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# STUDIES ON EPIZOOTIOLOGY AND AEROBIOLOGY OF *NOMURAEA RILEYI* (FARLOW) SAMSON

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## ABSTRACT

Abstract: Investigations on the epizootics and aerobiology of *Nomuraea rileyi* were carried out at the main campus of the University of Agricultural Sciences, Dharwad, Karnatak, India during 2001 to 2002. Mycosis due to *N. rileyi* prevailed from 28th to 43rd standard week during 2001 attaining peaks in 33rd (16.74%) and 41st week (11.65%). During the succeeding year, it prevailed from 27th to 38th week with peak during 33rd week (19.50%) only. Among the crops observed, epizootic was more in soybean followed by groundnut. Atmospheric spore load of *N. rileyi* failed to establish any definite relationship with disease incidence. Weather parameters prevailed during one and two weeks before disease incidence exhibited both positive and negative relationships of varied intensity with disease incidence than those prevailed during the same week.

**KEY WORDS:** *Nomuraea rileyi*, lepidopteran pests, mycosis, spore load**,** weather factors.

## INTRODUCTION

Insect mycopathogens form the most versatile group of biological control agents as they invade a variety of hexapods, infect at different ages and stages of their hosts, self-perpetuating and often cause epizootics. Infectivity by contact forms a unique feature of fungi besides active penetration making ingestion by insects as non-mandatory. Efforts to use fungi as a component in insect pest management are not of recent interest having around 60 years history to exploit them besides understanding their natural course of action in insect population regulation. Mycosis in insects is common, wide spread and often decimates insect populations in spectacular epizootics. Virtually all insect orders, in diverse habitats are susceptible to fungal infections (Hajek and Leger, 1994). Entomogenous fungi comprise a heterogeneous group of over 100 genera with more than 750 species on different insects (Maddox, 1994) and many of them hold great potential in pest management. Fungi, which cause diseases in insects belong to classes of Zygomycotina, Ascomycotina, Basidiomycotina and Deuteromycotina. Among the competent pathogen genera *viz., Metarhizium, Beauveria, Nomuraea, Verticillium, Paecilomyces, Hirsutella* and *Entomopthohora* only ten species are being used for insect control. *Nomuraea rileyi* (Farlow) Samson (Moniliales: Deuteromycetes) is one candidate fungus whose full potential has not been fully harnessed. Though the fungus was reported and described in 1883, concrete attempts to harness its potential as a biocontrol agent were made only after 1955. It has been studied extensively with respect to epizootics. It has the potential to cause spectacular epizootics under favourable environmental conditions (Ignoffo, 1981). Though the fungus was first described as early as 1883, a systematic documentation on the natural occurrence could be traced back only to 1915 (Anon, 1915). Its occurrence in different geographical areas/ regions has been documented in many studies (Lingappa and Patil, 2002). Given the pretext of all these aspects in the process of exploring *N. rileyi* as a cost effective and eco-friendly candidate in the IPM of noctuid pests, the present investigation was undertaken the epizootiology and aerobiology of *Nomuraea rileyi* at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, Karnataka, India during 2001-2002.

## MATERIALS AND METHODS

The atmospheric spore load of *N. rileyi* was estimated using Burkard's volumetric spore trap. During the first year, the trap was installed at site 1 (Botanical garden) where it ran from 6 to 18 hr from June to December 2001. In the second year, it was installed at site 2 (Sorghum scheme) where it ran round the clock from June to December 2002. A Glass microslide coated with a fine layer of adhesive on the exposed side was placed in the lid assembly of the trap. Slide was changed every day with a new slide and the exposed area was demarcated into four hour intervals commencing from 6 hr. From each of these exposure periods, 10 randomly selected microscopic fields were observed for spores of *N. rileyi* in compound microscope under 40 x objectives and from this atmospheric spore load in a liter of air were computed and weekly means for corresponding standard weeks were worked out.

Weekly observations were made on the incidence of *N. rileyi* on lepidopteran pests *viz., Helicoverpa armigera* (Hubner), *Spodopter litura* (Fabricius), *Thysanoplusia (Plusia) orichalcea* (F.) and *Mythimna seperata* in different crops in 100 m radius of spore trap. Observations were made from June to December 2001 and 2002. Incidence was recorded at ten spots of one square meter plots (groundnut, soybean and chickpea) and on ten plants (cotton, chilli, sorghum, niger and sunflower) selected randomly. Weather data were obtained from Meteorological observatory of MARS. The data on weekly mean disease incidence and atmospheric spore load of *N. rileyi* were subjected to stepwise regression analysis using SPSS software to quantify the relationship with each other and with weather parameters.

## RESULTS

### Incidence of *N. rileyi* on lepidopteran pests

During the first year of study, the crops found in the vicinity of the spore trap were groundnut, soybean, sunflower, chilli, niger and chickpea. The disease prevailed from 28th to 43rd standard week (hereafter referred as week only) excepting 38th week. The incidence ranged from 0.55 to 16.74 per cent with two distinctive peaks during 33rd (16.74%) and 41st (11.65%) weeks. Among the crops observed, maximum incidence of *N. rileyi* prevailed in soybean (11.13%) and groundnut (10.42%) followed by niger (5.14%). It was only 3.29, 2.15 and 2.14 per cent in sunflower, chickpea and chilli ecosystems, respectively (Table 1).

During the second year of study, there were only four crops viz., groundnut, soybean, cotton and sorghum around the 100 m vicinity of the trap. During the study period the disease prevailed from 27th to 38th week (Table 2) in the range of 0.03 (27th week) to 19.50 per cent (33rd week). Among the ecofeast crops, it was more prevalent in soybean (8.11%) and groundnut (7.26%) followed by cotton (4.15%) and least in sorghum (0.52%).

## RELATIONSHIP BETWEEN DISEASE AND WEATHER FACTORS

### Relationship between N. rileyi disease with same week spore load and weather factors:

From the models developed for 2001 and 2002 with respect to disease incidence on *S. litura* ($D_s$), it became evident that morning spore load ($S_m$) is having a positive relationship (Table 3). The goodness of fitness of the model developed for the first year is very low (33.3%) compared to the second year (85.0%). Pooled analysis exhibited a contrasting trend, where in the afternoon spore load ($S_a$) had a negative and intense influence (-2.176) but the total spore load ($S_t$) had a weak and positive relationship (+0.009). The goodness of fitness of this model is moderate (64.5%). During 2001, there was a positive relationship between noon spore load ($S_n$) and mycosis on *H. armigera* (Table 3). However, $R^2$ value of this model is just 50.6 per cent. During the second year a more reliable relationship was witnessed (86.3%). While disease incidence was positively influenced by the morning spore load ($S_m$), evening relative humidity ($RH_e$) had a negative impact. Pooled analysis also highlighted a positive and non reliable relationship between morning spore ($S_m$) load and disease intensity on *H. armigera*. The relationship between the same week spore load and prevailing weather indicated that disease incidence on T. orichalcea ($D_p$) was influenced positively by morning spore load ($S_m$) but, the total spore load had reverse impact ($S_t$). However, the confidence level in the association between the variables is of moderate level (65.3%) during the first year (Table 3). In the succeeding year, only $S_m$ had a positive relationship and the degree of reliability was also low (54.7%). Pooled analysis of two years data depicted a positive relationship with minimum temperature ($t_{min}$) and $S_m$ and a negative relationship with $S_t$. Dependability of the model was fairly high (78.5%). Cumulative account of disease incidence on all the three caterpillar species as influenced by spore load and weather factor was assessed (Table 3). A reliable (72.4%) and positive relationship with $S_m$ and negative relationship with $S_a$ was noticed in the first year. During the second year, with enhanced dependability (85.1%) $S_m$ exhibited a positive relationship; while evening relative humidity ($RH_e$) had a negative impact. Upon pooling the two years data, the analysis revealed that both $S_m$ and $S_n$ had a positive relationship with total disease incidence of the same week. The reliability of this model was fairly good (75.2%).

### Relationship between N. rileyi disease and first previous week's spore load and weather factors:

The data on the nature of relationship between disease incidence, spore load prevailed in the preceding week and weather factors on each of the test insects and together are presented in Table 4. The regression model developed for 2001 revealed a positive but weak (38.3%) relationship with $S_m$ (38.3%), however in the second year the confidence level was very high (85.0%). Strikingly different was the scenario that emerged from pooled analysis where the mycosis on *S. litura* was negatively influenced by the afternoon spore load ($S_a$) and positively by the total spore load. The reliability of this model was moderate (64.5%). In the first year of study, the disease on *H. armigera* was positively related to noon spore load ($S_n$) and maximum temperature ($t_{max}$). The reliability of relationship was fairly good (71.7%). In the year to follow, the model obtained had positive relationship with $S_m$ and negative relationship with $S_a$ with fairly high reliability (74.5%). The outcome of pooled analysis revealed negative relationship with $S_a$ and meager positive relationship with $S_t$ with a reliability of 68.20 per cent. A positive relationship between $S_m$ and a negative relationship between $S_a$ and death of caterpillar due to fungus was evident from the analysis of first year data. The reliability of this relationship was moderate (65.3%). During 2002, with reduced reliability (54.7%) $D_p$ was positively related to $S_m$. Upon pooling the two years data, the model thus developed indicated a positive relationship with $S_m$ and a negative relationship with $S_t$. The goodness of fit for the model was moderate (61.3%). Total disease incidence during 2001 was positively dependant on $S_m$ and had a negative and fairly higher relationship with $S_a$. Reliability of this model was fairly high (72.4%). During the second year (2002), the model exhibited a positive relationship with $S_m$ with greater reliability (72.8%). Pooled analysis showed that total disease was positively influenced by $S_m$ but, $S_a$ had a negative impact of greater weightage than $S_m$ (Table 4). Reliability of this model was also fairly high (75.2%).

### Relationship between disease incidence and second previous week's spore load and weather factors:

Regression model for 2001 indicated a positive but non dependable relationship with $S_m$ (Table 5) however, in the second year nature of relationship remained unchanged but the dependability was enhanced to 85.0 per cent. The relationship turned out to be negative with $S_a$ and positive with St when the pooled data subjected to analysis. The reliability of this model was moderate (64.5%). The data revealed a positive association with $S_n$ and negative relation with $t_{max,}$ and the impact of latter variable was almost nine fold to that of $S_n$. The reliability of this model was very high (83.4%). During 2002, with higher reliability, positive relationship with $S_m$ and a negative relationship with $S_a$ was noticed. Pooled analysis reiterated the impact of these two variables on disease incidence encountered in the first year. This model had a moderate level of reliability (63.4%). Positive impact of $T_{min}$ and $S_m$ was evident with higher degree of reliability (87.8%) in the first year, however, $t_{min}$ had five fold greater impact than $S_m$. Evening relative humidity ($RH_e$) exhibited positive relation with disease incidence on T. orichalcea and reliability of this association was low (55.3%) during 2002. Analysis of pooled data resulted in a model with high degree of reliability (79.0%) wherein $t_{min}$ and $S_m$ had emerged as potential variables to induce disease with slight negative impact of $S_t$. Model developed for 2001 conveyed a positive effect of both $S_n$ and $t_{min}$ on all the three test hexapods with high dependability of 84.7 per cent. During the second year, only $S_m$ exhibited positive relationship with fairly high dependability (72.8%). Pooled analysis of data showed a positive relationship with $S_m$ and a negative relationship of higher reliability with $S_a$ (75.2%).

## DISCUSSION

Among the alternatives for chemical insecticides, entomopathogens posses greater potential under selective environmental conditions. These pathogens have narrower spectrum of activity than chemicals but safer to environment. Epizootics due to fungi occur naturally and serve as natural regulators of pest populations (Tanada and Fuxa, 1987). Among the several entomopathogneic fungi, *N. rileyi* is a cosmopolitan species infecting noctuids. It forms the likely candidate for development as a microbial insecticide as it occurs naturally in different agro-ecosystems. The pathogen induces spectacular epizootics, attacks many noctuids and non virulent against beneficial fauna. Its temperature requirement is below the body temperature of homoeothermic vertebrates, non toxic to mammals through any route of entry. Successfully used in pest suppression and can be produced at a low cost on artificial media, thus encouraging industrial participation (Ignoffo, 1981). It has been identified as the key mortality factor of many noctuid pests occurring on major crops in northern transitional tract of Karnataka (Lingappa and Patil, 2002). Development of insecticide resistance in *H. armigera* and *S. litura* has been amply documented by many in general and by Basavanagoud (1994) and Ramegowda and Basavanagoud (2002) in specific in the agroecology under study on these two crops, respectively counteracting the pesticide usage for profitable crop production prompted the search for viable alternate eco-friendly options for insecticides. Among various eco-friendly options, *N. rileyi* holds promise owing to its efficacy in cotton (Hegde, 2001) groundnut and soybean in transitional tract, due to prevalence of favourable ecological features (Patil, 2000; Lingappa et al., 2000). Equally and more important feature of the fungus that makes it as the best candidate is simplicity in its mass production on low cost and easy available substrates like broken rice and sorghum (Hegde , 2001). Keeping all these comparative advantages in background, investigations were taken to probe into the relationship between disease incidence, atmospheric prevalence of spores and weather factors.

Epizootiological studies are usually initialized with detailed accounts describing the natural history of the disease, phenology of both pathogen and its host, impact of pathogen on host populations and association of epizootics with weather parameters with frequent emphasis on moisture in the form of RH, condensation or rainfall. Dispersal of infective propagules to a new host represents a most perilous part of the fungal life cycle. Process of spore production and discharge, spore dispersal and spore survival and germination depend on environmental conditions. Processes influencing spore production at the biochemical or physiological level for many host pathogen systems is not well understood. Host death is necessary before spores are produced in many, but not all systems. Fungal pathogens spread in a variety of ways over varying distances. Fungal pathogens of arid and epigeal insect stages are frequently anemochorous and active spore liberation can aid spore dispersal (Hajek and Leger, 1994).

Epizootics of *N. rileyi* on various insect pests in different crop habitats worldwide (Ignoffo, 1981; Ignoffo, et al., 1976; Burliegh and Katayama, 1983 and Thorvilson *et al*., 1985) have been well documented. In India, seasonal incidence has been studied by Phadke *et al.* (1978); Vimaladevi, *et al.* (1996); Sridhar and Devaprasad (1996a and b); Ambethgar and Loganathan (1988); Kulkarni and Lingappa (2002); Patil *et al.* (2003) and Manjula *et al* (2003 and 2004).

### Incidence of *N. rileyi* on lepidopteran pests

The entomopathogen prevailed for 6 weeks from 26th to 43rd weeks baring 38th week during 2001 at varying intensity (Fig 1). Attainment of peak activity varied in frequency and time in crop habitats on different hosts. While the fungus could find ideal situations twice in the cropping season of groundnut, soybean and sunflower, it could register maximum activity only once in chilli, niger and chickpea (sown in July). In the succeeding cropping season (2002), even though its occurrence was preponed by a week, activity was reduced to 12 weeks from 27th to 38th week (Fig 2). Unlike in the previous year, though two peaks were noticed in groundnut and soybean on selected insect hosts time separation was not distinct. The disappearance of the disease from 44th and 39th week during 2001 and 2002, respectively was due to reduction in the density of host insects and unfavourable weather conditions *i.e.*, increase in temperature and reduced relative humidity.

The disease prevailed for a prolonged period in soybean and groundnut ecosystems compared to other crop ecosystems (Fig. 1 and 2). It has dependence on the activity of host insects in respective crop habitats. Variation in severity of mycosis on three lepidopteron hosts was apparent in both the years. During 2001, variability in mycosis on the three caterpillar species in groundnut was marginal, highest being on T. orichalcea (12%) and lowest on H. armigera (9%). In contrast, S. litura became the major victim to the entomopathogen in soybean, sunflower and chilli. The fungal activity was confined only to H. armigera on chickpea and T. orichalcea on niger (Fig. 3). This shift in trend over years may be due to change in the host density. During both the years S. litura was more than T. orichalcea in soybean habitat. The trend in susceptibility of pest species on sunflower remained the same as in groundnut ecosystem during 2001. In chilli, N. rileyi caused higher mortality to S. litura than H. armigera. Pathogen prevalence on H. armigera in cotton ecosystem was almost ten folds higher than that to T. orichalcea. The host availability in differential density was the primary cause for discrepancy, while the environment remained the same. It has been established phenomenon that the effect of biocontrol agents is density dependent Incidence of the disease on M. seperata in sorghum was negligible.

The above findings are supported by Kulkarni and Lingappa (2002), Patil et al. (2003), Rachappa (2003) and Vimaladevi *et al.* (1996) who opined that the period between July to September is more favourable for *N. rileyi* incidence. The most favourable period for the pathogen has been from July to September in the transitional tract when the crop is most amenable for high incidence of defoliators and prevalence of cloudy and humid weather. On the contrary, Sridhar and Devaprasad (1996a and b) and Manjula et al. (2003) have reported its incidence in December-February from coastal Andhra Pradesh due to the availability of host insects and high humidity as groundnut is extensively cultivated after rice along the coastal belt. This clearly establishes the relationship of *N. rileyi* incidence with humidity and host insect activity. The higher intensity of disease in soybean habitat over groundnut contradicts the report of Kulkarni and Lingappa (2002). This variation could be due to the change in the pest density under study. In the present study, three pest species in groundnut and two species in soybean were observed compared to only one species (*S. litura*) reported by Kulkarni and Lingappa (2002). Present findings are in close agreement with Manjula *et al.* (2003) who noticed double the incidence of *N. rileyi* on S. litura compared to *H. armigera* in black gram habitat and contradict the higher mycosis on *H. armigera* than *S. litura* in groundnut habitat. Ignoffo *et al.* (1977) concluded that the peak epizootic in each season is largely determined by the load of active inoculum, density of hosts, canopy of the host plants, ideal environmental conditions and the extent of dispersal of conidia early in the season. Thus in the exploitation of this fungus for the management of target insect pests, dissemination of conidial load at the beginning of host activity and manipulation of microclimate in favour of the pathogen buildup to enhance mycosis and mortality assume grater importance.

## Relationship with disease incidence and weather factors

Step down regression models obtained with respect to weather factors and atmospheric spore load of *N. rileyi* of the same week, a week before and two weeks before the disease occurrence failed to establish any definite quantifiable relationships (Fig 4). Similarly the models obtained in individual years and for pooled data failed to maintain consistency in their intensity and nature of relationship with disease incidence on individual insect or on all the three insects together. Inconsistency in the relationship between spore load (forenoon/ noon/ afternoon) and disease incidence on three lepidopteron insect species (Table 3-5) lead us to infer that spore load at any specific time of the day had influence in inducing mycosis. Weather factors ($t_{min}$, $t_{max}$ and $RH_e$) figured less frequently when the same week parameters were analyzed compared to one or two weeks before, with either types of relationships of varied impact. Consequent upon absence of rainfall during 36th and 37th week of 2001, evening RH receded to 56 per cent and increase in maximum temperature caused the disease to disappear for a week, which reappeared in 39th week due to rainfall during 38th week (Fig 4).

Failure of establishment of any definite trend with the disease incidence and weather factors and atmospheric spore load could perhaps be due to a very limited period of study (16 + 2 weeks during 2001 and 12 + 2 weeks during 2002) and prevalence of drought situations for two years in the study location. The weather parameters especially temperature and RH were measured above the canopy. Kulkarni and Lingappa (2002) also opined that they failed to establish relationship between *N. rileyi* incidence and *S. litura* and *H. armigera* in different crops during 1996-98 except for positive significant influence of afternoon RH in groundnut, soybean and potato during kharif season due to shorter study period. On the contrary, incidence of *N. rileyi* showed positive association with morning RH and negative association with evening RH. Maximum and minimum temperatures were negatively correlated in 50 per cent of the cases and positively correlated in the rest (Manjula et al., 2003).

Due to short range studies spread over two to three cropping seasons either in present study or in the studies by earlier workers, it was not possible to establish any definite relationship between the disease incidence and weather factors. Hence, it is necessary to carryout long range studies enabling development of models for prediction of epizootics with greater confidence. In the absence of establishment of definite relationship between weather factors and disease incidence either in the present study or by earlier workers, it may not be appropriate to infer the favourable climatic conditions in a precise manner for epizootic of this entomopathogen. However, from the information available it can be safely be interpreted that the disease development is dependent on the pathogen inoculum and micro-climate. Therefore, detailed studies on the microclimatic conditions at different strata of the crop ecosystem over a period of time assume grater practical importance in prediction of its epizootics in different crop ecosystems.

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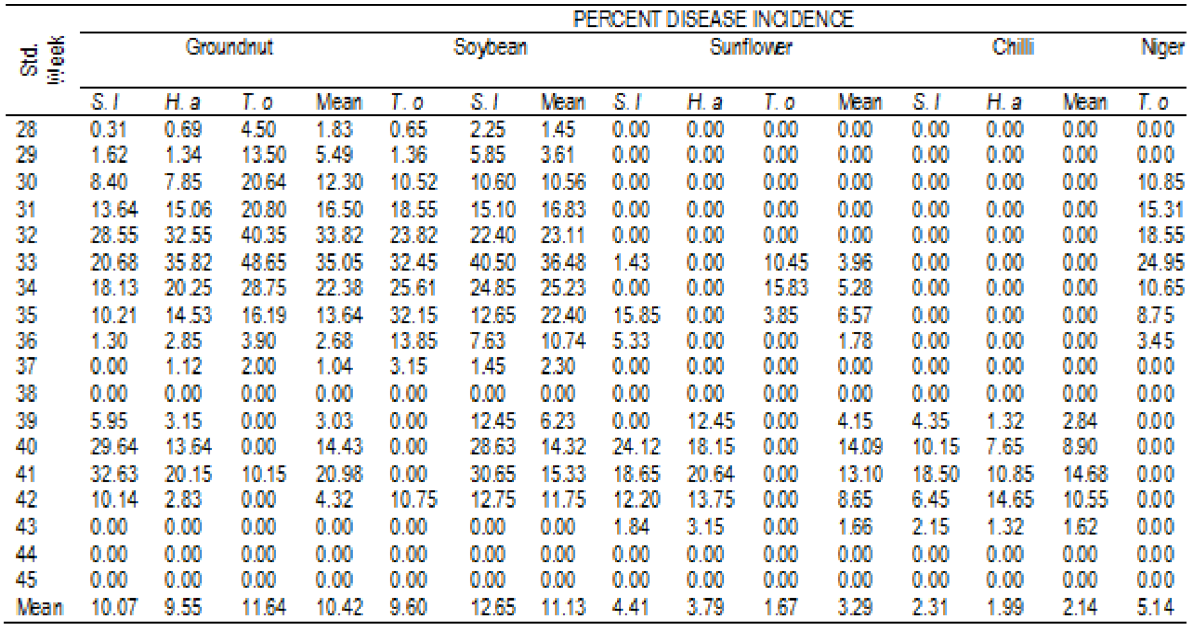
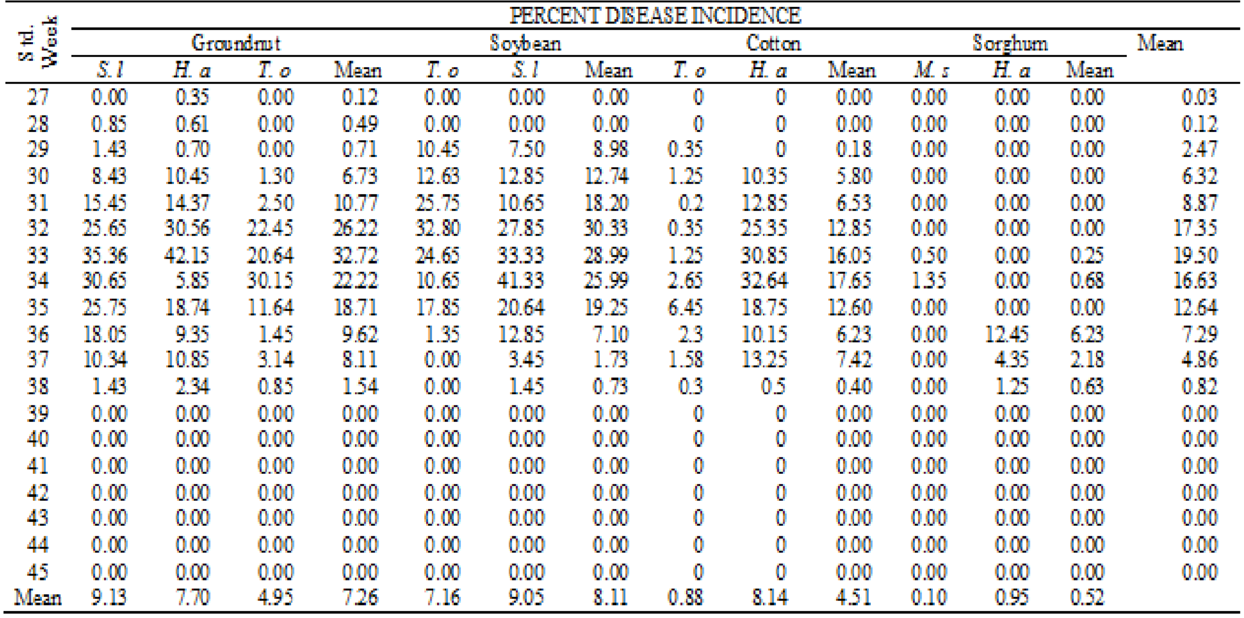
TABLE -1. Incidence of *Nomuraea rileyi* on *Spodoptera litura, Helicoverpa armigera* and *Thysanoplusia orichalcea* during 2001



| Std. Week | PERCENT DISEASE INCIDENCE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Groundnut | | | | Soybean | | | Sunflower | | | | Chilli | | | Niger |
| | *S. l* | *H. a* | *T. o* | Mean | *T. o* | *S. l* | Mean | *S. l* | *H. a* | *T. o* | Mean | *S. l* | *H. a* | Mean | *T. o* |
| 28 | 0.31 | 0.69 | 4.50 | 1.83 | 0.65 | 2.25 | 1.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 29 | 1.62 | 1.34 | 13.50 | 5.49 | 1.36 | 5.85 | 3.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 30 | 8.40 | 7.85 | 20.64 | 12.30 | 10.52 | 10.60 | 10.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.85 |
| 31 | 13.64 | 15.06 | 20.80 | 16.50 | 18.55 | 15.10 | 16.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.31 |
| 32 | 28.55 | 32.55 | 40.35 | 33.82 | 23.82 | 22.40 | 23.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.55 |
| 33 | 20.68 | 35.82 | 48.65 | 35.05 | 32.45 | 40.50 | 36.48 | 1.43 | 0.00 | 10.45 | 3.96 | 0.00 | 0.00 | 0.00 | 24.95 |
| 34 | 18.13 | 20.25 | 28.75 | 22.38 | 25.61 | 24.85 | 25.23 | 0.00 | 0.00 | 15.83 | 5.28 | 0.00 | 0.00 | 0.00 | 10.65 |
| 35 | 10.21 | 14.53 | 16.19 | 13.64 | 32.15 | 12.65 | 22.40 | 15.85 | 0.00 | 3.85 | 6.57 | 0.00 | 0.00 | 0.00 | 8.75 |
| 36 | 1.30 | 2.85 | 3.90 | 2.68 | 13.85 | 7.63 | 10.74 | 5.33 | 0.00 | 0.00 | 1.78 | 0.00 | 0.00 | 0.00 | 3.45 |
| 37 | 0.00 | 1.12 | 2.00 | 1.04 | 3.15 | 1.45 | 2.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 39 | 5.95 | 3.15 | 0.00 | 3.03 | 0.00 | 12.45 | 6.23 | 0.00 | 12.45 | 0.00 | 4.15 | 4.35 | 1.32 | 2.84 | 0.00 |
| 40 | 29.64 | 13.64 | 0.00 | 14.43 | 0.00 | 28.63 | 14.32 | 24.12 | 18.15 | 0.00 | 14.09 | 10.15 | 7.65 | 8.90 | 0.00 |
| 41 | 32.63 | 20.15 | 10.15 | 20.98 | 0.00 | 30.65 | 15.33 | 18.65 | 20.64 | 0.00 | 13.10 | 18.50 | 10.85 | 14.68 | 0.00 |
| 42 | 10.14 | 2.83 | 0.00 | 4.32 | 10.75 | 12.75 | 11.75 | 12.20 | 13.75 | 0.00 | 8.65 | 6.45 | 14.65 | 10.55 | 0.00 |
| 43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.84 | 3.15 | 0.00 | 1.66 | 2.15 | 1.32 | 1.62 | 0.00 |
| 44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 10.07 | 9.55 | 11.64 | 10.42 | 9.60 | 12.65 | 11.13 | 4.41 | 3.79 | 1.67 | 3.29 | 2.31 | 1.99 | 2.14 | 5.14 |

* *S.l = S. litura ; H. a = H. armigera ; T. o = T. orichalcea*

TABLE -2. **Incidence of *Nomuraea rileyi* on *Spodoptera litura, Helicoverpa armigera, Thysanoplusia orichalcea* and *Mythimna seperata* during 2002**



| Std. Week | PERCENT DISEASE INCIDENCE | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Groundnut | | | | Soybean | | | Cotton | | | Sorghum | | | Mean |
| | *S. l* | *H. a* | *T. o* | Mean | *T. o* | *S. l* | Mean | *T. o* | *H. a* | Mean | *M. s* | *H. a* | Mean | |
| 27 | 0.00 | 0.35 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| 28 | 0.85 | 0.61 | 0.00 | 0.49 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 |
| 29 | 1.43 | 0.70 | 0.00 | 0.71 | 10.45 | 7.50 | 8.98 | 0.35 | 0 | 0.18 | 0.00 | 0.00 | 0.00 | 2.47 |
| 30 | 8.43 | 10.45 | 1.30 | 6.73 | 12.63 | 12.85 | 12.74 | 1.25 | 10.35 | 5.80 | 0.00 | 0.00 | 0.00 | 6.32 |
| 31 | 15.45 | 14.37 | 2.50 | 10.77 | 25.75 | 10.65 | 18.20 | 0.2 | 12.85 | 6.53 | 0.00 | 0.00 | 0.00 | 8.87 |
| 32 | 25.65 | 30.56 | 22.45 | 26.22 | 32.80 | 27.85 | 30.33 | 0.35 | 25.35 | 12.85 | 0.00 | 0.00 | 0.00 | 17.35 |
| 33 | 35.36 | 42.15 | 20.64 | 32.72 | 24.65 | 33.33 | 28.99 | 1.25 | 30.85 | 16.05 | 0.50 | 0.00 | 0.25 | 19.50 |
| 34 | 30.65 | 5.85 | 30.15 | 22.22 | 10.65 | 41.33 | 25.99 | 2.65 | 32.64 | 17.65 | 1.35 | 0.00 | 0.68 | 16.63 |
| 35 | 25.75 | 18.74 | 11.64 | 18.71 | 17.85 | 20.64 | 19.25 | 6.45 | 18.75 | 12.60 | 0.00 | 0.00 | 0.00 | 12.64 |
| 36 | 18.05 | 9.35 | 1.45 | 9.62 | 1.35 | 12.85 | 7.10 | 2.3 | 10.15 | 6.23 | 0.00 | 12.45 | 6.23 | 7.29 |
| 37 | 10.34 | 10.85 | 3.14 | 8.11 | 0.00 | 3.45 | 1.73 | 1.58 | 13.25 | 7.42 | 0.00 | 4.35 | 2.18 | 4.86 |
| 38 | 1.43 | 2.34 | 0.85 | 1.54 | 0.00 | 1.45 | 0.73 | 0.3 | 0.5 | 0.40 | 0.00 | 1.25 | 0.63 | 0.82 |
| 39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 9.13 | 7.70 | 4.95 | 7.26 | 7.16 | 9.05 | 8.11 | 0.88 | 8.14 | 4.51 | 0.10 | 0.95 | 0.52 | |

* *S.l = S. litura ; H. a = H. armigera ; T. o = T. orichalcea; M. s = Mythimna seperata*

**TABLE - 3.** Stepwise regression models for the *Nomuraea rileyi* disease incidence with the same week's spore load and weather factors

| | Disease on- 2001 | Model | R | $R^2$ (%) |
|---|---|---|---|---|
| 1 | *S.litura* ($D_s$) | 2.605 (1.129) + 7.710 x $10^{-2}$ (0.26) ($S_m$) | 0.619 | 33.3 |
| 2 | *H. armigera* ($D_H$) | 4.061 (1.967) + 0272 (0.072) ($S_n$) | 0.712 | 50.6 |
| 3 | *T. orichalcea* ($D_p$) | 3.214 (1.823) + 1.485 (0.370) ($S_m$) – 0.606 (0.165) ($S_t$) | 0.808 | 65.3 |
| 4 | Cumulative ($D_t$) | 9.738 (3.241) + 1.392 (0.398) ($S_m$) – 1.743 (0.678) ($S_a$) | 0.851 | 72.4 |
| | 2002 | | | |
| 1 | *S.litura* ($D_s$) | 4.547 (1.998) + 0.465 (0.062) ($S_m$) | 0.922 | 85.0 |
| 2 | *H. armigera* ($D_H$) | 58.419 (11.893) + 0.272 (0.039) ($S_m$) – 0.733 (0.160) ($RH_e$) | 0.929 | 86.3 |
| 3 | *T. orichalcea* ($D_p$) | 3.065 (1.688) + 0.181(0.052) ($S_m$) | 0.740 | 54.7 |
| 4 | Cumulative ($D_t$) | 125.584 (42.008)+ 0.972 (0.136) ($S_m$) – 1.538 (0.565) ($RH_e$) | 0.922 | 85.1 |
| | Pooled | | | |
| 1 | *S.litura* ($D_s$) | 3.689 (1.495) – 2.176 (0.413) ($S_a$) + 0.009 (0.103) ($S_t$) | 0.803 | 64.5 |
| 2 | *H. armigera* ($D_H$) | 3.894 (1.485) + 0.187 (0.038) ($S_m$) | 0.693 | 48.0 |
| 3 | *T. orichalcea* ($D_p$) | -72.985 (17.352) + 3.638 (0.831) ($t_{min}$) + 0.850 (0.238) ($S_m$) – 0.319 (0.107) ($S_t$) | 0.886 | 78.5 |
| 4 | Cumulative ($D_t$) | 9.639 (2.793) + 1.894 (0.298) ($S_m$) + 2.570 (0.535) ($S_n$) | 0.867 | 75.2 |

$S_t$ = Total spore load
$S_m$ = Morning spore load
$S_n$ = Noon spore load
$S_a$ = Afternoon spore load
$T_{min}$ = Minimum temperature
$T_{max}$ = Maximum temperature
$RH_m$ = Morning relative humidity
$RH_e$ = Evening relative humidity
$R_f$ = Rain fall
$R_d$ = Rainy days

$D_s$ = Disease on *S. litura*
$D_h$ = Disease on *H. armigera*
$D_p$ = Disease on *T. orichalcea*
$D_t$ = Cumulative disease

TABLE- 4. Stepwise regression models for the *Nomuraea rileyi* disease incidence with previous first week's spore load and weather factors

| | Disease on -2001 | Model | R | $R^2$ (%) |
|---|---|---|---|---|
| 1 | *S .litura* ($D_s$) | 2.605 (1.29) + 7.710 x $10^{-2}$ (0.026) ($S_m$) | 0.619 | 38.3 |
| 2 | *H. armigera* ($D_H$) | 80.468 (24.570) + 0.237 (0.057) ($S_n$) + 2.686 (0.165) ($t_{max}$) | 0.847 | 71.7 |
| 3 | *T. orichalcea* ($D_p$) | 3.214 (1.823) + 1.485 (0.098) ($S_m$) – 0.606 (0.678) ($S_t$) | 0.808 | 65.3 |
| 4 | Cumulative ($D_t$) | 9.738 (3.241) + 1.392 (0.398) ($S_m$) – 1. 743 (0.678) ($S_a$) | 0.851 | 72.4 |
| | 2002 | | | |
| 1 | *S.litura* ($D_s$) | 4.547 (1.998) + 0.465 (0.062) ($S_m$) | 0.922 | 85.0 |
| 2 | *H. armigera* ($D_H$) | 2.656 (1.738) + 1.015 (0.303) ($S_m$) – 1.840 (0.693) ($S_a$) | 0.863 | 74.5 |
| 3 | *T. orichalcea* ($D_p$) | 3.065 (1.688) + 0.181 (0.052) ($S_m$) | 0.740 | 54.7 |
| 4 | Cumulative ($D_t$) | 11.778 (5.435) + 0.867 (0.168) ($S_m$) | 0.853 | 72.8 |
| | Pooled | | | |
| 1 | *S. litura* ($D_s$) | 3.689 (1.495) – 2.176 (0.413) ($S_a$) + 0.609 (0.103) ($S_t$) | 0.803 | 64.5 |
| 2 | *H. armigera* ($D_H$) | 182.070 (53.496) + 0.183 (0.031) ($S_m$) – 3.142 (0.806) ($t_{max}$) – 1.037 (0.411) ($Rh_e$) | 0.826 | 68.2 |
| 3 | *T. orichalcea* ($D_p$) | 2.878 (1.253) + 1.294 (0.283) ($S_m$) – 0.519 (0.127) ($S_t$) | 0.783 | 61.3 |
| 4 | Cumulative ($D_t$) | 9.639 (2.793) + 1.894 (0.298) ($S_m$) – 2.570 (0.535) ($S_a$) | 0.867 | 75.2 |

$S_t$ = Total spore load
$S_m$ = Morning spore load
$S_n$ = Noon spore load
$S_a$ = Afternoon spore load
$T_{min}$ = Minimum temperature
$T_{max}$ = Maximum temperature
$RH_m$ = Morning relative humidity
$RH_e$ = Evening relative humidity
$R_f$ = Rain fall
$R_d$ = Rainy days

$D_s$ = Disease on *S. litura*
$D_h$ = Disease on *H. armigera*
$D_p$ = Disease on *T. orichalcea*
$D_t$ = Cumulative disease

**TABLE 5.** Stepwise regression models for the *Nomuraea rileyi* disease incidence with second previous week's spore load and weather factors

| | Disease on | Model | R | $R^2$ (%) |
|---|---|---|---|---|
| | 2001 | | | |
| 1 | *S. litura* ($D_s$) | 2.605 (1.29) + 7.710 x $10^{-2}$ (0.076) ($S_m$) | 0.619 | 38.3 |
| 2 | *H. armigera* ($D_H$) | 97.371 (18.461) + 0.257 (0.043) ($S_n$) – 3.294 (0.650) ($t_{max}$) | 0.913 | 83.4 |
| 3 | *T. orichalcea* ($D_p$) | -85.378 (18.881) + 4.267 (0.908) ($t_{min}$) 0.824 (0.268) ($S_m$) – 0.313 (0.119) ($S_t$) | 0.937 | 87.8 |
| 4 | Cumulative ($D_t$) | -159.198 (36.087) + 0.372 (0.055) ($S_m$) + 8.121 (1.715) ($t_{min}$) | 0.920 | 84.7 |
| | 2002 | | | |
| 1 | *S.litura* ($D_s$) | 4.547 (1.998) + 0.465 (0.062) ($S_m$) | 0.922 | 85.0 |
| 2 | *H. armigera* ($D_H$) | 2.656 (1.738) + 1.015 (0.303) ($S_m$) – 1.840 (0.693) ($S_a$) | 0.863 | 74.5 |
| 3 | *T. orichalcea* ($D_p$) | 75.179 (19.450) + 0.887 (0.252) ($Rh_e$) | 0.744 | 55.3 |
| 4 | Cumulative ($D_t$) | 11.778 (5.435) + 0.867 (0.168) ($S_m$) | 0.853 | 72.8 |
| | Pooled | | | |
| 1 | *S.litura* ($D_s$) | 3.689 (1.495) – 2.176 (0.413) ($S_a$) + 0.609 (0.103) ($S_t$) | 0.803 | 64.5 |
| 2 | *H. armigera* ($D_H$) | 61.141 (17.692) + 0.198 (0.033) ($S_m$) – 2.065 (0.637) ($t_{max}$) | 0.796 | 63.4 |
| 3 | *T. orichalcea* ($D_p$) | - 76.223 (17.580) + 3.774 (0.838) ($t_{min}$) + 0.924 (0.228) ($S_m$) – 0.354 (0.102) ($S_t$) | 0.889 | 79.0 |
| 4 | Cumulative ($D_t$) | 9.639 (2.793) + 1.894 (0.298) ($S_m$) – 2.570 (0.535) ($S_a$) | 0.867 | 75.2 |

$S_t$ = Total spore load
$S_m$ = Morning spore load
$S_n$ = Noon spore load
$S_a$ = Afternoon spore load
$T_{min}$ = Minimum temperature
$T_{max}$ = Maximum temperature
$RH_m$ = Morning relative humidity
$RH_e$ = Evening relative humidity
$R_f$ = Rain fall
$R_d$ = Rainy days

$D_s$ = Disease on *S. litura*
$D_h$ = Disease on *H. armigera*
$D_p$ = Disease on *T. orichalcea*
$D_t$ = Cumulative disease

FIGURE 1. Incidence of *Nomuraea rileyi* in different crop habitats during 2001.

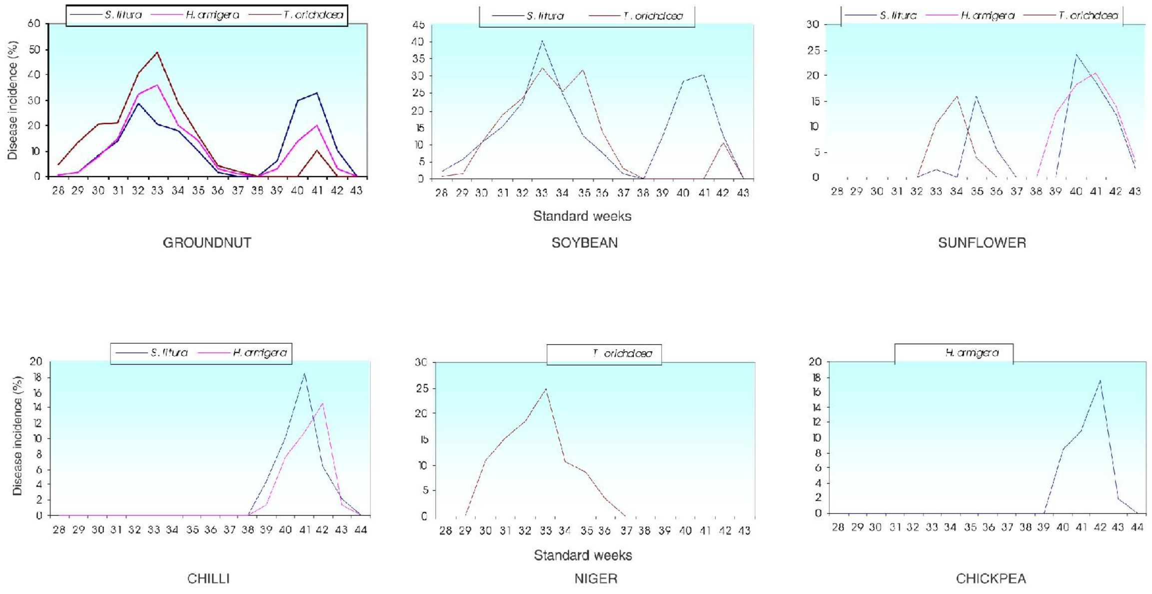


**Figure 1. Incidence of *Nomuraea rileyi* in different crop habitats during 2001**

**FIGURE 2**. Incidence of *Nomuraea rileyi* in different crop habitats during 2002

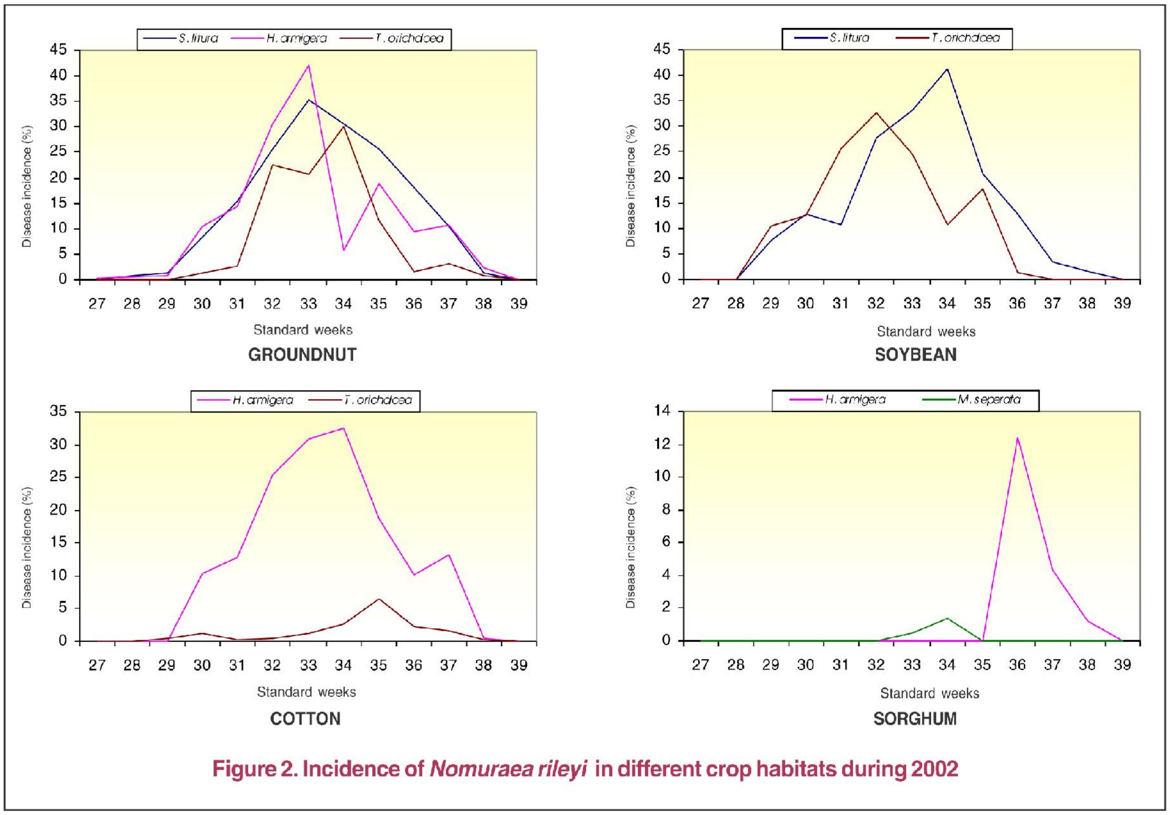


**FIGURE 3**. Incidence of *Nomuraea rileyi* on different insect pests during 2001 and 2002.

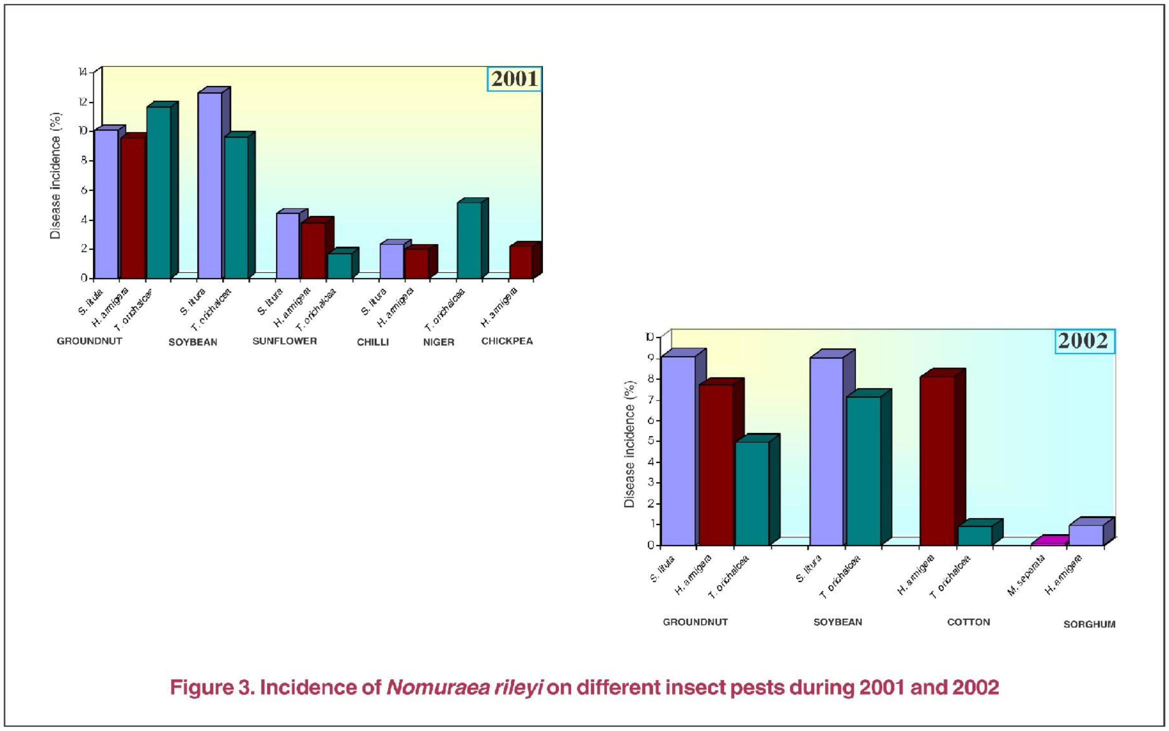


**FIGURE 4**. Prevalence of disease, atmospheric spore load of *Nomuraea rileyi* and weather factors during 2001 and 2002

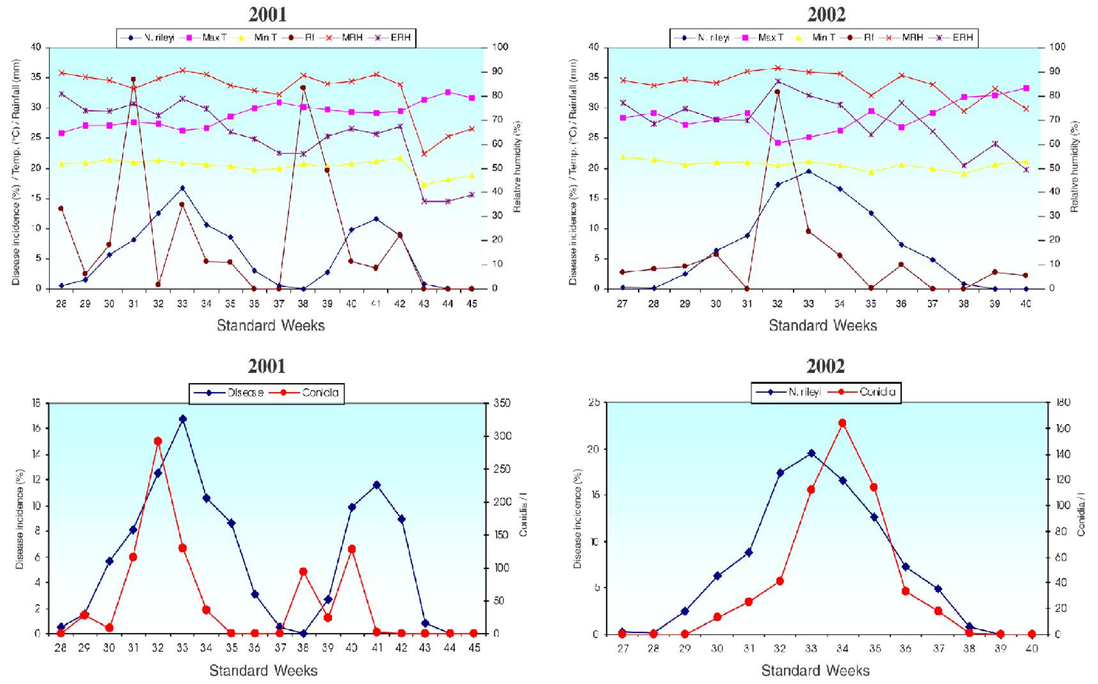


**Figure 4. Prevalence of disease, atmospheric spore load of *Nomuraea rileyi* and weather factors during 2001 and 2002**