Jour. Ind. Soc. Ag. Statistics
54(1), 2001 : 139–173

Symposium on "Statistical Issues in National Agricultural Insurance Scheme"

Chairman:	Prof. Prem Narain
Convenors:	Dr. A.K. Srivastava
	Shri D.K. Trehan

The Chairman introduced the topic and emphasised the role and importance of statistics in Crop Insurance in general and NAIS in particular. He recollected the role of Indian Society of Agricultural Statistics in the conduct of Comprehensive Crop Insurance Scheme (CCIS) in late eighties. It was pointed out that many statistical issues relating to premium rating, indemnity determination and crop yield estimation for assessing the losses at area unit level were tackled at that stage. Some research problems emanating from the practical experience were also tackled by M.Sc. and Ph.D. students at that time.

Dr. Srivastava, one of the convenors, presented the background of the symposium and discussed about papers invited in the symposium from different organisations involved in the planning and implementation of NAIS.

Following papers were presented in the symposium:

1. Role of yield data in National Agricultural Insurance Scheme — *B.M. Sharma*
2. Actuarial premium rating in crop insurance — *K.N. Rao*
3. Statistical issues in premium determination in crop insurance — *Shivtar Singh*
4. An approach for estimation of crop yield at Gram Panchayat level for National Agricultural Insurance Scheme — *A.K. Srivastava & Anil Rai*
5. Application of G.I.S. and Remote Sensing in crop yield estimation - Crop Insurance perspective — *Anil Rai, Randhir Singh & A.K. Srivastava*

Mr. Trehan one of the convenors, Mr. S.D. Chopra and Dr. Rajiv Mehta could not participate in the symposium due to their engagements at Delhi, however, the papers of Mr. S.D. Chopra and Dr. Rajiv Mehta were highlighted by one of the convenors.

Following recommendations emerged from presentation of papers and discussions held in the symposium:

1. In the NAIS, area unit level has been reduced from Block level to Village Panchayat level. The pros and cons of reducing the area unit level with respect to availability of estimates, at that level, of different crops under NAIS as well as with respect to assumption involved should be examined.
2. The approach of farmer's estimates for developing crop yield estimates at Village Panchayat level should be attempted with caution. Issues like assumption involved, acceptability of the approach and risks relating to response biases should be addressed at a pilot level.
3. Since interests of farmers are involved in the crop insurance, any methodology must be insulated from the pressures due to interests of stake holders. A continuous vigilance mechanism to maintain the reliability of the system must be an integral part of the approach.
4. Any approach to obtain the crop yield estimates at V.P. level should ensure that it does not have any adverse effort on the system of agricultural statistics.
5. In the farmer approach, besides obtaining yield information from farmer, related information from other experts should also be collected and appropriately utilised.
6. In the actuarial framework of crop insurance, at present the temporal yield variability is accounted for in premium determination. Keeping in view the risks and variability existing at spatial level, the spatial variability should also be accounted for in premium determination. Some research studies for this purpose may be needed which should be taken up.
7. With respect to application of remote sensing in NAIS context, issues relating to spatial regression and prediction models need to be addressed. Studies need to be carried out for RS and GIS applications to NAIS which should be integrated with the existing system of NAIS.
8. Crop insurance has got human and legal dimensions. Any viable alternative must have the objectivity and firmness to deal with legal aspects and it must have the human approach and confidence of the people for its wider acceptability.

Role of Yield Data in National Agricultural Insurance Scheme

B. M. Sharma
General Insurance Corporation of India, New Delhi-110 001

The yield data as generated under General Crop Estimation Surveys (GCES) has been used for macro level planning and production estimates since long, it is relatively recent that the yield data is being used for deciding compensation under crop insurance schemes. It is with introduction of Pilot Crop Insurance Scheme in 1979 and subsequently the Comprehensive Crop Insurance Scheme (CCIS) in 1985 which gave new dimension to the yield data generated under GCES. It is for the first time under Crop Insurance Schemes, the short fall in yield as decided based on GCES estimates, is converted to money in terms of compensation payable. In other words, the yield data assumed significance in view of its linkage with compensation under Crop Insurance Schemes.

While the primary purpose of yield data under CCIS was to decide the compensation, it gained more significance under National Agricultural Insurance Scheme (NAIS) due to its relevance in various other aspects of the scheme. The role of yield data in NAIS can be considered in the following areas :

(a) Payment of compensation :

I. Fixing of Indemnity Limits

II. Fixing Threshold Yield

III. Determining shortfall in yield

(b) Arriving actuarial premium rates

(c) Fixing maximum sum-insured limits

Let us have look at the details of each of the areas.

(a) Payment of Compensation :

I. Fixing of Indemnity Limits - As per the Scheme provisions three levels of indemnity has been fixed, viz. 60%, 80% and 90% corresponding to high, medium and low risk crops / areas. The Indemnity Limits vis-a-vis the variability in yield based on preceding 10 years' yield data are given in the table :

Coefficient of variation	Risk group	Indemnity Limit
Upto 15%	Low risk	90%
>15% and upto 30%	Medium risk	80%
>30%	High risk	60%

In practice, since the indemnity limits are fixed State as a whole, the majority principle is used to fix one indemnity limit at State level. In other words, the number of strata falling under each of the risk group shall decide the indemnity limit to be given at State level.

II. Fixing Threshold Yield - The threshold yield is average of past three or five years yield multiplied by the level of indemnity. In case of Paddy and Wheat, the average is based on past three years and for rest of the crops, it is based on five years. Threshold yield is also known as Guaranteed Yield and is a moving / rolling average.

III. Determining Shortfall in Yield - Shortfall is the difference between the threshold yield and the actual yield recorded during the season.

(b) Arriving Actuarial Premium Rates

Normal distribution method is being used to determine the pure premium rate under NAIS. Shri N.G. Pai, the consultant Actuary of NAIS recommended premium rating based on normal distribution which presumes that "irrespective of the population, the sample mean will always follow normal distribution". Shri Pai prepared readymade table of premium rates at various levels of indemnity corresponding to coefficient of variation (c.v.). As per the table, premium rate will go up with increase in c.v. and further the rates will be high at higher levels of indemnity.

(c) Fixing Maximum Sum-insured Limits

The NAIS is compulsory for farmers availing crop loans from Financial Institutions and is optional for others. The compulsory element in case of loanee farmers is applicable to the extent of amount of loan availed while in case of non-loanee farmers, the insurance coverage is given upto value of the threshold yield. Both, for loanee and non-loanee farmers the sum-insured can be extended upto the value of 150% of average yield on payment of premium at commercial rate for sum-insured exceeding value of threshold yield.

In the light of the multi-dimensional use of yield data in the NAIS, the accuracy of data under GCES assumes greater significance. While the GCES prescribes levels of accuracy required at different strata, statistically and operationally the system should be strengthened so as to maintain required levels of accuracy as desirable under NAIS. The conversion of shortfall into money as is done under NAIS is open to manipulations and pressures by vested interests, unless proper supervisory mechanism is developed. The multi-picking crops offer more scope for manipulation, unless steps are taken to streamline and strengthen the procedures.

Some of the flaws noticed by GIC in the course of witnessing of CCEs under CCIS are as follows:

1. Primary workers in many cases are not aware of system of conduct of CCEs, including selection of plot.
2. Crop cutting kit is in short supply in many States and those who have the kit hardly carry it to the field at the time of conduct of CCEs,
3. Many a time experiment is not conducted on the date confirmed few days earlier by the primary workers.
4. The produce separated for driage experiment in many cases is left to the care of farmers rather than managed by the primary workers.
5. There were many instances where the primary worker claimed to have conducted the experiment, while the farmer is unaware of any experiment being conducted in his field.
6. The absence of village map / "naksha" and delay in land record enumeration make it difficult in selection of the plot and supervision.

Actuarial Premium Rating in Crop Insurance

K.N. Rao

General Insurance Corporation of India, New Delhi -110 001

1. Premium rating techniques in the commercial insurance industry are intended to develop a price structure adequate to cover claims and the operating costs of the insurer and provide a reasonable profit while not being so high as to be noncompetitive. While in case of NAIS, it is intended to work on "no profit and no loss" basis. The secondary objectives of premium rating system are:

Stable — The technique normally incorporates stability, especially for a product that is subject to infrequent occurrences of extremely severe events.

Responsive — The technique should be responsive to changes in loss exposures. In some respects, responsiveness and stability are competing objectives. However, both must be pursued.

Provide for contingencies — The technique should include some loading for the unknown and unknowable.

Encouragement / Incentive to insured — Since premium rates are driven by expected losses, they can be made more affordable only if insured persons retain incentives to avoid losses when possible or to minimize the amount of loss, when it occurs.

Appropriately discriminatory — To be effective, premium rates must be appropriate for the risk that is presented.

2. Most insurance literature identify three generic methods for rate making:

(a) Judgement — This is the oldest method, in which the intuition of the rate maker plays a major role in setting the rate. It is very useful in setting a rate for a new crop, as reliable data for an extended historical period rarely exist.

(b) Loss ratio — Simply put, the losses paid to by those policyholders are summed up and then divided by the sum of the premiums paid by those policyholders expressed on current rate level. It is a method for adjusting an existing premium rate.

(c) Pure premium method (Loss cost) — It is a ratio of the losses paid to policyholders divided by the insurance provided to those policyholders. The pure premium method calculates a new premium rate each time it is used whereas the loss ratio method adjusts a previously established premium rate.

Besides the above, new set of methods based on mathematical or statistical modeling for losses occurring very infrequently with extremely unpredictable magnitude are also used as sophisticated techniques.

3. As per UNCTAD document on "Agricultural Insurance in Developing Countries" a standard Actuarial model for calculating the premium for crop insurance has not yet been developed. The document further states that specific formulae have been developed in different countries depending upon the parameters and variables of their programmes.

The various methods which are used world over are:

(a) The USA method: Essentially based on the idea that the set of seasonal crop yields obtained for a defined area during a representative period in the past will be repeated over a similar period in the future.

(b) The MPD method: Mean Percentage Deviation (MPD) takes into account every variation in the yield which occurs during the period and is expected to provide a stable estimate of the seasonal variability and consequently of the premiums which can be derived from such estimates.

(c) Dandekar model: Similar to MPD except that Dandekar used Mean Deviation in place of Standard Deviation.

(d) Normal Curve Technique (NCT) : It is based on the assumption that the average yields will follow normal distribution due to Central Limit Theorem, which states that whatever may be the parent distribution, the distribution of sample means is normal.

(e) Pearson Curve Technique: Based on Pearson distribution which is a function of skewness and kurtosis.

4. In addition, the available limited literature tells that premium can also be determined based on Non-parametric density methods like Histograms, the Naive Estimator and the Kernal Estimator. It has been learnt that, earlier during 1992, Ms. Geetha Lakshmi at Indian Agricultural Statistics Research Institute (IASRI) had done her thesis of Master of Sciences (Statistics) on Actuarial premium rating on Crop Insurance program and later she went on to complete her Doctorate in Statistics.

5. The author of this paper had met Dr. Geetha Lakshmi at Avikanagar (Rajasthan) during 1998 to discuss the details of methodology used in her study. She explained that almost all the parametric methods used are based on certain assumptions related data distribution etc. and sometimes these assumptions can go wrong giving less than perfect results. The method devoid of these assumptions totally or rigid assumptions is Non-parametric method, although there is no proof of it's usage in Crop Insurance premium rating. She told that the project was given to her through Dr. Prem Narain, who was Director of IASRI in the eighties and early nineties.

6. Some of the Non-parametric density methods which can be utilized in calculation of premium rates are Histograms, the Naive Estimator and the Kernel Estimator. Dr. Lakshmi had selected Kernel Estimator method and she had worked out premium rates by using two different Kernels, viz. Epanechnikov and Gaussian and compared the results with those worked out by NCT, a parametric method. She went on to compare the results of all the above three methods based on Percentage Standard Error (PSE) of Indemnity. She has statistically proved that PSE of Non-parametric method is less than that of NCT and concluded that Non-parametric method is better than parametric methods.

7. Shri N.G. Pai consulting Actuary for NAIS, on request from GIC studied some of the premium rating techniques and recommended in favour of "fitting past yield data into Normal distribution with a view to projecting the future risk premium". The method is also called Exposure Rating Method based on the statistical assumption of Normal distribution, i.e. irrespective of the population, the sample mean will always follow Normal distribution. As per Shri Pai, this method is also used in other countries. On the basis of this technique, Shri Pai has prepared readymade table of premium rates at various levels of indemnity corresponding to coefficient of variation, for simple use.

8. The technique is very useful where the data fits into Normal distribution, but the same can not be said, if the data fitting is not proper, e.g., the technique has not considered linear trend in the data. Further, if there are two areas which had same productivity of a particular crop 10 years ago, but one showing increasing trend and the other showing decreasing trend at the same rate in the last 10 years, will now receive almost same premium rating under this technique. However, the chances of claims being paid is much more in case of area with decreasing trend and almost non-existent in case of area with increasing trend.

9. A premium rate is only an estimate of the future requirements to pay losses. There is no such thing as "the one and only true" premium rating technique and rate. Though, the techniques used in countries like USA, Spain, Japan etc. by and large are from the same generic background, but are refined by use of modeling techniques and additional data on weather parameters. Well, under NAIS, it may be justified to begin with technique based on Normal distribution, but the accuracy and success of premium rating in future lies in refining the technique based on inputs from other techniques / countries and based on our own judgement.

10. The premium rating technique produces only pure premium rate, whereas the final commercial rate charged normally includes loading in respect of (1) reserve for unexpected heavy losses (2) administrative cost (3) moral hazard (4) anti-selection (5) escalation in scale of finance/sum insured (6) inconsistency in yield data and (7) profit margin etc.

The suggested loading for an illustration can be as follows:

(a) Escalation in scale of finance / sum insured – 10%

(b) Data inconsistency * – 5% for each year
(but not exceeding 20% for the parameter)

(c) Reserve for future heavy losses – 10%

(d) Anti-selection – 5%

(e) Moral hazard – 5%

(f) Admn. expenses – 5%

(g) Profit margin – 5%

*Data inconsistency indicates non-availability of certain years yield data at a given insurance unit level out of past 10 years, necessitating adoption of parent unit' data for those years.

Statistical Issues in Premium Determination in Crop Insurance

Shivtar Singh
Retired Principal Scientist, IASRI, New Delhi- 110 012

Farmers in India continually face risks in crop production right from the time of sowing to harvesting. Floods may wash away growing fields, droughts may wither plants, diseases and pests may attack during crop growth and rain or hailstorm may wipe out months of farmers' labour and likely production in a single stroke. Crop insurance is a technique of protecting the farmers from such risks. Under crop insurance by paying small amounts as premium, farmers purchase the right for compensation in the event of crop failure. Moreover, the liability of the Government to bear the cost of relief measures to the farmers following crop failure is reduced to some extent as through crop insurance the farmers themselves contribute to their own relief.

This paper is based on a project completed at IASRI, in which the statistical issues namely variation in yields, their distributions, determination of premium rates by well known methods and their comparisons, have been discussed. Data collected in the Comprehensive Crop Insurance Scheme (CCIS) implemented by the Government of India and operated through the General Insurance Corporation of India (GIC) with the active involvement of the State Governments and Union Territories were used.

The ten-year yield data of paddy and wheat crops available for the defined areas in the States of Bihar, Madhya Pradesh, Uttar Pradesh and West Bengal were used to test normality. The premium and indemnity tables were prepared following Dandekar's Mean Percentage Deviation Method (MPD), Normal Curve Technique, Square Root Transformation, Logarithmic Transformation and Type I Pearson method for comparison of the procedures. However, the MPD method was used for working out the premium rates at 80 per cent level of coverage, utilizing 5 years taluk/block yields for the period ending 1985-86 from 12 states for paddy crop, 10 states for wheat, 7 states for millets, 6 states for oilseeds and 9 states for pulses. These rates for a crop in a state were pooled to get the statewise average rate.

The premium rates in a given homogeneous defined area depend on two parameters : (i) year to year variability in the average annual yield (measured in terms of coefficient of variation) and (ii) the level of coverage. The actuarial premium rates are directly proportional to these parameters. Larger the variability, higher is the premium for a fixed level of coverage. Alternatively higher the level of coverage, higher is the premium for a fixed level of variability.

The CCIS was based on area approach. The premium rate was kept fixed, 2 per cent for paddy, wheat, and millets and one per cent for oilseeds and pulses. The threshold yield was 80 per cent of the average yield in the defined area. Claim, if any, was payable to all insured farmers uniformly and it was equal to the short fall in yield for the defined area during an insured season for an insured crop. The average yield of a crop for a given area was based on at least 16 crop cutting experiments (CCE).

It may be mentioned that the Indian Society of Agricultural Statistics (ISAS) was actively associated with the CCIS. In fact, GIC had given consultancy work including the work of preparation of premium-indemnity tables for the CCIS during the first three years of its implementation to the Society. A symposium on crop insurance was organized in 1985 during the 39^{th} Annual Conference of ISAS. The author was the convenor of that symposium and also presented a joint paper, which in sum indicated that as the CCIS was not self-supporting, the Union Government should be prepared to contribute a large sum to the insurance fund if CCIS is to take off. The claims paid under the CCIS during the first year of its operation confirmed the above conclusion.

The distribution of crop yields in the defined crop strata was tested for normality by Shapiro Wilk test at 5 per cent level of significance. It was seen that out of 529 crop strata, the normality was positive in 59 cases for paddy and in 24 cases out of 411 crop strata for wheat. The empirical findings thus showed that distribution of crop yields need not be normal. Crop strata in which the test of normality was negative were further tested for normality after applying square root and logarithm transformations of crop yields. The results indicated that these transformations were not of much help to transform the yield data to normality.

Pearson system of distributions was tried on crop yields in the unit of insurance. It was found that 80 per cent of crop strata for paddy as well as wheat followed Type I Pearson distribution and 15 to 17 per cent of crop strata confirmed Type II Pearson distribution. Only one per cent of crop strata showed a normal distribution.

Premium rates did not vary much among themselves based on normal curve technique, USA method and as worked out by Mean Percentage Deviation (MPD) method. However, premium rates estimated by Type I Pearson curve and regression techniques were lower than those estimated by other techniques. The crop strata not following normal distribution over estimated the premium rate in comparison to Type I Pearson distribution. The reduction in premium in regression technique was due to the fact that a part of variation due to systematic trend in crop yields was removed in premium estimation. The MPD procedure was preferred in premium estimation because of its simplicity in practical application and also due to accounting the variation in crop yields, which is not so in USA method. Further, it avoids estimation of parameters as is being done in normal curve and Type I Pearson techniques for each crop strata. The MPD procedure had been used in premium determination in this investigation.

The average premium rate at 80 per cent indemnifiable limit in 1985-86 at All India level was estimated at 5.3 per cent for paddy, 5.5 per cent for wheat, 9.1 per cent for millets, 9.3 per cent for oilseeds and 8.6 per cent for pulses. The corresponding figures at 90 per cent indemnifiable limit were 7.7 per cent for paddy, 7.9 per cent for wheat, 12 per cent for millets, 12.2 per cent for oilseeds and 11.4 per cent for pulses. The premium rates were more or less of the same order in the year 1986-87.

The premium rates for paddy at 80 per cent indemnifiable limit in the year 1985-86 ranged from 2.7 to 3.3 per cent in Bihar, Kerala, U.P., A.P. and Assam; from 4.7 to 8.5 per cent in West Bengal, Tamil Nadu, Orissa, Madhya Pradesh, Karnataka and Maharashtra, however, premium was 13.2 per cent in Gujarat. For wheat crop, the rates ranged from 1.2 to 4.4 per cent in U.P., Bihar, Assam, West Bengal and Gujarat; from 5.3 to 9.4 per cent in Rajasthan, Madhya Pradesh, Maharashtra and Himachal Pradesh except Karnataka (11.9 per cent). In the case of millets the premium rates were high ranging from 6.0 to 15.8 in Andhra Pradesh, Uttar Pradesh, Madhya Pradesh, Karnataka, Maharashtra and Gujarat. The premium rates for oilseeds were also high, the lowest in Bihar (5.7 per cent) and highest in Karnataka (14.6 per cent). These rates for pulses varied from 4.2 to 4.8 per cent in Bihar, U.P. and Assam and 7 to 9.8 per cent in Gujarat, Madhya Pradesh, Andhra Pradesh, Rajasthan and

Maharashtra. Karnataka state had the highest premium rate of 17.0 percent for pulses.

Variability in crop yields was observed to be more in millets, oilseeds and pulses as compared to paddy and wheat crops. Negligible percentage of crop strata had coefficient of variation less than 5 per cent for all crops. Majority of crop strata had coefficient of variation more than 20 per cent particularly for millets (73%), oilseeds (72%) and pulses (67%). Stability in crop production was noticed for wheat and paddy crops only.

Distribution of crop strata according to premium rates showed that in 39 per cent of crop strata for paddy, 43 per cent of strata for wheat, 19 per cent of strata for each of millets and oilseeds and 24 per cent of crop strata for pulses, the premium rates were upto 2 per cent at 80 per cent level of coverage. In a large number of crop strata the estimated actuarial premium rates were more than the flat rates charged in the CCIS. This implied that CCIS lacked actuarial soundness and would involve heavy losses from year to year. A further examination of variability in actuarial rates between states and between crop strata within a state for different crops revealed that a larger proportion of the total variability in premium rates ranging from 70 to 90 in 1985-86 was accounted for between crop strata within states. This implied that differential rates of premium for different crops would be more meaningful than flat rates.

The criterion of fixing the threshold yield at 80 per cent of the average yield was debated in the course of implementation of the CCIS in the states. Some of the states willing to join the scheme suggested to raise the level of coverage from 80 to 90 per cent. The progressive states with assured irrigation facilities had even claimed that the level of coverage could be as high as 100 per cent. The suggestions made by the states were examined both theoretically as well as empirically. Assuming crop yield to follow normal distribution with mean 'm' and standard deviation 'σ', the premium rates defined as average indemnity expressed as percentage of the threshold yield were calculated for coefficient of variation (CV) ranging from 5 to 40 per cent and indemnity limits varying from 65 to 100 per cent. It was seen that the raising of threshold yield to 100 per cent even in most progressive states would not be possible as 5 per cent CV may be obtainable in very few crop strata. It was perused that in broad five categories viz. CV less than 5 per cent, 5-10 per cent, 10-15 per cent, 15-20 per cent and more than 20 per cent, the level of coverage would respectively be 100, 95, 90, 85 and 80 per cent. This criterion for level of coverage would only apply for paddy and wheat and not for millets, oilseeds and pulses in which case it would be only 80 per cent. It may be mentioned that for determination of coefficient of variation in yield, the calculation of variation should take into account technological trend if found significant on the basis of at least 10 years yield data. Since CV would be on the basis of 10 years moving average for each crop strata, it should be calculated afresh every year before determining the level of coverage. An empirical study for the possible level of coverage using 10 year data on the above referred basis ranged between 80 to 90 per cent in a good number of crop strata in 9 states for paddy and 3 states for wheat.

It has been agreed upon in CCIS that average yield of a crop in a crop strata should be based on at least 16 crop cutting experiments (CCE). However, when the number of CCE conducted in a defined area was less than 16, it was suggested that the area may be clubbed with the adjoining area(s) such that the number of CCE is 16 or more and the average yield was calculated as if both the areas form a single homogeneous unit.

It is heartening to note that keeping in view the welfare of the farmer and his family, the Government of India has announced National Agricultural Insurance Scheme (NAIS) ignoring the huge claims paid in the implementation of CCIS. It may be relevant to mention that the amounts of insurance protection and premium rates should be determined not only by technical considerations alone namely the average yield of a crop and its crop loss probability but also by economic and social considerations like paying capacity of the farmers, the resources that the Government is willing to allocate as also the desirability and feasibility of income transfer from non-agricultural to the agricultural sector.

Crop Insurance as a Measure of Risk Management in Agriculture

S.D. Chopra
NCCT, New Delhi

Risk and Uncertainty

Risk and uncertainty are generally used synonymously and the events involving any one of the two relate to the future. But from the economic point of view, they are considered different from each other. Some events can be predicted at least in probabilistic terms. These occurrences can be foreseen on the basis of past experience. Such events are said to involve risk and not uncertainty. In other words, all risks are uncertain, but all uncertainties are not strictly risks. Only uncertainties which can be concretized into specific happenings - past, present or future - can be covered by Insurance. According to Wallat existence of uncertainty is the fundamental condition for the existence of insurance. But uncertainty in abstract form is the state of mind of the individual which correspond to the degree of probability of an occurrence (or chance) in the objective situation. Thus, Uncertainty is a function of probability.

From insurance point of view, probabilities can be divided into three categories : first, those in which a definite mathematical expression of probability can be attained in advance of the occurrence of the uncertain event; second, those in which probability can be obtained in advance and third in which no method of obtaining probability exists.

Risk Management Measures

In order to cope with these risks, farmers and rural societies have developed a range of risk management measures. These can be classified into Risk-reducing and Risk-coping Strategies.

Risk-reducing strategies include crop diversification, inter-cropping, farm-fragmentation and diversification into non-farm sources of income. Crop-sharing arrangements in land renting can also provide an effective way of sharing risks. Risk-reducing strategies can be effective in addressing many production and market risks. But while they help to stabilize family income, they are typically costly for those with average income because they require that farmers forego their most profitable alternatives. For example, crop diversification is usually less profitable on average than crop specialization and land fragmentation imposes costs in the form of labour and transport inefficiencies.

Risk-coping strategies are relevant for dealing with catastrophic income losses once they occur. Under such circumstances farmers may need new credit (especially consumption credit) the sale of assets, or temporary off farm employment. Risk-coping strategies also prove costly to the farmers. The sale of assets for example affect adversely the long-term growth of a farm business. The loans raised during time of occurrence of catastrophic losses are required to be repaid. And if it is raised from informal sources then it will be quite at a higher rate of interest.

But a more fundamental problem with traditional risk-coping strategies is that they can not deal effectively with the co-variability problem that characterizes most agricultural risks. For example, production and price risks affect nearly all farmers simultaneously in a region. Many farmers seek consumption credit, at the same time, thereby driving up local interest rates. Similarly, local wages are driven down by a surge in the labour supply, and the value of farm assets declines as too many farmers try to sell at the same time. Once the crises is over, farmers will find it difficult to replace assets as prices are generally go up again because of competition. For co-variate risks, local risk-coping strategies need to be reinforced by risk pooling arrangements that cut across one region to another. Here lies, in fact the role of Crop Insurance which covers all regions of the country.

By means of Crop Insurance, the farmers can insure himself against certain chance of occurrence of crop loss due to weather hazards, insect infestations and diseases. Crop Insurance can be classified into several categories:

(i) Single peril or Multi-peril Crop Insurance

(ii) Individual farm based or area based Crop Insurance

(iii) Specific crop or all crops based Crop Insurance

(iv) Voluntary or Compulsory Crop Insurance

Introduction of NAIS

In view of the limitations in CCIS, the scheme has been modified so as to enlarge its coverage in terms of farmers, crops and risks. From Rabi 1999-2000, a new scheme called 'National Agricultural Insurance Scheme (NAIS) has been introduced in place of CCIS.

NAIS covers all farmers-loanee and non-loanee both irrespective of their size of holding. It envisages to cover all food crops, oilseeds and annual commercial/horticultural crops in respect of which past yield data is available. The new scheme is proposed to cover higher level of risk i.e. sum insured upto the value of threshold yield and required to operate at a lower unit of insurance (*i.e.* within a period of three years implementing States are required to reduce unit of insurance to Gram Panchayat). To bring about some amount of financial viability in the scheme premia - structure in the new scheme has been rationalized. Main features of NAIS has been annexed.

Conclusion

Whatever improvement we make in designing the crop insurance scheme, one thing should be clearly understood, wherever crop insurance has been implemented by the public agencies/Govt. bodies up till now, it has been proved financially un-viable. There are various reasons for this. Firstly, Public Crop Insurance Schemes generally try to cover un-insurable risks which occur frequently and the required premiums are too high for most of the farmers (small and marginal farmers) to pay. Secondly, where there are large number of small and marginal farmers scattered over the country, administration cost will be very high. Again, if the Government decides to guarantee the financial viability of the insurer, it may further aggravate the situation as sound insurance practices may not be pursued by the insurer as he is nothing to loose.

Crop Yield Variability and Actuarial Framework of Crop Insurance — An Analysis of Pearl Millet

Rajiv Mehta
National Crop Forecasting Centre, Department of Agriculture & Cooperation, Government of India, New Delhi

Introduction

The economic activities are often subjected to financial risks occurring due to uncertainties of the factors governing the production. The extent of risk depends upon the parameters which are beyond the human control. Often, these parameters are dominated by natural and climatic phenomenon. The preponderance of climatic and natural phenomenon on the agricultural activities enhances the variability of production and thus increases the risk. The failure of crop due to drought, floods, pests and other such factors is a common feature for the agricultural sector. Generally, the farming community in India has a very weak risk bearing capacity due to scares resources and small holdings. This, in turn, makes them a vulnerable section of the socio-economic strata of the society. To safeguard the interests of the farmers from crop losses over space and time and to provide social security, self-help, encouragement for larger investment and increase in agriculture production, the Comprehensive Crop Insurance Scheme (CCIS) was initiated in 1985. The National Agricultural Insurance Scheme (NAIS) launched during the year 2000 has strengthened the scope and coverage of earlier crop insurance scheme.

For the viability and the benefits, it is essential that the crop insurance programme should be actuarially sound. This requires an in-depth study of probability distribution of the variability on which indemnities are based. The actuarial approach for crop insurance is area based and it takes into account the variation in yield over time. The criterion for indemnities are linked to yield averaged over time. This, however, does not take into account the spatial divergence of the probability distribution of average yield. The present paper analyses the spatial pattern of yield and its likely impact on crop insurance beneficiaries. The analysis and interpretations are built up on crop "Pearl Millet" for which a diversity in productivity over time and space is generally high.

Crop Insurance - Actuarial Framework

The actuarial framework of CCIS, which also formed the conceptual basis for NAIS, was evolved after detailed studies in seventies and eighties. The distinctive features of the scheme is the linking the scheme with credit (Dandekar [1]) and the indemnities for productivity of specified area (Narain, Prem *et al.* [3]). The main objectives of the scheme are:

(i) to provide a measure of financial support to farmers in the event of the crop failure due to natural calamities like droughts, floods, pests and diseases etc.

(ii) To encourage the farmers to adopt progressive farming practices, high value inputs and higher technology in agriculture

(iii) To help to stabilize farm income, particularly in disaster years

The NAIS is open to loanee as well as non-loanee farmers. However, since the scheme is based on area approach, the premium rates and credit facilities in terms of crop loans are uniform. The premium subsidy is linked to the land holding size and the small and marginal farmers have been provided the benefit. Claim, if any, is also payable to all insured farmers at the same rate and this is equal to shortfall in yield for that area during an insured season for an insured crop.

The premium rates depend upon (a) average crop production per hectare (b) year to year variability in the average yield and (c) the level of coverage. Thus, by setting aside the impact of technological changes, cyclical fluctuations and serial correlation in the crop yield, the crop yields are assumed to be independent over time and to follow same distribution in each time period. It also assumes the normal distribution of average yield for a specified area in accordance with central limit theorem. The actuarial framework for indemnities can be illustrated as under:

With area yields following normal distribution with mean μ and variance σ^2, one can work out the expected indemnities payable to the farmers in a defined area. The expected indemnity expressed as a percentage of the threshold yield gives the premium rate.

If the threshold yield is designated by Y_T and the area yield for the reference year by y, then the indemnity (I) paid to the farmers in the insured area is given by

$$I = Y_T - y \quad \text{if } y < Y_T$$
$$= 0 \quad \text{if } y > Y_T$$

The threshold yield Y_T is T% lower than μ. The average indemnity is the mathematical expectation of I, can be obtained as:

$$E(I) = ((Y_T - y)/y < Y_T) \ \Pr\ (y < Y_T) + 0.\Pr\ (y > Y_T)$$

$$= \int_{-\infty}^{Y_T} (Y_T - y) \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-1}{2}\ ((Y - \mu)/\sigma)^2\right) dy$$

$\propto$ The area under the normal curve to the left of the ordinate at

$Y = Y_T$

Or in other words, converting into the standard normal variate (snv)

$\propto$ The area under the standard normal curve to the left of the ordinate at $z = (Y_T - \mu)/\sigma$ where z is snv $(Y - \mu)/\sigma$

The aforesaid actuarial framework assumes the probability distribution of average yield of the specified area with distinct value of μ for the spatial units but with uniform σ. This may not be an appropriate assumption because the variability of average yield itself varies from one spatial unit to another spatial unit. The indemnities take into account standardized percentage variation in average yield. The following analysis of district-wise average yield and standard error (SE) of the average yield of Pearl Millet for Rajasthan for the year 1998-99 and 1999-2000 illustrates the above argument.

Spatial Variability and Probability of Indemnity Limits

Rajasthan as a production space of agriculture offers a diversity of natural and climatic endowments leading to a diverse profile of productivity. Pearl millet is an important crop of Rajasthan. Being rainfed, its productivity varies over time and space depending upon moisture availability during monsoon. Based on the district-wise average yield, SE of average yield for year 1998-99 and 1999-2000 and %SE (SE/average yield in %), the analysis of crop yield variability is annexed. For the purpose of the analysis the average yield of a year is taken as a proxy for μ and the ordinate value of SNV at 20% deviation from average yield (Y_T) is arrived at for both the years. The analysis also provides the probability of SNV at the ordinate value of SNV at 20% of average yield. The analytical interpretation of the exercise is as under:

(a) During 1998-99, average State productivity of Pearl Millet was 431 kg. per hectare. Due to poor monsoon and resultant moisture stress, the productivity declined by 23% to 330 kg/ hectare. The district-wise yield varied from 8 kg/ hectare in Jaisalmer to 1330 kg/hectare in Karoli district during 1998-99. During 1999-2000, the productivity in some of the districts declined by 75%. The yield variability over time as well as between districts was found to have distinct relationship with the SE of average yield within districts, per cent SE and also area under SNV at Y_T. The correlation table of the same is given below:

Variables	Average yield		% Change in Average yield
	1998-99	1999-2000	
SE of avg. yield	0.72	0.97	
% change in SE			0.80
% SE of avg. yield	–0.71	–0.60	
% change in % SE			–0.29*
P(SNV)*	–0.80	–0.78	

*Correlation found not significant. all other correlations are significant.

(b) The high correlation between the average yield and SE of average yield within district is as expected. What is noticeable is the increase in the correlation in 1999-2000 when the crop was affected by drought. The percentage change in productivity is also highly correlated with the percentage change in SE. On the other hand, the average yield and percentage SE (i.e. relative variability) were found to be negatively correlated. It means that high productivity areas have lower relative variability and vice versa. This requires further synthesis of probability distribution of average yield that follows distinct pattern in different spatial domains.

(c) The actuarial framework of crop insurance defines the indemnities based on per cent deviation from threshold yield (yield averaged on time) for all the spatial sub populations having distinct distribution. The probability of SNV at indemnity limit of different districts was found to be having significant negative correlation with average yield. This implies that the high productivity spatial units will have lower probability of indemnity coverage and vice versa.

Conclusions

The financial risk management is an ingrained component of insurance exercise. The farmers harvesting higher productivity make greater capital investment in terms of inputs and farm practices. The credit needs of such farmers is also greater. This increases the magnitude of financial stakes and in turn vulnerability of financial risk. The actuarial procedure therefore has to guard the interests of such farmers in a rationale manner. If the probability of risk management of high productivity gaining farmers is less than the low productivity gaining farmers then the crop insurance design may be missing its desired objective.

The above analysis is based on the results of crop estimation survey where the distribution of crop cutting experiments in districts is in proportion to crop area, subject to minimum of 20 and maximum of about 100 crop cutting experiments planned in a district. Thus, the design generally ensures harmonious sampling fractions. In NAIS the spatial units for crop insurance is a Panchayat. The spatial variability for the smaller area units is likely to be less than district, yet owing to the operational constraints to expand the sample size of CES, the district-wise yield and the distribution of district average yield will have a role. Further, there is no mechanism to analyse the sub-district variability. The aforesaid analysis is an attempt to highlight the possible distortions that may creep in the existing actuarial framework. There is need to further extend the analysis to more crops and more spatial domains for arriving at a sound actuarial system for crop insurance.

REFERENCES

[1] Dandekar, V.M., (1976). Crop insurance in India. *Economic and Political Weekly*. **11**, June 26, 1976.

[2] Ray, P.K., (1981). *Agricultural Insurance Theory and Practices, and Applications to Developing Countries*. 2nd ed., Pergomen Press Inc., New York.

[3] Narain, Prem, Shivtar Singh, Garg, J.N. and Mahesh Kumar, (1985). Statistical aspects of comprehensive crop insurance scheme. 39th Annual Conference of ISAS, Symposium on Crop Insurance, Akola.

Analysis of district-wise crop yield variability-Rajasthan-crop pearl millet (Bajra)

S. No.	Districts	Av. yield (kg/hect)		% change in yield	S.E. of av. yld. (kg/hect.)		% change in SE	SNV at 20% of avg. yield		% SE		% change in % SE	P(SNV)	
		98-99	99-2k		98-99	99-2k		98-99	99-2k	98-99	99-2k		98-99	99-2k
		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Ajmer	109.734	102.176	-6.89	54.38	64.14	17.95	-0.40	-0.32	49.55	62.78	26.700	0.3433	0.3750
2	Alwar	1226.833	1119.942	-8.71	98.17	178.97	83.31	-2.50	-1.25	8.00	15.98	99.750	0.0062	0.1054
3	Barmer	20.854	30.062	-44.11	13.51	9.89	-26.79	-0.31	-0.61	64.8	32.91	-49.210	0.3788	0.2717
4	Bharatpur	1417.750	1472.122	3.84	82.45	227.44	175.85	-3.44	-1.29	5.81	15.45	165.920	0.0003	0.0977
5	Churu	173.605	68.763	-60.39	35.49	21.80	-38.57	-0.98	-0.63	20.44	31.70	55.090	0.1640	0.2641
6	Dholpur	1189.373	1265.170	6.37	365.47	244.79	-33.02	-0.65	-1.03	30.72	19.34	-37.040	0.2576	0.1506
7	Jaipur	1110.123	657.568	-40.77	150.19	105.99	-29.43	-1.48	-1.24	13.52	16.11	19.160	0.0697	0.1073
8	Jaisalmer	8.216	13.286	61.71	5.09	6.35	24.75	-0.32	-0.42	62.05	47.83	-22.920	0.3734	0.3378
9	Jalore	111.042	24.129	-78.27	74.90	21.62	-71.13	-0.30	-0.22	67.45	89.63	32.880	0.3834	0.4117
10	Jhunjhunu	911.680	230.973	-74.67	114.06	51.60	-54.76	-1.60	-0.90	12.51	22.34	78.580	0.5550	0.1853
11	Jodhpur	26.001	76.042	192.46	10.54	38.28	263.19	-0.49	-0.40	40.55	50.34	24.140	0.3109	0.3456
12	Nagaur	425.023	341.293	-19.70	63.68	68.75	7.96	-1.33	-0.99	14.98	20.14	34.450	0.0910	0.1604
13	Pali	25.812	67.560	161.74	31.48	79.13	151.37	-0.16	-0.17	121.99	117.12	-3.990	0.4349	0.4322
14	Sawai Madhopur	1177.175	1103.521	-6.26	177.07	203.65	15.01	-1.33	-1.08	15.04	18.45	22.670	0.0918	0.1392
15	Sikar	669.066	584.821	-12.59	103.66	105.84	2.10	-1.29	-1.11	15.49	18.09	16.790	0.0984	0.1346
16	Tonk	499.423	488.183	-2.25	143.14	110.43	-22.85	-0.70	-0.88	28.66	22.62	-21.070	0.2426	0.1883
17	Dausa	1223.351	1047.131	-14.40	178.22	208.65	17.07	-1.37	-1.00	14.56	19.92	36.810	0.0849	0.1578
18	Hanumangarh	657.643	299.740	-54.42	187.97	106.69	-43.24	-0.70	-0.56	28.58	35.59	24.530	0.2420	0.2871
19	Karoli	1329.829	1428.177	7.40	260.42	286.50	10.01	-1.02	-1.00	19.58	20.06	2.450	0.1536	0.1594
	Area Covered by	431.029	330.487	-23.33	18.99	19.10	0.58			4.40	5.78	31.360		

Source : Average Yield, SE and % SE Crop Estimation Survey, Government of Rajasthan, SNV and P (SNV) Author

An Approach for Estimation of Crop Yield at Gram Panchayat Level for National Agricultural Insurance Scheme

A.K. Srivastava and Anil Rai
Indian Agricultural Statistics Research Institute, New Delhi

1.0 Background

Crop insurance offers insurance against fluctuations in the output of a crop from one year to another or from one crop season to another. The insurance provides a safeguard against crop failures as a result of natural calamities like drought, floods etc. Crop yield estimation attains a central role in any crop insurance plan since crop fluctuations/failures are measured as a deviation of crop output from the normal yield. Current crop yield estimates as well as the crop yield rates for previous years are needed to work out the deviations in crop output.

In the available literature on crop insurance, the indemnity assessment at individual level and for a unit area level has been debated at a considerable length. Without going into details of advantages and limitations of the two approaches, it may be mentioned that *a scheme based on the individual approach may be the most appropriate and in a sense ideal but it is impracticable* due to the fact that the assessment of crop yield at the individual level poses practical difficulties. The area unit in a crop insurance scheme could be Community Development (CD) Block / tehsils / taluks etc. Ideally, the area unit should be homogeneous from the stand point of a crop insurance scheme based on area approach. An area is homogeneous if the annual crop cut estimates for a majority of the farmers in the area move together above or below their own normals. Thus homogeneity of an area is defined in relation to the crop risk. "For a crop insurance scheme based on the homogeneous area approach all that is needed is a delineation of agro-climatic regions, small enough to be homogeneous in the sense that the annual crop experience of a majority of the farmers in the area accords and coincides with average experience of the area and large enough to have an adequate data base of annual crop cutting experiments to enable the determination of the normal yield and estimating annual average yields with reasonably small statistical error". In the present context, Gram Panchayat (GP) has been identified as an area unit to be considered in NAIS, and therefore, reliable estimates of crop yields at GP level become essential.

In the present agricultural statistics scenario, crop yield/production estimation, for most of principal crops, is available at district/block level. The method of crop estimation has been through crop cutting approach. The estimation at small area levels such as village panchayat has not been attempted so far. At present, nearly 5 lakh crop cutting experiments are being conducted in the country through General Crop Estimation Surveys (GCES) scheme. In recent years, there have been questions and criticism regarding the quality of data obtained in the crop estimation surveys. Qualitative checks on crop estimation surveys are provided by specialised supervision through a scheme 'Improvement of Crop Statistics (ICS)' which is conducted by National Sample Survey Organisation (NSSO). There has been a general feeling that increasing the crop cutting experiments is likely to be too heavy a burden on the present data collection infrastructure in crop estimation surveys, particularly in view of the findings of ICS scheme, which indicates large amount of Non-Sampling Errors.

2.0 Number of Crop Cutting Experiments Required for Crop Yield Estimation at Gram Panchayat Level

In the past, for block level estimation, 16 crop-cutting experiments per crop had been suggested. This had been on statistical considerations in view of the inherent variability in crop yield estimates available at block level. Recently an analysis of data for crop yields for paddy crop as available from two districts of Orissa revealed that coefficient of variation (cv) of crop yield estimates at Gram Panchayat levels was at least 20 percent. For this amount of variability and for 95 percent precision level of the estimates, the required sample size at Gram Panchayat level should be at least 8 to 10 crop cutting experiments. Thus, if reliable Gram Panchayat level estimates are needed at least 8 to 10 crop-cutting experiments should be conducted in each Gram Panchayat for each crop. It is likely that this requirement will increase the total sample sizes of crop cutting experiments manifold (estimated to be around 74 lakh), which would increase the Non-Sampling Error considerably and may have its obvious impact on the quality of data in GCES.

3.0 An Alternative Suggestion for Crop Yield Estimation - Small Area Estimation Approach

In recent years, there have been a lot of developments in the field of small area statistics. In this approach the estimates obtained through sample surveys for a larger area level are scaled down to smaller area levels, through the use of additional ancillary information available from various sources. The basic rationale in this approach is that certain assumptions/models are conceptualised which are assumed to hold good at small as well as large area levels. Such models / relationships are utilised for scaling down the estimates to lower levels. In this particular situation, some ancillary information at Gram Panchayat level may be generated, which is not necessarily based on crop cutting approach and this information may be utilised to scale down the crop yield estimates obtained through GCES at district/block level for developing Gram Panchayat level estimates. To be more specific, information about the crop area and crop yield obtained from other sources such as farmers' appraisal using well tested structured questionnaires obtained through random sampling approach has been found to perform satisfactorily in many practical situations. Studies conducted in several African countries (Verma, Merchant and Scott; Longacre Report, 1988) suggest that such estimates as obtained through farmers' appraisal are in close agreement with the actual production figures as obtained by the whole field harvest. Studies conducted at IASRI also revealed a fairly high degree of correlation between the farmers' estimate and the estimates obtained through the crop cutting approach. However, in crop insurance scenario, it is apprehended that farmers' appraisal is likely to be affected qualitatively in view of interest of the stakeholders at Gram Panchayat level. On the other hand this information, if used judiciously, only to workout (say) proportions for scaling down the estimates of crop yields of GCES series is likely to minimize the effect of stakeholders interest. It is realised that the farmers' estimates are likely to be influenced by the interested parties but it is expected that the proportions are free from such effects provided farmer's behaviour in underestimation / overestimation is consistent over the entire area. This approach is, in fact, a standard small area estimation technique known as Synthetic method of estimation. The method has got wide application in different areas particularly in demographic studies because of the availability of stable ratios like birth rates, death rates etc. from various population censuses. Its application in the field of agriculture has, however, been relatively limited. Some studies in this context have been carried out at IASRI through Ph.D. thesis as well as research projects. However, the technique has not been experimented on a large scale in agriculture and hence it is suggested that the above approach may be tried on a pilot basis in few selected areas before it may be adopted at the national level. It may also be mentioned that to start with, even though we may have limited ancillary information to be used but in due course of time as more and more information is generated regarding area, production and productivity of crops as well as regarding irrigation, variety etc. at Gram Panchayat level, the method has enough flexibility to utilise these information for more reliable estimation. Consequently, the Gram Panchayat level estimates will be more and more precise in due course of time. In future, even if some information is available from remotely sensed data at village level, it may also be utilised in the small area estimation approach.

In order to conduct farmer appraisal survey at Gram Panchayat for yield estimation, the frame for selection of fields as available from village records (Khasra register) may be used. The information to be collected in the inquiry at the village level will be area under various crops, area irrigated etc. while those from the selected cultivators will include farmers' estimate on yield besides the area, irrigation status, various inputs, soil type etc. at the field level.

The cost incurred on data collection in this approach will be substantially less than the existing crop cutting based approach. Assuming that the data collection responsibility is entrusted to the village officials and also taking into account training and supervision aspects, on an average it would cost not more than seventy five rupees for data collection per farmer per crop within a Gram Panchayat. In a village, on an average four crops may be covered under the insurance scheme. Considering that data are to be collected at the rate of ten farmers' per Gram Panchayat, the total estimated cost of data collection works out to be fifteen hundred rupees per Gram Panchayat. Salient features of this approach are given in the next section.

4.0 Salient Features

The proposed plan has the following important features :

- The method of data collection is based on farmers' appraisal as well as other ancillary information available at GP level.
- The yield estimates developed through this approach are to be used only for generating correction factors for scaling down the estimates of GCES based on crop cutting approach and not to be used as yield estimates as such.
- The approach if adopted is not likely to affect the existing system of GCES adversely.
- Data collection is likely to be much cheaper, as such, the reduction in the number of selected cultivators may not be required.
- Data may be collected through an alternative agency utilising village officials/resources e.g. unemployed youth etc. who can be paid on per questionnaire basis.

5.0 Procedure for Estimating Average Yield at Gram Panchayat Level

The proposed approach for estimation of data collection is primarily based on the availability of information regarding production at higher level i.e. block, tehsil or district through usual GCES. This may be indicated here that the assumption regarding the availability of information regarding area under a particular crop at all levels has been made while developing this proposal. The procedure can be implemented without affecting the quality of usual GCES by following the steps given below:

Step-1 Formulation of frame of survey numbers separately for each notified crop under crop insurance scheme in a given season in a gram panchayat through area enumeration records such as Girdawari of the pervious year. The process of formulation of frame may be started approximately three weeks before the current season harvesting period.

Step-2 Make the separate list of the survey numbers for each crop covered under crop insurance scheme.

Step-3 Select 10 survey numbers by circular systematic sampling scheme and identify owner(s). Verify whether in the selected survey numbers the crop grown is same as in the previous year. If so, retain that survey number in the sample, otherwise, replace it by next survey number from the list and verify again. Repeat the same procedure till 10 survey numbers for each crop are selected in the sample.

Step-4 Collect detailed information from the selected farmers of the corresponding survey number of each category before 2 weeks of expected harvesting time of each crop grown by the farmer.

Step-5 Collect the farmers estimate from all the farmers covered under step-4 for each crop within 3 days after harvest of crop.

Step-6 Calculate the average yield of each crop of Gram Panchayat (GP) as equation-1 of estimation procedure.

Step-7 Calculate total production of each crop of GP through farmer appraisal with the help of equation-2 of estimation procedure.

Step-8 Calculate estimated production for each crop in the Gram Panchayat as given in equation-3 of estimation procedure.

Step-9 Calculate estimated adjusted production for each crop in the Gram Panchayat given in equation-4 of estimation procedure.

Step-10 Calculate adjusted estimated average yield for each crop in the Gram Panchayat given in equation-5.

The above estimation procedure is explained through an example, in which part of the data from Rohtak district of Haryana has been taken for illustrative purpose.

6.0 Estimation of Adjusted Crop Yield at Gram Panchayat Level

Let,

V = No. of Gram Panchayats (V.P.) in a block

N_{ij} = No. of farmers growing j-th crop in i-th Gram Panchayat

n_{ij} = No. of selected farmers growing j-th crop in i-th Gram Panchayat

y_{ijk} = Farmer's appraisal of production for k-th selected farmers growing j-th crop in i-th Gram Panchayat

a_{ijk} = Area of k-th selected farmer for j-th crop in the i-th GP

A_{ijk} = Area of k-th farmer belonging to j-th crop in i-th GP

A_{ij} = Total area of i-th V.P. under j-th crop

$\hat{Y}_{j(i)}$ = Total estimated production of j-th crop through GCES

The average yield of the GP for j-th crop can be obtained by

$$\overline{Y}_{ij(R)} = \frac{\overline{y}_{ij}}{\overline{a}_{ij}} \overline{A}_{ij} \qquad (1)$$

where

$$\overline{y}_{ij} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} y_{ijk}$$

$$\overline{a}_{ij} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} a_{ijk}$$

$$\overline{A}_{ij} = \frac{1}{N_{ij}} \sum_{k=1}^{N_{ij}} A_{ijk}$$

The total estimated production of the j-th crop in the i-th GP is given by

$$\hat{Y}_{ij(P)} = A_{ij} \hat{\overline{y}}_{ij(R)} \qquad (2)$$

The total estimated producction of the j-th crop in the block through farmer's appraisal is

$$\hat{Y}_{j(P)} = \sum_{i=1}^{V} A_{ij} \hat{\overline{Y}}_{ij(R)}$$

The total estimated production of the j-th crop in i-th GP is

$$\hat{p}_{ij(P)} = \frac{\hat{Y}_{ij(P)}}{\hat{Y}_{j(P)}} \tag{3}$$

The estimated adjusted production of the j-th crop in i-th GP can be given by

$$\hat{Y}_{ij(AP)} = \hat{p}_{ij(P)} Y_{j(G)} \tag{4}$$

Now the estimated average yield of the j-th crop in the i-th GP can be obtained as

$$\hat{\bar{Y}}_{ij(AP)} = \frac{\hat{Y}_{ij(AP)}}{A_{ij}} \tag{5}$$

Hence, the average adjusted crop yield for a GP can be obtained by equation (5).

7.0 Example

Consider a block consisting of 19 Gram Panchayats. Following table presents the calculation of estimated average yield at Gram Panchayat level with the help of farmer's appraisal using crop estimates available at block level through GCES. The example is based on data collected in a study conducted in Rohtak district of Haryana for wheat crop, year 1997-98. The example is only illustrative in nature.

Column No.	Description
1.	Identification particulars of Gram Panchayat
2.	Farmer's appraisal estimates in Qt./ha.
3.	Area under wheat crop (ha.) in panchayat
4.	Estimated production (Qts.) based on farmer's estimates
5.	Production proportions based on farmer's estimate
6.	Estimated production (Qts.) of Gram Panachayat using GCES estimates
7.	Estimated average yield (Qt./ha.) of Gram Panchayat using GCES

1	2	3	4	5	6	7
1	13.60	1800	24480.00	0.0166	27208.74	15.12
2	29.80	2644	78791.20	0.0534	87573.90	33.12
3	28.40	2200	62480.00	0.0423	69444.52	31.57
4	42.30	1240	52452.00	0.0355	58298.72	47.02
5	40.20	3560	143112.00	0.0970	159064.42	44.68
6	28.12	3620	101794.40	0.0680	113141.22	31.25
7	16.50	840	13860.00	0.0094	15404.95	18.34
8	29.69	2200	65318.00	0.0443	72598.87	33.00
9	30.20	2684	81056.80	0.0549	90092.04	33.57
10	40.20	3528	141825.60	0.0961	157634.62	44.68
11	41.70	1620	67554.00	0.0458	75084.11	46.35
12	30.47	1884	56405.48	0.0389	63804.36	33.87
13	34.90	2688	93811.20	0.0636	104268.15	38.79
14	23.40	3924	91821.60	0.0622	102056.78	26.01
15	26.80	2348	62926.40	0.0426	69940.68	29.79
16	30.98	1756	54400.88	0.0369	60464.84	34.43
17	37.90	3076	116580.40	0.0790	129575.39	42.12
18	44.60	2360	105256.00	0.0713	116988.68	49.57
19	21.00	2884	60564.00	0.0410	67314.95	23.34
Total		46856	1475489.96	1.0000	1639960.00	

Total production of the block through GCES = 1639960 Qts.

Applications of GIS and Remote Sensing in Crop Yield Estimation - Crop Insurance Perspective

Anil Rai, Randhir Singh and A.K. Srivastava
Indian Agricultural Statistics Research Institute, New Delhi-12

Introduction

The Geographic Information System (GIS) is a powerful tool for storing, retrieving, analysis and integrating spatial and non-spatial geographical data apart from drawing any kind of maps. In last few decades there have been substantial developments in the field of GIS and spatial statistical techniques (Ripley, 1981, Griffth, 1988, Haining, 1990). Unfortunately, the level of integration between these two rapidly growing fields is at very low profile. However, recent advances of computer hardware and GIS software have a great potential to change substantially the statistical approach to the study of geographical reality. The ability shown by GIS to handle various kind of information through their geographical coordinates has a vast capability, particularly, for applications of spatial statistical methods in the field of agriculture. Various spatial data sets such as soil maps, maps of meteorological variables etc. are some of the important factors influencing agricultural production. The digital data from Remote Sensing satellites has great potential to be used in crop area and production estimation. In this article an attempt has been made to suggest spatial models for estimation of crop yield at village panchayat level using digital data from Indian Remote Sensing satellites.

Spatial Statistics in Agriculture

Historical spatial data appear to have arisen in the form of data maps. Halley (1686) superimposed, maps of land forms, direction of trade winds and monsoon to assign them a physical cause. R.A. Fisher in 1920s and 1930s at Rothamsted experiment station in U.K. conducted agricultural experiments and proposed the principles of randomization and local control to reduce the effect of spatial correlation coefficient. Fairfield and Smith (1938) applied empirical method to determine the shape and size of the experimental plots. It recognized the presence of spatial correlation in the field experiments. A large number of articles published recently are based on nearest neighbours methods for analyzing agricultural field trial considering spatial dependence.

Recently launched National Agricultural Insurance Scheme (NAIS) is based on area approach. In this, homogeneity of an area is based on variation of crop yields of the farmers in relation to risk of crop failure in a particular season. Keeping in view the sensitivity of the matter, there is a need to evolve a statistical methodology for delineation of suitable smallest area unit for which normal yield as well as seasonal yield of the crops can be determined with reasonable precision. Presently, it has been decided to take Village Panchayat as a area unit for this purpose. Therefore, reliable estimation of crop yields at village panchayat level becomes essential.

At present the yield estimation of all principal crops are available at district/block level, through nearly 5 lakh crop cutting experiments. It has been estimated that around 74 lakh crop-cutting experiments are needed to obtain 90 percent precise estimates at village panchayat level. Approximately 15 times increase in crop-cutting experiments need huge resources and reliability of the estimates will be poor due to increase in non-sampling errors. Therefore, there is need to improve the reliability of the estimates without increasing the number of crop cutting experiments using the modern technologies spatial statistics, Remote Sensing, Global Positioning System (GPS) and Geographic Information System (GIS).

Estimating Crop Yield at Village Panchayat (VP) Level

The availability of high spatial resolution data (5.6 m) through Indian Remote Sensing satellites and reliable hand held Global Positioning System (GPS), it become possible to approximately identify fields of crop cutting experiments at relatively lower scale. As a consequence of this, production of crops at various point locations in a map of a region, say, district can be assigned. Further, with the help of available literature in the field of spatial statistics, it is possible to apply suitable spatial models to predict the production surfaces, i.e. values of production at each point of the map, of the target region. Similarly, spatial time series production surfaces can be generated with the help of GIS software. The time series information of NDVI for almost all major crops of the country based on digital classified data of each point of the map can be generated and utilized for estimation of crop yield at village panchayat level. Further, the information of soil parameters, and meteorological variables can also be generated and used for improving the efficiency of crop yield prediction at VP level. In the following sections simple spatial regression model as well as spatial prediction model are discussed briefly in context of crop yield estimation at VP level. Reliability of these models increases with increase in homogeneity of areal units with respect to the character under study. Hence, spatial technique based on spatial correlation coefficient for forming spatial homogeneous zones is discussed in the next section.

Homogeneous Grouping of Village Panchayats

Let β_i is spatial correlation coefficient of auxiliary character based on classified digital data from remote sensing for i-th Village Panchayats. Now, stationarity β_i's will be tested with the help of following hypotheses.

Hypothesis

$$H_0 : \beta_i = \beta \qquad \forall\, i$$

$$H_1 : \beta_i \text{ not all same} \qquad \forall\, i$$

The statistic to measure the variability of β's is the variance of β which is given as

$$V_C = \frac{1}{N} \sum_{i}^{N} (\beta_i - \bar{\beta})^2$$

where, $\bar{\beta} = \frac{1}{N} \sum_{i}^{N} \beta_i$

Clearly, lower the value of V_c, stronger the evidence that the coefficient corresponding to V_c is fixed. Since the mathematical derivations regarding the distributional properties for testing the above hypothesis are complex, so Monte Carlo technique (Hope, 1968) can be applied as an alternative approach. This approach is based on testing the effect of assigning observations randomly to different locations on spatial correlation coefficient. The test can be carried out using following steps.

Step 1 Make a note of V_c for correctly located observations

Step 2 Randomly interchange the data of each polygon with any other and calculate different V_i's

Step 3 Repeat the previous step (P – 1) times, noting V_i's each time

Step 4 Compute the ascending order rank of V_c , among V_i's for correctly located observations, R

Step 5 Calculate the p value for listing the hypothesis, p = R/P

If p is not significant, add one more polygon to this zone and repeat the above steps. If p is significant, reject the newly added polygon and stop the procedure in this direction.

Spatial Regression Model

Let, $\underline{s} \in R^2$ be data location in two dimensional Euclidean space and suppose the yield $Y(\underline{s})$ at datum point $\underline{s}$ is a random quantity. Let $\underline{s}$ vary over index set $D \subset R^2$ so as to generate the bi-variate random field. Let $\{y(\underline{s}) : \underline{s} \in D\}$ denotes the realization of $y(\underline{s})$. Suppose the spatial data $\{y(\underline{s}_1), y(\underline{s}_2) ..., y(\underline{s}_n)$ observed at spatial locations $\{s_1, s_2, \dots, s_n\}$ and modeled as a collection of random process.

$$\underline{Y} = \underline{X}\,\underline{\beta} + \underline{\epsilon} \tag{1}$$

where, $\underline{X}$ is an $n \times q$ matrix of q – explanatory variables at n-spatial location points $:\beta = (\beta_1, ..., \beta_q)'$ is $q \times 1$: vector of coefficients and $\underline{\epsilon} = \{\epsilon(\underline{s}_1), \dots \epsilon(\underline{s}_n)$ is $n \times 1$ vector of spatial random errors. Here, basic interest is estimation of large-scale-variation parameters i.e. $\underline{\beta}$. Let

$$V(\underline{\epsilon}) = \underset{\sim}{\Sigma}$$

where, $\underset{\sim}{\Sigma}$ is $n \times n$ symmetric, nonnegative definite matrix. Elements of this can be generally given by

$$\text{Cov}(y(s_i), y(s_j)) = \sigma^2 \, || \, \underline{s_i} - \underline{s_j} \, || \quad \forall \; i \neq j \tag{2}$$

$$= 0 \qquad \text{otherwise}$$

where $\sigma^2 = \text{Var}[y(s_i)] \;\; \forall \;\; i = 1, 2, ..., n$

The best linear unbiased estimator of β is also the generalized least square.

$$\hat{\underline{\beta}}_{gls} = (X' \Sigma^{-1} X')^{-1} X' \Sigma^{-1} Y' \tag{3}$$

and its variance can be given by

$$V_{ar}(\hat{\beta}_{gls}) = (X' \Sigma^{-1} X)^{-1} \tag{4}$$

Now, substituting the vector $\hat{\beta}$ and known matrix values at each point locations of the maps $Y(s_0)$ can be obtained for any location with some reliable precision. Further, by aggregating all the points in a VP yield of the crop in each VP can be obtained.

Spatial Prediction Model

The synonymous word of optional prediction is kriging. It is minimum mean-squared-errors or method of spatial prediction that usually depends on the second order properties of Y(.). This name is given by Matheron (1963) after D.G. Krige, a south African mining engineer. In other words, it refers to making inferences on unobserved values of the random process Y(.). These number of spatial models are available in the literature for prediction. This article is confined to simplest model under following assumption.

Model Assumption

$$\underline{Y}(\underline{s}) = \mu + \epsilon(\underline{s}), \underline{s} \in D, \quad \mu \in R \text{ and } \mu \text{ is unknown} \tag{5}$$

Prediction Assumption

$$p(\underline{Y} : \underline{s}_0) = \sum_{i=1}^{n} \lambda_i \, y(\underline{s}_i), \quad \sum_{i=1}^{n} \lambda_i = 1, \quad \lambda_i > 0 \tag{6}$$

Minimizing mean squared prediction error

$$\sigma_e^2 = E\,[Y(\underline{s}_0) - p(\underline{Y} ; \underline{s}_0)]^2$$

under the condition that model (5) hold with variation

$$2r(\underline{h}) = \text{Var}\,[Y(\underline{s} + \underline{h}) - Y(\underline{s})], \quad \underline{h} \in R^2$$

This is equivalent to minimize

$$E\left[\underline{Y}(\underline{s}_0) - \sum_{i=1}^{n} \lambda_i \, Y(\underline{s}_i)\right] - 2m\left(\sum_{i=1}^{n} \lambda_i - 1\right)$$

with respect to $\lambda_1, \lambda_2 \ldots \lambda_n$

The optimal $\lambda_1, \lambda_2 \ldots \lambda_n$ can be obtained from

$$\underline{\lambda}_0 = \Gamma_0^{-1} \underline{r}_0$$

where

$$(\underline{\lambda}_0 = (\lambda_1, \lambda_2 \ldots \lambda_n, m)'$$

$$\underline{r}_0 = (r(\underline{s}_0 - \underline{s}_1), \ldots, r(\underline{s}_0 - \underline{s}_n), 1)'$$

$$\Gamma_0 = \begin{bmatrix} r(s_i - s_j), & i = 1, 2, \ldots, n; \ j = 1, 2, \ldots, n \\ 1 & , i = n+1, \ j = 1, 2, \ldots, n \\ 0 & , i = n+1, \ j = n+1 \end{bmatrix}$$

The $\underline{\Gamma}_0$ is a symmetric $(n + 1) \times (n + 1)$ matrix. The prediction estimation can be obtained as $\hat{p}(\underline{y} : \underline{s}_0)$ from equation (6). The prediction variance can be derived as

$$\sigma_k^2 (\underline{s}_0) = 2 \sum_{i=1}^{n} \lambda_i \ r(\underline{s}_0 - \underline{s}_i) - \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_i \lambda_j \ r(\underline{s}_i - \underline{s}_j)$$

Hence, with the help of this technique production values can be assigned to each point in the spatial map.

The above model can also be further improved by using information on auxiliary variables, spectral satellite data, soil parameters, meteorological variables etc. in the model as suggested in earlier section.