom arises. To avoid this problem, we constructed different sets by taking different combinations of variables and carried on separate regressions for the different sets of explanatory variables. Hence, we obtained a large number of regression equations. However, among them, we have taken for analysis only those equations which have relatively high explanatory power. Results of regression analysis are given in Table 3. From Table 3, we find that for equation (1) only the variable X_3 is significant at the 10% level of significance. No other variables in equation (1) are significant and F-statistic is, also, not significant.

Therefore, on the basis of equation (1) we can say that only irrigation have significant effect on the rate of diffusion of HYV wheat and the other two variables viz. incremental yield of HYV over non-HYV wheat (X_1) and importance of the crop in the state (X_2) have no significant effect on the rate of diffusion of HYV wheat. Moreover, on the basis of the F-value, eqn.(1) reveals that those three variables considered in eqn.(1) jointly also have no significant effect on the rate of diffusion of HYV wheat.

Let us now compare the eight regression equations we have estimated. From Table 3 we find that most of the equations reflect good explanatory power judging on the basis of the value of R^2 (varying from 0.56 to 0.84). But if we look at the values of $\bar{R}^2$ then we find that those values vary largely from equation to equation, from 0.01 to 0.74. The only variables which have significant co-efficient (on the basis of t-test) are as follows:

(i) in eqn.(1) X_3 is significant at the 10% level,

(ii) in eqn.(4) X_7 is significant at the 5% level,

(iii) in eqn.(6) X_8 is significant at the 10% level,

(iv) in eqn.(8) X_7 is significant at the 10% level.

It is to be noted here that, although the co-efficient of X_8 is positive and significant in eqn.(6) it is negative in eqn.(3). The reason is multicollinearity of X_8 with X_7. Because from Table 4 we find that X_8 have very high correlation with X_7 (0.76) and therefore, as in eqn.(6) X_7 is dropped coefficient of X_8 became positive.

Moreover, we find that the F-value is significant only in eqn.(4). This means that the variables X_3, X_6 and X_7 jointly have significant effect on the rate of diffusion of HYV wheat. In none of the other seven combinations, the explanatory variables jointly have any major effect on the rate of diffusion of HYV wheat.

However, as we noted earlier, some variables do have an influence on the diffusion of HYV wheat of a kind that we find plausible on the basis of theoretical arguments. Discussions in this respect follow in the appendix - II.

V. SUMMARY AND CONCLUSIONS

Based on our model on the pattern of diffusion of HYV technology we have estimated the rate of diffusion of HYV wheat in nine states of India by fitting the logistic growth curve. We find that, the rate of diffusion of HYV wheat differ from state to state. Regarding this inter-state variation in the rate of diffusion of HYV wheat, we have tested a number of propositions.

The results show that, the rate of diffusion of HYV wheat is higher in those states where the irrigation facility, the rate of literacy in rural sector and per capita state domestic product are relatively high. Our finding also shows that, controlled water i.e. irrigation is much more necessary than rainfall for the success of HYV technology because we find that rainfall has no significant effect on the rate of diffusion of HYV wheat.

However, some of the variables initially considered have an insignificant effect on the diffusion of HYV wheat viz. incremental yield of HYV, importance of the crop in the state, farm-size and agricultural credit. This result seems quite inconsistent. Perhaps the reason behind is the problem of aggregation. It has not been possible to carry out disaggregative analysis due to data constraint. If it was possible we might get some new light in this respect. However, subject to this limitation, the result should be taken for granted. Therefore on the basis of our results as a policy implication we can say that, for the diffusion of HYV technology stress should be given on infrastructural development and economic development, specifically on three factors viz., irrigation, rate of literacy in rural sector and per capita state domestic product.

Appendix - I

(Refer to Sec. II)

I.A. :

Eqn.(11) is as follows :

$$Z_{it+1} = \frac{\sigma_{ni}^{2*} Z_{it}}{\sigma_{ni}^{2*} + Z_{it}}$$

From the above eqn. we get :

$$Z_{it} = \frac{\sigma_{ni}^{2*} Z_{io}}{\sigma_{ni}^{2*} + Z_{io}} \qquad (Z_{it} = Z_{io} \text{ for } t = 0)$$

$$Z_{i2} = \frac{\sigma_{ni}^{2*} Z_{i1}}{\sigma_{ni}^{2*} + Z_{i1}}$$

$$= \frac{\sigma_{ni}^{2*}\left(\frac{\sigma_{ni}^{2*} \cdot Z_{io}}{\sigma_{ni}^{2*} + Z_{io}}\right)}{\sigma_{ni}^{2*} + \frac{\sigma_{ni}^{2*} Z_{io}}{\sigma_{ni}^{2*} + Z_{io}}}$$

$$= \frac{[(\sigma_{ni}^{2*})^2 Z_{io}]\,[Z_{io} + \sigma_{ni}^{2*}]}{(Z_{io} + \sigma_{ni}^{2*})\,[\sigma_{ni}^{2*}(2Z_{oi} + \sigma_{ni}^{2*})]}$$

$$= \frac{\sigma_{ni}^{2*} Z_{io}}{\sigma_{ni}^{2*} + 2Z_{io}}$$

Similarly, $Z_{i3} = \dfrac{\sigma^{2*}_{ni} \; Z_{i2}}{\sigma^{2*}_{ni} + Z_{i3}} = \dfrac{\sigma^{2*}_{ni} \; Z_{io}}{\sigma^{2*}_{ni} + Z_{io}}$

We can write :

$$Z_{it} = \frac{\sigma^{2*}_{ni} \; Z_{io}}{\sigma^{2*}_{ni} + tZ_{io}}$$

I.B. :

From eqn. (10) we have :

$$\mu_{nit} = \frac{X_{it-1} \; Z_{it-1} + \sigma^{2*}_{ni} \mu_{nit-1}}{Z_{it-1} + \sigma^{2*}_{ni}}$$

$$\therefore E(\mu_{nit}) = \frac{E(X_{it-1}) \; Z_{it-1} + \sigma^{2*}_{ni} \mu_{nit-1}}{Z_{it-1} + \sigma^{2*}_{ni}}$$

$$= \frac{\mu^{*}_{ni} + (\sigma^{2*}_{ni} \mu_{nit-1}) \cdot \dfrac{[\sigma^{2*}_{ni} + (t-1) \; Z_{io}]}{Z_{io} \; \sigma^{2*}_{ni}}}{1 + \dfrac{\sigma^{2*}_{ni}}{Z_{io} \, \sigma^{2*}_{ni}} [\sigma^{2*}_{ni} + (t-1) \; Z_{io}]}$$

$$= \frac{\mu^{*}_{ni} + \dfrac{\mu_{nit-1}}{Z_{io}} [\sigma^{2*}_{ni} + (t-1) \; Z_{io}]}{\dfrac{(\sigma^{2*}_{ni} + tZ_{io})}{Z_{io}}}$$

$$\frac{[\mu^{*}_{ni} \; Z_{io} + \mu_{nit-1} \, \sigma^{2*}_{ni} + (t-1) Z_{io} \mu_{nit-1}]}{\sigma^{2*}_{ni} + tZ_{io}} \quad \ldots\ldots(1)$$

Now, from the above eqn. we can write :

$$\mu_{ni1} = \frac{\mu^{*}_{ni} Z_{io} + \sigma^{2*}_{ni} \mu_{nio}}{\sigma^{2*}_{ni} + Z_{io}}$$

$$\mu_{ni2} = \frac{\mu^{*}_{ni} \; Z_{i1} + \sigma^{2*}_{ni} \mu_{ni1}}{Z_{it} + \sigma^{2*}_{ni}}$$

$$= \frac{\mu^{*}_{ni}\left(\frac{\sigma^{2*}_{ni} \; Z_{oi}}{\sigma^{2*}_{ni} + Z_{oi}}\right) + \sigma^{2*}_{ni}\left(\frac{\mu^{*}_{ni} \; Z_{io} + \sigma^{2*}_{ni} \mu_{nio}}{\sigma^{2*}_{ni} + Z_{io}}\right)}{\frac{\sigma^{2*}_{ni} \; Z_{io}}{Z_{io} + \sigma^{2*}_{ni}} + \sigma^{2*}_{ni}}$$

$$= \frac{2\mu^{*}_{ni} \sigma^{2*}_{ni} \; Z_{io} + (\sigma^{2*}_{ni}) \mu_{nio}}{2Z_{io} \sigma^{2*}_{ni} + (\sigma^{2*}_{ni})^{2}}$$

$$= \frac{2\mu^{*}_{ni} \; Z_{io} + \sigma^{2*}_{ni} \mu_{nio}}{2Z_{io} + \sigma^{2*}_{ni}}$$

$$\therefore \mu_{nit-1} = \frac{\sigma^{2*}_{ni} \mu_{nio} + (t-1) \mu^{*}_{ni} \; Z_{io}}{\sigma^{2*}_{ni} + (t-1) \; Z_{io}}$$

Substituting μ_{nit-1} in (1) we have :

$$E(\mu_{nit}) = \frac{\mu^{*}_{ni} Z_{io} + \left[\sigma^{2*}_{ni} + (t-1) \; Z_{io}\right]\left[\frac{\sigma^{2*}_{ni} \mu_{nio} + (t-1) \mu^{*}_{ni} \; Z_{io}}{\sigma^{2*}_{ni} + (t-1) \; Z_{io}}\right]}{\sigma^{2*}_{ni} + tZ_{io}}$$

$$= \frac{\mu^{*}_{ni} \; z_{io} + \sigma^{2*}_{ni} \mu_{nio} + (t-1) \mu^{*}_{ni} \; z_{io}}{\sigma^{2*}_{ni} + t z_{io}}$$

$$= \frac{\sigma^{2*}_{ni} \mu_{nio} + t z_{io} \mu^{*}_{ni}}{\sigma^{2*}_{ni} + t z_{io}} = \mu_{nit}.$$

Appendix - II

(Refer to Sec. IV)

The nature of the relationship between the rate of diffusion of HYV wheat and some of the variables are significant because, signs of some of the estimated co-efficients are strikingly opposite to their expected signs. We shall try to find out the reasons behind these results.

For analysing our findings, we shall divide the explanatory variables into two categories according to the signs of the estimated co-efficients :

Category (1) : variables having positive co-efficients

Category (2) : variables having negative co-efficients

Category (1)

From Table 3 we find that, X_1, X_3, X_6 and X_7, these four variables have positive co-efficients always. These imply that, average increase in yield of HYV wheat over non-HYV (X_1), percentage area irrigated under HYV wheat (X_3) agricultural credit (X_6) and percentage of literacy in rural sector (X_7) have positive contribution to the rate of diffusion of HYV wheat. Therefore, it needs no more explanation.

Category (2)

Three variables, X_2, X_4, X_5 and X_8 belong to this category (see Table 3). However, area under wheat as the percentage of the total cropped area of the State (X_2) and per capita SDP (X_8) are inversely related to the rate of diffusion of HYV wheat in some cases. But average size of farms (X_4) and annual rainfall (X_5) are inversely related to the rate of diffusion in all cases. These are opposite to the expected results. So, we shall try to find out the reasons behind.

The inverse relationship between X_2 and Y implies that in the states where the percentage area under wheat is high, the rate of diffusion of HYV wheat is less. X_2 is used as a measure of the importance of the crop in different states. Let us try to find out the reason behind the inverse relationship.

The negative co-efficient of X_2 is due to the presence of multicollinearity. From the correlation matrix (Table 4), we find that X_2 have high correlation with X_3 (0.62). Moreover, in eqn.(6) /Table 3/ the coefficient of X_2 is positive where X_3 is not present.

Thus we find that if X_3 is dropped then the estimated co-efficient of X_2 becomes positive. The implies that, reason for the negative co-efficient of X_2 is multicollinearity of X_2 with X_3.

From eqn.(3) we find that X_8 is inversely related with Y. However, the reason is that X_9 have high multicollearity with X_7 as discussed earlier. Therefore, in the absence of X_7, it became positive in eqn.(6).

We consider now, the case of X_4 i.e., average size of farms. From Table 4, we find that X_4 have no high correlation with the other variables. Therefore, the question of multi-collinearity does not arise. So the negative co-efficient of X_4 is due to some other reasons.

The inverse relationship between X_4 and Y implies that, the states where the average size of farm is larger, the rate of diffusion of HYV wheat is low relatively and vice versa. Small farmers operate their land individually and so, they devote their full effort on cultivation. The most important factor that drive the small farmers to more intensive effort is the need for survival. It is well-known that, in Indian agriculture, the small farmers operate subsistence farming. Having no alternative source of employment and income, these poor peasants try to produce the maximum output on his small piece of land. To achieve this goal, ignoring the marginal productivity calculations, they employ family labour and also hired labour, whenever necessary to supplement the family labour.

As a consequence, labour intensity (i.e. labour input per hectare) becomes relatively higher for these small farms, as empirically observed by Krishna Bharadwaj (1974), M. Chattopadhyay and Ashok Rudra (1976) etc. The small farmers also try to apply other inputs with maximum intensity. The studies of C.H. Hanumantha Rao (1966) and K. Bharadwaj (1976) reveal that the percentage of area irrigated declines with the increase in the size of holding, because the small farmers try to improve the quality of land by small-scale irrigation and other means as can be done with the help of labour, which lacks the large farmers. These small farmers also try to cultivate as many crops as possible, i.e. cropping intensity is higher for the small farmers. This is supported by the work of K. Bharadwaj (1974) and Chattopadhyay and Rudra (1976). Finally, if we consider all inputs in aggregate, we find that, the intensity of application of total inputs is higher in the case of small farmers.[7] Therefore, the yield per hectare of the small farms might be higher than that of the large farms. Some may express doubt about the inverse relationship between farm size and productivity, as it was found by several authors that, this relationship does not hold for all ranges of the size-class or for all regions of India.

However, by analysing the findings of different authors on this issue. Sen (1975) finally came to the conclusion that, excepting for data within a village, this inverse relationship holds both for the size-class average data and disaggregated inter-farm data from different villages in the same region.

Now, since the productivity is higher for the small farmers than large farmers, therefore, they will realise greater profit from HYV cultivation than large farmers. Therefore, once the HYV technology is adopted by the small farmers, they will spread this HYV technology to a larger percentage area of their holdings. Hence, it might be possible that, the rate of diffusion of HYV wheat is higher in those states where the average size of farm is smaller and vice versa.

Finally, let us consider the inverse relationship between X_5 and Y. This implies that, the states where annual rainfall in relatively high, the rate of diffusion of HYV wheat is relatively low and vice versa. The reason for such an inverse relationship is that, the states where annual rainfall is relatively low are the states of north-western region (e.g. Punjab, Haryana, Gujarat, Rajasthan) which have extensive irrigation facility. Therefore, excepting Rajasthan, with an assured water supply, they have high rate of diffusion of HYV wheat. In case of Rajasthan, although 69.9% area under wheat is irrigated, the rate of diffusion of HYV wheat is very low in this state (0.35). On the other hand, states with high rainfall have rather poor irrigation facilities viz., Karnataka and M.P. where irrigated area under wheat are 13.2% and 20.2% respectively and the rate of diffusion of HYV wheat is also very low in these states (viz. 0.34 in Karnataka and 0.22 in M.P.). Moreover, from Table 4, we find that, the correlation co-efficient between X_6 and X_3 is -0.71. Therefore, the inverse relationship between rainfall and irrigation in the wheat growing states, is also supported by the correlation co-efficient between them.

We can conclude that the diffusion of HYV wheat is much more dependent on irrigation than on rainfall, although we expected some positive influence of rainfall. However, the case of Maharashtra is very interesting. For this state, figures for both the annual rainfall and irrigation are very low. But the rate of diffusion of HYV wheat is very high (1.20) comparative to other states. We also note that agricultural credit (X_6) and literacy rate in the rural sector (X_7) are highest in this state among all other states considered and per capita state domestic product (X_8) is also very high in this state. Therefore, from the experience of Maharashtra, we can say that agricultural credit and literacy in the rural sector play much more important role than irrigation in the diffusion of HYV wheat.

Table 1

Logistic Trend Functions by States for HYV wheat

States	Rate of acceptance 'b'	Ceiling 'k'	R^2
Bihar	0.78	80.41	0.59
Gujarat	2.43	65.67	0.56
Haryana	1.04	88.88	0.63
Karnataka	0.95	36.39	0.30
Madhya Pradesh	0.58	38.16	0.15
Maharashtra	1.54	78.17	0.39
Punjab	0.79	84.95	0.27
Rajasthan	0.69	51.11	0.22
Uttar Pradesh	0.48	76.19	0.49

Table - 2

Final set of data used for the analysis-crop : Wheat

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ates	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
har	0.63	614.00	14.30	57.90	1.67	131.60	23.31	17.17	413.20
jarat	1.59	1006.00	5.40	70.30	5.80	87.60	116.66	28.33	810.30
ryana	0.92	1009.30	23.30	83.40	5.37	80.80	102.63	21.72	929.70
rnataka	0.34	1030.50	3.20	13.20	5.06	170.90	66.35	25.13	682.10
dhya radesh	0.22	1151.80	15.70	20.20	4.29	120.20	45.36	16.81	475.20
harashtra	1.20	534.80	5.20	36.80	4.83	77.05	82.68	30.63	880.90
njab	0.67	692.00	39.80	86.80	5.81	67.60	165.60	27.81	[illegible]
jasthan	0.35	687.80	9.30	69.90	8.22	55.40	24.71	13.85	558.90
ttar radesh	0.36	403.90	26.80	70.60	2.71	102.10	48.85	18.13	473.30

Contd ...

Table 2 contd..

Note : Y = Adjusted rate of acceptance of HYV wheat = $\frac{bk}{100}$;

X_1 = Average increase in yield of HYV over traditional wheat; (in kg./hectare);

X_2 = Area under wheat as the percentage of total cropped area;

X_3 = Percentage of area irrigated under wheat;

X_4 = Average size of farms; (in hectare);

X_5 = Actual annual rainfall; (in centimeter);

X_6 = Agricultural credit per hectare of the total cropped area of the state (Rs./hectare)

X_7 = Percentage of literacy in rural sector;

X_8 = Per capita net state domestic product at 1970-71 prices; (in Rs.).

Source : (i) Figures of Col.(3) are constructed on the basis of data from "Fertiliser statistics", "Estimates of Area and Production of Principal crops in India" and "Consolidated Results of crop Estimation Surveys on Principal Crops".

(ii) Figures of Col.(4) are from "Estimates of Area and Production of Principal crops in India".

(iii) Sources of Col.(5) are "Indian Agricultural Statistics","Indian Agriculture in Brief" and "Estimates of Area and Production of Principal crops in India."

(iv) Source of Col.(6) is "Indian Agriculture in Brief".

(v) Col.(7) is constructed on the basis of data from "Estimates of Area and Production of Principal Crops in India".

(vi) Col.(8) is constructed on the basis of data from "Review of the co-operative movement in India", "Statistical Abstract, India", and "Indian Agricultural Statistics".

(vii) Source of Col.(9) is "Census of India,1981".

(viii) Source of Col.(10) is "Estimates of State Domestic Product : 1960-61 to 1982-83".

Table - 3

Multiple Regression Results - Crop : Wheat

Sl. No.	Intercept	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	SEE	R^2	$\bar{R}^2$	F-Value
1.	0.18	0.00023 (0.351)	-0.025 (-1.54)	0.013 (2.14)**						0.45	0.63	0.21	1.12
2.	0.91				-0.042 (0.39)	-0.004 (-0.64)	0.005 (1.22)			0.47	0.58	0.01	0.85
3.	0.39						0.002 (0.203)	0.057 (1.49)	-0.0004 (-0.27)	0.41	0.71	0.45	1.68
4.	-1.55			0.011 (2.017)			0.007 (1.393)	0.007 (2.79)*		0.31	0.84	0.74	4.19*
5.	0.69			0.0008 (0.093)		-0.003 (-0.439)	0.005 (1.152)			0.48	0.56	0.01	0.77
6.	0.37	0.0003 (0.496)	0.021 (1.531)						0.0012 (2.15)**	0.42	0.69	0.42	1.58
7.	0.53		-0.028 (-1.59)	0.013 (1.68)	-0.032 (-0.35)					0.45	0.63	0.21	1.12
8.	1.05	0.0002 (0.457)		0.006 (1.27)				0.054 (2.58)**		0.36	0.79	0.62	2.71

NOTE :- (i) Figures in parentheses are the t-values of the corresponding coefficients,

(ii) * implies significant at 5% level of significance,

(iii) ** implies significant at 10% level of significance.

Table - 4

Correlation Matrix : Wheat

X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Y
1.00								
-0.26	1.00							
-0.35	0.62	1.00						
0.28	-0.14	0.19	1.00					
0.32	-0.33	-0.71	-0.55	1.00				
-0.28	0.0008	-0.03	0.02	-0.26	1.00			
0.05	-0.07	-0.02	0.12	-0.08	0.70	1.00		
0.08	0.39	0.40	0.44	-0.46	0.39	0.76	1.00	
0.04	-0.23	0.31	0.13	-0.36	0.48	0.70	0.49	1.00

FOOTNOTES

1. See Johnson and Kotz (1970)
2. See Lindley (1965)
3. For this method of estimation of the logistic function see Davis (1941).
4. See Desai (1987).
5. See R.B.I. (1980).
6. There is another important aspect of considering the agricultural credit provided by the co-operatives only. Relative consciousness of the farmers to demand credit for the technological improvement of cultivation and credit provided by the co-operatives are correlated. Therefore the co-operative credit represents the force of demand for credit by the farmers that leads to the formation of co-operative society. On the other hand credit given by the commercial banks represents the supply side picture only whatever be the demand. Now, since it is much more important to reflect the demand side picture, credit provided by the co-operatives is considered only in our study.
7. See Chattopadhyay and Rudra (1976.

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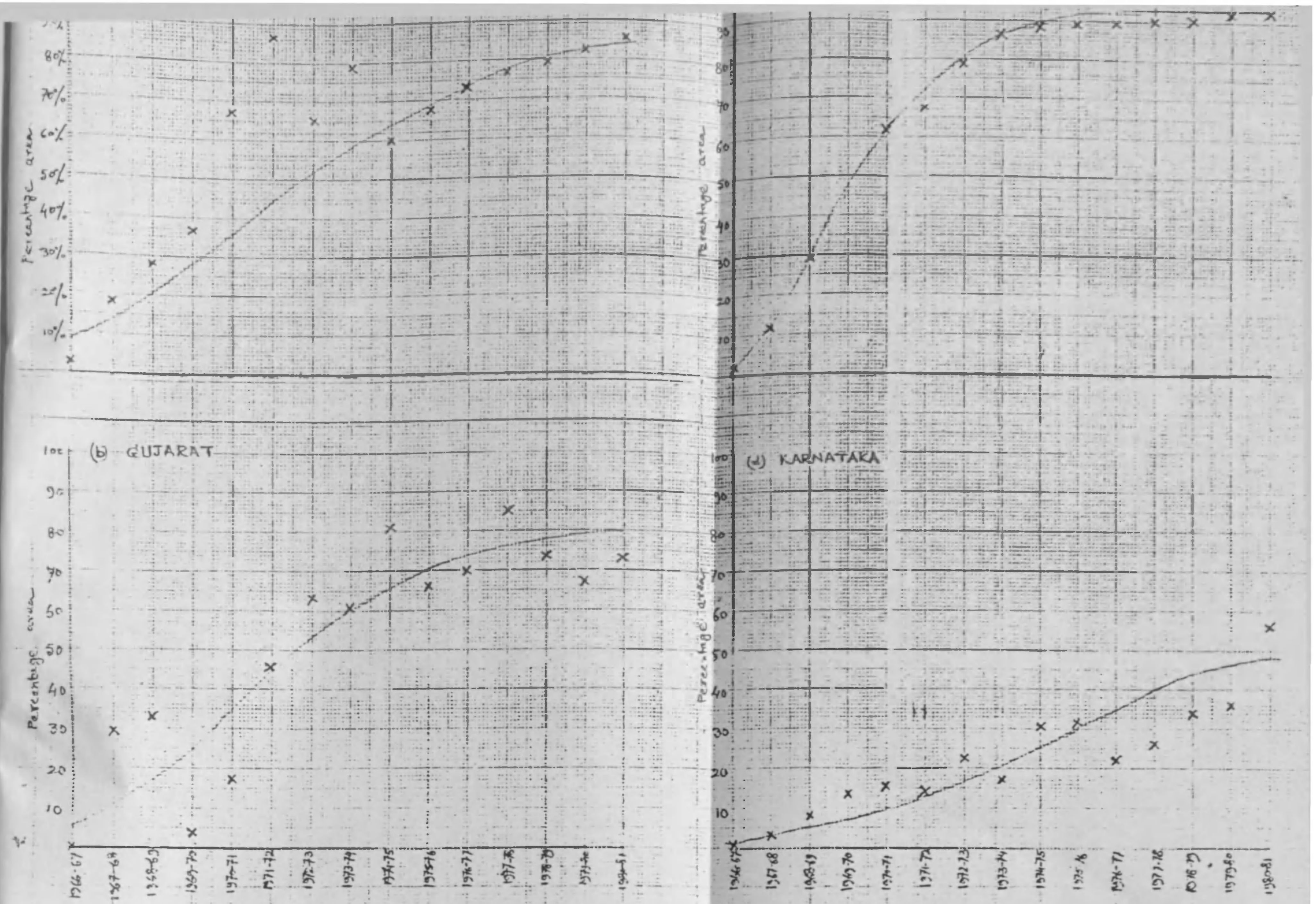
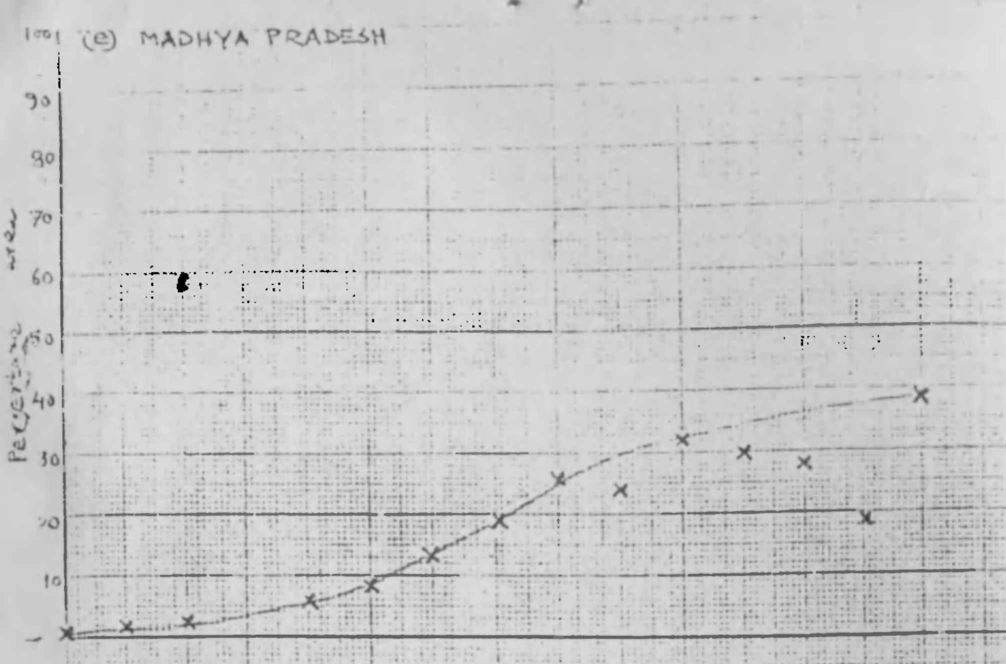
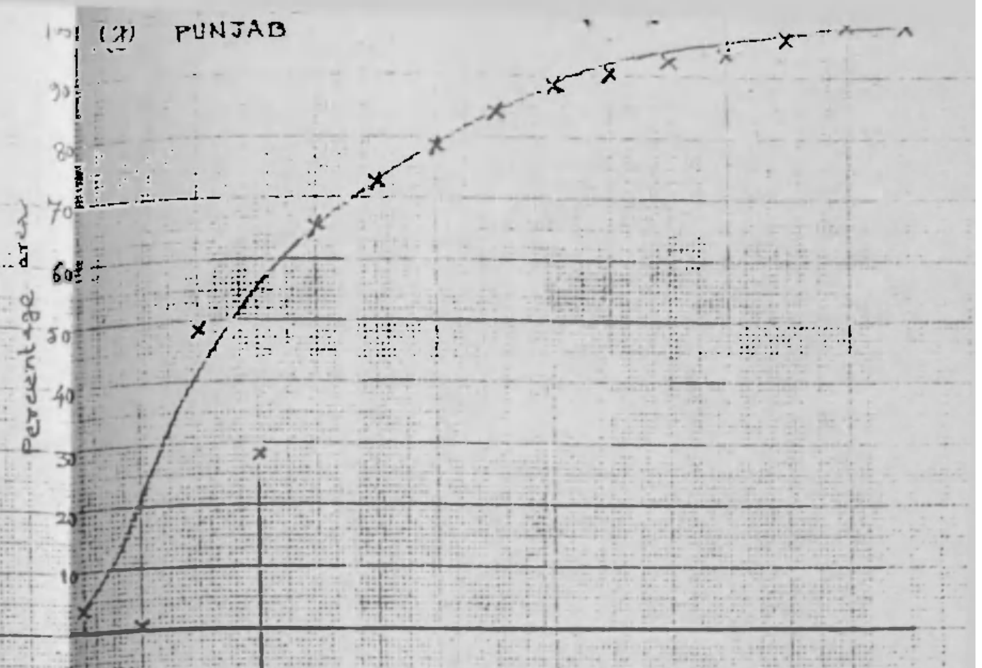
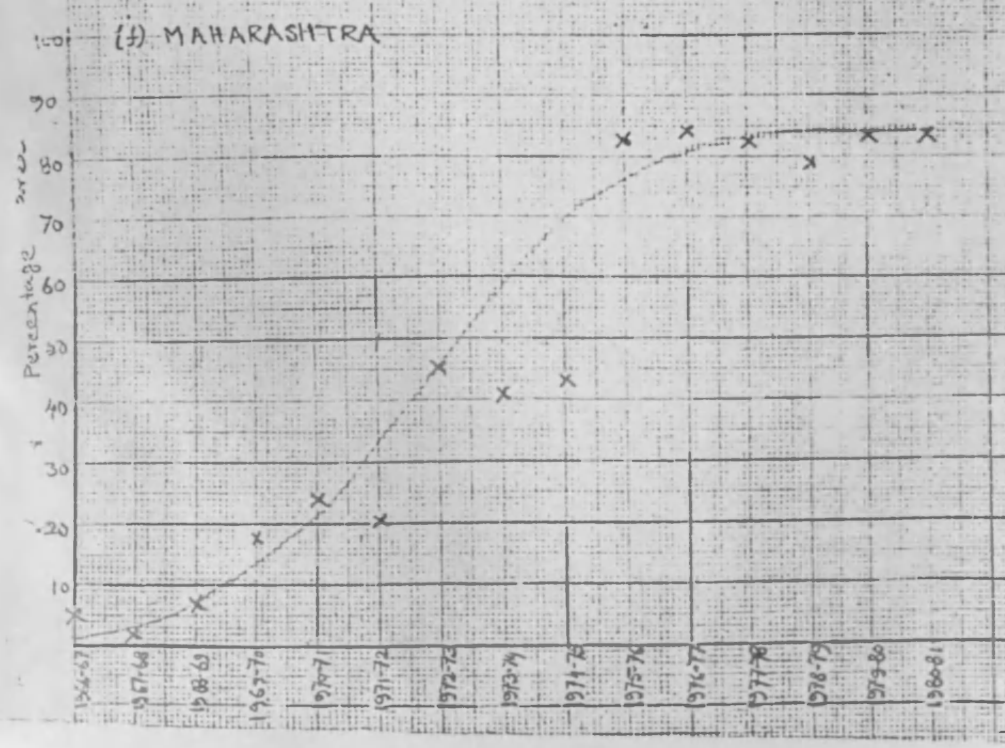


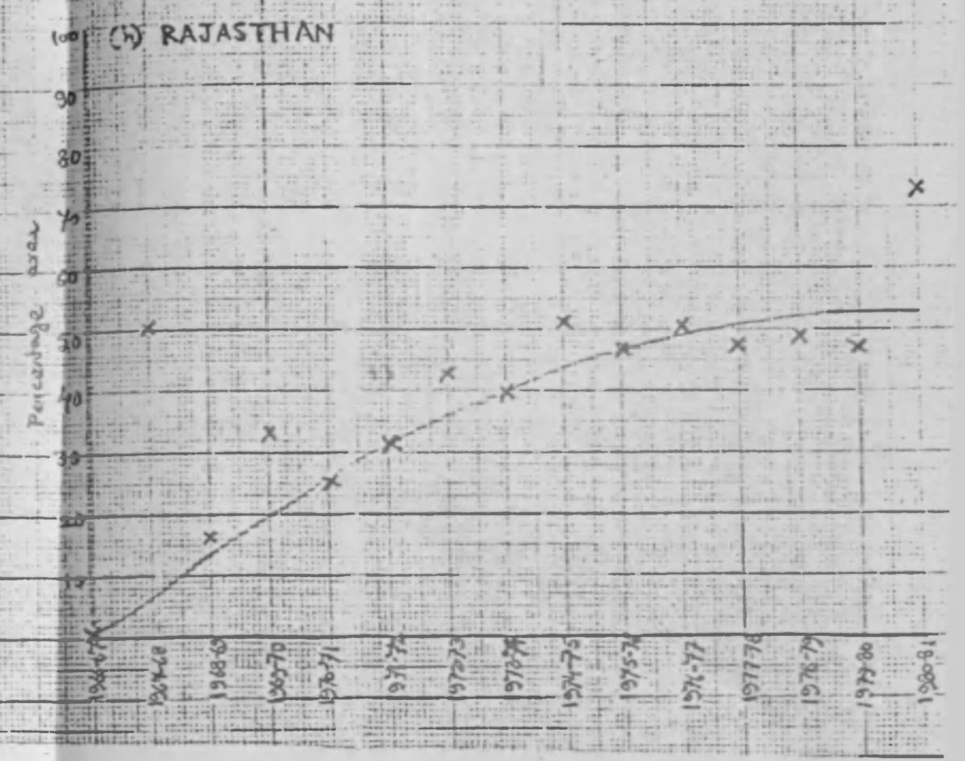
Fig. 1 : DIFFUSION OF HIGH-YIELDING VARIETY OF WHEAT IN DIFFERENT STATES OF INDIA

(contd.)


(e) MADHYA PRADESH
Percentage area


PUNJAB
Percentage area


(f) MAHARASHTRA
Percentage area


(h) RAJASTHAN
Percentage area

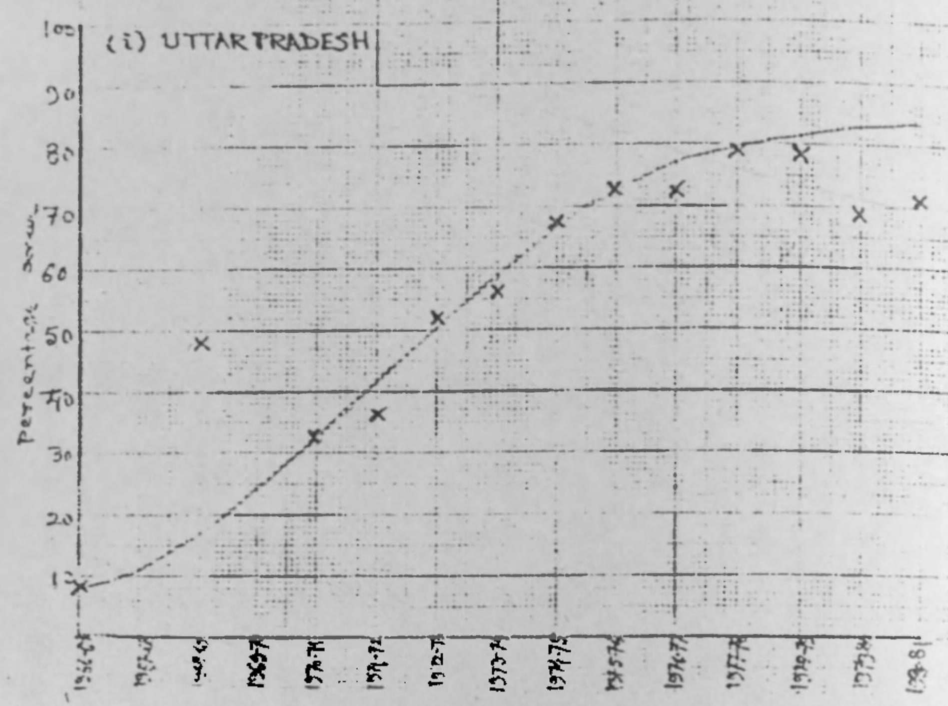


FIG. 1 (a) DIFFUSION OF HIGH-YIELDING VARIETY OF WHEAT IN DIFFERENT STATES OF INDIA

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