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Using Measurement of Risk Attitude in Modeling Farmer's Technology Choices

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Abstract

The paper comprises a description of the use of some experimental measurements of risk attitudes of rural households in semi-arid tropical India in a modelling study of technology choice by farmers. A quadratic risk programming approach which has merit in modeling farmers' decision making in high risk, mixed cropping situations in SAT India and which can be specified in a whole-farm context requires consideration of farmers' risk attitude. Values of absolute risk aversion as defined by Pratt are derived from the estimates of partial risk aversion coefficients which were estimated by Binswanger by doing a relatively large-scale study of risk attitudes of rural households. The derivation has allowed us to establish relationship between absolute risk aversion coefficient and net income of farm plan. On the scant of evidence that we have obtained in the paper, the merit of the approach used for deriving absolute risk aversion coefficients may be regarded as 'not yet proven'. There is need to accumulate more results comparing computed farm plans with actual at various levels of risk aversion and for a variety of locations.

USING MEASUREMENTS OF RISK ATTITUDES IN MODELING FARMERS' TECHNOLOGY CHOICES

J.B. Hardaker and R.D. Ghodake*

INTRODUCTION

In efforts to improve the productivity of agriculture in developing countries attention has been directed to the friction to adoption of improved technologies caused by farmers' aversion to risk. This paper comprises a description of the use of some experimental measurements of risk attitudes of rural households in semi-arid tropical (SAT) India in a modeling study of technology choice by farmers in the same region.

In modeling decision making by farmers in high-risk, mixed-cropping situations in SAT India, Ghodake and Hardaker (1981) have argued that the quadratic risk programming (QRP) approach of Freund (1956) has merit. A QRP model may be specified in a whole-farm context in the form:

(1) maximize $M = C'X - \frac{\alpha}{2} X'QX$

(2) subject to $AX \leq B$

(3) $X \geq 0$,

where M = certainty equivalent (CE) of income (to be maximized to optimize the farmer's expected utility);

C = vector of activity expected net revenues;

X = vector of activity levels;

= absolute risk aversion coefficient describing the tradeoff the farmer makes between expected value and variance of income;

Q = variance-covariance matrix of activity net revenues;

A = matrix of input-output coefficients;

B = vector of levels of resources and constraints.

It follows that, to implement this model, it is necessary to know the value of α appropriate to a particular

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farm or group of farms.

Following Binswanger (1981), the risk attitudes of an individual can be defined in terms of Bernoullian utility theory. Let W be final wealth, consisting of initial wealth w plus the CE of income in the current period, M, i.e.

$$(4) \qquad W = w + M$$

Then for a utility function U(W) = U(w+M), Pratt (1964) defined a measure of absolute risk aversion

$$(5) \qquad \alpha = -U''(W)/U'(W) = -U''(M)/U'(M)$$

where the single and double primes indicate first and second derivatives, respectively. Furthermore, both Menezes and Hanson (1970), and Zeckhauser and Keeler (1970) have defined partial risk aversion

$$(6) \qquad P = -MU''(W)/U'(W) = M\alpha$$

It is clear from this equation that $\alpha = P/M$.

The absolute risk aversion measure traces the attitude of an individual to a risky prospect as wealth rises but the prospect remains the same, whereas the partial risk aversion measure traces the attitude when the prospect changes by a constant proportion but wealth remains the same.

MEASUREMENT OF RISK ATTITUDES

In a relatively large-scale study of risk attitudes of rural households in SAT India, Binswanger (1980) used an experimental approach, involving lotteries with real money payoffs [1]. Respondents were offered a choice among a set of lotteries of increasing expected payoff associated with increasing dispersion. From the choices recorded, each respondent was classified on a scale of risk aversion, as shown in Table 1. As indicated in the table, the experiment was repeated with progressive increases in scale of the payoffs. The Rs. 500 game was conducted with hypothetical payoffs only.

By the nature of the experiment, it was not possible to determine precisely each respondent's degree of risk aversion. Instead, Binswanger used a constant partial risk

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[1]. Earlier attempts by agricultural economists to measure farmers' risk attitudes have been based on utility functions derived from elicited CEs of hypothetical lotteries (e.g. Officer and Halter. 1968; Dillon and Scandizzo 1978). Binswanger claims to have demonstrated that the experimental approach is superior to the approach using hypothetical payoffs.

Table 1. Effects of payoff size on distribution of risk aversion measured by partial risk aversion coefficients, with associated certainty equivalents[a]

	Risky prospects						Total sample	Inefficient choices
	O	A	B	C	E	F		
PAYOFFS[b]	Alternatives at Rs. 50							
x_g (50%)	50	45	40	30	10	0		
x_b (50%)	50	95	120	150	190	200		
GAME SIZE	Frequencies of choice (%)						no.	no.
Rs. 0.50	1.9	8.9	15.9	32.0	23.3	18.1	119	12
Rs. 5	1.0	9.2	27.7	39.9	13.3	9.2	117	9
Rs. 50	2.8	5.6	38.4	43.9	7.5	1.9	118	11
Rs. 500	2.6	14.0	53.0	29.5	0.0	0.9	118	3
	Risk attitudes[c]							
RANGE OF P								
From	∞	7.51	1.74	.812	.315	0		
To	7.51	1.74	.812	.315	0	−∞		
RANGE OF M[d]								
From	-	50.0	62.1	71.3	82.9	100.0		
To	50.0	62.1	71.3	82.9	100.0	-		

a. Taken from Binswanger (1981).
b. x_g='good luck' payoff; x_b='bad luck' payoff.
c. P = partial risk aversion coefficient.
d. M = Certainty equivalent for Rs. 50 game.

aversion utility function:

$$(7) \qquad U = (1-P)M^{(1-P)}$$

to fix upper and lower limits of P for each lottery. These limits are also shown in the table.

A summary of Binswanger's results of relevance to the present study is presented in Table 2. Because the experimental method used only allowed each respondent to be assigned to an interval of the scale of P, in preparing the summary in Table 2 it was necessary to work with grouped data. By plotting the observed frequencies of responses representing different degress of risk aversion in cumulative form, it was possible to estimate the distributions of P of the sample population for games of different sized payoffs. The mean values of P shown were derived from these estimated distributions. Because of the skewed nature of the distributions, geometric means were computed (see footnote a to Table 2).

For each size of game the mean value of P was associated with a corresponding value of M - the certainty equivalent of the preferred lottery for that value of P. These M values were obtained from the cosntant partial risk aversion utility function by solving

$$(8) \qquad M = [\tfrac{1}{2}\{x_g^{(1-P)} + x_b^{(1-P)}\}]^{1/(1-P)}$$

where x_g and x_b are the 'good luck' and 'bad luck' outcomes, respectively, for the preferred lottery and P is set at the corresponding mean value.

From the four pairs of values of P and M, the values of α shown can be obtained via equation (6), i.e. $\alpha = P/M$. Finally, to complete the table, the standard deviations of the preferred lotteries at each mean value of P were computed.

The results summarized in Table 2 show that the average degree of risk aversion of the same group of respondents, measured by either P or α, changes with the size of the game. The geometric means of partial risk aversion, together with both the CEs and the standard deviations of the payoffs of the preferred lotteries at these values of P, all increase with game size, while the corresponding values of α decline. Moreover, there is a substantial variation in the values of α across game sizes, so the question arises of how to derive from these data the value of α appropriate for modeling choices of risky alternatives at the whole-farm level.

Table 2. Geometric means of partial risk aversion with corresponding levels of absolute risk aversion associated with certainty equivalents and standard deviations of payoffs.

Item	Game size[a]			
	Rs 0.5	Rs. 5	Rs. 50	Rs. 500
Mean partial risk aversion[a] (P)	0.4936	0.6225	0.7609	1.1341
Implied preferred lottery[b]	C	C	C	B
Corresponding certainty equivalent (M) (Rs.)	0.7869	7.566	72.45	679.0
Corresponding absolute risk aversion (α)	0.6273	0.08228	0.01050	1.6703×10^{-3}
Standard deviation of lottery payoffs, (σ) (Rs.)	0.6	6	60	400

a. Derived from the cumulative distributions of responses. Negative values of P at the lower tails of the distributions for the Rs. 0.5 and Rs. 5 games were combined as arithmetic means with the geometric means of the positive values.

b. See Table 1 for details.

Quizon, Binswanger and Machina (1982), in a reinterpretation and correction of the results and conclusions reported by Binswanger (1981), point out that the experimental results are inconsistent with the joint hypotheses of asset integration and linearity in probabilities. The results do not, however, permit discrimination between behavior consistent with asset integration alone, with linearity in probabilities alone, or with neither [2]. This uncertainty about the choice of an appropriate model complicates the use of Binswanger's results for our purposes.

ALTERNATIVE INTERPRETATIONS OF THE EXPERIMENTAL RESULTS

If linearity in probabilities is assumed without asset integration, serious anomolies are encountered in attempting to use the results summarized in Table 2 for whole-farm planning. It may be seen that α decreases sharply from 0.6273 to 0.001670 for an increase of M of about Rs. 678 only. Clearly, the assumption of approximately constant absolute risk aversion made in relation to the QRP models is inconsistant with these results.

Setting aside this difficulty for the present, a relationship can be established between risk aversion and M. A convenient approach is to relate P to M and then to derive α as P/M. A good fit to the four data points is given by

$$\ell n\ P = -0.70815 + 0.11957\ \ell n\ M, \tag{9}$$

confirming the expectation of Zeckhauser and Keeler (1970) of increasing partial risk aversion. To find the appropriate value of P (and hence of α) for any risky prospect, it would seem plausible to substitute the appropriate value of M in equation (9). (The simultaneity problem that M for a risky prospect depends on P can be solved iteratively, starting with M set at the expected value of the prospect).

To follow the above procedure it is necessary to make a judgment about how the respondents in the experiments viewed the gains they received in the games, relative to the way they would view other risky prospects such as an uncertain annual income from farming. One possibility is that respondents viewed the game payoffs as net additions to their current incomes, so that in building a model of a whole-farm situation with current technology, structured to represent the current situation of a farmer, the value of M would be approximately zero. For low positive values of M, α is very large, and it is undefined for $M \leqslant 0$, making this

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[2]. More light would have been shed on these matters had Binswanger not confined his experiment to games with constant proportionate changes in payoffs.

interpretation untenable.

On the other hand, respondents may have viewed the game payoffs relative to a zero level of income, and might view farm incomes similarly. In this case, the definition of farm income becomes crucial - for example, is subsistence income to be included? - but, at least for large farmers, low values of α are obtained. If M = Rs. 12,000, for example $\alpha = 0.000126$.

Clearly, the predicted values of α are very much affected by the reference level of income adopted. In fact, the adoption of any fixed reference level amounts to an assumption of income integration. According to Binswanger (1981), this is equivalent to asset integration and so is inconsistent with the other assumption of linearity in probabilities. The unsatisfactory nature of the results is therefore not surprising.

Without income (or asset) integration, even with linearity in probabilities, it must be expected that different prospects will be evaluated by a decision maker in different ways, depending on the reference point he choses for each (Kahneman and Tverskey 1979). In this case, therefore, there is no reliable way of extrapolating from the results in Table 2 to the whole-farm situations of interest.

If on the other hand, asset (and hence income) integration is assumed, the experimental results may be interpreted in terms of nonlinearity in probabilities, which can be regarded as equivalent to variance preference. For risks of the same variance, equation (5) may be presumed to hold. While on a priori grounds absolute risk aversion may be expected to decline with wealth (Pratt 1964), Binswanger (1980) found only a weak effect of wealth on P. We may therefore assume constant partial risk aversion, again for constant variance, and can seek to explain the results in Table 2 in terms of shifts in the constant absolute risk aversion utility function arising from different levels of variance.

From the data in Table 2 it is possible to relate the values of α to σ, the standard deviations of the preferred lotteries. The function chosen using regression and graphical comparison with the data points to describe this relationship is

$$(10) \quad \ell n \, (1/\alpha) = 0.89557 + 0.90904 \, \ell n \sigma$$

To estimate the appropriate value of α for the whole-farm planning model the value of σ, the standard deviation of net income for the optimal farm plan, should be substituted in the above equation. Since this cannot be known initially, an upper bound can be set as the σ value of the linear programming (LP) solution. The value of σ found for the optimal solution of the QRP model solved using this initial α can be used to obtain a second estimate of α, and so on as necessary [3]. As illustrated below, this procedure yields values of α for the whole-farm models that are broadly constant with prior expectations.

In summary, the explanation of the experimental risk measurements in terms of variance preference has a marked pragmatic advantage over an attempted explanations in terms of linearity in probabilities without asset or income integration, in that it does yield seemingly plausible estimates of α for the whole-farm situations of interest. The alternative approach based on assumed linearity in probabilities yields widely variable results, depending on the reference point(s) of income chosen. In using the variance-adjusted α values it is, however, important not to overlook Binswanger's (1981) conclusion that the risk measurements are in fact inconsistent with the subjective expected utility (SEU) theory on which QRP is founded. Nevertheless, as Binswanger argues, SEU coupled with approximate estimates of risk aversion measured in the experiments, may still provide the best operational model of behavior under uncertainty.

APPLICATION IN SAT AGRICULTURE

The procedure outlined in the previous section for estimating appropriate values of α under the assumption of variance preference has been applied to a series of relatively large-scale QRP models of three 'typical' family farm situations in aurepalle village, Andhra Pradesh, in SAT India. Table 3 shows the main steps in deriving values of α for typical small, medium and large farms. It can be seen that α declines with farm size, which is consistent with expectations (Pratt 1964). The result arises, however, from the variance effect rather than from the wealth effect.

Table 3 also contains 'high' and 'low' values for α for each farm size. These limits were obtained by extrapolating from the dispersion of risk attitudes found by Binswanger in the Rs. 50 and Rs. 500 games. Approximately two-thirds of farmers may be expected to have risk attitudes within the range indicated [4].

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[3]. Experience shows that the process generally converges quickly.

[4]. Assuming, of course, that the risk preference assumptions are valid. The range was deduced from the standard deviation of ℓn P for the Rs. 50 and Rs. 500 games.

Table 3. Initial and revised values of α for three typical farms of different sizes, Aurepalle village.

Farm size	Risk aversion level[a]	Standard deviation from LP solution (Rs.)	Initial value of α	Revised value of α
	Low	-	-	7.267×10^{-4}
Small	Medium	537	1.348×10^{-3}	1.392×10^{-3}
	High	-	-	2.666×10^{-3}
	Low	-	-	4.219×10^{-4}
Medium	Medium	942	8.082×10^{-4}	8.081×10^{-4}
	High	-	-	1.548×10^{-3}
	Low	-	-	1.032×10^{-4}
High	Medium	5434	1.643×10^{-4}	1.977×10^{-4}
	High	-	-	3.787×10^{-4}

a. 'Medium' values are based on equation (10), derived from the geometric means of P in Table 2. 'Low' and 'high' values are estimated using the standard deviations of ℓn P.

Using the low, medium and high levels of risk aversion for each farm size category, the utility-maximizing farm plans were computed. Table 4 contains information about the results.

The extent to which risk aversion may be presumed to act as a friction on farmers' choices of technologies can be assessed first by the precentage reductions in expected incomes compared with the risk-neutral solutions. If society as a whole may be presumed to be risk indifferent, these differences indicate what would be the social costs of farmers' risk aversion if farmers adopted the optimal plans. It may be seen from the table that, in most cases, the reductions in expected income are low. They exceed 5 per cent only for small and medium farms when risk aversion level is high.

As might be expected, the effects of accounting for risk aversion on the variability of farmers' incomes, as measured by the percentage reduction in the standard deviation of income compared with the risk-neutral solution, are somewhat more substantial. Reductions in excess of 20 per cent are recorded at the high risk aversion levels for medium and large farms. However, for the medium farm no reduction is recorded at lower levels of risk aversion, while the effect for the small farm is quite minor at low and medium risk aversion levels.

A further indication of the effect of risk aversion on choice of technology is provided by the crop diversification indexes shown in Table 4. The index used is computed from the cropping patterns of the optimal solutions as:

$$(11) \qquad I = 1-\Sigma_j \, p_j^{\,2}$$

where p_j is the proportion of land allocated to crop j. The index I has an upper bound of 1.0 and takes a value of zero for monoculture.

The results are generally consistent with those just discussed. Crop diversification generally does increase with risk aversion, but not universally so. (On the large farm diversification declines as risk aversion goes from the medium to the high level.) A notable feature is that diversification increases with farm size when the lower risk aversion of larger farmers, considered in isolation, might have been expected to cause less diversification. The reverse result, which is consistent with observed behavior, can be attributed to differences in patterns of resource availability, particularly to increased access to irrigation and a need to spread labor peaks on larger farms.

Table 4. **Effect of size of typical farm and of farmers' risk attitudes on mean and standard deviation of farm income and on crop diversification for optimal farm plans, Aurepalle village.**

Farm size	Degree of risk aversion[a]	Percent reduction in[b] Expected income	Percent reduction in[b] Standard deviation of income	Crop diversification index[c]
	Low	0.52	3.54	0.626
Small	Medium	0.52	3.54	0.626
	High	5.25	11.73	0.665
	Low	0	0	0.723
Medium	Medium	0	0	0.723
	High	7.81	20.38	0.785
	Low	0.72	10.86	0.820
Large	Medium	2.35	18.40	0.830
	High	3.66	21.33	0.799

a. As in Table 3.

b. This is in relation to the level obtained from the risk neutral farm plan.

c. Crop diversification index; $I = 1 - \sum_{j=1}^{n} p_j^2$, where p_j = proportionate area under j^{th} land use activity and n = total number of land use activities in an agricultural year.

It should be noted that these comparisons provide only a weak test of the method used to estimate α and of its magnitude. The optimal solutions are influenced by many factors of which degree of risk aversion is but one. Moreover, it is conceivable that other approaches to the estimation of α, based on other assumptions, would have given similar results. Nevertheless, it can be seen from Table 5 that, for the small farm case, conformity with actual land-use pattern is better at the medium and low levels of risk aversion than at either the high level or the risk neutral level. For the medium farm, risk aversion has no effect until it is set at the high level, when land use is less well predicted than otherwise. Finally, in the large farm case, conformity with the actual farm plan decreases consistently as assumed level of risk aversion rises.

In summary, only in the case of the small farm does it appear at all important to account for risk aversion, when use of the medium value of α leads to as good or better prediction of behavior than higher or lower values. On the medium farm, the 'best estimate' of α yields plans no better, but also no worse, than lower values. For the large farm, however, it seems that α may have been overestimated since even the low value used predicts behavior less well than does the LP solution.

The seemingly reasonably reliable estimate of α for the small farm case may be explainable by the relatively small amount of extrapolation required from the experimental data. For the other two farm size categories, however, and particularly for the large farm, it seems that risk aversion may have been overestimated.

CONCLUSIONS

It is disappointing but perhaps not surprising, given the extent of extrapolation involved, that using Binswanger's experimental measurements of risk attitudes in whole-farm modeling proved not to be straightforward. Because of obvious financial constraints, the magnitudes of the payoffs used in the games were limited. Moreover, for the initial lower-value games, there was a wide dispersion of responses across individuals. The dispersion was reduced when the payoffs were increased, suggesting that many respondents may have applied little introspective effort in the initial games. Too much emphasis should not be placed, therefore, on the responses to these low-value games and on apparent inconsistencies between these responses and those to higher value games. Ideally, further experimentation including, for example, spread-preserving as well as proportionate changes in game size, and, if possible, games involving possibilities of losses, is needed to establish more clearly the nature of behavior under risk and to assess how serious are the departures from the axioms of expected utility

Table 5. Mean absolute deviation between observed and predicted land use patterns under different levels of risk aversion for small, medium and large typical farms, Aurepalle village[a].

Farm size	Risk aversion level[b]			
	Risk neutral (ha)	Low (ha)	Medium (ha)	High (ha)
Small	0.161	0.154	0.154	0.159
Medium	0.068	0.068	0.068	0.342
Large	0.937	0.945	1.229	1.449

a. The detailed activity-wise land use patterns are given in Appendix Table 1.

b. As in Table 3.

theory.

The difficulty encountered in interpreting the risk measurements in a whole-farm modeling context does not detract from the insights gained from Binswanger's measurements into differences in economic behavior that Binswanger, Jha, Balaramaiah and Sillers (1980) showed to be associated with interpersonal differences in risk aversion. Their findings clearly signal the need to find the means of accounting for risk aversion in at least some models of risky choice.

Since interpretation of Binswanger's results based on assumed linearity in probabilities was shown to give inconsistent results, extrapolations to the whole-farm level had perforce to be based on an assumption of variance preference. An attempt to validate the procedure used by comparing actual and predicted patterns of land use for three typical farms was not conclusive. It appears that risk aversion was not important in determining land use on the medium and large farms, presumably because, as the LP results show, a diversified cropping pattern is necessary on these farms to satisfy the resource constraints.

The extrapolation procedure used gave a relatively good prediction of actual cropping pattern for the small farm, and a satisfactory prediction for the medium farm. For the large farm, risk aversion was apparently overestimated. The degree of extrapolation from the experimental data was small in the small farm case but was substantial for the large farm. It is therefore not possible to determine whether the discrepancy between predicted and observed behavior in the large farm case was due to the no doubt substantial errors of extrapolation, to a false assumption of variance preference, to other factors.

On the scant evidence so far accumulated, the merit of the approach used for deriving α values for whole-farm planning must be regarded as 'not proven'. There is a need to accumulate more results comparing computed farm plans with actual at various levels of risk aversion and for a variety of locations. Such data would permit a more reliable assessment of the importance of risk and risk aversion in farmers' technology choices, and would allow the appropriate levels of the risk aversion coefficient to be assessed. By making available such data on revealed risk preferences, a better interpretation of Binswanger's experimental risk aversion measurement should be possible.

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Appendix Table 1. Observed and predicted land allocation to different land use activities under various risk aversion levels (small farm).

(ha)

Land use activity	Observed	Risk neutral	Low	Medium	High
1. Paddy (First season)	-	-	-	-	-
2. Paddy (Second season)	-	-	-	-	-
3. Chillies	-	-	-	-	0.064
4. Sorghum+pearl millet+pigeonpea	0.782	0.612	0.650	0.650	0.618
5. Local paddy followed by HYV paddy paddy	-	-	-	-	-
6. Local paddy (First season)	-	-	-	-	-
7. HYV paddy followed by HYV paddy	-	-	-	-	-
8. Castor	-	0.846	0.803	0.803	0.763
9. Local sorghum	0.513	0.082	0.087	0.087	0.083
10. Pulses	-	-	-	-	0.012
11. Fallow (First season)	0.243	-	-	-	-
12. Fallow (Second season)	0.243	-	-	-	0.012

Appendix Table 2. Observed and predicted land allocation to different land use activities under various risk aversion levels (medium farm).

(ha)

Land use activity	Observed	Risk neutral	Low	Medium	High
1. Paddy (First season)	--	0.10	0.10	0.10	0.10
2. Paddy (Second season)	-	-	-	-	-
3. Chillies	-	-	-	-	0.10
4. Sorghum+pearl millet+pigeonpea	1.056	1.182	1.182	1.182	0.649
5. Local paddy followed by HYV paddy	-	-	-	-	-
6. Local paddy (First season)	-	0.152	0.152	0.152	0.152
7. HYV paddy followed by HYV paddy	-	-	-	-	-
8. Castor	1.488	1.459	1.459	1.459	0.801
9. Local sorghum	-	0.158	0.158	0.158	0.087
10. Pulses	-	-	-	-	1.162
11. Fallow (First season)	0.220	-	-	-	-
12. Fallow (Second season)	0.220	0.252	0.252	0.252	0.252

Appendix Table 3. Observed and predicted land allocation to different land use activities under various risk aversion levels (large farm).

(ha)

Land use activity	Observed	Risk neutral	Low	Medium	High
1. Paddy (first season)	0.526	-	-	-	-
2. Paddy (Second season	0.175	0.421	0.421	0.421	0.421
3. Chillies	0.648	-	-	-	-
4. Sorghum+Pearl millet+pigeonpea	1.889	2.830	3.852	2.400	1.885
5. Local paddy followed by HYV paddy	0.148	1.446	1.446	1.446	1.446
6. Local paddy (First season)	0.270	-	-	-	-
7. HYV paddy followed by HYV paddy	0.782	0.285	0.285	0.285	0.285
8. Castor	5.288	6.610	4.756	2.963	2.327
9. Local sorghum	0.512	0.377	0.514	0.320	0.251
10. Pulses	-	0.421	1.116	4.555	5.775
11. Fallow (First season)	2.242	-	-	-	-
12. Fallow (Second season)	2.698	-	0.695	4.134	5.355