SAMPLING OF INSECT POPULATIONS-A STATISTICAL STUDY

By

J.ASHOK KUMAR
B.Sc.(Ag.)

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CERTIFICATE

Mr.J.ASHOK KUMAR has satisfactorily prosecuted the course of research and that the thesis entitled **"SAMPLING OF INSECT POPULATIONS-A STATISTICAL STUDY"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part there of has not been previously submitted by him for a degree of any university.

Date : 8th Nov. 1996.

(Dr.G.NAGESWARA RAO)
MAJOR ADVISOR

CERTIFICATE

This is to certify that the thesis entitled **"SAMPLING OF INSECT POPULATIONS-A STATISTICAL STUDY"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** of the Andhra Pradesh Agricultural University, Hyderabad is a record of the bonafide research work carried out by **Mr.J.ASHOK KUMAR** under my guidance and supervision. The subject of the thesis has been approved by the Student Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. Published part has been fully acknowledged. All assistance and help received during the course of the study has been duly acknowledged by the author of the thesis.

(Dr.G.NAGESWARA RAO)
Chairman of the Advisory Committee

Thesis approved by the Student Advisory Committee

Chairman : **(Dr.G.NAGESWARA RAO)**
Professor and University Head
Department of Statistics and Mathematics
College of Agriculture
Rajendranagar, Hyderabad.

Member : **(Dr.B.S.KULAKARNI)**
Associate Professor
Department of Statistics and Mathematics
College of Agriculture
Rajendranagar, Hyderabad.

Member : **(Dr.K.KRISHNAIAH)**
Project Director
Directorate of Rice Research
Rajendranagar, Hyderabad.

Member : **(Dr.T.RAMESH BABU)**
Associate Professor
Department of Entomology
College of Agriculture
Rajendranagar, Hyderabad.

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(J.ASHOK KUMAR)

DECLARATION

I, **J.ASHOK KUMAR** hereby declare that the thesis entitled **SAMPLING OF INSECT POPULATIONS-A STATISTICAL STUDY** is a result of the original research work done by me. It is further declare that the thesis or any part thereof has not been published earlier in any manner.

J. Ashok Kumar

(J.ASHOK KUMAR)

Date : 8-11-96

Name of the Author	:	**J.ASHOK KUMAR**
Title of the thesis	:	**SAMPLING OF INSECT POPULATIONS-A STATISTICAL STUDY**
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University	:	**ANDHRA PRADESH AGRICULTURAL UNIVERSITY**
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ABSTRACT

An attempt has been made to study the distribution pattern and sampling aspect of BPH population in rice using the data collected from seven different fields in Tenali area of Guntur District (A.P.).

Frequency distribution of BPH counts for each rice field (A to G) was constructed. The dispersion parameter 'K' and 'K_c' were estimated for each field and for overall season respectively. The dispersion parameter indicated an aggregated type of distribution for each field. Further this conclusion was confirmed by using χ^2, U and T statistic tests. Morisitas index of dispersion was found to be greater than unity and this confirmed the negative binomial pattern of distribution of BPH counts in rice fields (A to G). David and Moores index and Cole's index were also computed and found to be greater than maximum regularity and randomness thus confirming the above results.

By taking economic injury levels as 25 and 20 hoppers/hill for without predator and with predator cases respectively, sequential sampling plans were developed for all the fields under investigation and for overall season separately. It was found that the probability of taking right decision using above sequential sampling plans was 95 per cent.

INTRODUCTION

CHAPTER I

INTRODUCTION

Rice, the staple food of millions in Asia and in many parts of the world, is subjected to attack by more than 100 insect pests. Among them brown planthopper (BPH), *Nilaparvata lugens* (Stal.) is considered to be of major pest because of its nature of infestation and severe damage. In India, severe out breaks of BPH were recorded in Andhra Pradesh (Tirumala Rao, 1950), Tamil Nadu (Das *et al.*, 1972), Kerala (Koya, 1974) and West bengal (Nath and Sen, 1978).

Rice occupies around 42.18 lakh ha., of the cropped area with total production of 106.21 lakh tonnes per annum in Andhra Pradesh. BPH is one of the major rice pests of Andhra Pradesh and cause severe economic loss to the farmer if not properly controlled at right time.

Eventhough lot of work was done on various aspects of rice BPH, the ecological aspects of this pest remained unexplored. Knowledge of distribution pattern of BPH in space is vital as it affects the sampling, particularly the number of samples required for estimating the population density, and the pattern of sampling. Insect distributions most often were described as binomial, negative binomial and poisson.

In general, changes in distribution pattern are reflected in changes in the mean-variance relationship. If the mean and variance are equal for a population then the distribution is called poisson distribution, if the mean is greater than variance it is binomial distribution and for negative binomial distribution the variance is greater than mean.

Sequential sampling was developed by Wald (1945) is a rapid method of classifying populations into broad categories such as light, medium and heavy. The ability to do this is useful in pest management in order to determine the necessity to use insecticide treatments. As the name implies, with sequential sampling, samples are taken in sequence and the decision to take the next sample depends upon what is found in the one just made. Using this technique, it is not necessary to estimate population parameters and less number of samples can be adequate when the population density is low or high, which is in contrast to most conventional procedures as they require a fixed number of sampling units regardless of population density.

Before developing sequential sampling plans, three types of information are necessary.

1) the spatial distribution pattern of insect species 2) the damage threshold and 3) the level of risk.

The use of pesticides is a important tactic in management of the insect pests. Although pesticide applications should be made only when pest population exceeds a threshold level, growers often apply these chemicals indiscriminately. This practice is expensive and contributes to pest resistance, resurgence and environmental contamination.

To determine the necessity for a insecticide application, a sampling technique which is reliable, in-expensive and easy to use should be developed. Proper timing of chemical application is cost effective and will also help to conserve natural enemies which are important factors in regulating populations of BPH. In view of these the following objectives are framed in the present investigation.

1) to study the distribution of BPH in rice
2) to study the sampling plan for BPH population.

LIMITATIONS

The economic threshold value of the pest was assumed as 25 hoppers/hill and 20 hoppers/hill for without and with predator cases respectively.

PLAN OF THESIS

The thesis is presented in six chapters. The first one which was introduction chapter explains importance of developing sequential sampling plan for rice BPH.

The literature related to the spatial distributions of insects and sequential sampling plans that were laid out for different crop pests are presented in the second chapter.

In the third chapter, statistical methods adopted to meet the objectives of the investigation with regard to distribution and sequential sampling plan of BPH are described.

In the fourth chapter results are presented.

A discussion of the results of the analysis in chapter 4 is presented in fifth chapter.

Sixth and final chapter included summary and conclusions.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Many workers have attempted to review the available information on ecological aspects of various pests (Krishnaiah, 1987; Shepard *et al.*, 1986, 1988, 1989) but it appears that no concerted effort was made in the past to bringout the ecological aspects of rice brown planthoppers. Therefore the review of the literature relevant to and in conformity with the objectives of the investigation is sub divided under the following heads :

1. Distribution of insect populations on the crop
2. Studies on sequential sampling plan

2.1 DISTRIBUTION OF INSECT POPULATIONS ON THE CROP

'Population' was defined differently by different workers. Nicholson (1957) defined population as a group of inter-acting and inter-breeding individuals which normally has no contact with other groups of the same species. Milne (1957) described population as a number of individuals of a particular species existing in a particular space.

The manner in which the members of a pest population were distributed through space is the distribution pattern or the dispersion of the population. Dispersion is different from dispersal, which usually means the movement of individuals away from the population. Spatial distribution is one of the most important characteristics of ecological significance of a species, unlike rates of growth and reproduction, which often vary more between generations with in a species than they do between species. The spatial pattern of an insect is of specific interest in both applied and fundamental studies. No field sampling is viable without understanding the underlying spatial distribution.

Most of the workers described the natural insect populations as negative binomial model (Anscombe, 1948; Harcourt, 1960, 1961, 1963, 1965, 1967; Lyons, 1964; Morris, 1955, 1960; Putnam and Shklov, 1956). Thus it was a basis for expecting organisms to be aggregated.

The type of distribution obtained is often influenced by a variety of factors, such as the sampling method, the size of the sampling unit, the effect of age of individuals, the density of population, the effect of the habitat, etc.

The distribution of gall midge on soybean was aggregated if the plant was taken as the sampling unit but it was random if the numbers per pod were considered (Shibuya and Onchi, 1955).

It was observed by Sylvester and Cox (1961) and Shiyomi and Nakamura (1964) that the distribution of aphids during the initial phase of infestation was random and it became aggregated as their number increased.

Shepard and Ferrer (1990) observed the pattern of rice brown planthopper (BPH) infestation changed as the pest intensity progressed in a field. BPH distribution at first was observed to be random, as the pest progressed aggregation appeared. Later in the season when more plants became infected, the spread of pest approached a regular distribution.

The dispersion studies indicated the nature of distribution of an insect in its habitat. The knowledge of spatial distribution was fundamental for developing of reliable sampling programme as the number of an insect species recovered per sample by a distribution of that insect. The spatial distribution also governed the number of samples required to estimate populations with in a given probability and accuracy levels. Samples thus obtained, based on distribution studies, served as the basis for decision making and implementing tactics in the field (Bechinski and Pedigo, 1981).

The three basic models of distribution of insect populations (Fig.1) as suggested by Southwood (1978) are :

1) Binomial, uniform or regular.

2) Random or poisson.

3) Negative binomial, clumped, aggregated, over-dispersed or contagious.

Dispersion

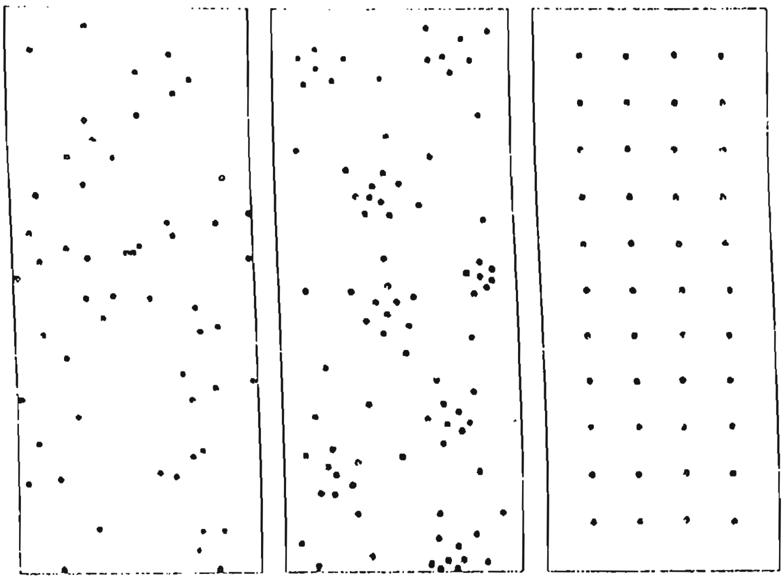

Fig. 1. Different types of distribution

The mathematical models which describe the pattern of distribution were proposed by Anscombe (1950) and could be determined by the relationship between the variance (S^2) and the arithmetic mean ($\bar{X}$), viz.,

1) Binomial uniform or regular distribution

   Variance less than the mean ($S^2 < \bar{X}$)

2) Random or poisson distribution

   Variance is equal to mean ($S^2 = \bar{X}$)

3) Negative binomial, clumped, aggregated, over dispersed or contagious distribution.

   Variance is greater than mean ($S^2 > \bar{X}$)

Generally in ecological studies, the variance was found to be greater than the mean, leading to negative binomial distribution and the population was clumped or aggregated. The negative binomial distribution was described by two parameters, the mean ($\bar{X}$) and the exponent 'K' which is a measure of the amount of clumping and was often referred to as dispersion parameter. Many aggregated insect populations that were studied could be adequately expressed by this distribution (Bliss and Owen, 1958; Harcourt, 1965; Safranyik and Raske, 1970; Allen *et al.*, 1972; Danielson and Berry, 1978; Nachman, 1981; Suman and Wahi, 1981; Faleiro *et al.*, 1982; Rai *et al.*, 1982; Mabbett *et al.*, 1984; Shepard *et al.*, 1986).

The value of 'K' was not constant for a population, but often increased with mean (Anscombe, 1948, Bliss and Owen, 1958). Generally value of 'K' for negative binomial was less than 8, as it becomes larger, the distribution approaches and would be eventually (at infinity) identical with that of poisson (Southwood, 1978).

Calculation of 'K' of the negative binomial.

Anscombe (1949, 1950), Bliss and Fisher (1953), Debauche (1962) and Katti and Gurland (1962) computed the value of 'K' by several methods. Most commonly used methods are as given below (Southwood, 1978).

1) Moment estimate of 'K'

$$K = \bar{X}^2/S^2 - \bar{X}$$

Where $\bar{X}$ is mean, S^2 is variance of the sample

2) Estimation of 'K' from proportion of zeros

$$K \log \left(1 + \frac{\bar{X}}{K}\right) = \log \left(\frac{N}{n_0}\right)$$

Where N = total number of samples

n_0 = number of samples recording zero population

3) Maximum likelihood method of estimation of 'K' or trial and error (Iterative) method

$$N \log_e \left(1 + \frac{\bar{X}}{K}\right) = \left(\frac{Ax}{K + X}\right)$$

Ax = sum of all frequencies of sampling units containing more than 'x' individuals,

and $\log_e$ is Napierian logarithm.

4) Determination of common 'K' (K_c)

The common K (K_c) was given by $K_c = \dfrac{\bar{X} - S^2/N}{S^2 - \bar{X}}$

Where $\bar{X}$ = mean
S^2 = variance
N = Number of plants on which X is based

Bliss (1958) and Bliss and Owen (1958) gave moment and regression method of calculating a common value of the parameter 'K', when there were several values of 'K' pertaining to samples taken from various fields or from one field for many times.

The goodness of fit was tested by χ^2 (chi-square) test by comparing the observed and expected frequencies (Bliss and Fisher, 1953) by second and third moment as described by Southwood (1978).

Bradley (1952) studied the distribution of three species of aphid on the plants of four varieties of potato and found *Myzus persicae* and *Aphis abbreveata* were most numerous on the bottom and least numerous on top leaves, whereas *Macrosiphum solani folii* was most numerous on the top leaves of plant of these varieties.

Kuehl and Fye (1972) found that enumerative samples of various insects of cotton showed poisson distribution at low density populations, while samples from dense insect populations followed negative binomial distribution. They found that the insect populations tend to cluster, only under heavy intensive sampling or at high population densities.

Latheef and Pass (1974) found that the field counts of *Hypera postica* in two adjacent plots where the populations were relatively low, showed over-dispersion, while in the plots where the density was high, the population aggregates were formed and dispersed in the direction of randomness.

Pieters and Sterling (1974) quantified the aggregation of cotton arthopods based on parameter 'K' of the negative binomial distribution. The nymphs of cotton flea hopper *Pseudatomoscelis seriatus* (Reuter) were more aggregated than the adults. The eggs of boll weevil *Anthonomous grandis* (Boh.) and boll worms, *Heliothis zea* (Boddie) showed greater degree of aggregation than their respective adults and larvae. The predatory cotton arthopods like lady bird beetles and flower bugs (*Orius* sp.) displayed greatest amount of aggregation.

Young and Price (1975) studied the distribution pattern of *Heliothis zea* on sorghum and alfalfa and found that 'K' values ranged from 3.00 in sorghum to >5.00 in alfalfa, thereby indicating a negative binomial type of distribution.

Myers (1978) stated that variance/mean was weekly correlated with density and the dispersion indices related to 'K' of the negative binomial was not appropriate for data which is either more or less clumped than the negative binomial, therefore should be used with caution. He further opined that Green's coefficient of dispersion (Greene 1966) and standardized Morisita's coefficient of dispersion (I_δ) were not influenced by population density and were good measures of dispersion.

Boiteau *et al.* (1979) found that the dispersion of mature been leaf beetle populations approximated a negative binomial distribution.

Reeve *et al.* (1980) quantified the aggregation indices of flying southern pine beetle *Deudroctonus frontalis*, and the clerid predator *Thanasmus dubius* (F.) using index of patchiness and the regression of mean crowding and mean density. Eventhough the densities of the two species did not follow the same trends, both the methods showed a high degree of clumping. Lioyd's index of patchiness indicated overlapping aggregate distribution.

Bechinski and Pedigo (1981) studied the dispersion patterns of *Orius insidiosus* (Say) and nymphs of *Nabis* spp. which showed slight aggregation, while the adults of the latter showed random distribution.

Buntin and Pedigo (1981) studied micro spatial pattern of green clover worm, *Plathypena scabra* (F.) eggs within and among the soybean plants. The green clover worm followed a random dispersion pattern.

Verghese and Tandon (1987) found that mango leafhopper (*Idioscopus niveosparsus*) and *thrips palmi* karny were spatially distributed in a aggregated manner with a low 'K' value and required logarithmic transformations to stabilize the variance.

Daigle *et al.* (1988) studied the distribution pattern of eggs in three cornered alfalfa hopper, *Spissistilus festinus* (Say) which indicated a negative binomial (clumped) distribution.

Schulthess *et al.* (1989) analysed the with in and between plant distribution of cassava mealy bugs (*Phenococcus manihoti* Matile-Ferrero) in dry and rainy season using mean crowding statistics. The between plant distribution was of highly aggregated nature in the wet season while the distribution was less aggregated in dry season. Out of the two sampling plans tested, binomial plan was found to be less time consuming than enumerative plan. The sample estimates were found to be higher binomial sampling.

Rai *et al.* (1992) studied the distribution pattern of diamond back moth *Plutella xylostella* (L.) on cabbage and cauliflower through field experiments at

Panipet, Jannpur, Ranchi and Delhi, India in 1988-89. They observed aggregation of larvae in both cases.

Spatial distribution of rice leaf and planthoppers was studied by Reddy *et al.* (1993) and they observed aggregation in all three groups of insects i.e., *Nephotettix* spp., *Sogatella furcifera* and *Nilaparvata lugens*. The same negative binomial distribution was observed in case of rice stem borer, *Scirpophaga incertulas* (Wlk.) (Bora *et al.*, 1994).

2.2 STUDIES ON SEQUENTIAL SAMPLING PLAN

Since decision making and cost reduction are vital to pest management programmes, sequential sampling plans are becoming more and more important components of sophisticated pest management programme.

Sequential sampling in which the number of samples required to classify an insect population level, is determined as sampling progresses. It permits the sampler to rapidly classify insect population that are either of low or high density with out a fixed sample number. However, intermediate population levels may require more sampling but an average sampling time reduction of 50 per cent can be expected through the use of sequential sampling (Wald, 1947). It is also advantageous because pre determined accuracy and the range of economic injury levels can be incorporated in sequential sampling plans (Onsager, 1976).

Sequential sampling plan was first developed during world war II (Wald, 1945) and was originally used for quality approval of manufactured goods. Forest entomologists, however, were the first to use sequential sampling in insect populations (Stark, 1952; Ives, 1954; Morris, 1954; and Waters, 1955). In agricultural entomology, Sylvester and Cox (1961) made the application of sequential sampling for the first time.

Sequential sampling to classify beneficial insects was also utilized by Waddill *et al.* (1974). Likewise sequential sampling plans were confined to yield information about several insect populations simultaneousely by Sterling and Pieters (1974, 1975) and Sterling (1976).

Sequential sampling techniques were developed for several economically important insect species on the basis of three mathematical models applicable in respective cases.

The pest which followed the negative binomial series for which sequential sampling plans were developed are tape worm, *Triaenophorus crassus*, in white fish, *Coregonus clupea formis* (Oakland, 1950); Sprucebud worm, *Choristoneura fumiferana*, (Morris, 1954); the red pine saw fly, *Neodiprion nanulus* Schedl., on red pine (Cannola *et al.*, 1959); white grubs in soil (Ives and Warren, 1965) imported cabbage worm *Pieris rapae* (L.) on cabbage (Harcourt, 1966a); the cabbage looper *Trichoplusia ni* (Hb.) on cauliflower (Harcourt 1966b, Shepard, 1973); *Monochamus* sp. larvae in lodge pole logs (Safranyik and Raske, 1970); American boll worm of cotton, *Heliothis zea* Boddie on cotton (Allen *et al.*, 1972) the fruit borer, *Earias vittella* Fab., on Okra (Krishnaiah *et al.*, 1978; Rai *et al.*, 1982), the red backed cut worm, *Euxoa ochrogaster*, in pepper mint (Danielson and Berry, 1978); onion thrips, *Thrips tabaci* (Lind.) (Suman and Wahi, 1981); armyworm, *Pseudolatia unipuncta* (Haw.) on small grain crops (Coggin and Dively, 1982); leafhoppers, *Amrasca biguttula biguttula* Ishida on Okra (Faleiro *et al.*, 1982); tomato fruit worm, *Heliothis armigera* (Hb.) on tomatoes (Nilakhe *et al.*, 1982); the alfalfa blotch leaf miner, *Agromyza frontella* (Rond.) on lucerne (Harcourt, 1983); the cabbage leaf webber, *Crocidolomia binotalis* (Sell.) (Suman and Wahi, 1983); the Japanese beetle larval populations on turf grass, (Yuen *et al.*, 1983) and the immigrant adults of *Plathypena scabra* (F.) on soybean (Pedigo and Schaik, 1984); planthoppers in rice (Shepard *et al.*, 1986); the rice gall midge, *Orseolia oryzae* wood-mason mani (Krishnaiah *et al.*, 1987); the shoot and fruit borer on brinjal (Rao and Rai, 1988); the rice planthoppers and predators (Shepard *et al.*, 1988); the leaf webber, *Antigastra catalaunalis* (Dup.) on sesame (Choudhary *et al.*, 1989); the pyralid *Leucinodes orbonalis* on egg plant (Tewari and Rao, 1989); the pod borer, *Helicoverpa armigera* (Hubner) in pigeonpea (Venkataiah *et al.*, 1994) the gram pod borer, *Helicoverpa armigera* (Hubner) in chickpea (Sekhar, 1994).

Based on poisson distribution, sequential sampling plans were developed for the winter moth *Operaphtera brumata* (L.) (Reeks, 1956) and the green clover worm on soybeans (Hammond and Pedigo, 1976).

Based on the binomial distribution pattern the technique was developed for Larch Saw fly, *Pristiphora erichsonii* (Htg.), on forest trees (Ives and Prentice 1958); the corn earworm, *H.zea* on sweet corn (Wolfenbarger and Dorroch, 1965); the cotton fleahoppers, *Pseudotomoscelis reriatus* (Reuter), on cotton (Pieters and Sterling, 1974); the boll weevil *Anthonomus grandis* Bon. and *Heliothis* spp. on cotton (Pieters and Sterling, 1975), the mexican bean beetle on soybeans (Bellinger *et al.*, 1981) and the cabbage aphid, *Brevicoryne brassicae* (L.), and green peach aphid *Myzus persicae* (Sulz.) on brussel sprouts (Wilson, *et al.*, 1983).

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

In this chapter, data base, source of its coverage, statistical tools and procedure of estimation adopted to meet the objectives of the study are described.

3.1 DATA, SOURCE AND COVERAGE OF STUDY

For achieving the objectives mentioned, the data on BPH counts for Kharif and Rabi seasons of 1985-86 were made available from Directorate of Rice Research, Rajendranagar, Hyderabad. The data available were collected from farmers fields at Kolakaluru village in Guntur district of Andhra Pradesh. Sampling was done in the fields where Mahsuri variety (IET 5688) of Rice was grown. Five sets of sampling data were collected in Kharif season in different farmers fields and two sets of data were collected in Rabi season. For convenience sake five fields (Kharif) were named as A, B, C, D and E, two fields (Rabi) were named as F and G. Sampling was done at panicle initiation stage i.e., 60 days after transplanting and 50 days after transplanting in Kharif and Rabi fields respectively. In A, B, C, D, E, F and G fields 130, 500, 798, 245, 250, 150 and 150 plants respectively sampled. Low infestation was observed in case of A, B and C fields and severe infestation was observed in D, E, F and G fields. Data on predator counts were also collected for

A, F and G fields. These are denoted as A_1, F_1 and G_1 respectively. All sets of data were analysed to meet the objectives mentioned.

3.2 METHODOLOGY

3.2.1 Distribution of BPH on the crop

In order to find the distribution of BPH, the data were arranged in frequency distribution for each field i.e., A, B, C, D, E, F and G. Mean and variance were then worked out for each frequency distribution. It may be noted that for poisson distribution mean and variance are equal, for binomial distribution mean is greater than variance and for negative binomial distribution mean is less than the variance.

3.2.1.1 Determination of dispersion parameter 'K' : The parameter 'K' (Elliott, 1979) which measures the degree of aggregation of BPH in the natural population was calculated. A negative binomial series $(q-p)^{-K}$ has a mean, $\bar{X}$ = Kp and variance, S^2 = Kpq, therefore, q = Kpq/Kp since q - p = 1, hence p = q - 1 and

$$K = \frac{Kp}{p} = \frac{Kp}{q-1} = \frac{Kp}{\frac{Kpq}{Kp} - 1} = \frac{Kp}{\frac{Kpq-Kp}{Kp}} = \frac{Kp \times Kp}{Kpq - Kp}$$

$$= \frac{\bar{X} \times \bar{X}}{S^2 - \bar{X}} = \frac{\bar{X}^2}{S^2 - \bar{X}}$$

In order to find the intensity of aggregation of BPH, 'K' values (moment estimate of 'K') for each of the 7 frequency distributions were calculated.

Other methods of computing 'K' (Southwood, 1978) were also employed and discussed here.

3.2.1.2 Estimation of 'K' from proportion of zeros :

$$\log\left(\frac{N}{n_0}\right) = K \log \left(1 + \frac{\bar{X}}{K}\right)$$

Where,

N = Total number of sampling units

n_0 = Number of sampling units containing zero BPH

K = moment estimate

This method of calculating 'K' was done in such fields only, where zero population of BPH were observed during sampling.

3.2.1.3 Trial and error (Iterative) method : This method was worked out for every set of sampling.

$$N \log_e \left(1 + \frac{\bar{X}}{K}\right) = \left(\frac{A_x}{K + X}\right)$$

Where,

$\log_e$ = Napierian logarithm

A_x = The sum of all frequencies of sampling units containing more than x individuals

The value of 'K' obtained by this method was used for all further analysis and was considered as real and accurate estimate of 'K' value (Southwood, 1978).

3.2.1.4 Determination of common K (K_c) : The common value of 'K' i.e., K_c for entire season was computed by following moment and regression method. (Bliss, 1958; Bliss and Owen, 1958). The statistic K_c was obtained as follows.

$$K_c = X^1/Y^1$$

Where

$X^1 = (\bar{X})^2 - S^2/N$

$Y^1 = S^2 - \bar{X}$ and

$\bar{X}$ = mean

S^2 = variance

N = Number of plants on which X is based

3.2.1.5 χ^2 (chi-square) test of goodness-of-fit : The goodness of fit for each of the seven frequency distribution (A, B, C, D, E, F and G) was done for agreement with negative binomial distribution with the help of chi-square (χ^2) test with degrees of freedom V = (n-2-1) where n is the total frequency, and 2 refers to parameters, mean and variance.

3.2.1.6 Testing the fit of negative binomial by statistic 'U' and statistic 'T' tests : These two tests are based on a comparison of observed and expected moments (mean, variance and skewness). Which of these two tests will be applied for fitting the negative binomial distribution depends upon the $\bar{X}$ and accurate K. Evans (1953) found these tests satisfactory to accept the negative binomial as a satisfactory model. The U-statistic was based upon the difference between the actual variance and the expected variance and is given by

$$U = S^2 - (\bar{X} + \frac{\bar{X}^2}{K})$$

Where,

$\bar{X}$ = mean

S^2 = variance

K = accurate 'K'

And the standard error of U [SE (U)] is given as

$$SE\ (U) = 2\ \bar{X}\ (K + 1)\ Pq^2\ \frac{[1-R^2/-1_n\ (1-R)-R]}{N + P^4\ Var.\ K_3}$$

Where,

$P = \bar{X} / K$

$q = 1 + P$

$R = \bar{X}/K + X$

-1_n = Napierian logarithm

If 'U' is significantly less than its standard error (SE) then the negative binomial is taken as satisfactory model for all the weeks.

Statistic 'T' was based on the third moment and is the difference between the actual third moment (Skewness) of the field data and its value predicted from the first two moments (mean and variance) and is given as

$$T = \left(\frac{\Sigma fx^3 - 3\ \bar{X}\ \Sigma fx^2 + 2\ \bar{X}^2 \Sigma f\ X}{N} \right) - S^2 \left(\frac{2S^2}{\bar{X}} - 1 \right)$$

The standard error [SE (T)] was calculated from

$$SE\ (T) = \sqrt{\frac{2\bar{X}\ (K+1)\ \bar{X}^2/K^2\ (1+\bar{X}/K)^2\ \left[2\ (3+5\ \bar{X}/K) + 3K\ (1-\bar{X}/K)\right]}{N}}$$

Here also negative binomial was considered satisfactory if 'T' statistic was found significantly smaller than its standard error [SE (T)].

A large positive value of 'U' or 'T' indicates that the actual BPH population is more skewed than described by the negative binomial and a large negative value indicates that the actual distribution of BPH is less skewed.

3.2.2 Indices of dispersion

Many different indices were proposed to compare the different patterns of dispersion in population. The following are some of the indices of dispersion which are commonly used for measuring the distribution pattern of the BPH.

3.2.2.1 Variance to mean ratio or index of dispersion (I) : This test was based on the equality of variance and mean in a poisson series (Patel and Stiteler, 1974). The variance to mean ratio, or index of dispersion (I), would approximate to unity in a true poisson expectation. The index of dispersion equation was

$$I = \frac{\text{variance}}{\text{mean}} = \frac{s^2}{\bar{X}} = \frac{\sum(X - \bar{X})^2}{\bar{X}(n-1)}$$

Where,

S^2 = variance

$\bar{X}$ = mean

n = sampling units

This index of dispresion would often depart from unity, a value of zero for the index implied regular distribution and a value greater than one implied for aggregation or contagious type of distribution.

3.2.2.2 Cole's index of dispresion (Cole, 1946) : Cole's index was calculated from the formula

$$I = \frac{\Sigma(X)^2}{(\Sigma X)^2}$$

3.2.2.3 David and Moore's index of dispersion : This index (David and Moore, 1954) was computed out by the formula $S^2/\bar{X} - 1$ and the data were accepted as negative binomial when it departed from zero.

3.2.2.4 'K' of negative binomial - an index of aggregation in the population : The reciprocal of the exponent 'K', i.e., 1/K, was also used as a measure of the excess variance or clumping of individuals in a population (Elliott, 1979).

3.2.2.5 Morisita's index of dispersion : The Morisita's index of despersion (Morisita, 1962) was worked using the formula.

$$I = n.\frac{\sum[X(x-1)]}{\sum X(\sum X-1)} = n.\frac{\sum(X^2) - \sum X}{(\sum X)^2 - \sum X}$$

$$F_0 = I_\delta(\sum X - 1) + (n - \sum X)$$

3.2.2.6 **Index of mean crowding :** The degree of crowding experienced by hopper individual was worked (Lloyd, 1967) as

$$\overset{*}{X} = \bar{X} + [(S^2/\bar{X})-1].$$

3.2.3 Developing a sequential sampling plan

Sequential sampling is a technique which permits to make rapid decisions about the level of pest infestations with predetermined accuracy. In this procedure sampling was done in sequence, then the progressive information gained from the cumulative samples estimates the degree of infestation. The procedure had to be continued upto a point till a decision was arrived at a low probability of error in the estimate.

The sequential sampling method might reduce the sampling time by more than 50 per cent (Waters, 1955). The greatest time saving occurs when the infestation was either heavy or light. If the infestation was moderate, greater number of samples were to be taken to obtain a reliable decision.

3.2.3.1 **Sequential plan :** Pre requisites for developing a sequential sampling plan include knowledge of type of frequency distribution which can best describe the insect counts, economic thresholds or pest density treatment levels, and an acceptable probability of error in the ultimate decision (Pieters, 1978). Based on these factors sequential sampling plan can be developed using the formulae developed by Oakland (1950), Waters (1955) and Onsager (1976).

Two types of error were involved in sequential sampling i.e., the probability of ' α ' of recommending an unnecessary treatment and ' β ' the probability of failing to recommend a needed one. The values of ' α ' and ' β ' were set at 0.05 as recommended by Waters (1955).

The mathematical equation for the acceptance and rejection lines in the sequential plan based on negative binomial series was given by the formulae (Waters, 1955; Shepard, 1980 and Southwood, 1978).

$$d_1 = Sn + h_1$$

$$d_2 = Sn + h_2$$

Where,

n = number of samples

S = slope of the decision lines

d_1 = maximum value for the lower class

d_2 = minimum value for the upper class in terms of cumulative infestation level of BPH

h_1 = intercept of the lower line

h_2 = intercept of the upper line

$$\text{Slope (S)} = K \frac{\log (q_2/q_1)}{\log (P_2 q_1/P_1 q_2)} ;$$

Where,

$P_1 = m_1/K$

$P_2 = m_2/K$

$q_1 = 1 + P_1$

$q_2 = 1 + P_2$

m_1 and m_2 are class limits or economic threshold

K = dispersion parameter

The 'm' values were obtained from the economic injury level and these levels 'm_1' and 'm_2' were set at 1/3 and 2/3 of the economic injury level, respectively.

This 'm_2' level corresponds to the economic threshold level (Stern *et al.*, 1959) at which treatment should be initiated to prevent economic damage.

$$h_1 = \frac{\log B}{\log (P_2 q_1/P_1 q_2)}$$

Where,

$$B = \frac{\beta}{1 - \alpha}$$

$$h_2 = \frac{\log A}{\log (P_2 q_1/P_1 q_2)}$$

Where,

$$A = \frac{1 - \beta}{\alpha}$$

Where α = the risk of calling a low infestation high

β = the risk of calling a high infestation low

In presence of predators in the field the hopper counts must be adjusted by subtracting five hoppers for each major predator found. After finding the distribution of adjusted hoppers sequential analysis can be carried out usually with the above formulae.

3.2.3.2 **Operating characteristic (OC) curve** : The OC curve is not essential for the development of sequential sampling plan but it helps in predicting the chances of making a correct decision at various infestation levels. The OC curve for this sequential sampling gives the probability, L(P) of making a correct decision at the various infestation levels. Thus L(P) is the probability of accepting m_1 and m_2 and P the population mean per sample, then

$$L(P) = \frac{A^h - 1}{A^h - B^h} \quad \text{when } h \neq 0$$

Where A and B are defined earlier

$$P = \frac{1 - (q_1 / q_2)^h}{(P_2\ q_1/P_1\ q_2)^{h-1}}$$

Where h is a dummy variance

3.2.3.3 **Average sample number (ASN) curve** : It indicates the average number of samples needed at various infestation levels for a particular plan. The average number of inspection required is given by

$$E_{p(n)} = \frac{h_2 + (h_1 - h_2)\ L(P)}{K.P - S}$$

Where h_1, h_2, L(P), K, P and S are defined earlier.

RESULTS

CHAPTER IV

RESULTS

The results of the experiment carried out are presented under the following heads.

1. Distribution of pattern of BPH on the crop
   i) Frequency distribution
   ii) Estimation of dispersion parameter 'K'
   iii) Determination of common 'K' (K_c)
   iv) χ^2 (chi-square) test for "goodness-of-fit"
   v) Statistics 'U' and statistic 'T' tests
   vi) Indices of dispersion
2. Sequential sampling plan

4.1 DISTRIBUTION PATTERN OF BPH ON THE CROP

4.1.1 Frequency distribution

The mean and variance were computed for the data obtained on BPH population. Then frequency tables with different class intervals were screened and the frequency table having mean nearer to actual mean was considered. After arriving at such frequency tables for all sets of field data, mean and variance were calculated and presented in Table 1. From the Table (1) it can be seen that the values of variance are greater than the corresponding mean values ($S^2 > \overline{X}$) for all the fields i.e., from A to G. Hence BPH population was considered as clumped or aggregated.

Table 1 : Mean and variance for the fields A to G

S.No.	Field	Sample number	Mean	Variance
1.	A	130	10.2769	48.6669
2.	A_1	130	5.1384	18.8489
3.	B	500	3.0240	4.5284
4.	C	798	5.5889	11.2430
5.	D	245	96.1530	2969.2860
6.	E	250	68.6000	2977.1990
7.	F	150	75.7333	2139.7270
8.	F_1	150	64.8000	2038.2150
9.	G	150	91.0000	3571.8120
10.	G_1	150	80.5000	2868.3720

1. Data including predator counts

4.1.2 Estimation of dispersion parameter 'K'

The negative binomial nature of distribution of rice BPH was further confirmed by calculating the value of dispersion parameter 'K'. By using mean and variance and the formulae given in previous chapter 'K' values were calculated for all seven fields. The values of 'K' are presented in Table 2. The values of dispersion parameter 'K' were found to be less than eight in all cases.

Table 2 : Determination of dispersion parameter (K) by various methods

S.No.	Field	K / $(\overline{X}^2)/S^2-\overline{X}$	K from proportion of zeros	K from trial and error method
1.	A	2.7111	--	0.380
2.	A_1	1.9157	0.3246	0.440
3.	B	6.0785	0.6000	0.570
4.	C	5.5244	3.5290	0.400
5.	D	3.2179	--	0.162
6.	E	1.6179	--	0.168
7.	F	2.7788	--	0.175
8.	F_1	2.1278	--	0.179
9.	G	2.1379	0.5460	0.150
10.	G_1	2.3244	0.7800	0.163

The 'K' values were also estimated from proportion of zeroes (wherever zero counts present in the data) and also by 'trial and error method' and the results are presented in Table 2. The 'K' value calculated from proportion of zeroes ranged from 0.3246 to 3.529, whereas 'K' by trial and error method ranged in between 0.15 to 0.57. Thus, the maximum value of 'K' obtained did not exceed 8. Therefore it further confirmed aggregated nature of distribution of BPH (Southwood, 1978).

4.1.3 Determination of common 'K' (K_C) by moments and regression method

A separate common clumping parameter (K_C) was worked out for with and without predator cases by moments and regression method. The 'K_C' thus obtained were 2.2351 and 2.4667 for with and without predator cases respectively (Table 3).

Table 3 : Determination of moments and regression for rice BPH

S.No.	Filed	$X^1 = (\bar{X})^2 - (S^2/N)$	$Y^1 = S^2 - \bar{X}$
Without predators			
1.	A	105.2400	38.3900
2.	B	9.1355	1.5044
3.	C	31.2217	5.6541
4.	D	9233.2790	2873.1330
5.	E	4694.0500	2908.5990
6.	F	5721.2680	2063.9940
7.	G	8257.1880	3480.8120
With predators			
1.	A_1	26.2580	13.7105
2.	F_1	4185.4520	1973.4150
3.	G_1	6461.1270	2787.8700

Common K (K_C) for without predators $= X^1/Y^1 = 28051.3822/11372.0865 = 2.4667$

Common K (K_C) for with predators $= X^1/Y^1 = 10672.8370/4774.9955 = 2.2351$

The regression estimate of common K (K_c) was made to test whether this is true representative of various K values with the help of statistics Y^1 and X^1 or not.

The values of dispersion parameter 'K' and its reciprocal 1/K were frequently used as indices of dispersion. As 1/K approaches zero and 'K' approaches infinity, then distribution coverages to poisson series. Conversely if clumping increases, 1/K approaches infinity and distribution coverages to logarithmic series. The observed values of 'K' and its reciprocal 1/K for rice BPH population in the present investigation sloped towards contagiousness of the population. A graph was drawn by plotting mean (X) and 1/K for all the fields (Fig.2). It was observed that there is no relationship between mean (X) and 1/K and therefore the calculation of common K (K_c) is justified. The estimates of the slope of the regression lines were given for with and without predator cases as follows.

$$\text{Without predators}: \frac{1}{K_c} = \frac{Y^1}{X^1} = \frac{11372.08650}{28051.38822} = 0.4054$$

$$\text{With predators}: \frac{1}{K_c} = \frac{Y^1}{X^1} = \frac{4774.9955}{10672.8370} = 0.4474$$

4.1.4 χ^2 (chi-square) test

The computed data of Rice BPH was subjected to χ^2 test for "goodness-of-fit" for agreement with negative

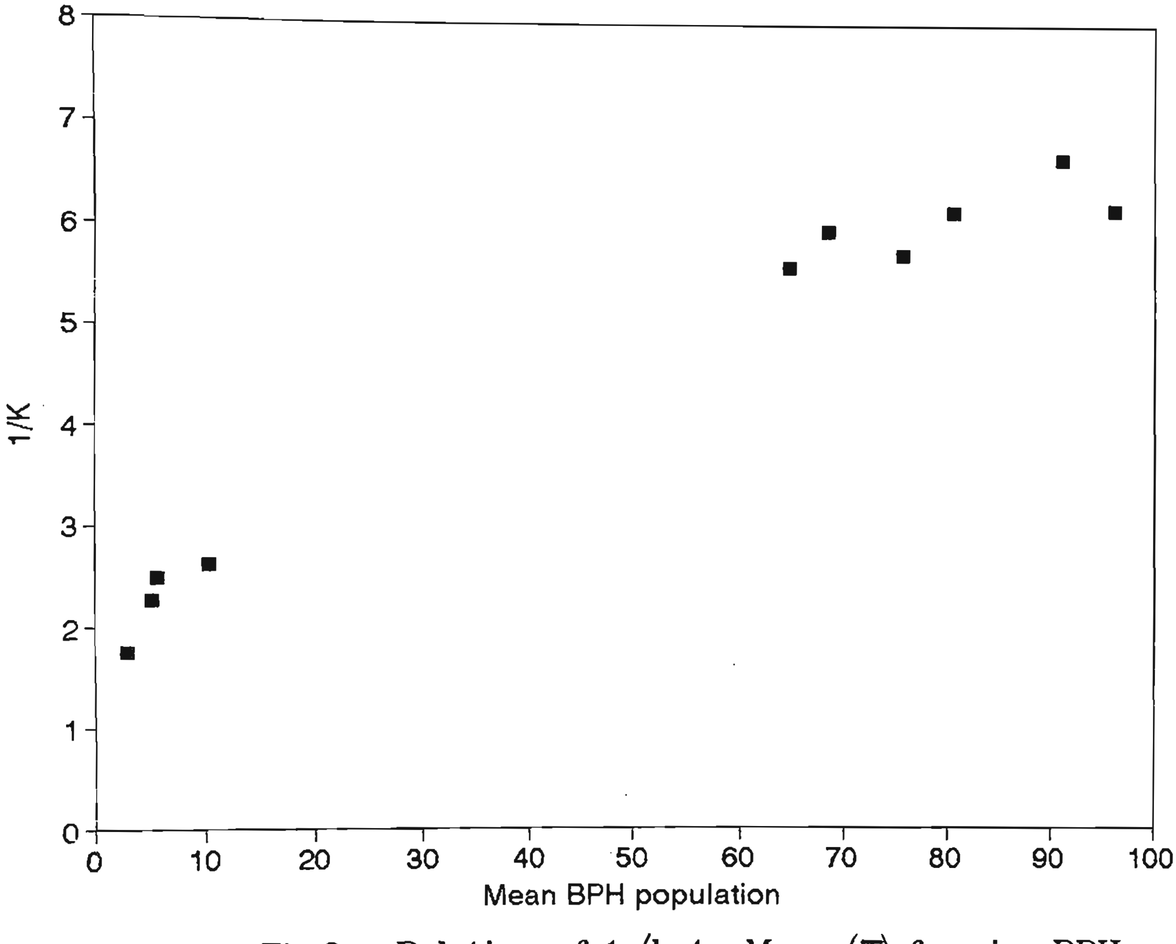

Fig.2. Relation of $1/k$ to Mean ($\overline{x}$) for rice BPH

binomial distribution. The expected frequencies were compared with the observed frequencies to find out the χ^2 value.

The two parameters estimated from the negative binomial distribution were mean ($\bar{X}$) and variance (S^2) hence the degrees of freedom for this test was V = (total frequency) - 3.

Table 4 : χ^2 test of "goodness-of-fit" for agreement with a negative binomial distribution of Rice BPH

S.No.	Field	Chi-square value
1.	A	12.4307
2.	A_1	7.6228
3.	B	39.0466
4.	C	16.0296
5.	D	57.6050
6.	E	6.9847
7.	F	60.1155
8.	F_1	52.3846
9.	G	8.2042
10.	G_1	11.2540

The χ^2 values for Rice BPH were given in the Table 4, ranged from 6.9847 to 60.11555 and all the calculated values were less than the table values at 5 per cent level of significance (Pearson and Hartley, 1966). Therefore it may be concluded that negative binomial gave an adequate description of the frequency distribution of hopper counts at 5 per cent level of significance (P<0.05).

4.1.5 Statistic 'U' and statistic 'T' tests

Statistic 'U' is the difference between the actual and expected variance. The statistic 'U' calculated for all fields from A to G of experimentation were given in Table 5. The standard error of 'U' was also calculated and it was found that standard error was significantly greater than statistic 'U' in all the cases, indicating the negative binomial pattern of distribution for the Rice BPH. The values of 'U' ranged in between -54197.2 to -14.539 and SEs(U) ranged in between 5.059417 to 3505.107.

Table 5 : Statistic 'U' and statistic 'T' test for the Rice BPH

S.No.	Field	Statistic		Statistic	
		U	SE(U)	T	SE(T)
1.	A	-239.543	1190.748	-21905.1	1735.965
2.	A_1	-46.2967	231.0023	-2463.85	229.7443
3.	B	-14.539	5.059417	-29.3491	19.0588
4.	C	-72.4354	75.5803	-467.167	141.3718
5.	D	-54197.2	3466.842	-5.44E+08	2584143
6.	E	-25103.10	3505.107	-7.69E+8	1006932
7.	F	-30710.40	2055.175	-2.58E+8	1505732
8.	F_1	-21484.90	2042.708	-2.61E+8	965289.30
9.	G	-51725.80	2205.514	-1.0E+9	3476578
10.	G_1	-36968.20	2125.151	-5.8E+8	2087233

The statistic 'T' was calculated involving the difference between the calculated third moment (Skewness) of every field (A to G) data and its value predicted from the first two moments and presented in Table 5 itself.

The value of 'T' ranged in between -1.0×10^9 to -29.3491 and SE(T) values ranged between 19.0588 to 3476578. It is observed from Table 5 that the statistic 'T' was significantly less than standard error of 'T' confirming the negative binomial distribution pattern of BPH population.

4.2 INDICES OF DISPERSION

The poisson distribution, resulting from random dispersion, makes a useful yard stick by which the actual distributions are compared. As an alternative to random dispersal, Rice BPH are commonly aggregated, so the scatter of the population values tend to be increased by aggregation. Many different indices were used to measure the distribution pattern. The following indices were tried.

4.2.1 Variance to mean ratio of index of dispersion (I)

This test is based on equality of variance and mean in a poisson series. The results obtained indicated that 'I' departed from unity employing contagious type of distribution (Table 6).

Table 6 : Variance to mean ratio of index of dispersion (I) for the Rice BPH

S.No.	Field	I $s^2/\bar{X}$
1.	A	4.7356
2.	A_1	3.6682
3.	B	1.4975
4.	C	2.0116
5.	D	30.8808
6.	E	43.3994
7.	F	28.2534
8.	F_1	31.4539
9.	G	39.2507
10.	G_1	35.6319

4.2.2 Cole's index of dispersion

Cole's index of dispersion was calculated by the formula

$$I = \frac{\Sigma(X^2)}{(\Sigma X)^2}$$

The results (Table 7) showed that the observed Cole's index value for all fields of experimentation was greater than the corresponding values of maximum regularity and randomness given in the same Table. This further confirmed the aggregated nature of dispersion.

Table 7 : Cole's index value

S.No.	Field	Maximum regularity 1/n	Random $\frac{1}{n} + \frac{n-1}{n}\left(\frac{1}{\Sigma X}\right)$	Maximum contagion	Observed cole's index $I = \frac{\Sigma(X)^2}{(\Sigma X)^2}$
1.	A	0.00769	0.00847	1	0.011567
2.	A_1	0.00769	0.00959	1	0.018970
3.	B	0.002	0.00293	1	0.004390
4.	C	0.00125	0.00149	1	0.001696
5.	D	0.00408	0.004123	1	0.536500
6.	E	0.004	0.004058	1	0.006448
7.	F	0.00667	0.00676	1	0.009200
8.	F_1	0.00667	0.006776	1	0.010230
9.	G	0.00667	0.00674	1	0.009495
10.	G_1	0.00667	0.00675	1	0.010070

4.2.3 David and Moore's index

David and Moore's index of dispersion was also calculated (Table 8) and it was found that observed value of David and Moore's index was greater than the table value of maximum regularity (-1) and randomness (0), confirming the contagious or aggregated distribution of BPH.

Table 8 : David and Moore's index of dispersion

S.No.	Field	Maximum regularity	Random	Observed index
1.	A	-1	0	3.7550
2.	A_1	-1	0	2.6682
3.	B	-1	0	0.4974
4.	C	-1	0	1.0116
5.	D	-1	0	29.8808
6.	E	-1	0	42.3994
7.	F	-1	0	27.2534
8.	F_1	-1	0	30.4539
9.	G	-1	0	38.2506
10.	G_1	-1	0	34.6319

4.2.4 'K' of the negative binomial - an index of aggregation in the population

'K' calculated from trail and error method is usually considered as appropriate 'K' value and is frequently used as an index of dispersion in negative binomial distribution. The reciprocal of the exponent 'K', i.e., 1/K was calculated for all sets of data (A to G fields) for BPH population (Table 9) to know the clumping behaviour of individuals in a population. When 1/K approaches zero as 'K' approaches infinity, the distribution coverages to the poisson series. From Table 9, calculated values of $K < 8$ and its reciprocal $1/K > 0$

with positive sign for all fields, confirmed that Rice BPH distribution was of contagious nature.

Table 9 : Reciprocal of K (1/K) index of dispersion

S.No.	Field	'K'	'1/K'
1.	A	0.380	2.6316
2.	A_1	0.440	2.2727
3.	B	0.570	1.7544
4.	C	0.400	2.5000
5.	D	0.162	6.1728
6.	E	0.168	5.9524
7.	F	0.175	5.7143
8.	F_1	0.179	5.5866
9.	G	0.150	6.6667
10.	G_1	0.163	6.1349

4.2.5 Morisita's index of dispersion (I_δ)

Morista's index of dispersion (I_δ) is independent of the sample mean ($\bar{X}$) but is influenced by total number of sampling units (N). I_δ values were calculated and presented in Table 10, which ranged from 1.3088 to 2.2717. The calculated index value was greater than unity (1) for all the fields (A to G) of BPH infestation on Rice crop, thereby confirming the contagious type of distribution of BPH.

Table 10 : Morisita's index of dispersion

S.No.	Field	I_δ	$F_o = I_\delta(\Sigma X-1) + (n - \Sigma X)$	d.f.	Tab. Chi-square 0.95
1.	A	1.4019	638.21	129	161.84
2.	A_1	2.2717	765.50	129	161.84
3.	B	1.7285	1275.58	494	562.31
4.	C	1.1597	1452.08	797	876.65
5.	D	1.3088	7388.70	244	288.67
6.	E	1.5975	10387.38	249	294.12
7.	F	1.3665	4160.34	149	184.19
8.	F_1	1.5193	4971.74	149	184.19
9.	G	1.4131	5644.68	149	184.19
10.	G_1	1.4991	6230.03	149	184.19

4.2.6 Lloyd's index of mean crowding

The $\bar{X}$ and S^2 estimates obtained from each field data were also used to estimate mean crowding ($\overset{*}{X}$) which is obtained as $\overset{*}{X} = \bar{X} + ([S^2/\bar{X}]-1)$.

The mean crowding values obtained departed from poisson series indicating the aggregated behaviour of BPH.

4.3 SEQUENTIAL SAMPLING PLAN

In the present study sequential sampling plans for the rice BPH infestation were developed for all sets of data with a view to classify infestation levels as light, medium and severe, so as to initiate chemical control measures by inspecting minimum number of plant samples. The sequential sampling plans were developed for all fields (A to G) with respective dispersion parameters 'K' (X^2/S^2-X) and overall sequential sampling plans were developed by using common K (K_c) values. The economic injury levels used were 25 hoppers/plant and 20 hoppers/plant for without predator and with predator cases respectively. The method of arriving at these levels was outlined in the 'Materials and Methods chapter. The decision lines for the two hypotheses 'to treat' and 'not to treat' the crop were worked out by taking two levels of infestation as light and severe as given in Table 11.

Table 11 : The decision lines for light versus severe (1/3 EIL Vs 2/3 EIL)

Fields	d_1 (Lower limit)	d_2 (upper limit)
A	11.4930 n - 20.4665	11.4930 n + 20.4665
A_1	9.4392 n - 28.1931	9.4392 n + 28.1931
B	11.5765 n - 11.3457	11.5765 n + 11.3457
C	11.5649 n - 17.8761	11.5649 n + 12.0838
D	11.5080 n - 17.8761	11.5080 n + 17.8761
E	11.4567 n - 31.5675	11.4567 n + 31.5675
F	11.4951 n - 20.0654	11.4951 n + 20.0654
F_1	9.4438 n - 25.8670	9.4438 n + 25.8670
G	11.4826 n - 22.7605	11.4826 n + 22.7605
G_1	9.4479 n - 24.0898	9.4479 n + 24.0898
S	11.4854 n - 22.0946	11.4854 n + 22.0946
S_1	9.4460 n - 24.8583	9.4460 n + 24.8583

S = Overall season; [1]Field with predators

Where d_1 is the maximum value for the lower class (i.e., no treatment required), d_2 is the minimum value for the upper class (i.e., treatment required) in terms of cumulative per cent infestation and n is the number of plants sampled

The numerical values of lower and upper limits of sequential sampling plan for different fields were given in Tables 12 to 14. The decision lines for all the fields from A to G are depicted in Figures from 3 to 9 respectively and the overall season decision lines dipicted in the Fig.9a. Tables 12 to 14 could be used for taking on the spot decision with respect to control measures of rice BPH using following procedure.

Table 12 is used for sequential sampling plan of Field A. For example, if 10 plants are sampled randomly and the cumulative BPH count is found to be less than 94, the decision of not spraying will be taken. But if the cumulative BPH population is more than 135 then the decision of spraying should be taken. If the cumulative BPH populations falls between 94 and 135, continue taking more samples and if after 13th sample also decision is still to continue sampling, than the decision to treat will be taken (Shepard and Ferrer, 1990).

Table 13 is used for sequential sampling plan for Field A^1 which is having predator counts. In this, random samples are taken and number of hoppers and number of predators on the sample plant are recorded. The adjusted number of hoppers was determined by subtracting 5 hoppers for each major predator found (Shepard and Ferrer, 1990). The cumulative adjusted number of hoppers provides a running total of the adjusted number of hoppers. If ten

Table 12 : Sequential sampling plan for rice brown plant hoppers (Field A)

Date________ Location__________ Days after transplanting________
Field No.______ Variety__________

Sample number	Number of hoppers	Cumulative no.of hopper		Lower limit		Upper limit	
1.	--	--		--		--	
2.	--	--		--		--	
3.	--	--		--		--	
4.	--	--		--		--	
5.	--	--		< 37		78 >	
6.	--	--		< 48		89 >	
7.	--	--		< 60		101 >	
8.	--	--		< 71		112 >	
9.	--	--	DO NOT TREAT	< 83	CONTINUE SAMPLING	124 >	TREAT
10.	--	--		< 94		135 >	
11.	--	--		< 106		147 >	
12.	--	--		< 117		158 >	
13.	--	--		< 129		170 >	
14.	--	--		< 140		181 >	
15.	--	--		< 150		193 >	
16.	--	--		< 163		204 >	
17.	--	--		< 175		216 >	
18.	--	--		< 186		227 >	
19.	--	--		< 198		239 >	
20.	--	--		< 210		250 >	

Table 13 : **Sequential sampling plan for rice brown plant hoppers and predators (Field A_1)**

Date________ Location_________ Days after transplanting__________
Field No.________ Variety________

Sample number	Hopper number	Predators number	Adjust no.of hoppers	Cumulative no.of hoppers		Lower limit		Upper limit	
1.	--	--	--	--		--		--	
2.	--	--	--	--		--		--	
3.	--	--	--	--		--		--	
4.	--	--	--	--		--		--	
5.	--	--	--	--		< 19		75 >	
6.	--	--	--	--		< 28	CONTINUE SAMPLING	85 >	
7.	--	--	--	--	DO NOT TREAT	< 38		94 >	
8.	--	--	--	--		< 47		104 >	TREAT
9.	--	--	--	--		< 57		113 >	
10.	--	--	--	--		< 66		122 >	
11.	--	--	--	--		< 76		132 >	
12.	--	--	--	--		< 85		141 >	
13.	--	--	--	--		< 94		151 >	
14.	--	--	--	--		< 104		160 >	
15.	--	--	--	--		< 113		170 >	
16.	--	--	--	--		< 123		179 >	
17.	--	--	--	--		< 132		189 >	
18.	--	--	--	--		< 142		198 >	
19.	--	--	--	--		< 151		207 >	
20.	--	--	--	--		< 160		214 >	

Table 14 : Lower and upper class limits of sequential sampling plan for all fields i.e., A to G

S.No.	Field A		Field A_1		Field B		Field C		Field D	
	LL	UL	LL	UL	LL	UL	LL	UL	LL	UL
1.	-9	32	-19	38	0	23	0	24	-6	29
2.	2	43	-9	47	12	34	11	35	5	41
3.	14	55	0	56	23	46	23	47	17	52
4.	25	66	9	66	35	58	34	58	28	64
5.	37	78	19	75	46	69	46	70	40	75
6.	48	89	28	85	58	81	57	81	51	87
7.	60	101	38	94	70	92	69	93	63	98
8.	71	112	47	104	81	104	80	105	74	110
9.	83	124	57	113	93	115	92	116	86	121
10.	94	135	66	122	104	127	103	128	97	133
11.	106	147	76	132	116	139	115	139	109	144
12.	117	158	85	141	127	150	127	151	120	156
13.	129	170	94	151	139	162	138	162	132	167
14.	140	181	104	160	151	173	150	174	143	179
15.	152	193	113	170	162	185	161	185	155	190
16.	163	204	123	179	174	196	173	197	166	202
17.	175	216	132	189	185	208	184	209	178	213
18.	186	227	142	198	197	220	196	220	189	225
19.	198	239	151	207	209	231	208	232	201	236
20.	210	250	160	217	220	243	219	243	212	248

Contd...Table 14

S.No.	Field E		Field F		Field F_1		Field G		Field G_1	
	LL	UL	LL	UL	LL	UL	LL	UL	LL	UL
1.	-21	44	-8	31	-16	35	-11	34	-15	33
2.	-9	55	3	43	-7	45	0	46	-5	43
3.	2	66	14	54	2	54	12	57	4	52
4.	14	78	26	66	12	64	23	69	14	62
5.	25	89	37	77	21	73	35	80	23	71
6.	36	101	49	89	31	82	46	92	32	81
7.	48	112	60	100	40	92	58	103	42	90
8.	59	124	72	112	50	101	69	115	51	100
9.	71	135	83	123	59	111	80	126	61	109
10.	82	147	95	135	68	120	92	137	70	118
11.	94	158	106	146	78	130	103	149	80	128
12.	105	170	118	158	87	139	115	160	89	137
13.	117	181	129	169	97	149	126	172	99	147
14.	128	192	141	181	106	158	138	183	108	156
15.	140	204	152	192	116	167	149	195	118	166
16.	151	215	164	204	125	177	161	206	127	175
17.	162	227	175	215	135	186	172	218	136	185
18.	174	238	187	227	144	196	184	229	146	194
19.	185	250	198	238	153	205	195	241	155	203
20.	197	261	210	250	163	215	207	252	165	213

LL = Lower Limit; UL = Upper Limit; 1 = Sampling Plan with Predators

Contd...Table 14

S.No	Overall season			
	Without predators		With predators	
	LL	UL	LL	UL
1.	-11	33	-15	34
2.	0	45	-6	44
3.	12	45	3	53
4.	24	56	13	63
5.	35	68	22	72
6.	47	91	32	81
7.	58	102	41	91
8.	70	114	51	100
9.	81	125	60	110
10	93	137	70	119
11.	104	148	79	129
12.	116	160	88	138
13.	127	171	98	148
14.	139	183	107	157
15.	150	194	117	166
16.	162	206	126	176
17.	173	217	136	185
18.	185	229	145	195
19.	196	240	155	204
20.	208	252	164	214

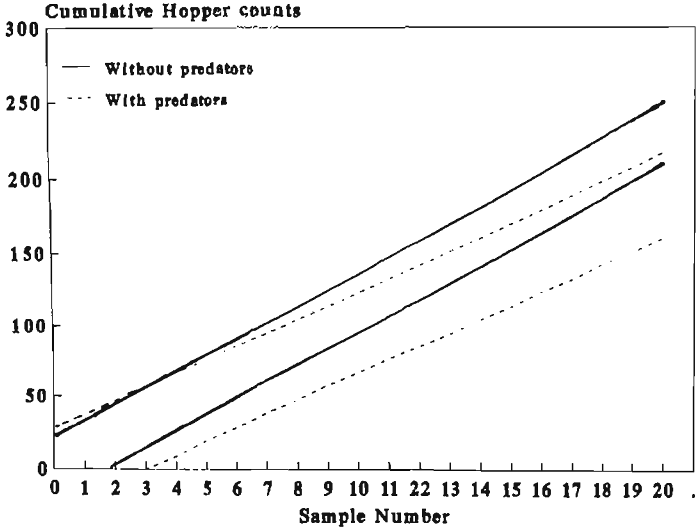

Fig.3. Sequential sampling plans for A and A1 fields

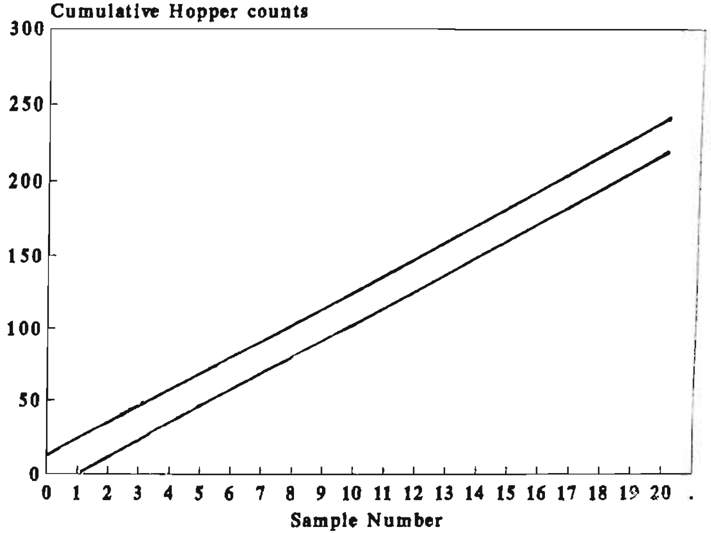

Fig.4. Sequential sampling plan for B field

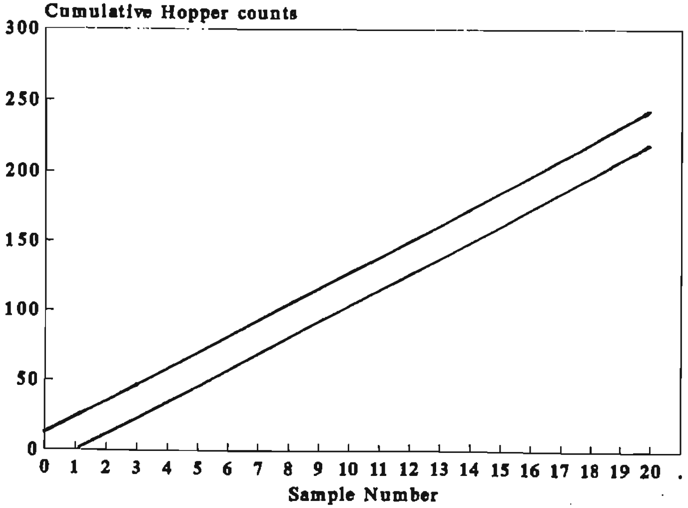

Fig.5. Sequential sampling plan for C field

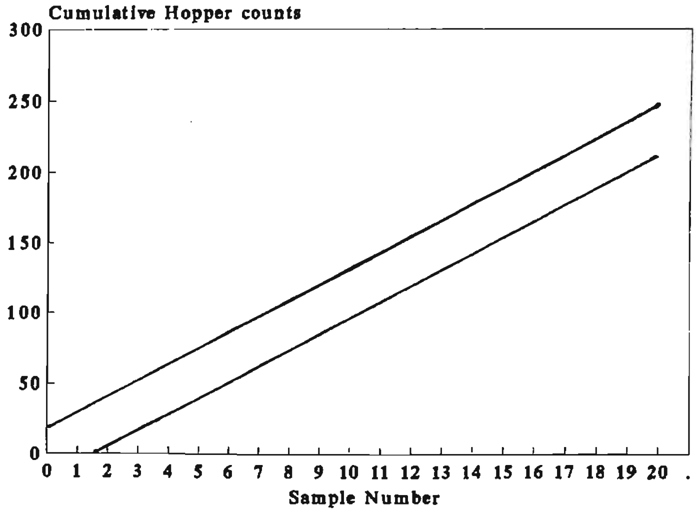

Fig.6. Sequential sampling plan for D field

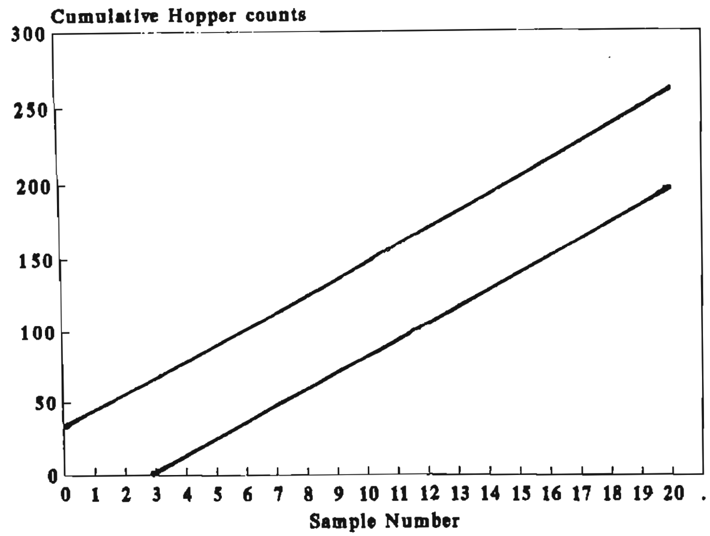

Fig.7. Sequential sampling plan for E field

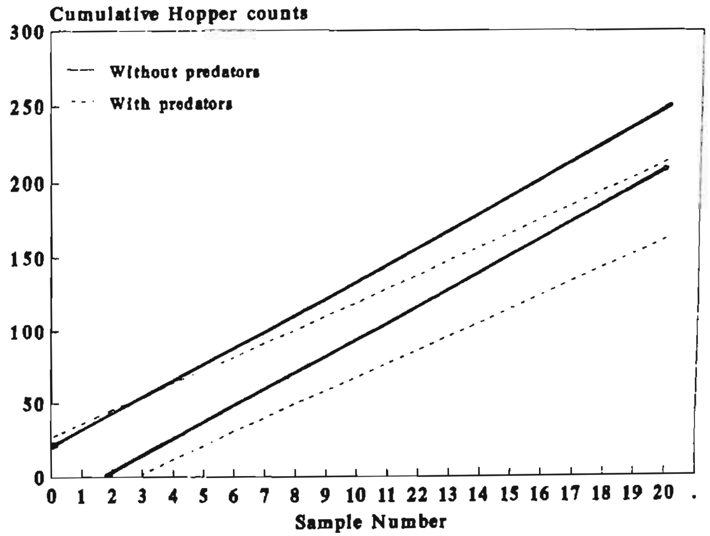

Fig.8. Sequential sampling plans for F and F1 fields

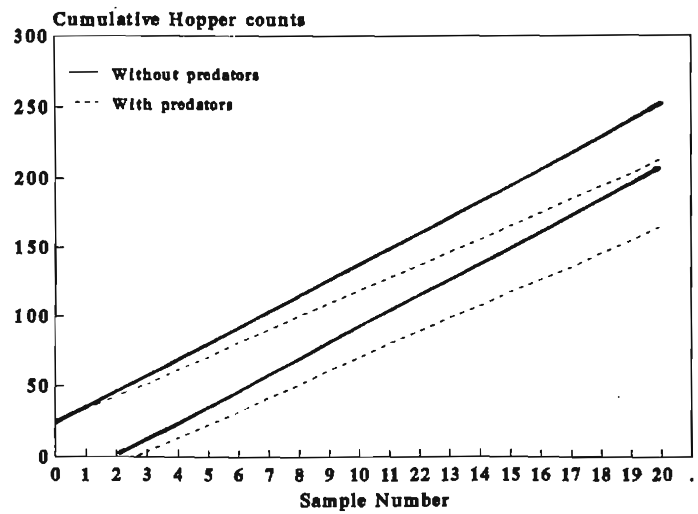

Fig.9. Sequential sampling plans for G and G1 fields

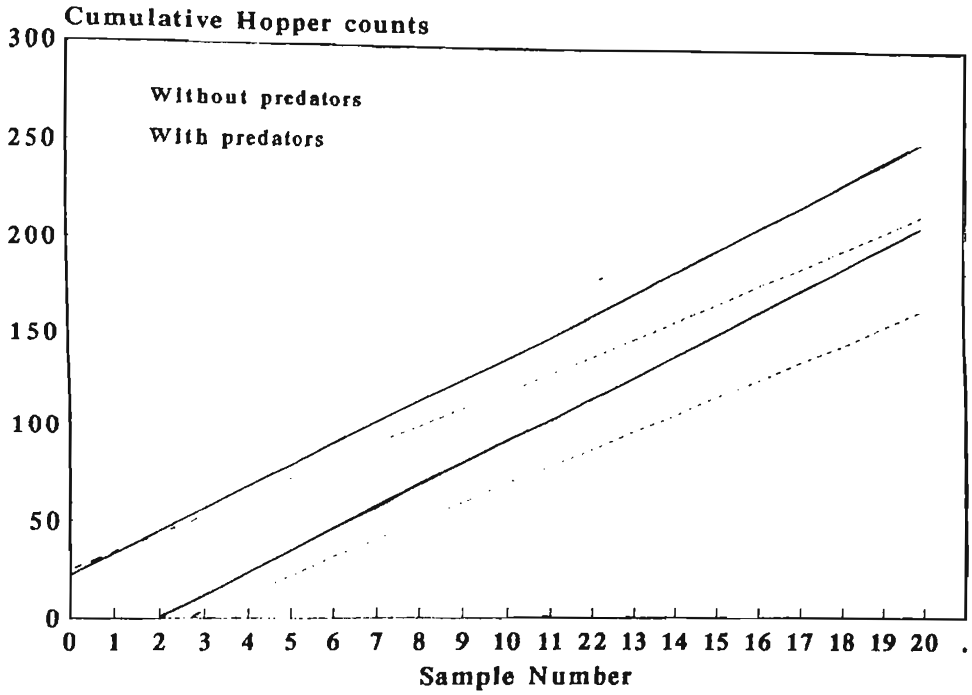

Fig.9a. Sequential sampling plans for overall season

plants are randomly sampled and the cumulative BPH population is found to be less than 66, the decision of not spraying will be taken. But if the cumulative BPH population is more than 122 then the decision of spraying should be taken. If it falls between 66 and 122 then the decision to continue sampling will be taken.

4.4 THE OPERATING CHARACTERISTIC (OC) CURVE

The operating characteristic curve gives the probability L(P) of accepting the hypothesis (i.e., not spraying) and for reaching a correct decision for a range of population means (P). The values of L(P) of and P were calculated by using the formulae given in the chpater "Materials and Methods". The curves were depicted in Figures from 10 to 16a and the values are presented in Table 15. From Table 16 for Field A (without predators) it can be observed that when mean population is 2.9500 the probability of labelling the infestation as light is 0.95. Hence the probability of labelling it as severe is 0.05. If mean is 6.2707 the probability of labelling the infestation as light was 0.05 and the probability of labelling it as severe was 0.95. In case with predators i.e., Field A_1 when mean is 3.6540 the probability of labelling it as severe is 0.05. However when mean was 6.786 the probability of labelling the infestation as light was 0.05 and the probability of labelling it as severe was 0.95.

Table 15 : Rice BPH infestation (P) and the probability L(P) at different values of h

Value of 'h'	Value of L(P)	Field A P	Field A_1 P	Filed B P	Field C P	Field D P	Field E P	Field F P	Field F_1 P	Field G P	Field G_1 P
$\propto$	$\propto$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.0000	0.0000	0.0000
3	0.9998	1.5556	2.1373	0.6560	0.7270	1.2974	2.6700	1.5154	1.9171	1.7849	1.7490
2	0.9972	2.1137	2.7668	0.9227	1.0183	1.7739	3.5748	2.0610	2.4874	2.4151	2.2741
1	0.9500	2.9500	3.6540	1.3161	1.4481	2.4861	4.9447	2.8789	3.2898	3.3627	3.0115
1/2	0.8134	3.5241	4.2320	1.5803	1.7375	2.9719	5.8912	3.4386	3.8115	4.0132	3.4902
-1/2	0.1866	5.1373	5.7672	2.3037	2.5328	4.3322	10.5070	5.0123	5.1942	5.8502	4.7564
-1	0.0500	6.2707	6.7860	2.7967	3.0772	5.2829	16.1420	6.1177	6.1096	7.1458	5.5928
-2	0.0027	9.5447	9.5425	4.1669	4.5983	8.0114	25.6200	9.3049	8.5791	10.9050	7.8435
-3	1.4577E-4	14.9260	13.6900	6.2948	6.9799	12.4490	0.0000	14.5420	12.2790	17.1270	11.2030
$-\propto$	0.0000	$\propto$	$\propto$	$\propto$	$\propto$	$\propto$	$\propto$	$\propto$	$\propto$	$\propto$	$\propto$

Contd...Table 15

Value of 'h'	Value of L(P)	Overall season without predators P	Overall season with predators P
		0.0000	0.0000
3	0.9998	1.7183	1.8217
2	0.9972	2.3276	2.3664
1	0.9500	3.2432	3.1318
1/2	0.8134	3.8712	3.6292
-1/2	0.1866	5.6432	4.9457
-1	0.0500	6.8918	5.8163
-2	0.0027	10.5105	8.1615
-3	1.4577E-4	16.4879	11.6683
-	0.0000		

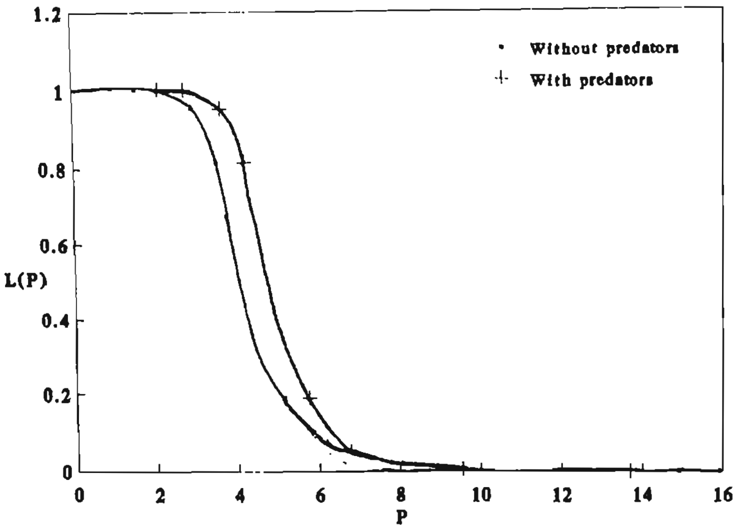

Fig.10. Operative characteristic (OC) curve for A and A1 fields

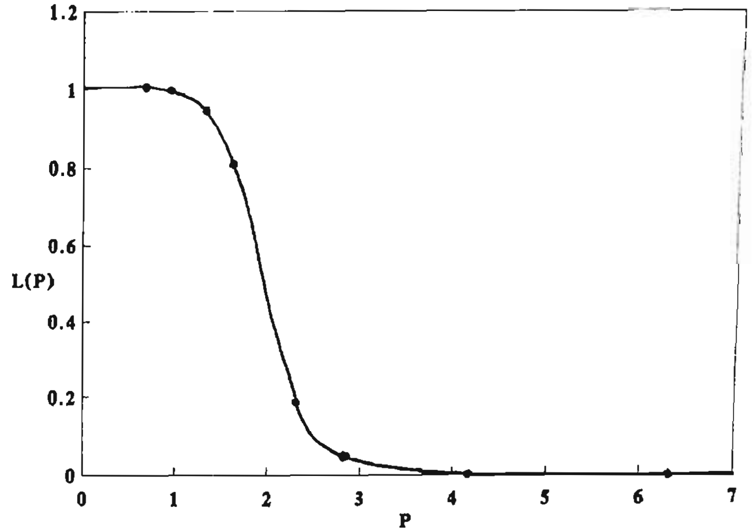

Fig.11. Operative characteristic (OC) curve for B field

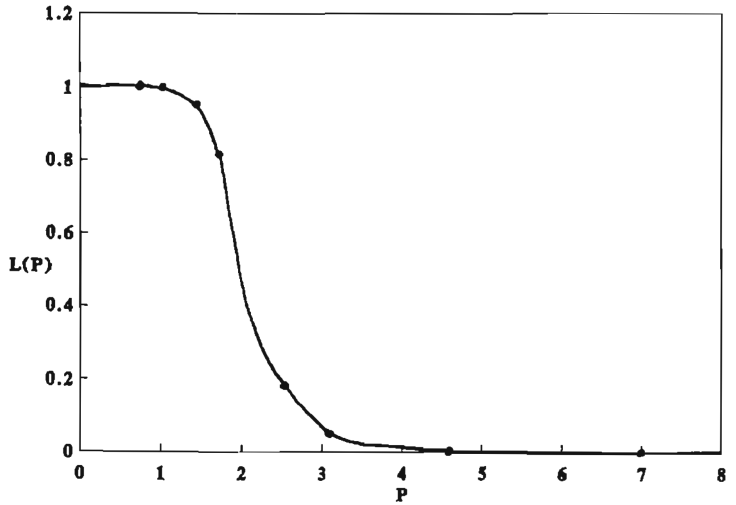

Fig.12. Operative characteristic (OC) curve for C field

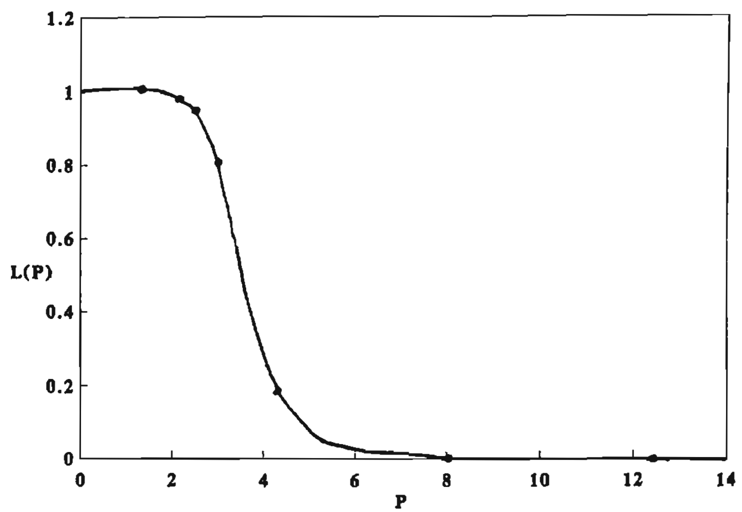

Fig.13. Operative characteristic (OC) curve for D field

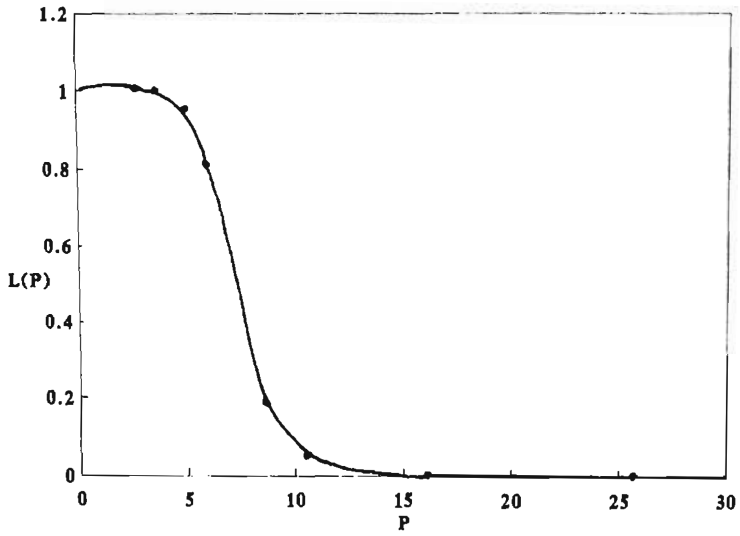

Fig.14. Operative characteristic (OC) curve for B field

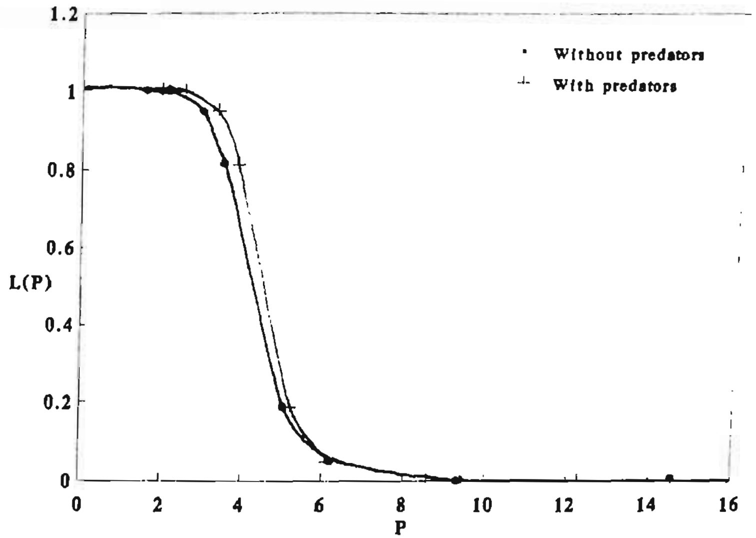

Fig.15. Operative characteristic (OC) curve for F and F1 fields

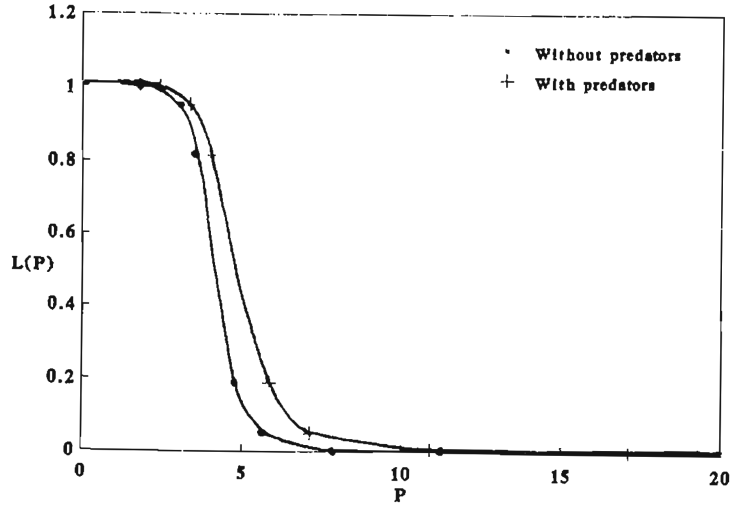

Fig.16. Operative characteristic (OC) curve for G and G1 fields

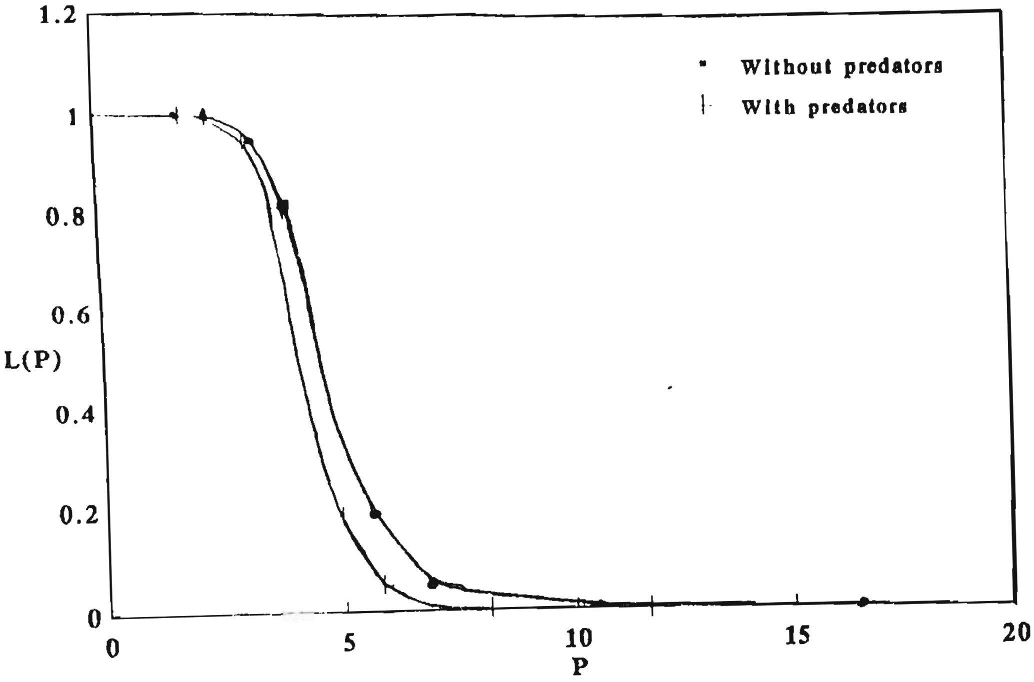

Fig.16a. Operative characteristic (OC) curve for overall season

4.5 AVERAGE SAMPLE NUMBER (ASN) CURVE

The average sample curves for light versus severe infestation at $\alpha = \beta = 0.05$ are illustrated graphically for all the fields and for overall season separately in Figs.17 to 23a and were based on results presented in Table 16. Under the present sequential scheme for Field 'A' (without predators), when mean P = 2.1137 corresponding to light infestation level, the average sample number was 3.5319 and at P = 9.5447 corresponding to severe level of infestation, the average sample number was 1.4151.

Similarly in the curve of Field A_1 (with predators) if P = 2.1373 corresponding to high infestation, the average sample number was 5.2733. The ASN has reached maximum of 13.2671 samples when P = 4.2320 and for P = 13.690 corresponding to heavy infestation the average sample number was 1.6789.

Table 16 : Average sample number EP(n) at various values of Rice BPH infestation (P)

Value of 'h'	Field A		Field A_1		Field B		Field C		Field D	
	P	EP(N)	P	EP(N)	P	EP(N)	P	EP(N)	P	EP(N)
∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000	∞
3	1.5556	2.8121	2.1373	5.2733	0.6560	1.4946	0.7270	1.6007	1.2974	2.4370
2	2.1137	3.5319	2.7668	6.7742	0.9227	1.8907	1.0183	2.0233	1.7739	3.0652
1	2.9500	5.2734	3.6540	10.4020	1.3161	2.8551	1.4481	3.0507	2.4861	4.5862
1/2	3.5241	6.6156	4.2320	13.2670	1.5803	3.6086	1.7375	3.8521	2.9719	5.7614
-1/2	5.1373	5.2701	5.7672	10.9810	2.3037	2.9309	2.5328	3.1200	4.3322	4.6058
-1	6.2707	3.3448	6.7860	7.1258	2.7967	1.8827	3.0072	2.0009	5.2890	2.9294
-2	9.5447	1.4151	9.5425	3.1711	4.1669	0.8204	4.5983	0.8684	8.0104	1.2458
-3	14.9260	0.7062	13.6900	1.6789	6.2948	0.4250	6.9799	0.4475	12.4490	0.6258
$-\infty$	∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000

Contd....Table

Value of 'h'	Field E		Field F		Field F_1		Field G		Field G_1	
	P	EP(N)	P	EP(N)	P	EP(N)	P	EP(N)	P	EP(N)
∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000	∞
3	2.6700	4.4219	1.5154	2.7539	1.9171	4.8203	1.7849	3.1444	1.7490	4.4743
2	3.5748	5.5337	2.0610	3.4596	2.4874	6.1970	2.4151	3.9454	2.2741	5.7562
1	4.9447	8.2190	2.8789	5.1669	3.2898	9.5263	3.3627	5.8819	3.0115	8.8569
1/2	5.8912	10.2760	3.4386	6.4832	3.8115	12.1570	4.0132	7.3719	3.4902	11.3090
-1/2	8.5878	8.1175	5.0126	5.1674	5.1942	10.0790	5.8502	5.8589	4.7564	9.3902
-1	10.5070	5.1252	6.1177	3.2805	6.1096	6.5464	7.1458	3.7127	5.5928	6.1037
-2	16.1420	2.1414	9.3069	1.3889	8.5791	2.9196	10.9050	1.5651	7.8435	2.7275
-3	25.6200	1.0521	14.5420	0.6937	12.2790	1.5499	17.1270	0.7775	11.203	1.4514
$-\infty$	∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000	∞	0.0000

Contd...Table 16

Value of 'h'	Overall season			
	Without predators		With predators	
	P	EP(N)	P	EP(N)
	0.0000		0.0000	
3	1.7183	3.0479	1.8217	4.6239
2	2.3276	3.8253	2.3664	5.9469
1	3.2432	5.7052	3.1318	9.1465
1/2	3.8712	7.1524	3.6292	11.6764
-1/2	5.6432	5.6878	4.9457	9.6881
-1	6.8918	3.6059	5.8163	6.2950
-2	10.5105	1.5215	8.1615	2.8105
-3	16.4879	0.7568	11.6683	1.4940
-		0.0000		0.0000

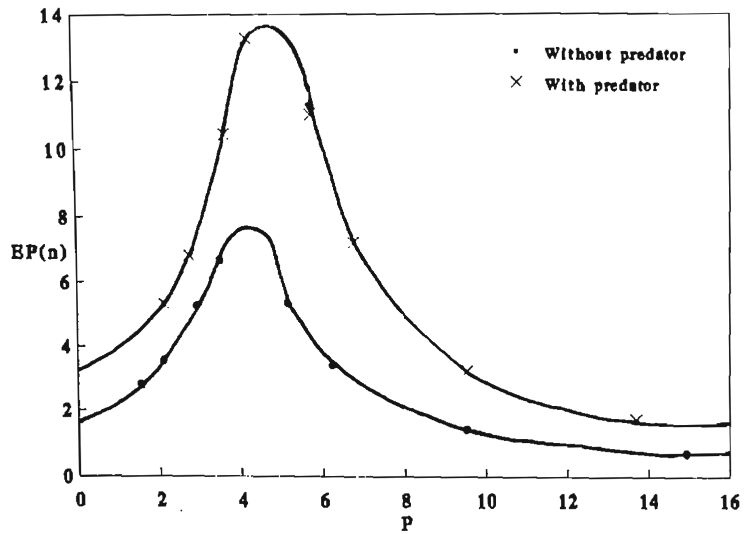

Fig.17. Average sample number curve for A and A1 fields

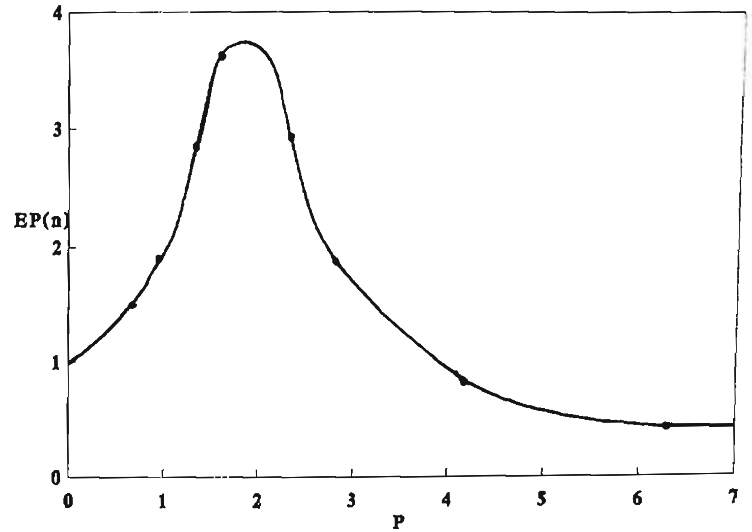

Fig.18. Average sample number curve for B field

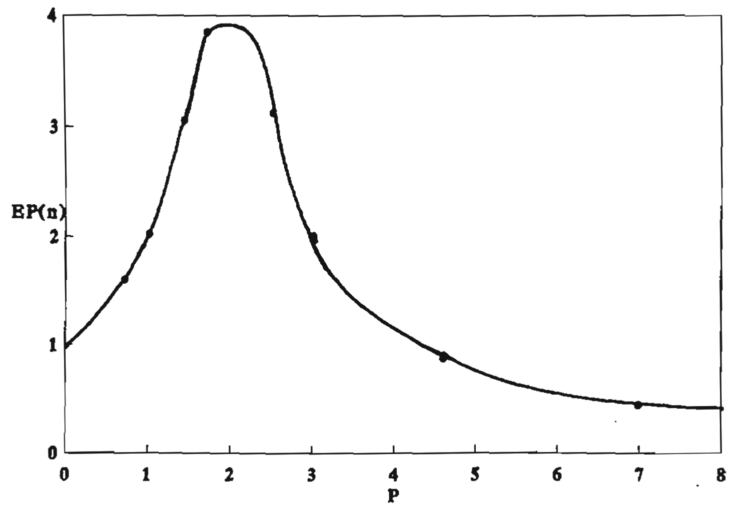

Fig.19. Average sample number curve for C field

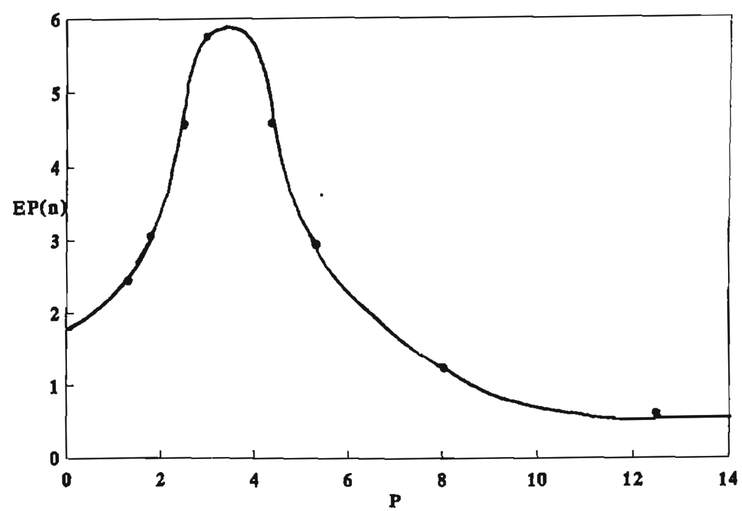

Fig.20. Average sample number curve for D field

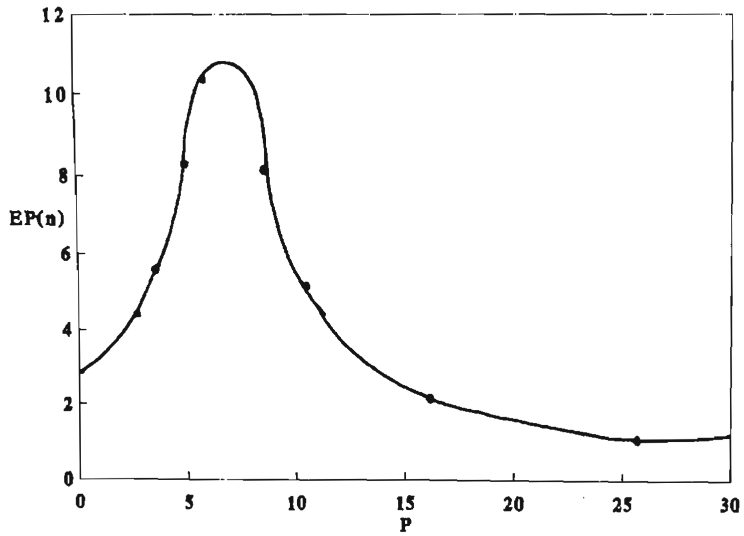

Fig.21. Average sample number curve for E field

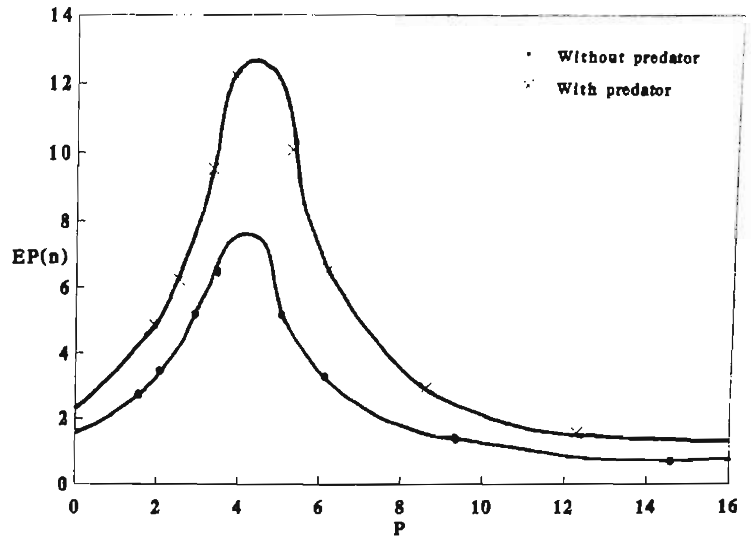

Fig.22. Average sample number curve for F and F1 fields

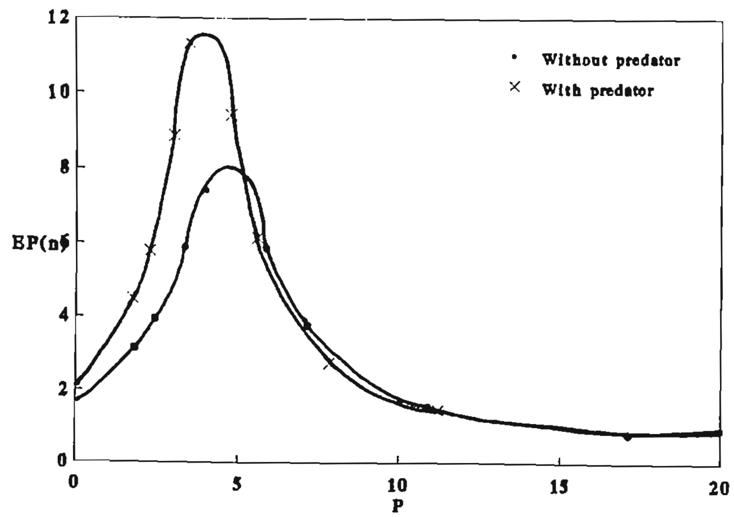

Fig.23. Average sample number curve for G and G1 fields

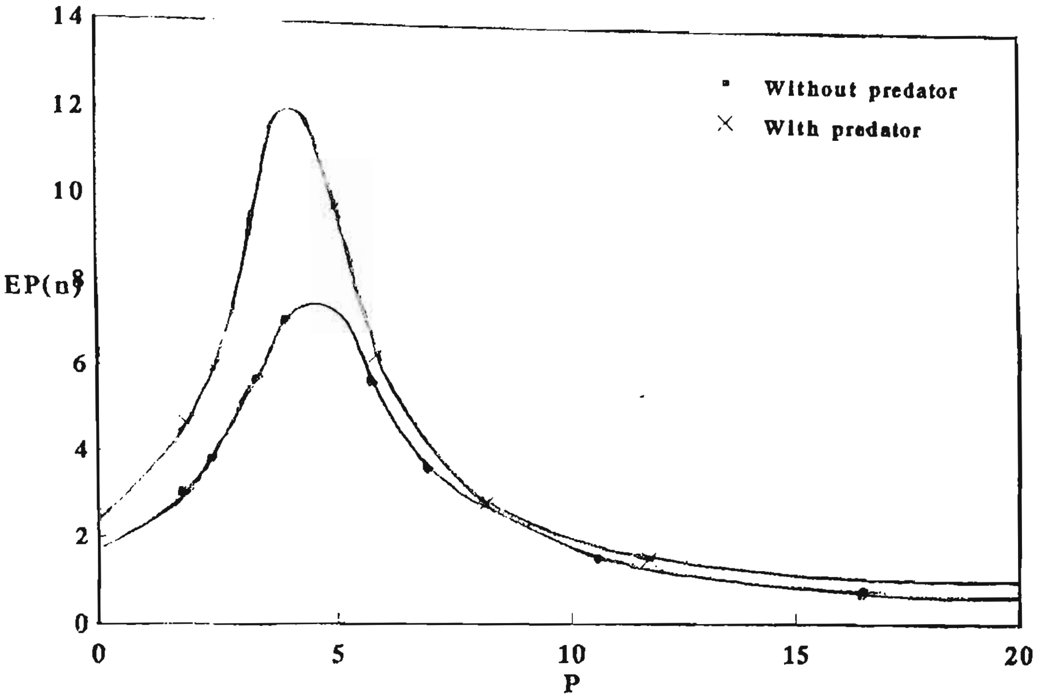

Fig.23a. Average sample number curve for overall season

DISCUSSION

CHAPTER V

DISCUSSION

Rice is the staple food crop of India. In Andhra Pradesh it occupies around 42.18 lakh ha. of the cropped area with a total production of 106.21 lakh tonnes per annum. This crop has been affected by more than 100 insect pests. Among them, brown planthopper (BPH) *Nilaparvata lugens* (Stal.) is considered as major pest due to its nature of infestation and severe damage that it can cause. Severe out breaks of BPH were recorded earlier in Andhra Pradesh, Tamil Naddu and Kerala by so many workers.

Although there is a wealth of documented work on the various aspects of Rice BPH, there remains lacunae particularly on the ecological aspects. With a view to have a clear understanding of these aspects, the distribution pattern of BPH has been computed and sequential sampling plans were developed. The results presented in chapter 4 are discussed in this chapter.

5.1 DISTRIBUTION OF BPH ON THE RICE CROP

Plant samples drawn for BPH infestation were formulated into a frequency distribution. The variance (S^2) and mean ($\bar{X}$) were then calculated (Table 1). From Table 1, it was found that variance was always greater than mean for all Fields A to G. Thus variance (S^2) to mean ($\bar{X}$) ratio was always more than unity, indicated the

BPH on the crop followed a negative binomial distribution, can which also be termed as contagious, clumped or aggregated distribution.

The mean ($\bar{X}$) (number of BPH per plant) values in case of low infestation fields (i.e., A, B & C) ranged from 3.024 to 10.2769 and highly infesting fields in Kharif (D and E) was ranging from 68.6 to 96.153 and for Rabi fields they were from 64.8 to 91.0 (Table 1).

Dispersion parameter 'K' is an important parameter and normally its value is below 8, if the pattern of insect distribution is negative binomial. Values more than 8 signify that the distribution is approaching towards random or poisson (Southwood, 1978). The value of 'K' was computed by several methods. The value of 'K' computed by approximation as suggested by Katti and Gurland (1962) ranged in between 1.6179 to 6.0785 (Table 2) and its value from proportion of zeros was in between 0.3246 to 3.529 (zero counts of BPH were observed in only 5 fields (i.e., A_1, F_1, G_1 and C). The present investigation showed that 'K' values from trial and error (iterative solution) method were 0.38, 0.44, 0.57, 0.40, 0.162, 0.168, 0.175, 0.179, 0.15 and 0.163 for A, A_1, B, C, D, E, F, F_1, G and G_1 Fields respectively (Table 2). Lower values of the 'K' for Fields (D to G_1) indicated that distribution was highly aggregated but they did not exceed the maximum limit i.e., 8, was confirmed.

This finding is in conformity with the findings of many scientists with respect to distribution of insect population [Anscombe, (1948); Bliss and Fisher, (1953); Shepard and Ferrer, (1990); Reddy *et al.*, (1993)].

The present finding revealed that the Rice BPH *Nilaparvata lugens* too followed a negative binomial distribution.

Negative binomial distribution pattern of insect population might be due to the fact that the species may aggregate in the same habitat because it does not disperse or that it reproduces more only on certain plants of the habitat which are suitable for it (Southwood, 1978). It is difficult to explain this phenomenon in the present case i.e., BPH populations with certainty. However, this might have happened due to the fact that BPH selects some sites of Rice fields and multiplied itself with in the fields.

A common dispersion parameter (K_C) suggested by Elliott (1979) was calculated by moments and regression method for with and without predator cases (Table 3) and these were found to be 2.2351 and 2.4667 respectively. These values were smaller than 8 confirming negative binomial distribution (Southwood, 1978).

The χ^2-test for "goodness-of-fit" was tested for negative binomial distribution. The expected frequencies were compared with the observed frequencies to findout χ^2 value. The resulted χ^2 values for all the fields (Table 4) ranged from 6.9847 to 60.11555 which were less than the table values at 5 per cent level of significance. This indicated the negative binomial nature of Rice BPH. The results are in agreement with the results obtained by Reddy *et al.* (1993).

The statistics 'U' and 'T' revealed that the negative binomial model was a good fit for all the Fields (A to G) observed during experimentation (Table 5). The contagious distribution might have arisen due to predation of the habitat including differential prediction (Waters, 1959) or from the behaviour of the insects themselves or a combination of both. The results are inconformity with the results obtained by Nath and Nang (1989).

5.1.1 Indices of dispersion

Several indices of dispersion were tested to confirm the aggregated nature of BPH.

The index of dispersion (I) departed from unity (Table 6) for the all fields of experimentation, indicating the contagious type of distribution pattern of Rice BPH.

The Cole's index value (Table 7) for all fields of experimentation (i.e., A to G) was greater than the value of maximum regularity and randomness confirming the negative binomial distribution and similar results were obtained by Reddy *et al.* (1993) for rice plant and leaf hoppers.

David and Moore's index values (Table 8) were also found to be greater than the maximum regularity (-1) and randomness (0), confirming the contagious nature of BPH.

The observed values of dispersion parameters 'K' and its reciprocal 1/K for Rice BPH population were found to be less than 8 and greater than zero respectively (Table 9) in the present investigation which again confirmed the earlier findings. Similar results were obtained by Reddy *et al.* (1993).

From Table 10, it can be seen that the Morisita's index of dispersion values also showed greater than unity for the BPH population. This index value possessed ecological significance, and it indicated that the clumping of the population is an important characteristic associated with fluctuation of the population density (Southwood, 1978).

5.2 SEQUENTIAL SAMPLING PLAN

A sequential sampling plan, originally developed for quality approval of manufacturing goods, is characterised by its flexible sample size. It is a sampling procedure where the information gained from each observation is added to the earlier one until a decision is reached. In case of insect sampling, the population density fluctuates with time and a fixed sampling procedure cannot provide an accurate estimate of population. Hence sequential sampling can be advantageously used for insect sampling. At very high or low pest population density, its efficiency is more and a few samples are only needed to be observed but at intermediate densities, more number of samples are required. Thus, sequential sampling leads to rapid classification of population and may be used as a reliable technique for undertaking decision about chemical control measures.

The spatial distribution pattern of the insect population is essential for developing a sequential sampling plan. As revealed by the results of the preceding section, the Rice BPH population was found to follow negative binomial distribution pattern. Based on the negative binomial pattern, the sampling plans were developed by assuming the economic threshold levels as 25 and 20 hoppers/hill for with out and with predator cases respectively. Further insect control decision lines were worked out using the method given in chapter "Materials and Methods". The decision lines for classifying the population and taking decisions with regard to application of insecticide were obtained with the risk factors as $\alpha = \beta = 0.05$ where α = probability of labelling light infestation as severe i.e., recommending an unnecessary insecticidal treatment and β = probability of rating severe infestation as light, there by failing to recommend a necessary insecticidal treatment.

The decision lines thus formulated for different field were given in the Table 11.

From Table 11, it can be observed that for the Field 'A', the decision lines were obtained as

$$d_1 = 11.4930\ n - 20.4665$$

$$d_2 = 11.4930\ n + 24.4665$$

Where d_1 is the maximum value for the lower class and 'd_2' is the minimum value for the upper class in terms of cumulative hopper population and 'n' is the number of plants sampled,' d_1' and 'd_2' values could be worked out for any value of 'n' by substituting it in the above equation.

As mentioned earlier with the help of the Figs.3 to 9, the plant samples should be selected at random. The running total of BPH population are to be checked against the table after every additional sample has been selected. Sampling is to be continued so long as the total insect population remains lying between light and severe bands and till the cumulative hopper population falls either in light or severe infestation zones so that an appropriate decision can be taken. In case of the fields considering predator counts, random samples are to be taken and the number of hoppers and number of predators on the sample plant are to be recorded. For calculating calculate the cumulative totals the number of BPH are to be adjusted by subtracting 5 hoppers for each major predator found (Shepard and Ferrer, 1990). After calculating the adjusted cumulative total, sampling procedure can be carried out as in the earlier case. The results obtained by these methods are in confirmity with the results obtained by Shepard and Ferrer (1990).

5.2.1 Operating characteristic (OC) curve

The operating characteristic (OC) curve (Figs.10 to 16) gives the probability of reaching a correct decision for a range of population means. In otherwords, it helps in assessing the performance and accuracy of the sequential plan. There is practically no overlapping of the curves and consequently very little likelihood of mis-classifying a light infestation as severe or severe infestation as light.

From Fig.10 and Table 15, it is evident that Field A (without predators), when mean is 2.95 the probability of labelling the infestation as light is 0.95. Hence the probability of labelling it as severe is 0.05

and when mean is 6.2707 the probability of labelling the infestation as light is 0.05 and the probability of labelling it as severe is 0.95. For A_1 field (with predators) when mean is 3.654, the probability of labelling the infestation as light is 0.95 and the probability of labelling it as severe is 0.05. Similarly, when mean is 6.786, the probability of labelling the infestation as light is 0.05 and the probability of labelling it as severe is 0.95. Thus with the help of sequential sampling, the probability of taking a right decision for rating the infestation is 95 per cent. Thus in 5 per cent cases only a wrong classification of infestation is possible. Therefore a sequential sampling plan for the Rice BPH as found in the investigation could be considered as accurate and quite effective.

5.3 AVERAGE SAMPLE NUMBER (ASN) CURVE

The average sample number function can be used to determine the average number of samples which must be considered at different infestation stages. For a Field A (without predators) the sequential scheme of light Vs severe, when mean (P) is 2.1137, the average sample number obtained as 3.5319 and at P = 9.5447 corresponding to severe level of infestation, the average sample number obtained as 1.4151 (Table 16).

Similarly in the curve of Field A_1 (with predators) for P = 2.1373 corresponding to light infestation, the ASN was 5.2733 and at P = 13.690 corresponding to heavy infestation, the average sample number was 1.6789 and for mean P = 4.232, the average sample number reached maximum to 13.2671. Therefore, it can be inferred that at light or severe infestation levels, very few samples were required for taking a decision with regard to using chemical control measures but moderate infestation require more number of samples.

SUMMARY

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present investigation on sampling of insect populations was undertaken by taking the BPH counts on Rice crop during Kharif and Rabi seasons of 1985-86 at Tenali area of Guntur District (A.P.). The ecological aspects of the BPH was studied in this investigation. Data pertaining to the BPH population were collected from 5 fields in Kharif and 2 fields in Rabi (A to G). Based on the insect data obtained, distribution pattern of the BPH counts was studied and finally, based on negative binomial distribution of Rice BPH, sequential sampling plans were formulated.

From the study, the following conclusions are drawn.

1. The distribution of Rice BPH indicated that the variances (S^2) for all the fields of the crop (i.e., A to G) were greater than their corresponding means ($\overline{X}$) which showed that the BPH population was distributed in an aggregated or clumped manner or negative binomial pattern.

2. The dispersion parameter 'K' calculated by the proportion of zeros and also by the trial and error method conclusively proved that the Rice BPH distribution followed aggregated nature. Same type of distribution was

observed by computing the data for other tests like χ^2, U and T statistic.

3. The various indices of dispersion used in the study such as Cole's index,David and Moore's index and Morisitas index have further confirmed the contagious distribution of the Rice BPH.

4. Based on the negative binomial distribution, sequential sampling plans were developed for all fields and for overall season (A to G) and decision lines were formulated for light Vs severe infestations.

5. The operating characteristic (OC) curve drawn indicated that the probability of taking a correct decision was high by using sequential sampling plans.

6. The average sample number showed that at light and severe infestations, very few samples were required to decide about a chemical treatment to be effected whereas moderate infestation required continuous sampling.

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