BIOLOGY, ECOLOGY AND HOST PLANT RELATIONS OF THE BROWN PLANTHOPPER *NILAPARVATA LUGENS* STÅL

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Biology, ecology and host plant relations of the brown planthopper, Nilavarvata lugens Stål" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles of any other University or society.

Place: Vellayani,
Date : 31-10-1977.

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CERTIFICATE

Certified that this thesis, entitled "Biology, ecology and host plant relations of the brown plant hopper Nilaparvata lugens Stål" is a record of research work done independently by Sri M. J. Thomas, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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INTRODUCTION

INTRODUCTION

The brown planthopper <u>Nilaparvata lugens</u> Stål (Homoptera, Delphacidae) forms the most serious insect menace faced by rice farmers in Asia today. The insect has a wide distribution, being reported from South, South-east and East Asia, the Pacific islands and Australia (Dyck 1977). This insect has been in the past, known as a minor pest of rice in many of the tropical countries. Since the introduction of high yielding varieties of rice and improved agronomic practices, some of the pests of minor importance have become of major economic significance. Among these, <u>N. lugens</u> ranks the foremost and from the early 1970's epidemics of it have become frequent in the tropics.

Though much studies have been done elsewhere on the different phases of the problems posed by the brown planthopper, studies on the pest undertaken in India are limited and much remains to be known about it under the Indian agro-ecosystems. In India the insect made its appearance as a major pest of rice in South India, especially in the State of Kerala in 1972 (Das <u>et al</u>. 1972). Rice production in the Kuttanad rice tract was adversely affected during 1973 owing to severe outbreaks of brown planthopper and the grassy stunt virus.

The high yielding Jaya and IR 8 varieties were the worst affected (Kulshreshtha _et al_. 1974). By 1973 the pest had spread to the states of Orissa, Hariyana, Punjab, Uttar Pradesh, Bihar and Andhra Pradesh (Chatterjee 1975). Severe outbreaks and hopperburn occurred in West Bengal, Himachal Pradesh and in Tamil Nadu during the years 1973 and 1974 (Anon. 1975a, Bhalla and Pawar 1975, Veluswamy _et al_. 1975). The peak population ofthe insect was associated with a maximum temperature range of 30 to 32°C, a minimum temperature range of 15.4 to 22.6°C and a humidity range of 70 to 79 per cent in Orissa (Misra and Israel 1967). Peak infestation and widespread hopperburn occurred on the summer crop during December to January in Kerala (Abraham and Nair 1975). The insect completed 4 to 5 generations during a cropping season (Das _et al_. 1972). Nalinakumari (1973) studied the morphology and biology of the insect in Kerala. The lady bird beetle _Coccinella arcuata_ F., the mirid bug _Cyrtorhinus lividipennis_ R. and forty species of spiders have been observed predacious on _N. lugens_ in the different parts of India (Israel and Rao 1968, Abraham _et al_. 1973, Pawar 1975, Samal and Misra 1975, Murthy _et al_. 1976). There are many reports on the varietal resistance of rice to _N. lugens_ in India, the prominent among them being those of Jayaraj _et al_. (1974), Kulshreshtha _et al_. (1976), Thomas (1976) and Kalode and Krishna (1977). Effect of the application of higher doses of potash on the incidence of the hopper has also been investigated by Indian workers (Vaithilingam 1975, Subramanian and Balasubramanian 1976). Apart from these, many field trials have been made on the control of brown planthopper at the different rice research centres ofthe country. But full knowledge on response of the insect to the various stimuli (factors) of the agro-ecosystem is still lacking. Knowledge on these insect-environment reactions is important in ultimately fixing criteria for the management of the pest and the fact that the biotype of brown planthopper occurring in Kerala is different from all other known biotypes, renders added significance to it. It was these considerations which prompted the present studies. In these studies the oviposition behaviour of N. lugens and the effect of different constant temperatures and constant humidities and density of nymphal population on the biological features of the insect, have been studied under laboratory conditions. The much neglected nutrition ecology of the insect has been studied with reference to the age and nutrition of the host rice plant. Suitability of some common wet land weeds as alternate hosts or as oviposition hosts has also been examined. Infestation responses of N. lugens on 56 cultivars of rice have been studied with reference to differing stages of growth. Attempts have been made to detect the possible correlations between plant characters and insect orientation and damage on the varieties. The effect of silica and protein contents of plants on the damage intensity of the plant has been studied. Host-biology relations of *N. lugens* on eight rice varieties have been worked out.

REVIEW OF LITERATURE

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Distribution

The brown planthopper, Nilaparvata lugens Stål has been reported as a major pest from most rice growing countries. The first published report on a widespread occurrence of this insect is that by Hutson (1923) from Ceylon. Later, Jardin (1925), Hutson (1941) and Dyck (1974) have reported its epidemics in Ceylon (Sri Lanka). In India, Rao (1928) has recorded it as a minor pest of rice. Serious outbreaks have then been reported from India by Chakrabarthi et al. (1971), Das et al. (1972), Koya (1974) and Kulshreshtha et al.(1976).

Corbett (1935) and Singh et al.(1971) have recorded it from Malaysia. Esaki and Mochizuki (1941), Kisimoto (1971), Springette et al (1973) and Hirao (1976) reported its havoc in Japan. Lee and Wang (1958) recorded the pest from China. Hinckley (1963) recorded its occurrence in Fiji. King (1968) and Wongsiri (1974) observed the brown hopper incidence in Thailand. Pathak (1968) reported that it was a major pest in Philippines.

Soehardjan (1973) reported it from Indonesia. It has also been reported from Solomon Islands (Anon. 1974, 1975 b). Hale and Hale (1975) reported a severe incidence of the pest in New Guinea islands. Dyck (1977 states that the brown planthopper is found in South, South-east and East Asia, the Pacific islands and Australia.

Biology and ecology

Nilaparvata lugens was first described by Stål in 1854 as *Delphax lugens*. Later Distant (1906) erected the Genus *Nilaparvata* based on *Nilaparvata lugens*.

Caresche (1933) was the first to work on the biology and ecology of the brown planthopper, in Indonesia. He observed that the eggs laid in the leaf tissue in batches of 5 to 30, hatched in six days; development was completed in fifteen days and the adults lived for three weeks. Both adults and nymphs remained on the lower parts of the plants near the water level sucking the sap and secreting honey dew; they seldom left the plant until it was completely exhausted. Kisimoto (1956) studying the effect of crowding of nymphs on the development of wing forms of the adult hoppers found that low density and optimum conditions of food supply during larval development were necessary for the appearance of the brachypterous females whereas optimum density under favourable conditions of food supply produced brachypterous males. Overcrowding of the nymphs and wilting of the host plants resulted in the production of macropterous forms and these conditions prolonged the developmental period of the nymphs.

Suenaga (1958) found that the adults lived for 10 to

20 days in summer and 30 to 50 days during autumn. Females kept at 20°C had an oviposition period of 21 days and it was reduced to 3 days when kept at 30°C.

Takezava (1961 a) studied the over wintering of the brown planthopper eggs and found that they hibernated quite successfully in the laboratory under normal temperature conditions. He (1961 b) further observed that in eggs laid in late autum, the number that hibernated increased with lateness of oviposition. Hatching ability decreased with time after January and with the onset of spring temperature. Miyake and Fujiwara (1962) studied the overwintering and diapause of N. lugens in Japan. According to them, the eggs destined to diapause, were laid by females bred on mature rice plants and high nymphal densities, lower temperature and short-day photoperiod.

Jhono (1963) found that short day length and high temperature increased the percentage of brachypterous males while the day length had no effect on development of winged females.

Suenaga (1963) in his detailed study on the biology and ecology of the pest with special reference to outbreaks observed that a macropterous female laid about 300 to 350 eggs and brachypterous females laid more eggs. The flight dispersal took place during the preoviposition period in the evenings of hot humid days. The adult hoppers remained active in a wide range of temperature from 10° to 32°C and the macropterous females were non tolerant of temperature extremes than the males. The insect overwintered either as eggs or as fifth instar nymphs. Hinckley (1963) observed that factors like the amount of rainfall, type of cultivation, age of the rice crop, the species composition of the populations and the abundance of the parasites influenced the outbreak of brown planthopper.

Mochida (1964 a) studying the relationship between climatic conditions and occurrence of planthopper pests in Japan observed that N. lugens caused severe damage in the south west, but was not severe in cooler areas. Population tended to increase in autum and it increased with hours of sunshine. Temperature in autum appeared to favour population increase. Later, he (1964 b) found that the temperature affected the fecundity of N. lugens. There was no difference in the number of eggs per group between macropterous and brachypterous females or between groups maintained at different temperatures.

Kisimoto (1965) studied polymorphism and its rôle in the population growth of the pest and found that the pre-oviposition period was shorter for brachypterous than for the macropterous females. Under favourable conditions the brachypterous forms were adapted to rapid multiplication whereas the macropterous forms were better adapted for unfavourable conditions. Wetanebe (1967) agreed with these findings regarding the development of brachypterous forms. Laboratory experiments at the International Rice Research Institute (Anon., 1967) showed that temperatures over 25°C were generally unfavourable to the insect, and there was reduction in the life span, fecundity and survival percentage. Alternating high and low temperatures proved less unfavourable than constant high temperature. This observation led them to believe that part of the population was likely to survive in natural conditions of hot days and cooler nights.

Misra and Israel (1968) observed that the brown planthopper laid eggs in the mid ribs of both the leaf sheath and leafblade, placing them in the air cavities of the mid ribs.

Pathak (1968) found that the preoviposition period of brachypterous forms were usually shorter than that of macropterous forms. The macropterous forms were adapted for migration and they were formed under conditions of crowding and shortage of host plants. More brachypterous forms developed at low temperatures.

Bae and Pathak (1969) observed that the brown plant-hopper was abundant in the field towards the time of crop maturity in contrast to *Nephotettix* sp., and *Sogatella* sp., which were abundant during the early stages of plant growth. Anon. (1969) reported the abundance of the insect in irrigated and waterlogged fields in Fiji.

Ho and Liu (1969) stated that in Formosa the insect overwintered in all stages in rice stubbles, wheat and other plants and that an outbreak could be expected if the cumulative average temperature during the overwintering exceeded 2100°C. Bae and Pathak (1970) observed that the optimum development was at 25°C to 29°C; 33°C was detrimental to all stages of the insect. The detrimental effect was modified considerably by rearing the insect at 12 hour alternations of high and low temperatures.

Kuno and Hokyo (1970) worked out the duration of life of adult brachypterous females under natural conditions in rice fields in Japan. They observed that the females lived for about eight days as compared to twenty days in the laboratory and that each laid about 400 eggs as compared to 800 in outdoor cages. Predation by spiders was thought to be a possible reason for reduced life expectancy.

Asahina (1971) collected N. lugens on a weathership about 500 kilometers south of mainland of Japan and reported mass flights of the insect.

Ohkubo and Kisimoto (1971) in their studies on the flight behaviour of the insect in Japan observed that the adults flew at sunrise and sunset. Activity was of a bimodal crepusular type. The threshold temperature for take off was 17°C. Flight was suppressed by wind speeds in excess of eleven kilometers per hour. The proportion of females in flight varies from 20 to 60 per cent.

Hirao (1972) observed that N. lugens under went four generations in a year. Brachypterous adult females were observed with the emergence of the third generation and hopperburns first appeared at such sites.

Ohkubo's (1973) studies on the flight activity of the insect showed that most individuals were capable of continuous flight for several hours and could migrate for long distances. The threshold temperature for flight was about 16.5°C. There existed a negative correlation between wind velocity and flight duration, flight ceasing at velocities above 5.5 miles per second. There was a positive correlation between duration of flight and relative humidity. At 27.5°C, 60 per cent RH and a wind velocity of 3 m/sec., flight lasted for about 4 hours. He concluded that plant hoppers could migrate to long distances during the rainy season when the temperature was low and relative humidity high.

Ichikawa and Ishii (1974) observed that virgin females vibrated their abdomen. The vibration was transmitted through the substrate and males which came in contact with the plant responded to the vibration and approached the females. Takeda (1974) made similar observations and found that the abdominal vibration was in response to a visual clue from the male. Later, Ichikawa et al. (1975) confirmed that female abdominal vibration was the only stimulus and that no other stimulus was involved. The substrate vibrations were electrically detected and recorded on sound tape. Playback of these vibrations elicited the same response in males as in the original.

MacQuillan (1975) observed that the flight activity of the insect reached a peak around sunset. There was no difference between mean monthly catches of adults in two windy seasons. Mochida (1977) found that the duration required for the completion of the embryonic and post embryonic development was considerably dependant upon the temperatures. Further the oviposition rate was higher as the temperature became higher. It was also observed that the pre-oviposition period was shorter for the brachtyperous females than for the macropterous form.

All stages of the insect, namely, egg, nymph and adult are reported to be attacked by the natural enemies in the field. These include parasites, predators, and pathogens.

Esaki (1932) recorded Elenchus japonicus as a parasitc of the nymphs and adults of N. lugens in Japan. Other species of Elenchus were reported from Fiji (Hinckley 1963) and

Thailand (Kifune and Hirashima 1975). A few species of parasites belonging to the family Dryinidae were reported from Japan and Solomon islands (Esaki and Hashimoto, 1936, MacQuillan 1974).

l species of egg parasites belonging to the family Eulophidae, Mymaridae and Trichogrammatidae were observed on N. lugens eggs by many workers. Of these, Ootetrastichus beatus and Anagrus spp. were common and effective (Fukuda 1934, Yasumatsu and Wetnabe 1965, Otake 1970, Lin 1974).

The mirid bug Cyrtorhinus lividipennis was reported as an efficient predator on the eggs and nymphs of N. lugens from many countries (Suenaga 1963, Bae and Pathak 1966, MacQuillan 1968, Wan 1972, IRRI 1973, Pawar 1975, Murthy et al. 1976, Stapley 1976). Israel and Rao (1968) observed Coccinella arcuata as a predator on the brown planthopper. Later it was also reported from Kerala by Abraham et al.(1973). Samal and Misra (1975) recorded twenty species of spiders feeding on N. lugens in India. According to them salticids, lycosids oxyopids were the most voracious groups.

Most of the reports on microbial pathogens affecting the brown planthopper relate to that of entomogenous fungi and nematodes. Bae (1966) reported a suspected field infection of N. lugens by the fungus Entomophthora sp., Okada (1971) isolated an entomophthoraceous fungus Conidiobolus sp. from the insect. A parasitic nematode Agamermis unka was recorded on N. lugens by Kuno and Hokyo (1970) from Japan.

Feeding and honeydew excretion

The feeding behaviour of the brown planthopper has been the subject of study of many workers since it causes the characteristic hopperburn to rice plants. Sogawa (1971) found that in the course of stylet penetration the insect ejected a coagulable salivary secretion which rapidly set to a gel enclosing the protruded stylets and thus forming the 'Stylet sheath' in the plant tissue. This secretion also left a circular spot at the site of stylet insertion on the plant surface. The 'Stylet sheath' showed a single or branched tubular structure being 3.5 to 5.0 /u in diameter amd sometimes over 300 /u in length. The stylet was mainly inserted intra-cellularly passing the parenchyma. The sheath was curved towards the vascular bundles indicating that the insect fed from the vessels. The sheath terminated more frequently in the phloem than in xylem tissues. In the course of feeding the hopper excreted honeydew. The honeydew excretion by males was only about one tenth of that of females. The hopperburn was suggested to be due to the disturbance of protein metabolism in the leaf blades as a result of drainage of the free amino acids, passing through the vascular tissues, by the insect.

Mochida (1972) studied the rate of sap ingestion using C^{14} labelled seedlings. There was no difference in the quantity ingested by macropterous females during the preoviposition and oviposition periods. The quantity ingested by adults was closely correlated to the body weight and water contents. Fifth instar nymphs ingested the largest quantity despite their lighter body weight. Cagampang _et al_. (1974) studying the metabolic changes in the rice plant during infestation by the brown planthopper found that the leaves of infested plants declined in moisture, chlorophyll, soluble protein, and protease activity, but increased in free amino-N and amino acid. Heavy infestations resulted in over 30-fold increase in the levels of arginine, asparagine, lysine, proline and tryptophan, with a sixfold increase in free aminoacids of leafblades. Severe damage was accompanied by decline in the rate of leucine uptake by the plant. They also contended that the feeding sheaths plugged the xylum and phloem vessels of the plant. Such plugging might impair the plants' water balance or its water potential which contributed to the hopperburn symptom.

Kurata _et al_. (1976) observed in laboratory biossay that certain aromatic amines were feeding inhibitors to the insect when added to the sucrose solution fed to it.

Sakai _et al_. (1976) studied the effects of nutrient compounds on sucking response of the brown planthopper and found that the fluid intake was markedly enhanced on 20 per cent sucrose solution. The acceptability of sucrose solution was further improved when aminoacids, vitamins and minerals were incorporated.

Sekido _et al_. (1976) noted that salicylic acid was a specific probing stimulant for _N. lugens_. It was also proved that more potential probing stimulants other than salicylic acid were present in the rice plant sap.

Sogawa and Chen (1977) reviewed the possible causes of hopperburn damage and suggested as follows: "The drain of phloem sap and the physiological disruption of active transportation in the phloem by sustained feeding could reduce the rate of translocation of photosynthates to the root system. That would disturb physiological activities of the root system and then enhance leaf senescence. The proteolitic products such as aminoacids and amides will be accumulated in the leaves".

Honeydew excretion by the hoppers is related to feeding. Sogawa (1970 b) observed that frequency of honeydew excretion in the adult females varied from 7 to 40 droplets per hour. The rate of excretion during feeding was 0.5 μl to 5 μl per hour. The total amount of daily excretion by one female averaged 13 μl. The insect excreted considerable amount of sugarfree matter as well as matter containing sugar, which showed that the insect ingested sap from both phloem and xylem. The honeydew also contained amino compounds. Noda et al. (1973) observed that the honeydew excreted by the hopper contained 18 aminoacids. When the insects were fed on distilled water alone only traces of aminoacids could be detected in the honeydew and thus concluded that the free aminoacids were derived from the ingested plant sap.

Alternate hosts

The sporadic occurrence of the pest in rice growing areas have led many workers to suspect the existence of alternate hosts for the brown planthopper. The availability of non-rice host plants is believed to have a positive effect on the pest abundance (Kulshreshtha et al., 1974, Fernando, 1975, Varca and Feuer 1976).

It was reported from Philippines (IRRI 1970, 1976) that various weeds served as temporary food and even breeding plants for the insect. It was also noted that the insect laid eggs on barnyard grass Echinocloa crusgalli. However, Kim et al. (1975) observed that in Japan, barnyard grass showed no signs of being damaged in rice fields. Nymphs could not grow on the grass and died in a few days. An extract of barnyard grass showed an antifeedant effect when added to sucrose solution. Mochida and Okada (1971) compiled 90 species believed to be host and oviposition plants of N. lugens. But, Mochida (1977) expressed the view that Oryza sativa was the main host plant and some other species of Oryza probably became host plants in the open field. N. lugens may be unable to repeat the generations on other plants under natural conditions.

Damage

The studies undertaken at the IRRI (IRRI 1968) showed that plants 25 days after planting could withstand infestation of 100 nymphs or 8 adult per clump without any apparent damage. But infestation with 200 nymphs or 16 adults severely reduced tillering and killed some plants while that with 400 nymphs per plant caused wilting in two days. Older plants were less easily killed; 400 nymphs or 32 adults per plant, at 50 or 75 days after planting caused wilting in two weeks, but when the insects were removed the plants recovered. Further studies at IRRI (IRRI., 1970) yielded quantitative data on yield losses caused by different levels of population of both nymphs and adults, feeding for varying periods on plants of different age groups. When first instar nymphs were caged for two days on plants 25 days after planting all plants caged with 400 nymphs and 75 per cent of plants caged with 200 nymphs wilted completely. Infestations with smaller populations of 50 and 100 nymphs per plant for two days did not show wilting. Plants infested at 50 and 75 days after planting were more tolerant to damage. Such plants caged with 400 nymphs started wilting two weeks after infestation, but recovered when the insects were removed. Infestation with 50 nymphs for two weeks, though did not show apparent symptoms, produced high percentages of empty grains which was not manifested on 25 days old plants. High levels of insect populations on test plants of all age groups reduced the number of tillers, number of panicles and total grain weight per plant.

Bae and Pathak (1970) found that higher populations caused hopperburn while lower levels of population reduced the number of panicles and total grain weight of the plants. They further observed that unfilled grains resulted from infestations during the reproductive growth stage of the plants but not from infestation dring the vegetative stage.

Kalode (1971) found that hopperburn was population dependent. The initiation of hopperburn was first manifested within two days in plants infested with 320 insects. Complete burn was observed within three to five days of initiation of wilting.

Investigations at IRRI (IRRI 1974) showed that the brown plant hopper nymphs caused greater damage to plants at 21 to 39 days after seeding. For most of the growing period the plants could tolerate 5 or 10 nymphs per tiller for two weeks. The economic injury was closely related to crop age. Plants above 40 days after seeding could tolerate larger densities for a short time. Studies on hopperburn indicated that total aminoacids particularly proline level was higher in leaf blades of infested plants and this phenomenon was attributed to water stress in leaves. Susceptible varieties could tolerate a limited number of insects for a limited time without appreciable yield losses (IRRI 1975). However, Kisimoto (1976) found that hopperburn usually occurred on rice plants nearing maturity. The percentage of yield loss due to hopperburn varied greatly according to when the burn occurred; 80 to 90 per cent loss occurred when the plants suffered burn within 30 days after heading.

Fernando (1975) observed that in tropical areas where rice is grown throughout the year hopperburn could occur at any stage of growth. Park and Lee (1976) found that hopperburn appeared in the field in 40-60 days after infestation and caused more than 60 per cent yield losses.

Varietal resistance

Experiments at the IRRI (IRRI, 1969, 1970) showed that the variety Mudgo was resistant in that it showed the least survival percentage and population build up. The insect lost weight on this variety. Pathak et al. (1969) also observed that the variety Mudgo was highly resistant to the pest. The reduced feeding on this variety was attributed to the lack of a necessary feeding stimulus or due to the presence of a strong repellant. Bae and Pathak (1970) studied the susceptibility of 20 selected rice varieties to N. *lugens*. They observed that while there was some antibiosis effect, tolerance to hopperburn was the major factor in the difference in susceptibility.

Sogawa and Pathak (1970) investigated the mechanism of resistance in Mudgo variety and suggested that lower asperagine contents was a factor for its hopper resistance. At the IRRI (IRRI 1971) the nymphs of N. *lugens* suffered high mortality and grew slowly on resistant varieties. Consequently the population build up was also low. Morphological differences in varieties were not correlated with differences in resistance. Chang and Chen (1971) evaluated differcnt varieties for resistance to N. *lugens* and observed that strains H.105, Muthumanikam and IR4-60 were highly resistant while most local varieties were highly susceptible. Genetic studies revealed that resistance was determined by a single recessive gene.

Pathak (1971) found that resistance to N. *lugens* was mainly due to non-preference by the insect and was biochemical. He confirmed the earlier finding that resistance in Mudgo was on account of lower asparagine contents. It was further observed that population sufficient to kill seedlings of susceptible varieties caused little damage to those of resistant varieties. Sogawa (1971) observed that one of the resistant factors of Mudgo was located in the chemical quality of the plant sap, probably lowered concentration of phagostimulation aminoacids. It influenced the hopper feeding through gustatory response and consequent reduction in food uptake. The reduced ingestion was responsible for lowered fecundity and subsequent failure of population build up. Pathak (1972) observed that the insect exhibited distinct non-preference to certain varieties. The occurrence of any mechanical barrier was ruled out.

Parker *et al*. (1973) reported that varieties Mudgo and Mashuri were resistant to brown planthopper in Malaysia. Jayaraj *et al*. (1974) tested 31 rice varieties for resistance to *N. lugens* in Coimbatore and observed that six varieties escaped attack while others suffered medium to severe damage. Gunavardane *et al*. (1975) reported five varieties resistant to the insect in Sri Lanka. Hirao and Todoroki (1975) studied the mechanism of resistance to the brown hopper and observed that non preference was the most important factor followed by tolerance and antibiosis. Kulshreshtha *et al*. (1976) reported that varieties Ratna and Shakti showed tolerance under Indian conditions. Thomas (1976) found that varieties Ptb 19, Ptb 33 and ARC 6650 showed resistance in seedling tests in Kerala, India. Most varieties recorded as resistant in Philippines were found to be susceptible in South India and Sri Lanka due to the existence of different biotypes. Varieties Ptb 33 and ARC 6650 were found to resist all the three biotypes (IRRI 1976).

Saxena (1975) found in laboratory experiments that the odour of susceptible varieties like Taichung Native-1 and IR8 strongly attracted the hopper, while the odour of resistant varieties Mudgo and IR26 were unattractive. Karim (1975) concluded that the principal mechanisms of resistance to brown planthopper were non preference and antibiosis. Saxena and Sogawa (1977) investigating on the factors that govern the susceptibility and resistance of rice varieties to the brown planthopper, observed that although all the tested varieties were equally suitable for oviposition, significantly lower number of eggs hatched on the resistant varieties than on susceptible ones. Further, the reduced quantities of food ingested from resistant varieties and its inefficient utilisation because of lower nutrition value of the ingested sap lead to the poor growth of larvae and reduced longevity and egg production in adults.

Pathank and Kush (1977) observed that the insect exhibited distinct gustatory non-preference for certain varieties and no mechanical barrier to the insects' feeding was apparent in any of the resistant varieties. They further stated that several biotypes of the brown plant hopper existed. According to them the brown plant hopper biotype in India and Sri Lanka is apparently different from all the three biotypes and is more prolific.

<u>Effect of plant nutrients on outbraks of *N. lugens*</u>

Abraham (1957) was the first to show that planthoppers were dense on plants treated with a large amount of nitrogen. Sogawa (1970 a) observed that nitrogen deficient plants were less attractive to the female planthopper. They fed less on such plants and their fecundity was reduced. The lowered feeding was attributed to lower concentration of amino nitrogen and the reduction in fecundity was attributed to the failure of the hopper to take sufficient sap rather than to any lack of nutrition value of the sap that was ingested.

Cheng (1971) observed that nitrogen treatment resulted in increased attractiveness of the plants to the pest, increased survival rate and multiplication of the insect on the one hand and increased plant vigour and tolerance towards planthopper attack on the other. In susceptible varieties a high dose of nitrogen favoured the development of the insect. No differences were observed in resistant varieties treated with different doses of nitrogen. When plant damage was taken as the criterion, the level of damage to resistant varieties was not affected by the dose of nitrogen, but a local susceptible variety was as resistant as Mudgo in the absence of nitrogen, but suffered moderate damage after nitrogen treatment. Kalode (1971) also studied the effect of different levels of nitrogen on the varietal susceptibility and survival of

N. lugens. He observed that in the susceptible variety Taichung Native-1, there was a significant difference in the survival among the different levels of nitrogen treatment. There was increased fertility of females reared on higher nitrogen doses. The treatment had no effect on the hopper susceptibility of Mudgo. Adult survival was not affected by the treatment. The favourable effect of nitrogen on the fecundity of the insect was further elucidated by Cheng (1975).

Apart from these critical studies, many workers have attributed the use of nitrogenous fertilizers as a probale reason for hopper outbreaks in recent years (Israel and Rao, 1968, Sogawa and Pathak, 1970, Ngoan 1971, Das et al. 1972, Soehardjan 1973, Abraham and Nair 1975, Veluswamy et al. 1975, Kulshreshtha et al. 1976, Varca and Feuer 1976).

Dyck et al. (1977) reviewing this aspect contended that addition of nitrogenous firtiliser was a factor in increasing planthopper abundance. According to them the reason for this abundance had something to do with the nutritional status of the plant and the insects' physiology rather than the mere change in the microenvironment.

Effect of potash nutrition on brown hopper incidence has been studied by relatively few workers. Vaithilingam (1975) studied the effect of potash application on the incidence of rice pests and observed that incidence of brown planthopper was least in plots which received higher levels of potash. The hoppers that fed on plants receiving higher potash excreted less ninhydrin-positive compounds possibly indicating its non preference for feeding. Similar results on the lower incidence of the hopper in plots receiving higher doses were reported by Subramanian and Balasubramanian (1976)

MATERIALS AND METHODS

MATERIALS AND METHODS

Materials

Culture of *N. lugens*

Adults of the brown planthopper were collected from Kole lands in Trichur District in February 1974. These insects were reared in the laboratory. A pair of adults were isolated from this colony and they were allowed to multiply in rearing cages on potted plants. The progenies of this pair were maintained in pure culture and they were used for the experiments.

Aspirator

A glass aspirator was used for collecting the hoppers from the field and also for transferring the insects in the laboratory.

Field cages

Field cages of the size 1.8m x 1.2m x 0.9m made of wooden frame and bottom and covered with fine nylon net on all the sides and top were used for keeping the potted plants to rear the insect under field conditions.

Laboratory rearing cages

Cylindrical rearing cages were made with polythene sheets supported on iron frames. The top ends of these cages were covered with muslin cloth. Cages of the sizes 40 cm diameter x 65 cm height, 30 cm x 50 cm and 20 cm x 45 cm were used to suit the size of pots used for raising the seedlings.

Paper cups

Icecream cups were used for growing single seedlings for biology studies of the planthopper and also for planting single plants for studying the egg laying of the insect on different varieties etc.

Rice plants

For bulkrearing and biology studies of the brown planthopper, plants of the variety 'Jaya' were used.

Seeds of the different varieties of rice used for rearing and varietal screening studies were obtained from Rice Research Station, Pattambi, Rice Research Station, Monkompu and Model Agronomic Research Station, Karamana.

Methods

Bulk rearing of *N. lugens*

Adult hoppers selected from colonies raised from a single pair of adults were liberated on 50 to 60 days old potted paddy plants (Jaya), kept in laboratory cages. After two days, the insects were collected back from the plants. The plants in the cages were kept watered, clean and free from predators in the insectary. When the plants showed symptoms of drying due to feeding by the insect colonies which had developed on the plants, the insects were collected and liberated on fresh plants.

Collection of eggs and first instar nymphs

Fifty to sixty days old paddy plants grown in small flower pots were used for this. The leaf blades of these plants were trimmed off and the plants kept in laboratory cages. Adult insects were released on these plants. After 24 hours the insects were removed. The plants were kept in the laboratory cages and examined daily. First instar nymphs emerged after 7 to 8 days and could be seen on the leaf sheaths.

Studies on the biology of *N. lugens*

One month old rice seedlings (variety, Jaya) planted singly in paper cups were used for biology studies of the insect. The plant in the paper cup was placed in a long beaker, over which a hurricane glass chimney was placed and the upper end of the chimney was closed with muslin cloth. A pair of freshly emerged adults were introduced into the

the chimney. The insects could be observed through the beaker. Observations were recorded on the mating, pre-oviposition and oviposition periods, fecundity, longevity etc. For determination of fecundity and longevity, fresh plants were introduced into the beaker daily, till the insects died. The exposed plants were taken out and examined under a binocular microscope to count the eggs.

To ascertain the number of moultings and nymphal instars, freshly emerged first instar nymphs were reared out singly on one month old rice seedlings planted in paper cups and enclosed in open specimen tubes (15 cm x 4 cm). The upper end of the tube was closed with muslin cloth.

To study the distribution of eggs on the different parts of the plants adult females were confined on 50-days old potted plants placed in cages. The side tillers were cut and removed, allowing only the main tiller to remain. After 48 hours the insects were removed, the plants were examined under a binocular microscope and the eggs counted.

Effect of temperature and humidity on the biology of *N. lugens*

The various constant humidities required for the experiment were obtained in dessicators of suitable size with the help of appropriate concentration of potassium hydroxide dissolved in distilled water according to Buxton(1931)

The dessicators were placed inside an incubator set at the desired temperature. Cut bits of the basal portion of the stem of 50 to 55 days old plants were placed inside specimen tubes and ten first instar nymphs were introduced into each tube and closed with muslin cloth. The specimen tubes were placed inside the dessicators. Fresh food was supplied everyday. There were three replications.

Effect of crowding on the biology of *N. lugens*

First instar nymphs of *N. lugens* in groups of 50, 100, 200 and 400 were put on 50-55 days old Jaya plants in laboratory cages. Three clumps were planted in each pot in the cages so as to ensure adequate supply of food for the nymphs. The plants were periodically examined. When adults started emerging, they were removed daily, counted and other features like sex ratio, number of brachypterous forms, weight of adults etc., noted.

Suitability of weeds as alternate hosts for *N. lugens*

Weed plants were grown in separate flower pots and five pairs of three days old adult hoppers were confined on them in glass hurricane chimneys. The upper ends of the chimneys were closed with muslin cloth. After 24 hours the exposed plants were examined for egg laying on them. Similar sets of plants were kept in the insectary for observing the emergence of nymphs. First instar nymphs were released on weed plants in glass chimneys in groups of ten and their survival recorded at fixed intervals. Freshly emerged adults were caged in groups of ten to observe the adult survival on weed plants.

Effect of age of host plant on the biology of *N. lugens*

Rice plants (variety Jaya) of different age groups, 15 days, 45 days, 75 days and 105 days to represent the seedling stage, maximum tillering stage, panicle initiation stage and flowering stage respectively, were uprooted, out and kept in moist glass bottles and first instar nymphs were introduced on them. Fresh food was supplied on alternate days. The duration of the nymphal period and percentage survival of the nymphs were observed.

Effect of nitrogen and potash nutrition of host plant on the biology of *N. lugens*

A pot experiment was conducted with varying doses of nitrogen.

Design	-	Completetely randomised
Replication	-	Three
Treatments	-	(Levels of nitrogen)
T_0	-	No nitrogen (Control)
T_1	-	20 kg N/hectare
T_2	-	40 kg N/hectare
T_3	-	60 kg N/hectare

T_4	-	80 kg N/hectare
T_5	-	100 kg N/hectare
T_6	-	120 kg N/hectare

Jaya rice seedlings were planted in pots at the rate of four seedlings per pot. P and K were applied at the rate of 50 kg per hectare as basal dressing in all the pots. N at the varied doses was applied half as basal and half 15 days after planting. The required quantities per pot were calculated, weighed and dissolved in water and then applied in the pots. N, P and K were applied as ammonium sulphate, super phosphate and muriate of potash respectively. Thirty days after planting ten pairs of adults were confined for egg laying on each plant in muslin cages supported on iron frames. These insects were removed after five days. On the eighteenth day the plants were out at the base and the nymphs developed were killed in chloroform and their number recorded.

Tillers from the plants were cut and kept moist in wide mouthed glass bottles and nymphs reared on them from first instar to study the nymphal duration and survival. Adults emerging from the different treatments were reared uniformly on single potted plants to study the longevity and fecundity. A similar experiment was conducted with varying doses of potash, keeping N and P constant at 80 kg and 50 kg per hectare respectively.

Levels of potash

T_0	-	0 (Control)
T_1	-	25 kg K_2O/hectare
T_2	-	50 kg K_2O/hectare
T_3	-	75 kg K_2O/hectare
T_4	-	100 kg K_2O/hectare
T_5	-	125 kg K_2O/hectare

Screening of rice varieties for resistance to brown planthopper infestation

The screening of the rice varieties for resistance was conducted at two stages of growth, (i) at the seedling stage and (ii) at the tillering stage.

For the screening at the seedling stage, the seeds were sown in 60 cm x 60 cm x 10 cm wooden seed boxes containing garden soil to a depth of 5 cm. Each variety was sown in a row of 25 cm length. Each box contained 24 lines, 5 cm apart as shown in Fig.(1). Of the 24 lines, four lines were of the susceptible check variety 'Annapoorna'. When the seedlings were 10 days old, they were thinned so that there were only ten seedlings in a row. The box was placed in a galvanised iron tray (80 cm x 100 cm x 10 cm) containing water to a depth of 5 cm and placed inside a field cage. A large number of second instar nymphs were

Fig. 1. Layout plan of Screening of rice varieties at seedling stage

LAY-OUT PLAN OF SCREENING AT SEEDLING STAGE

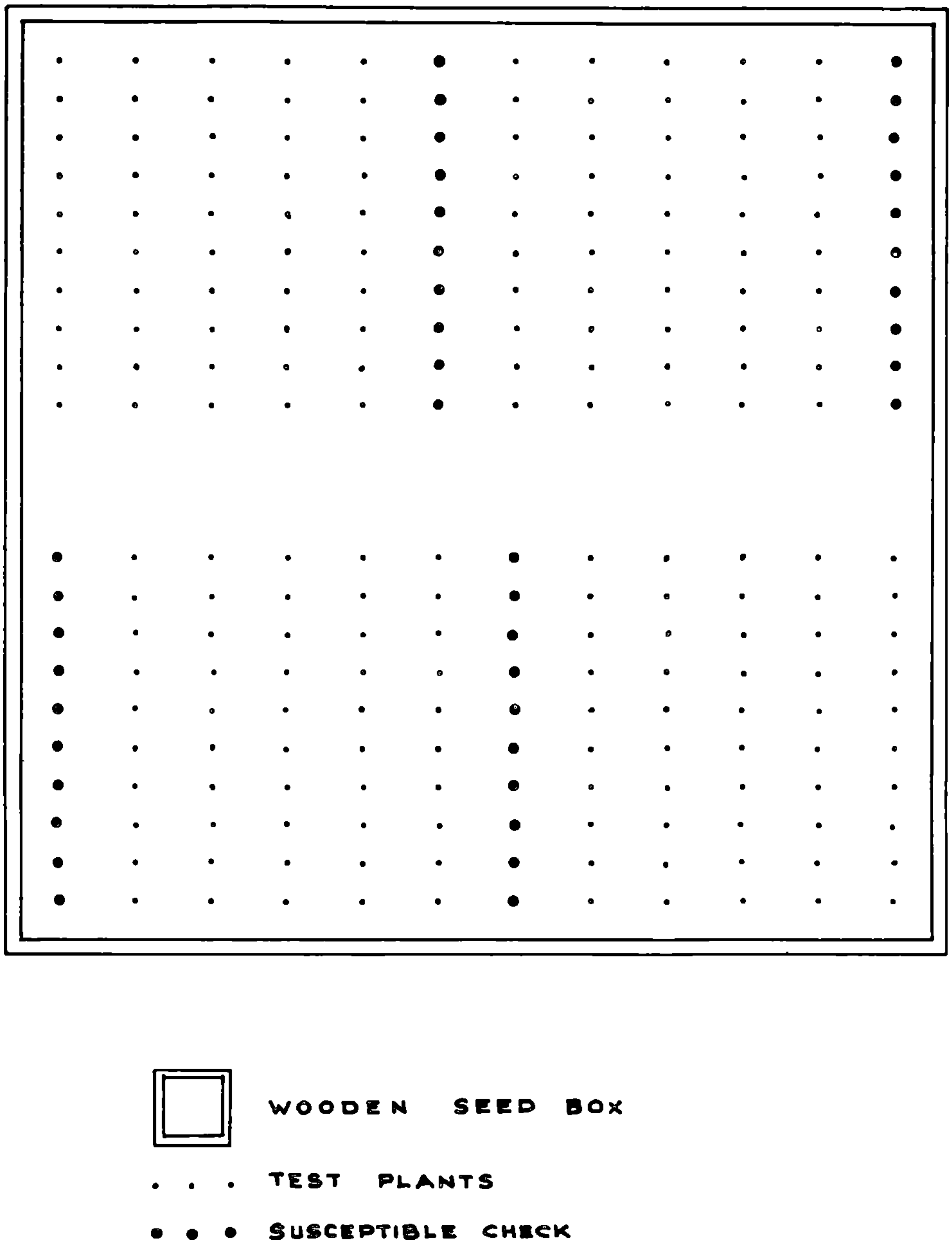


FIG 1

scattered within the seed box in such a way thatevery plant received an average of 10 to 12 nymphs. Water was kept in the iron tray throughout the period to irrigate the seedlings, to keep high humidity and to ward off ants. The damage on the seedlings caused by the nymphs (Plate 1) was recorded when most of the susceptible check plants died which happened on the fifth day. The plant damage was graded on a zero to nine scale as suggested by Anon. (1975 c). The damage scores and grades are:-

Damage score	Plant damage
0	No visible damage
1	Yellowing of one or two leaves
3	Initiation of wilting of leaves
5	Pronounced yellowing and wilting of all leaves except the youngest one
7	All leaves wilted, but the stem partly green
9	Plant wilted and dead

Damage grade	
Score 0 to 3	Resistant (R)
3.1 to 5	Moderately resistant (MR)
5.1 to 7	Susceptible (S)
7.1 to 9	Highly susceptible (HS)

Screening was repeated four times.

For screening at the tillering stage twenty days old seedlings of each variety were transplanted in separate pots at two seedlings per hill. The pots were manured at a uniform dose of 100 : 50 : 50 kg NPK per hectare respectively. Twentyfive days after planting the potted plants were pruned to 8 to 10 healthy tillers in a pot and placed inside the field cages. One hundred second instar nymphs were released on plants in each pot. There were three replications. Observations on the plant damage were recorded when the susceptible check variety Annapoorna wilted. The damage was graded on a zero to nine scale constructed for the purpose. The damage scores and grades are as follows :-

<u>Damage score</u>	<u>Damage symptom</u>
0	No damage
3	Yellowing of leaves
6	Leaves wilted but stem is fully or partially green
9	Plant dead

<u>Damage grade</u>

Score 0 - 3	Resistant (R)
" 3.1 - 5	Moderately resistant (MR)
" 5.1- 7	Moderately susceptible (MS)
" 7.1 to 9	Highly susceptible (HS)

<u>Determination of varietal preference of *N. lugens* for oviposition</u>

For this, 30 days old plants of different varieties were planted singly in paper cups, arranged at random in trays and placed in field cages. There were three plants in each variety. Macropterous females were released inside the cage at the rate of about ten insects per plant. After 48 hours the number of insects settled on each plant was recorded. The plants were taken out and examined under a binocular microscope for counting the eggs.

Host-biology studies of *N. lugens*

Rice plants, 40 to 50 days old, were cut and kept moist in wide mouthed glass jars and 25 first instar nymphs were introduced into each jar and closed with muslin cloth. Fresh plants were provided on alternate days. The duration and survival of the nymphs were noted. The emerging adults were kept in pairs in similar glass jars with 30 days old 'Jaya' rice plants for egg laying. The plants were changed everyday and the number of eggs counted.

Study of plant characters

Thickness of the stem, leaf sheath and leaf blades was measured by a 'Thickness dial gauge'. The anatomy of the sheath and stem was observed by taking cross sections. The sections were stained with safranin and observed under the microscope.

Analysis of chemical components of plant tissues

The nitrogen contents of the plant samples were estimated by the micro kjeldahl method (Poiduvin and Robinson, 1965). The percentage of nitrogen was multiplied by the factor 6.25 to get the protein content of the samples. The crude silica content of the plant samples were determined by following the method of Yoshida *et al.* (1971).

RESULTS

RESULTS

Biology of *N. lugens*

Oviposition: Under laboratory conditions adults of *N. lugens* emerge at night or during early hours of the day. Mating takes place soon after the emergence and oviposition starts a day hence. The female pierces the leaf tissues with the ovipositor and deposits the eggs inside the tissues; the operculum of the egg projects out. The eggs are mostly laid on the leaf sheaths of the plants; the mid ribs where the tissues are thick are preferred for egg deposition than the thinner wings of the sheaths. Eggs are laid within the mid ribs of the leaf blades also. In Table 1 is given a summary of the observations made on the distribution of egg-laying by ten groups of five females each in 24 hours on the leaves and leaf sheaths (Original data presented in Appendix I). It will be observed that when the number of egg masses laid on the leaf sheaths is on an average 6.0, it is only 3.4 on the leaf blades. The size of the egg masses also varies on these two locations. Thus the average number of eggs per mass is 13.26 when laid on the leaf-sheaths, while it is only 7.52 when laid on the leaf blades. Further, it is also seen that on a plant 77.59 per cent of the eggs are laid on the leaf sheaths and 22.33 per cent on the leaf blades.

Table-I. Nature and distribution of egg masses laid by *N. lugens* on the leaf sheaths and leaf blades of rice

Replication No.	On leaf sheath				On leaf blade				Total No.of eggs on the plant	Per cent number of eggs	
	Total No. of egg masses	Total No. of eggs	Range of eggs per mass	Mean No. of eggs per mass	Total No. of egg masses	Total No. of eggs	Range of eggs per mass	Mean No. of eggs per mass		On leaf sheath	On leaf blade
1	8	88	6 - 22	11.00	2	12	6 -	6.00	100	88.00	12
2	7	76	3 - 32	10.86	4	26	4 - 9	6.50	102	74.51	25.49
3	3	33	8 - 17	11.00	1	14	14 -	14.00	47	70.21	29.79
4	7	98	2 - 33	14.00	4	22	2 -13	5.50	120	81.67	18.33
5	6	77	8 - 21	12.83	3	10	2 - 4	3.33	87	88.50	11.50
6	6	70	4 - 24	11.67	2	32	2 -30	16.00	102	68.63	31.37
7	8	100	2 - 30	12.50	5	31	3 -13	6.20	131	76.34	23.66
8	5	61	4 - 20	12.20	6	27	3 - 9	4.50	88	69.32	30.68
9	6	101	2 - 31	16.83	4	22	2 -11	5.50	123	81.30	17.89
10	4	79	10 - 27	19.75	3	23	3 -12	7.67	102	77.45	22.55
Average	6.0	78.3		13.26	3.4	21.9		7.52		77.59	22.33

Plate I - Screening of rice varieties at seedling stage

(a) Healthy and damaged seedlings in separate 'seed boxes'

(b) Damage symptoms on seedlings caused by the infestation of *N. lugens*

PLATE - I(a)

PLATE - I(b)

Table 2 summarises the observations made on the number of eggs laid and the duration of the egg-laying periods of macropterous females of N. lugens (See Appendix II for the complete observations). It can be seen that the number of eggs laid by a female ranges from 151 to 308, the mean being 228.3 eggs. The preoviposition period ranges from 1 to 3 days, the average being 2.3 days. The egg-laying period varies from 13 to 25 days, the average oviposition period being 18.2 days. Egg-laying is generally continuous on all days once it is commenced, but instances of days when there is no egg laying also is observed (See Appendix I) which may vary from 1 to 4 days during the oviposition period of the insect. The number of eggs laid by a female per day varies from 0 to 60, the average being 12.86 eggs. Fig. 2(a) represents the number of eggs laid daily during the oviposition period. It is observed that the number of eggs laid per day increases rapidly during the first few days reaching the peak by about the 9th day. Thenceforth there is a reduction in the number of eggs laid per day, the rate of reduction on successive days being less rapid than the rate of increase seen in the beginning. Thus during an egg-laying period of 28 days the peak period of egg-laying is from 7th to the 13th day.

In Table 3 is given a summary of the observations made on the fecundity and egg-laying of brachpterous females

Fig. 2. (a) Daily egg laying in macropterous females of *N. lugens*

(b) Daily egg laying in brachypterous females of *N. lugens*

FIG 2a

DAILY EGG LAYING IN MACROPTEROUS FEMALES OF N *lugens*

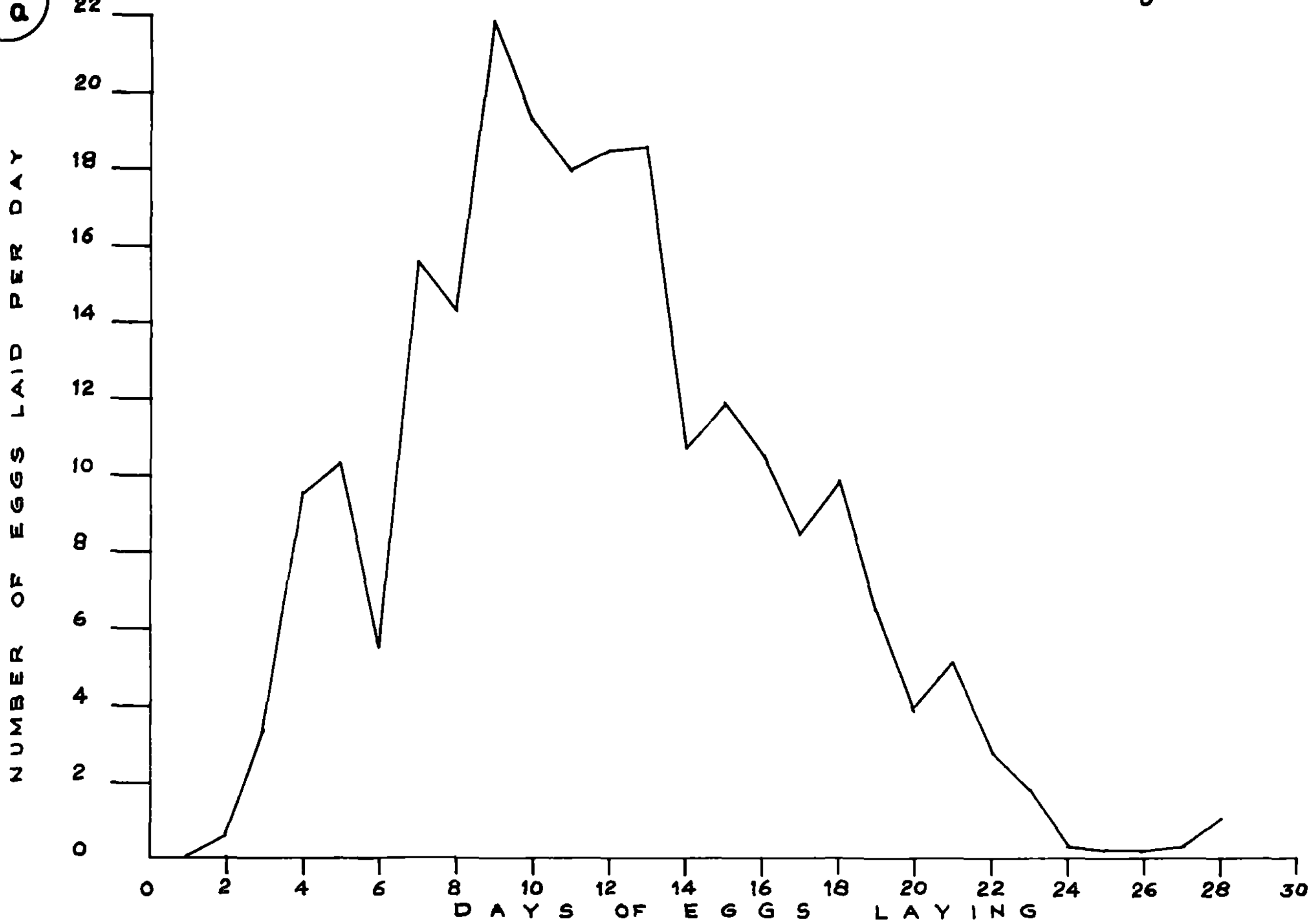


FIG 2b

DAILY EGG LAYING IN BRACHYPTEROUS FEMALES OF N *lugens*

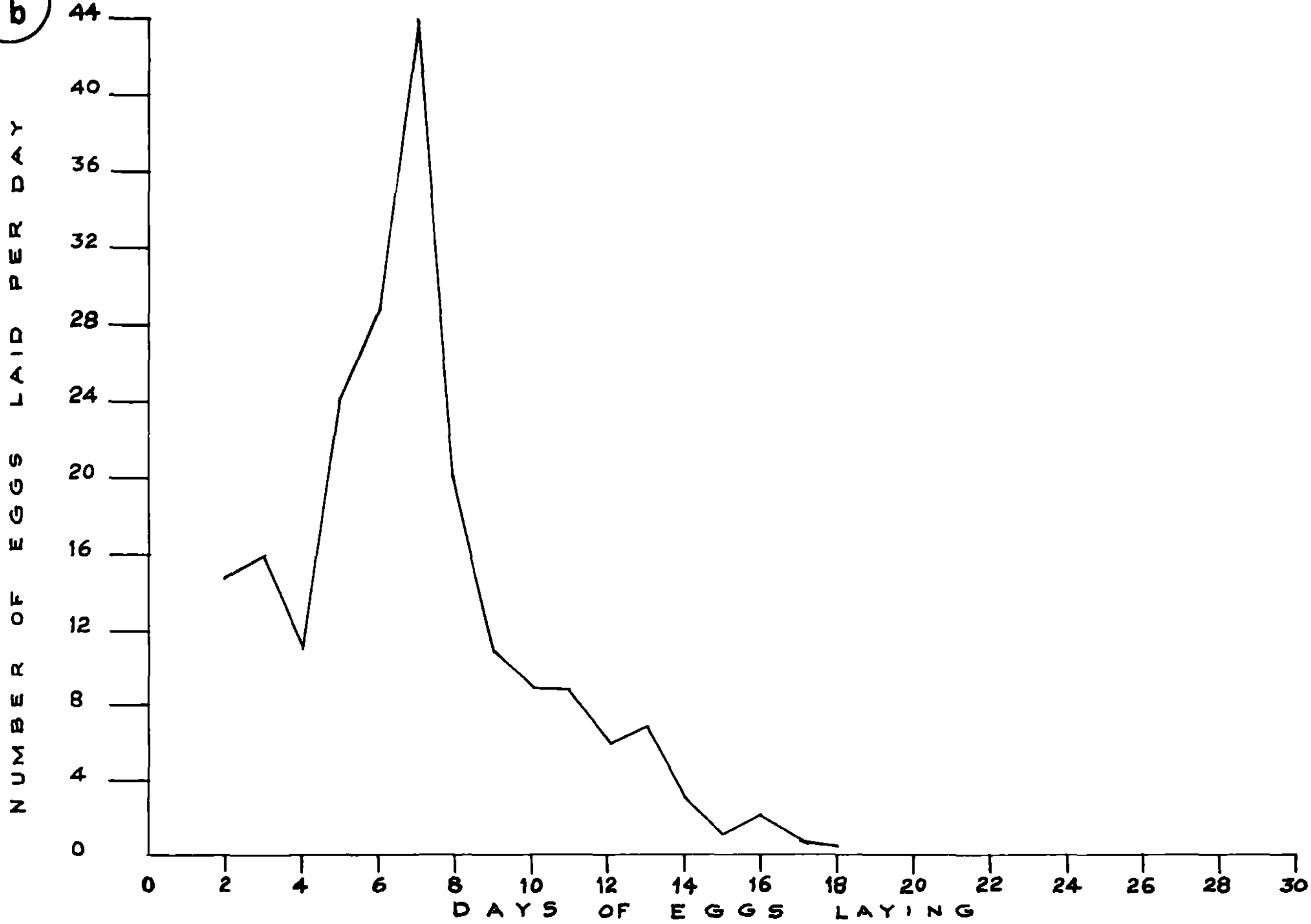


Table-2. Fecundity and egglaying of *N. lugens* (Macropterous)

Replication No.	Pre-oviposition period (days)	Oviposition period (days)	Total number of eggs laid	Range of number of eggs laid per day	Average number of eggs laid per day
1	1	13	172	0-55	13.23
2	3	13	210	0-48	16.15
3	3	25	291	0-33	11.64
4	2	13	221	2-49	17.00
5	3	18	284	0-51	15.78
6	2	17	203	0-48	11.94
7	1	21	212	2-55	10.10
8	3	20	231	0-47	11.55
9	2	25	308	2-60	12.32
10	3	17	151	0-31	8.88
Average	2.3	18.2	228.3		12.86

Period of study : 1-6-1975 to 30-7-1975

Table-3. Fecundity and egglaying of N. lugens (Brachypterous)

Replication No.	Pre-ovi-position period (days)	Oviposition Period (Days)	Total number of eggs laid	Range of number of eggs laid per day	Average number of eggs laid per day
1	1	17	319	0-99	18.76
2	1	10	208	0-73	20.80
3	1	12	175	0-48	14.58
4	1	13	298	2-78	22.92
5	1	15	131	0-63	8.73
6	2	10	184	0-69	18.40
7	1	13	199	2-98	15.31
8	1	16	205	0-47	12.81
9	2	14	189	2-41	13.50
10	1	17	158	0-69	11.06
Average	1.2	13.7	209.6	-	15.69

Period of study: 1-6-1975 to 30-7-1975

of N. lugens (See Appendix III for complete data). The mean pre-oviposition period is 1.2 days, the range being 1 to 2 days. The egg-laying period extends from 10 to 17 days the average being 13.7 days. The number of eggs laid per female varies from 131 to 319, the average being 209.6 eggs. The daily egg-laying varies from 8.73 to 22.92 with a mean of 15.69 eggs. Fig. 2(b) gives graphically the distribution of daily layings during the entire oviposition period. The initial daily increase in the number of eggs laid is rapid and reaches the peak on the 7th day. From the 7th to the 9th day there is a steep fall in the egg laying after which the fall is gradual and slow. Thus, during an oviposition period of 18 days the peak period of egg-laying is from the 5th to the 8th day.

Egg: The eggs are shaped and bunched like banana fruits. The egg is creamy white when freshly laid and turns yellowish-brown during the course of the development. The eyes of the developing embryo are seen as two yellow spots at the proximal end of the egg. For hatching, the nymph pushes open the operculum and emerges out, the egg shell remaining within the plant tissue. The incubation period of the egg varies from 7 to 9 days with an average of 8 days (Table 4). It is also seen that the percentage hatching is very high, ranging between 80.00 and 89.61 per cent.

Nymph: The eggs hatch normally during the early hours of the

Table-4. Incubation period and percentage hatching of eggs of N. lugens

Date of egg laying	Total No. of eggs	Date of emergence	No. of nymphs emerged	Incubation period in days	Hatching %
1-8-75	124	10-8-75	110	9	88.70
2-8-75	118	10-8-75	95	8	80.50
3-8-75	120	11-8-75	96	8	80.00
4-8-75	116	11-8-75	99	7	85.34
5-8-75	154	13-8-75	138	8	89.61
Mean				8.0	84.83

day. But, on humid days hatching is observed to take place throughout the day. In Table 5 is given the results of observations made on the duration of the different instars. It may be seen that the average duration of the instars 1 to 5 are 2.7, 2.8, 2.6, 3.1 and 2.8 days respectively. The total nymphal duration is 14.0 days. One characteristic feature of the nymphs is the change of body colouration during the different instars and changes in habits. Thus, the first instar nymph is cottony white in colour and moves on the plant reaching the leaf tips and getting distributed to the adjacent plants on which they settle at the basal portions. Just before moulting, the colour changes to light brown. The second instar nymph is brownish black in colour, remains on the basal part of the plant in clusters just above the water level. The third instar nymph has a light yellow body and brown head and thorax. Wing buds are seen developing at this instar. These nymphs remain clustered at the base of the plants. The fourth instar nymphs are yellowish brown in colour with the ventral surface creamy white and the wing pads are prominent. The fifth instar nymph is brown in colour. It moves about actively roaming on the leaf blades especially during the morning hours. When the sun becomes hot it goes down and settles at the base of the plant. (See Plate II)

The second to fourth instar nymphs are active feeders

Plate II - Settling of nymphs and adults of *N. lugens* at the base of the plant

PLATE - II

Table-5. Duration of nymphal instars of *N. lugens*

Replication No.	Duration of instars in days					Total
	I	II	III	IV	V	
I	3	2	2	3	3	13
II	3	3	3	4	2	15
III	3	3	4	3	2	15
IV	3	4	3	3	3	16
V	3	3	2	2	3	13
VI	2	3	2	4	3	14
VII	2	3	2	2	3	12
VIII	3	2	2	4	3	14
IX	2	3	3	3	3	14
X	3	2	3	3	3	14
Mean	2.7	2.8	2.6	3.1	2.8	14.0

Period of study: 2-8-1975 to 30-9-1975

and they remain at the base of the plants in colonies. But when the plants start wilting, they migrate to other plants. The nymphs when disturbed leap and fall into water; they can scate on the water surface to reach other plants.

Just before the final moulting the fifth instar nymph turns deep brown, stops feeding and hold firmly to the plant surface. Adult wriggles out through a dorsal slit on the nymph at the anterior end and the exuvium remains attached to the plant.

Adult: Immediately at emergence the adult is yellowish white in colour and gradually turns brown. Finally it is ochraceous brown dorsally and deep brown ventrally. Two types of adults viz. macropterous and brachypterous forms are produced. Among the brachypterous forms females are more abundant than males which occur very rarely. In the brachypterous forms the tegmina are transformed to small brownish scale like leathery structures covering only the anterior portion of the abdomen.

Life-cycle: The total duration of the life-cycle from egg to adult ranges from 19 to 25 days, the average being 22.0 days.

Longevity of adults: The longevity of males and females are shown in Tabbe 6. Macropterous males live for 14 to 22 days, the mean longevity being 18 days. The macropterous females live longer than the males, living for 14 to 28 days with an

Table-6. Longevity of adults of *N. lugens*

Replication	No. of days lived		
	Macropterous males	Macropterous females	Brachypterous females
I	15	18	12
II	19	26	14
III	14	25	13
IV	21	16	14
V	18	28	11
VI	16	15	12
VII	16	28	14
VIII	22	19	18
IX	19	27	11
X	20	14	17
Mean	18.0	21.4	13.8

Period of study: 1-6-1975 to 30-7-1975

average of 21.4 days. The brachypterous females live for 11 to 18 days, their mean longevity being 13.8 days.

Effect of Temperature and Humidity on the biology of N. lugens

Effect of different constant temperatures and relative humidities on the different biological features of N. lugens was ascertained in laboratory experiments. The biological features studied were survival of the nymphs, duration of the nymphal period, sex ratio of the emerging adults, proportion of brachypterous females, incubation period and hatchability of eggs. The results are presented below:-

Survival of nymphs

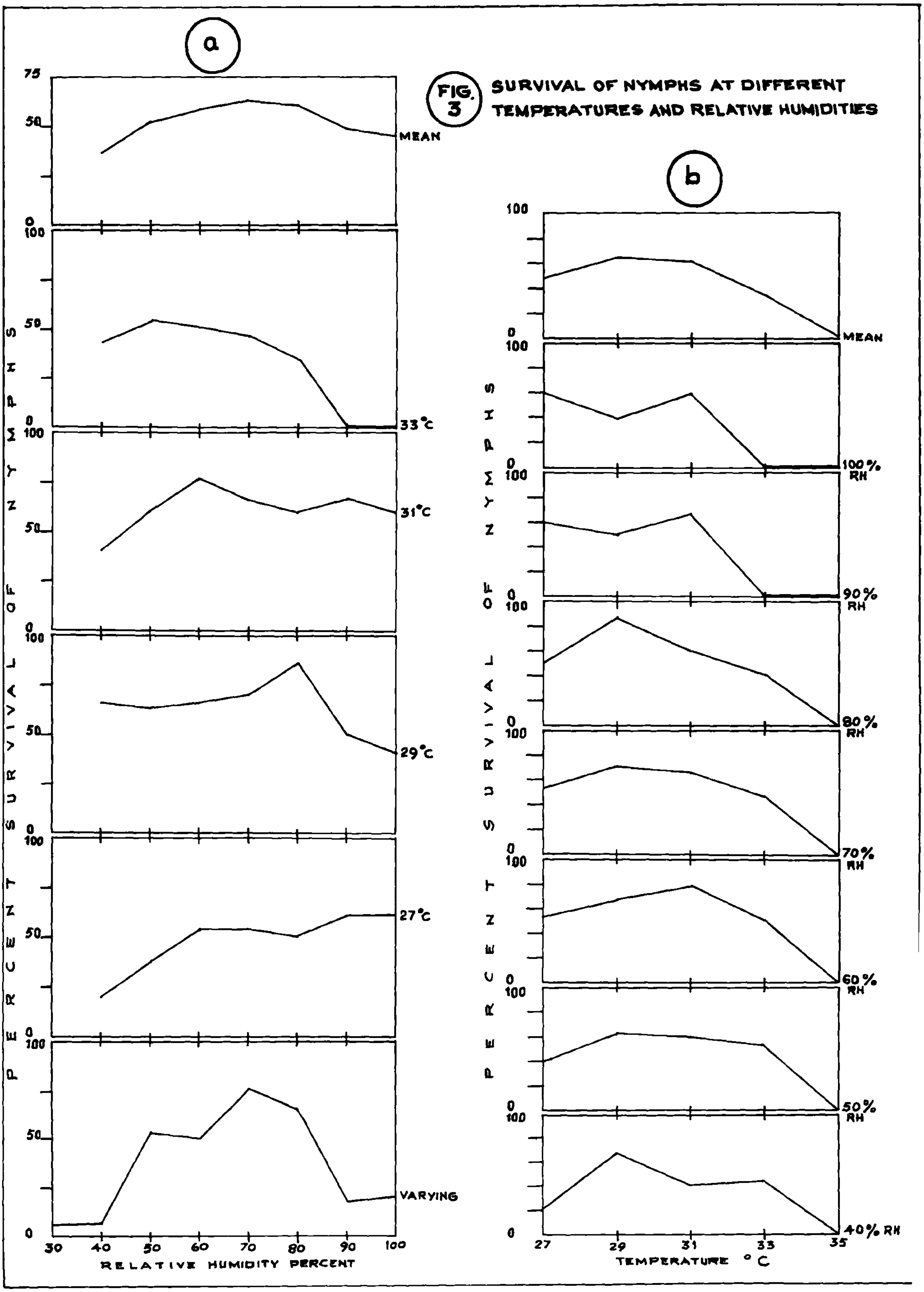
The percentage survival of the nymphs of N. lugens at different temperature - humidity combinations is given in Table 7 and represented in Fig.3(a) and (b). Statistical analysis has shown that the survival of the nymphs with reference to temperature variations and humidity variations are significant. The interaction between temperature and humidity also is significant.

Fig.3(a) shows that at the four fixed graded temperatures the variations in humidity cause variation in the survival of the nymphs. The per cent survival varies from 6.67 at 40% RH and varying temperature, to 86.67 at 80% RH

Fig. 3. Survival of *N. lugens* nymphs at different temperatures and relative humidities

(a) Per cent survival of nymphs at each temperature grade when the humidity is varied

(b) Per cent survival of nymphs at each constant humidity when the temperature is altered



a
b
FIG. 3
SURVIVAL OF NYMPHS AT DIFFERENT TEMPERATURES AND RELATIVE HUMIDITIES
PERCENT SURVIVAL OF NYMPHS
MEAN
33°C
31°C
29°C
27°C
VARYING
RELATIVE HUMIDITY PERCENT
100% RH
90% RH
80% RH
70% RH
60% RH
50% RH
40% RH
TEMPERATURE °C

Table-7. Per cent survival of nymphs of *N. lugens* at different temperatures and relative humidities and their analysis of variance.

Temp. °C		Relative humidity per cent							
		40	50	60	70	80	90	100	Mean
Varying	(T1)	6.67 (15.00)	53.33 (46.89)	50.00 (45.00)	76.67 (61.14)	66.67 (54.76)	20.00 (26.56)	23.33 (28.86)	42.38 (39.74)
27	(T2)	20.00 (26.56)	36.67 (37.29)	53.33 (46.89)	53.33 (46.89)	50.00 (45.00)	60.00 (50.77)	60.00 (50.77)	47.62 (43.45)
29	(T3)	66.67 (54.76)	63.33 (52.71)	66.67 (54.76)	70.00 (56.79)	86.67 (68.61)	50.00 (45.00	40.00 (39.23)	63.33 (53.13)
31	(T4)	40.00 (39.23)	60.00 (50.77)	76.67 (61.14)	66.67 (54.76)	60.00 (50.77)	66.67 (54.76)	60.00 (50.77)	61.43 (51.74)
33	(T5)	43.34 (41.15)	53.33 (46.89)	50.00 (45.00)	46.67 (43.11)	40.00 (39.23)	- -	- -	33.33 (30.77)
35	(T6)	-	-	-	-	-	-	-	-
Mean		36.00 (35.34)	53.33 (46.91)	59.33 (50.56)	62.67 (52.54)	60.67 (51.67)	49.17 (35.92)	45.83 (33.93)	

Values in parentheses are angular transformations

Contd. to page 52

Table-7. - Contd.

Analysis of Variance Table

Source	Sum of Squares	d.f.	M.S.	F
Total	29107.38	104		
Treatment	25173.69	34		
Temperature	7309.09	4	1827.27	32.52**
Humidity	7004.84	6	1167.47	20.78**
Temp. x humidity	10859.76	24	452.49	8.05**
Error	3933.69	70	56.19	

** Significant at 1% level

C.D. (0.05) for temperature = 4.63

C.D. (0.05) for humidity = 5.47

C.D. (0.05) for interaction = 12.24

<u>Ranking</u> Temperature: T3, T4, T2, T1, T5

Humidity : H4, H5, H3, H2, H6, H1, H7

and 29°C. At each of the temperatures 27, 29 and 31°C, starting from 40% RH the survival increases, reaches a peak and then decreases as the humidity increases to 100%. There is no survival at humidities below 40%. The highest survivals of 50.0 to 86.67 per cent of the nymphs are seen to be between the humidities 60 and 90%. It is also seen that at lower temperatures higher humidities are favourable for the survival, while at the higher temperature a low humidity is favourable. Thus, at 27°C, the maximum survival of 60% is at 90% RH and at 29°C the maximum survival of 86.67% is at 80% RH, while at the higher temperature of 31°C the maximum survival of 76.67% is at 60% RH. At 33°C there is no significant variation in the survival at the different humidities.

At varying temperatures the maximum survival of 76.67% is obtained at 70% RH.

Fig.3(b) shows that at constant humidities the survival of the nymphs varies at the different temperatures. The general trend is that starting from 27°C the survival percentage (47.62%mean) increases as the temperature increases, reaches a peak (63.33% mean), then falls as the temperature rises to 35°C (33.33% mean). At all the humidities excepting 90 and 100% there is a significant increase in the survival percentage of nymphs as the temperature increases from 27°C to 29°C. A significant decrease in the survival is observed as the temperature increases from 29°C to 31°C at all the humidities except 60% RH (besides 90 and 100% RH); at 33°C there is still further reduction in the survival. The nymphs do not survive at 35°C. Thus 29°C appears to be the most favourable temperature for the survival of the nymphs, the survivals varying from 40.0 to 86.67 per cent at different humidities the mean being 63.33 per cent.

The rankings given which indicate the overall effect of the different graded constant temperatures show that temperatures 29°C and 31°C are significantly more favourable for the survival of the nymphs than the other temperatures. Similarly the overall analysis of the effect of constant humidities (See the ranking in Table 7) shows that the humidity of 70% is the most favourable for the survival of the nymphs followed closely by 80%, 60% and 50%, there being no significant difference between these four humidity levels.

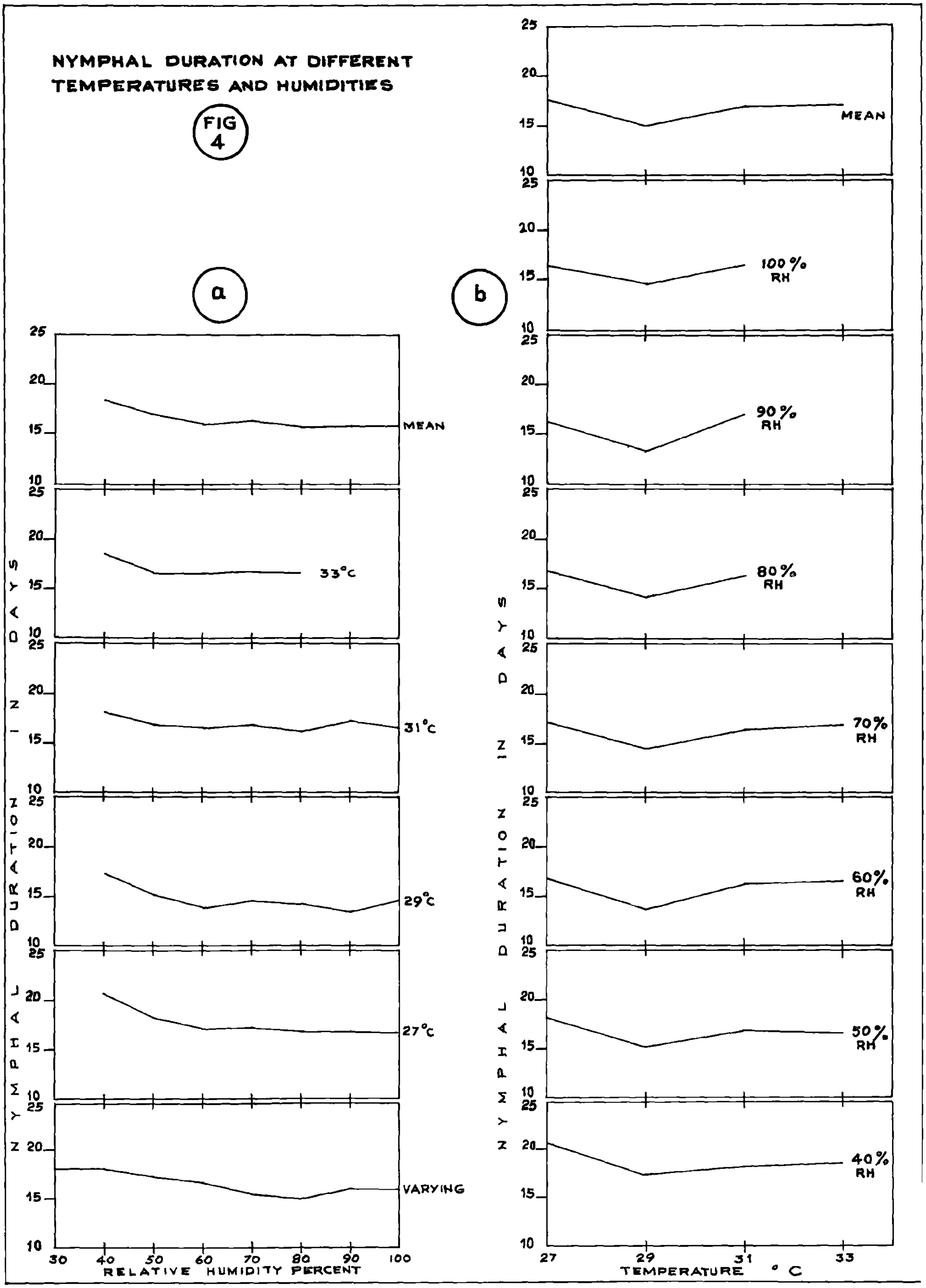
Duration of nymphal period

The nymphal durations of *N. lugens* observed at constant temperatures - humidity combinations are given in Table 8. The same data are represented in Fig.4(a) and (b). Analysis of variance of the data presented shows that the variations in nymphal periods due to variations in temperature and humidity are significant. The interaction between temperature and humidity also is significant. The nymphal period varies from 13.4 to 20.5 days under the different temperatures and

Fig. 4. Nymphal duration of *N. lugens* (in days) at different temperatures and humidities

(a) Nymphal duration at each temperature grade when the humidity is varied

(b) Nymphal duration at each constant humidity when the temperature is altered



NYMPHAL DURATION AT DIFFERENT TEMPERATURES AND HUMIDITIES
FIG 4
a
b
NYMPHAL DURATION IN DAYS
MEAN
33°C
31°C
29°C
27°C
VARYING
RELATIVE HUMIDITY PERCENT
100% RH
90% RH
80% RH
70% RH
60% RH
50% RH
40% RH
TEMPERATURE °C

Table-8. Average durations of nymphal period in days of *N. lugens* at different temperatures and relative humidities and their analysis of variance

Temp. °C		Relative humidity per cent							
		40 (H1)	50 (H2)	60 (H3)	70 (H4)	80 (H5)	90 (H6)	100 (H7)	Mean
Varying	(T1)	18.00	17.38	16.40	15.43	15.00	15.83	15.86	16.49
27	(T2)	20.50	18.00	16.88	17.00	16.67	16.61	16.44	17.44
29	(T3)	17.20	15.05	13.70	14.43	14.16	13.40	14.50	14.63
31	(T4)	18.08	16.78	16.44	16.75	16.33	17.30	16.45	16.88
33	(T5)	18.46	16.64	16.54	16.79	16.58	-	-	17.00
35	(T6)	-	-	-	-	-	-	-	-
Mean		18.44	16.77	15.99	16.08	15.75	15.79	15.81	

Contd. on page 56

Table-8. Contd.

Analysis of Variance Table

Source	Sum of squares	d.f.	M.S.	F
Total	2197.94	104		
Treatment	1797.04	34		
Temperature	361.68	4	90.42	15.79**
Humidity	414.34	6	69.06	12.06**
Temperature x humidity	1021.02	24	42.59	7.43**
Error	400.90	70	5.727	

** Significant at 1% level

C.D.(0.05) for temperature = 1.48

C.D.(0.05) for humidity = 1.65

C.D.(0.05) for interaction = 3.91

Ranking

Temperature: T3, T1, T4, T5, T2

Humidity H5, H6, H7, H3, H4, H2, H1

humidities. Fig.4(a) shows the fluctuation of nymphal periods due to variation in humidity at the four constant temperatures and under fluctuating temperature. It will be observed that at the four constant temperatures the nymphal duration is more at the lower relative humidities of 40 and 50%. The only point at which significant difference in the duration is seen is at the change from 40 to 50% RH (from 18.44 to 16.77 days mean). Thereafter, generally the nymphal duration does not show any significant change due to changes in humidity up to 100%. The ranking of the mean values also indicates the same relationship between humidity variations and nymphal period.

In the case of response of nymphal period to changes in temperature as may be seen from Fig.4(b), invariably the shortest nymphal duration under the different humidities is at 29°C the mean being 14.63 days (range 13.4 to 17.2 days). The duration increases at temperatures on either side of this point. It is also seen that the change from a longer (17.44 days mean) to the shorter (14.63 days mean) nymphal duration is significant as the temperature is raised from 27 to 29°C. On the other hand a significant increase in the duration is evident (14.63 to 16.88 days mean) as the temperature rises from 29°C to 31°C. Ranking of the mean values of the effect of different temperatures shows that at the constant temperature of 29°C the mean nymphal duration is the least

(14.63 days) while at 27°C it is the highest (17.44 days mean).

However, taking all the combinations into consideration, the shortest nymphal duration of 13.40 days is at 90% RH and at the temperature of 29°C. The longest duration of 20.50 days is at a temperature of 27°C and relative humidity of 40%.

Growth index

The growth index value (Srivastava 1959) was calculated for each temperature - humidity combination and is presented in Table 9. The same data are presented in Fig.5(a) and 5(b). Analysis of variance of the data shows that the effects of temperature and humidity are significant and their interaction not significant. The growth index varies from 0.56 to 6.12 under the different temperature - humidity combinations. The highest value of 6.12 is at the temperature and relative humidity combination of 29°C and 80% RH. The growth index value increases, reach a peak and then fall as the temperature increases from 27°C to 33°C at all the humidities. From the mean values it is seen that the maximum growth index of 4.35 is at 29°C, the next being at 31°C. The mean value is lowest (2.68) at the varying temperature.

The growth index values for the constant temperatures alone excluding the varying temperature have been analysed

Fig. 5. Growth index of _N. lugens_ when the nymphs are reared at different temperatures and relative humidities

(a) Growth index value at each constant humidity when the temperature is altered

(b) Growth index value at each temperature grade when the humidity is varied

FIG 5 GROWTH INDEX AT DIFFERENT TEMPERATURES AND HUMIDITIES

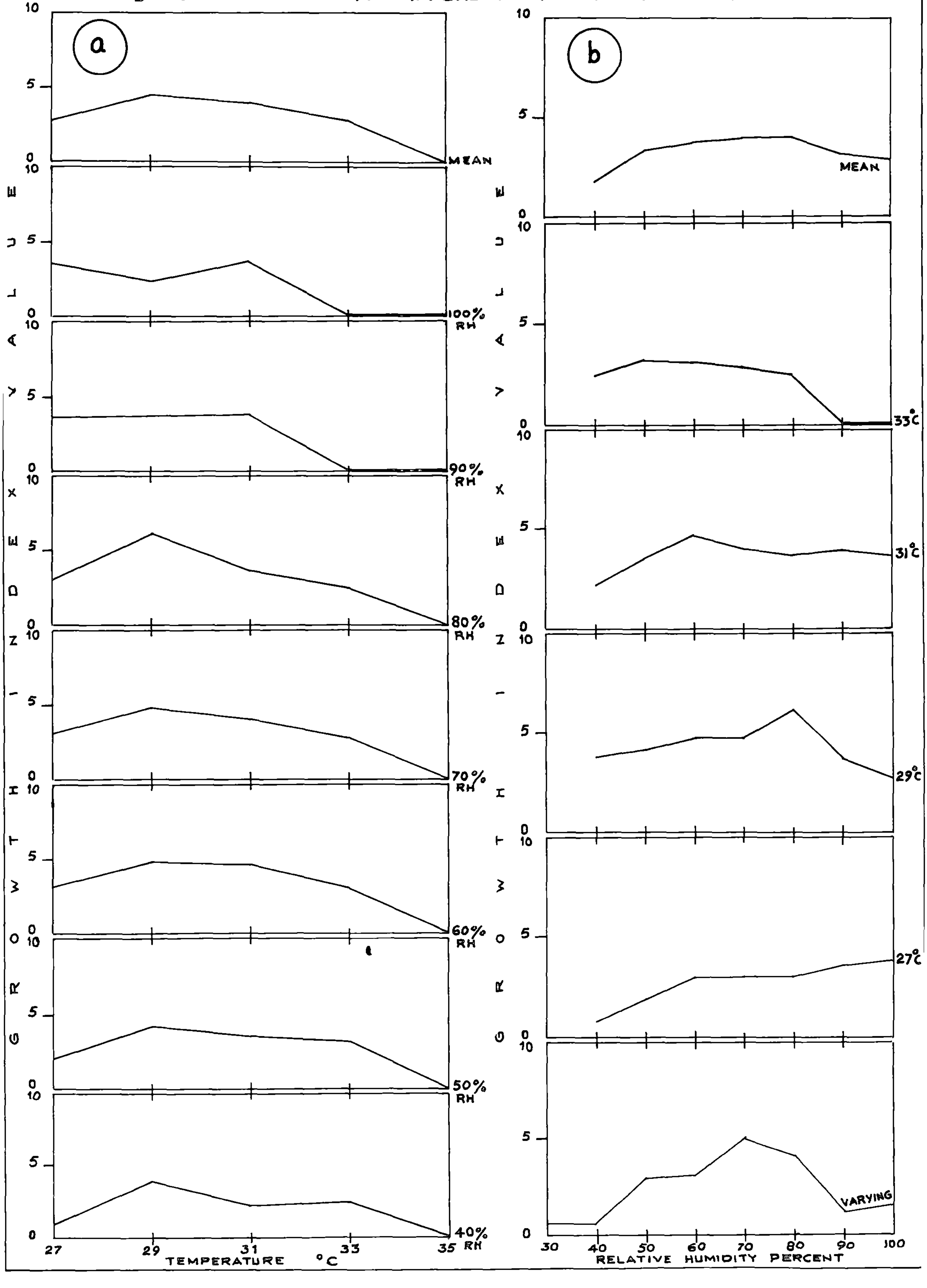


Table-9. Growth index values of *N. lugens* at different temperatures and humidities and their analysis of variance.

Temp. °C		Relative humidity per cent 40 (H1)	50 (H2)	60 (H3)	70 (H4)	80 (H5)	90 (H6)	100 (H7)	Mean
Varying	(T1)	0.56	3.00	3.05	4.97	4.44	1.26	1.49	2.68
27	(T2)	0.90	2.04	3.16	3.14	3.00	3.61	3.65	2.79
29	(T3)	3.88	4.21	4.87	4.85	6.12	3.73	2.76	4.35
31	(T4)	2.21	3.58	4.66	3.98	3.67	3.85	3.65	3.66
33	(T5)	2.35	3.20	3.02	2.78	2.41	-	-	2.75
35	(T6)	-	-	-	-	-	-	-	-
Mean		1.98	3.21	3.75	3.94	3.93	3.11	2.89	-

Contd. on page 60

Table-9. Contd.

Analysis of variance Table

Source	Sum of squares	d.f.	M.S.	F.
Total	423.9694	104		
Treatment	205.6859	34		
Temperature	67.4574	4	16.864	5.433 **
Humidity	68.4914	6	11.415	3.6775 **
Temperature x humidity	69.7371	24	2.905	0.936 NS
Error	217.2835	70	3.104	

** Significant at 1% level

NS : Not significant

C.D. (0.05) for temperature = 1.07

C.D. (0.05) for humidity = 1.26

Ranking T3, T4, T2, T5, T1

H4, H5, H3, H2, H6, H7, H1

separately. The effects of temperature, humidity and their interaction are found significant. The quadratic models for expressing the growth index in terms of temperature (humidity) were fitted. The model is

$$Y = a x^2 + b x + c$$

Temperature

$$Y = -0.2039 x^2 + 12.0855 x - 174.8921$$

where, Y = Growth index value

x = temperature °C

This is a good representation as can be seen by the high coefficient of determination of 0.979. Growth index is maximum when temperature is 29.64°C. The model to express the effect of temperature on growth index is graphically presented in Fig.6(a).

Humidity

$$Y = -0.0015 x^2 + 0.2150 x - 3.6900$$

where, Y = growth index

x = relative humidity %

The coefficient of determination is 0.903. Growth index is maximum when relative humidity is 69.53%. The model is graphically presented in Fig.6(b).

<u>Sex ratio of adults</u>

The percentage of males of *N.lugens* produced at the

Fig. 6. (a) Effect of constant temperature on growth index of *N. lugens* nymphs.

$$Y = -0.2039\ X^2 + 12.0855\ X - 174.8921$$

where,

Y = growth index

X = temperature °C

(b) Effect of relative humidity on growth index of *N. lugens* nymphs

$$Y = 0.0015\ X^2 + 0.2150\ X - 3.6900$$

where,

Y = growth index

X = relative humidity per cent

FIG 6a

EFFECT OF TEMPERATURE ON GROWTH INDEX

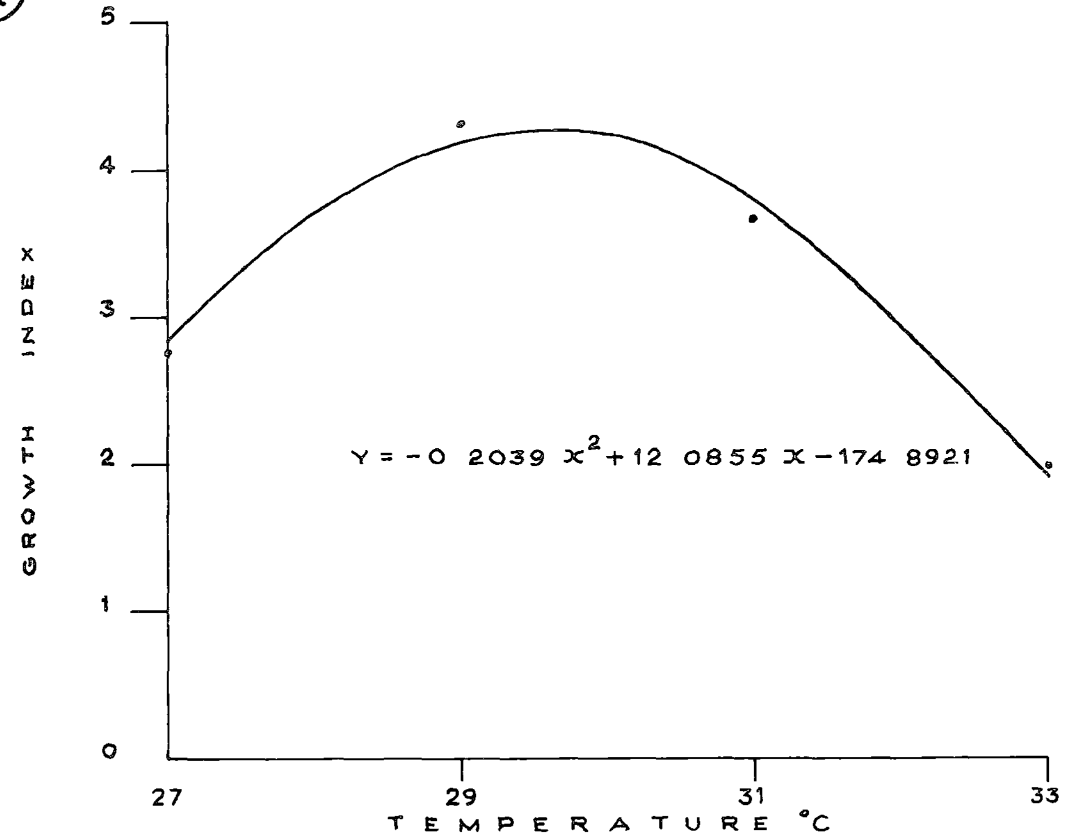
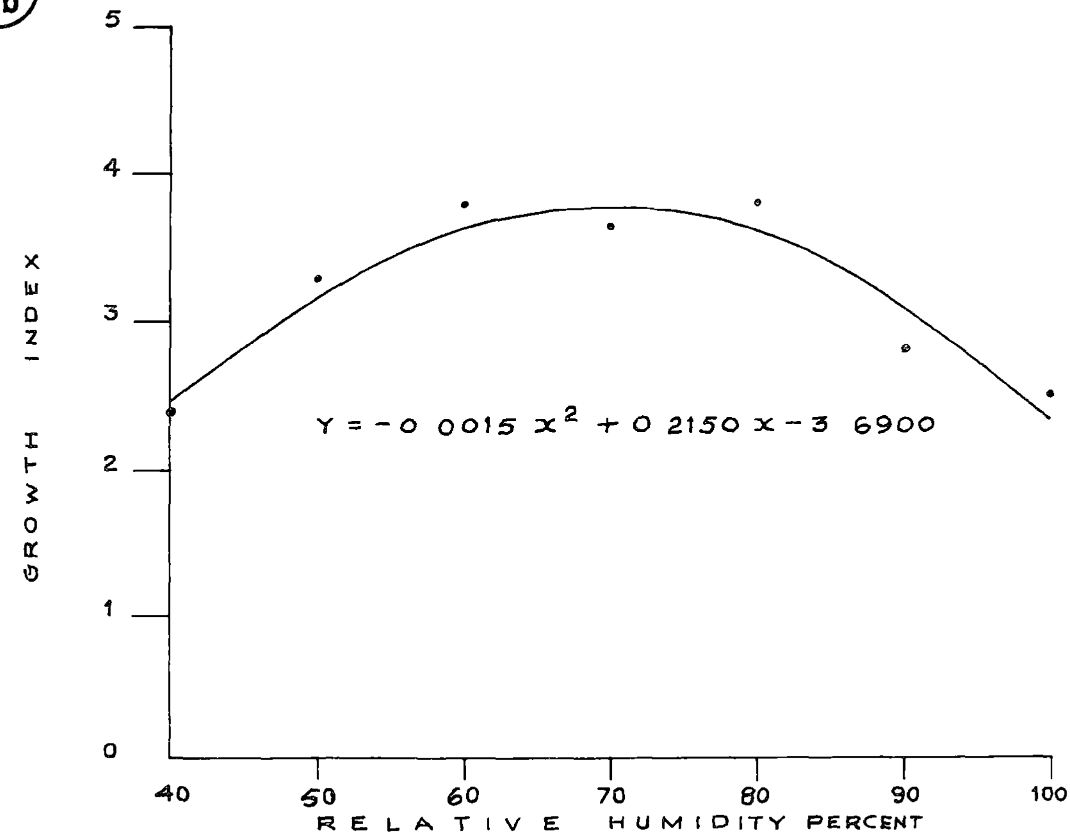


FIG 6b

EFFECT OF RELATIVE HUMIDITY ON GROWTH INDEX



different temperatures and humidities is given in Table 10 together with their analysis of variance. Analysis shows that the variations in the percentage of males produced are significant at the varying temperatures and varying humidities. There is however no sequential response to the different graded temperatures and humidities. Comparison of the means also indicate the same trend. Thus, for the different temperatures, 29°C produces the least percentage of males (43.57%), followed close by the fluctuating temperature (46.18%). At all the other temperatures the male production is significantly more than that at these temperatures. As regards humidity, the different humidities do not cause significant variation in the percentage of males produced. The highest percentage of 69.18 males is seen with 40% RH, followed in the descending order by 50%, 80%, 90%, 100%, 70% and 60%.

Production of brachypterous females

The effect of variations in constant temperature and humidities on the production of brachypterous females in *N. lugens* is given in Table 11 and represented in Fig.7(a) and (b). The variations are statistically significant. The percentage of brachypterous females produced varies from 6.25 to 41.67 under different temperature - humidity combinations. From Fig.7(a) it is seen that at all the

Fig. 7. Emergence of brachypterous females of N. lugens when the nymphs are reared at different temperatures and humidities

(a) Per cent brachtyperous females at each temperature grade when the humidity is varied

(b) Per cent brachtyperous females at each constant humidity when the temperature is altered

FIG 7 PERCENT BRACHYPTEROUS FEMALES AT DIFFERENT TEMPERATURES AND HUMIDITIES

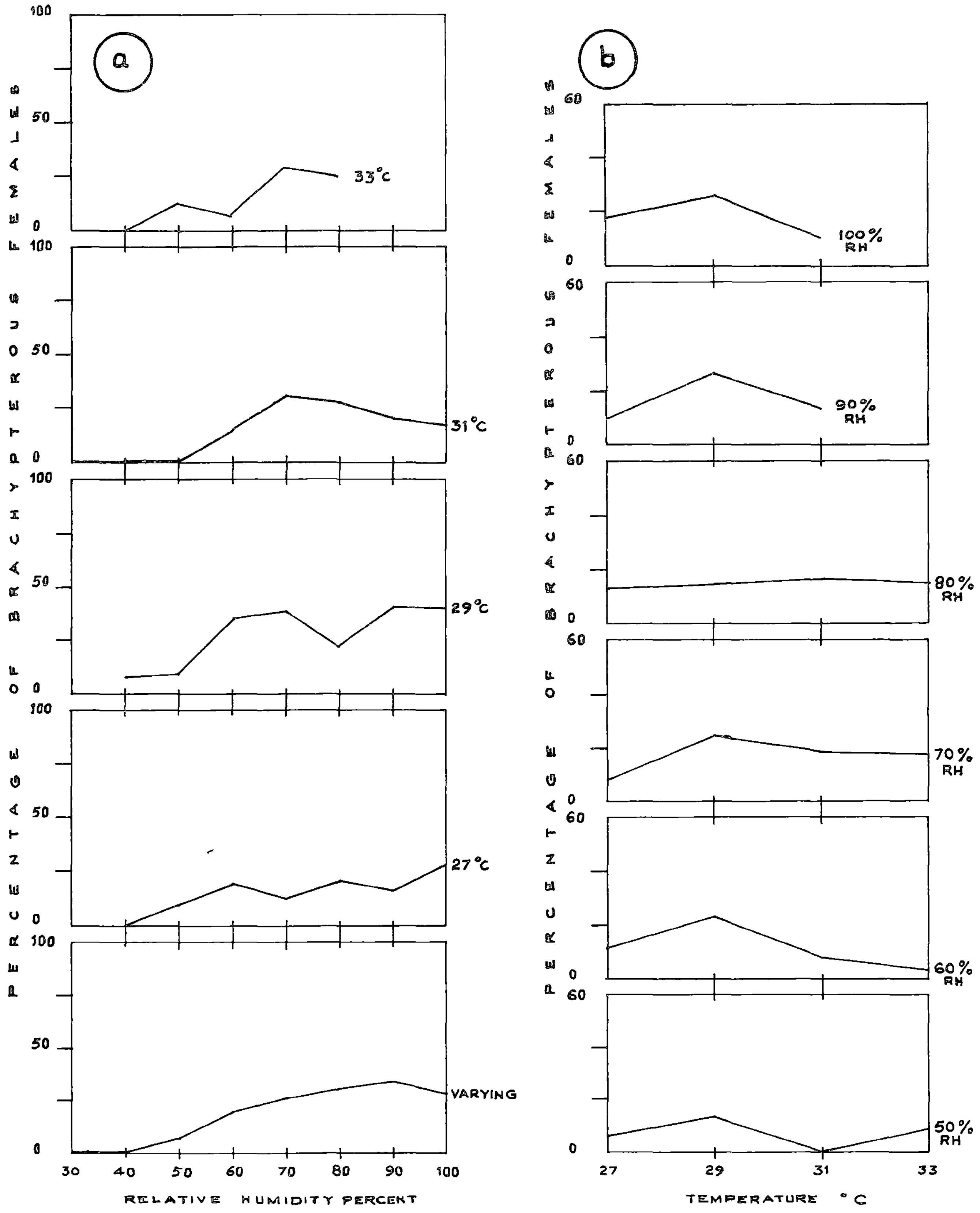


Table-10. Percentage of emerging males at different temperatures and humidities and their analysis of variance.

Temp. °C	Relative humidity per cent							
	40	50	60	70	80	90	100	Mean
Varying	66.67 (54.76)	56.25 (48.62)	40.00 (39.23)	39.13 (38.70)	45.00 (42.13)	33.33 (35.24)	42.86 (40.92)	46.18 (42.80)
27	66.67 (54.76)	54.55 (47.64)	37.50 (37.76)	43.75 (41.44)	46.67 (43.11)	66.67 (54.76)	38.89 (38.59)	50.67 (45.50)
29	60.00 (50.77)	52.63 (46.47)	45.00 (42.13)	42.86 (40.92)	46.15 (42.82)	33.33 (35.24)	25.00 (30.00)	43.57 (41.30)
31	83.33 (65.88)	50.00 (45.00)	26.09 (30.72)	50.00 (45.00)	50.00 (45.00)	50.00 (45.00)	66.67 (54.76)	53.73 (47.12)
33	69.23 (56.29)	56.25 (48.62)	46.67 (43.11)	35.71 (36.69)	41.67 (40.22)	-	-	49.91 (44.94)
Maen	69.18 (56.29)	53.93 (47.24)	39.05 (38.70)	42.29 (40.57)	45.89 (42.65)	45.84 (42.56)	43.36 (41.21)	

Values in parenthesis are angular transformaions.

Contd. on page 64

Table-10. Contd.

Analysis of Variance Table

Source	Sum of squares	d.f.	M.S.	F.
Total	38405.48	104		
Treatment	18303.61	34		
Temperature	4474.10	4	1118.525	3.89 **
Humidity	6167.77	6	1027.961	3.58 *
Temperature x humidity	7661.74	24	319.239	1.11 NS
Error	20101.87	70	287.18	

** Significant at 1% level
* Significant at 5% level
NS:Not significant

C.D. (0.05) for temperature = 10.459
C.D. (0.05) for humidity = 12.376

constant temperatures as well as under varying temperature, the number of brachypterous forms produced increased as the relative humidity is increased and reaching a peak at 70% or above. A comparison of the mean values shows that the differences between 70, 80, 90 and 100% RH are not statiscally significant.

In the case of temperature the percentage of brachypterous females under the different humidities increases as the temperature increases from 27°C and reaches a peak at 29°C and decreases thereafter as the temperature increases to 31°C or 33°C. The means also depict this picture clearly and the percentage of brachypterous females formed is significantly more at 29°C (31.27%) than at other temperatures. Thus a constant temperature of 29°C and a relative humidity of 90 to 100% is most favourable for the formation of brachypterous females. On the other extreme, 40% RH is not favourable for the formation of brachypterous females. At 40% RH brachypterous females are not at all produced in any of the temperatures except 29°C. The high temperature of 33°C and the low temperature of 27°C appear to be not favourable.

Incubation period of eggs and percentage hatching of eggs

Data on the incubation period of the eggs of *N. lugens*

Table-11. Percentage of brachypterous females emerging at different temperatures and humidities and its analysis of variance.

Temp. °C	Relative humidity per cent							
	40	50	60	70	80	90	100	Mean
Varying	0	6.25 (14.54)	20.00 (26.56)	26.09 (30.72)	30.00 (33.21)	33.33 (35.24)	28.57 (32.33)	20.61 (26.99)
27	0	9.09 (17.56)	18.75 (25.70)	12.50 (20.70)	20.00 (26.56)	16.67 (24.12)	27.78 (31.82)	14.97 (22.79)
29	20.00 (26.56)	21.05 (27.35)	35.00 (36.27)	38.10 (38.12)	23.08 (28.73)	40.00 (39.23)	41.67 (40.22)	31.27 (34.02)
31	0	0	13.04 (21.13)	30.00 (33.21)	27.78 (31.82)	20.00 (26.56)	16.67 (24.12)	15.36 (25.03)
33	0	12.50 (20.70)	6.67 (15.00)	28.57 (32.33)	25.00 (30.00)	-	-	14.55 (24.46)
Mean	4.00 (11.54)	9.78 (18.24)	18.70 (25.62)	27.05 (31.37)	25.17 (30.13)	27.50 (31.63)	28.67 (32.39)	

Values in parentheses are angular transformations.

Contd. on page 67

Table-11. Contd.

Analysis of Variance Table

Source	Sum of squares	d.f.	M.S.	F
Total	32984.53	104		
Treatment	15668.42	34		
Temperature	3794.19	4	948.55	3.83**
Humidity	6719.58	6	1119.93	4.53**
Temperature x humidity	5154.65	24	214.78	0.87NS
Error	17316.11	70	247.373	

** Significant at 1% level

NS: Not significant

C.D. (0.05) for temperature = 9.513
C.D. (0.05) for humidity = 11.256

at different temperatures and humidities are given in Table 12.

Table-12. Incubation period (days) of eggs of *N.lugens* at different temperatures and humidities.

Temp. °C	Relative humidity per cent						
	50	60	70	80	90	100	Mean
Varying	8	9	7	6	6	-	7.20
27	9	9	9	9	9	9	9.00
29	6	6	7	6	6	7	6.33
31	8	7	7	8	8	8	7.67
33	8	8	8	7	8	8	7.83
35	-	8	8	8	8	8	8.00
Mean	7.80	7.83	7.67	7.33	7.50	8.00	

Statistical analysis has shown that the variations in incubation period due to changes in temperature and humidity are not significant. The mean incubation periods over the different humidities vary from 7.33 days to 8.00 days, while the mean periods over the different temperatures vary from 6.33 to 9.00 days.

The percentage hatching of eggs in the different temperature and humidity combinations are given in Table 13 and represented in Fig.8(a) and (b). The data were statistically analysed by transforming to angles and

Fig. 8. Hatching of eggs of N. lugens when kept at different temperatures and relative humidities

(a) Per cent hatching of eggs at each constant humidity when the temperature is altered

(b) Per cent hatching of eggs at each temperature grade when the humidity is varied

FIG 8 HATCHING OF EGGS AT DIFFERENT TEMPERATURES AND HUMIDITY

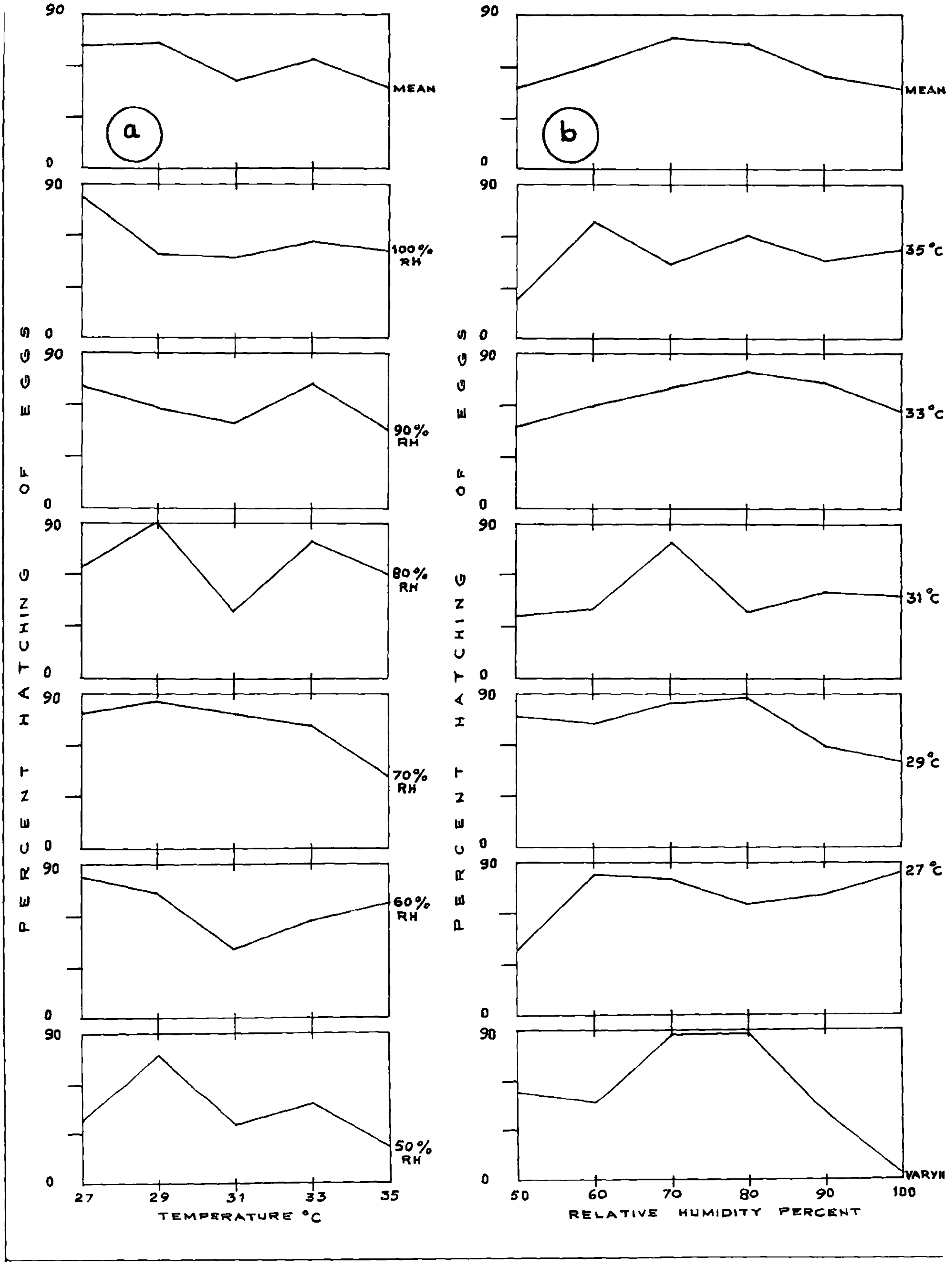


Table-13. Percentage hatching of eggs of N. lugens at different temperatures and humidities.

Temp. °C	Relative humidity per cent						
	50	60	70	80	90	100	Mean
Varying	53.57	47.25	87.56	88.83	39.38	0	58.61
27	37.70	82.26	79.41	65.25	70.69	84.09	71.19
29	76.03	73.38	85.39	89.47	58.33	50.47	73.26
31	35.71	39.80	78.98	38.18	49.33	48.46	51.09
33	47.25	58.39	70.94	80.23	72.35	56.31	64.33
35	22.99	67.24	43.87	60.71	45.42	52.68	48.75
Mean	47.69	62.64	77.47	72.10	54.35	48.35	

performing the test based on the proportions of the angular values. The angular values are ranked in the descending order in Table 14 for temperature variation and in Table 15 for humidity variation.

The hatching percentage is definitely high at 29°C, and at 27°C than the rest of the temperatures studied. The lowest hatching percentage is at 35°C.

As regards humidity, the percentage hatching is significantly more at humidities 70%, 80%, 60% and 90% RH in that descending order. Humidities 100% and 50% give significantly lower percentages of hatching.

Table-14. Analysis of the effect of temperature on hatching of eggs of *N. lugens*.

Ranking	Temperature °C	Mean% hatching of eggs	Angle	Difference	C.D. (0.05)
1	29	73.26	58.95	1.41	2.75
2	27	71.19	57.54	4.23	2.82
3	33	64.33	53.31	3.36	2.72
4	Varying	58.61	49.95	4.32	2.65
5	31	51.09	45.63	1.32	2.85
6	35	48.75	44.31		

Table-15. Analysis of the effect of humidity on hatching of eggs of *N. lugens*.

Ranking	Relative humidity%	Mean% hatching of eggs	Angle	Difference	C.D. (0.05)
1	70	77.47	61.68	3.50	2.78
2	80	72.10	58.18	5.88	2.87
3	60	62.64	52.30	4.78	2.59
4	90	54.35	47.52	3.44	2.85
5	100	48.35	44.08	0.40	3.02
6	50	47.69	43.68		

Effect of Population Density on the Biology of *N. lugens*

The data on the biological features of *N. lugens* as influenced by different densities of populations are given in Appendix IV and summarised in Table 16. The results on the different features are given below:-

Survival of nymphs

The mean percentage survivals of the nymphs are 79.6, 67.4, 61.2 and 47.15 at the levels of crowding of 50, 100, 200 and 400 nymphs per clump respectively. It is thus clearly seen that the survival percentage decreases as the level of crowding increases (Fig.9a). The analysis of the data presented in Table 17 shows that the effect of crowding on the survival of the nymph is significant.

Duration of nymphal period

The average nymphal durations at the different levels of crowding are as given below:-

Level of crowding	Nymphal duration in days
50 nymphs per clump	16.10
100 "	15.64
200 "	16.32
400 "	16.54

Statistical analysis of the date shows that the variations are not significant. Thus, the nymphal duration

Fig. 9. (a) Per cent survival of nymphs of *N. lugens* at different levels of crowding

(b) Effect of nymphal density on growth index

$$Y = 0.00563\,X + 5.01563$$

where,

Y = growth index

X = initial number of nymphs per clump of rice

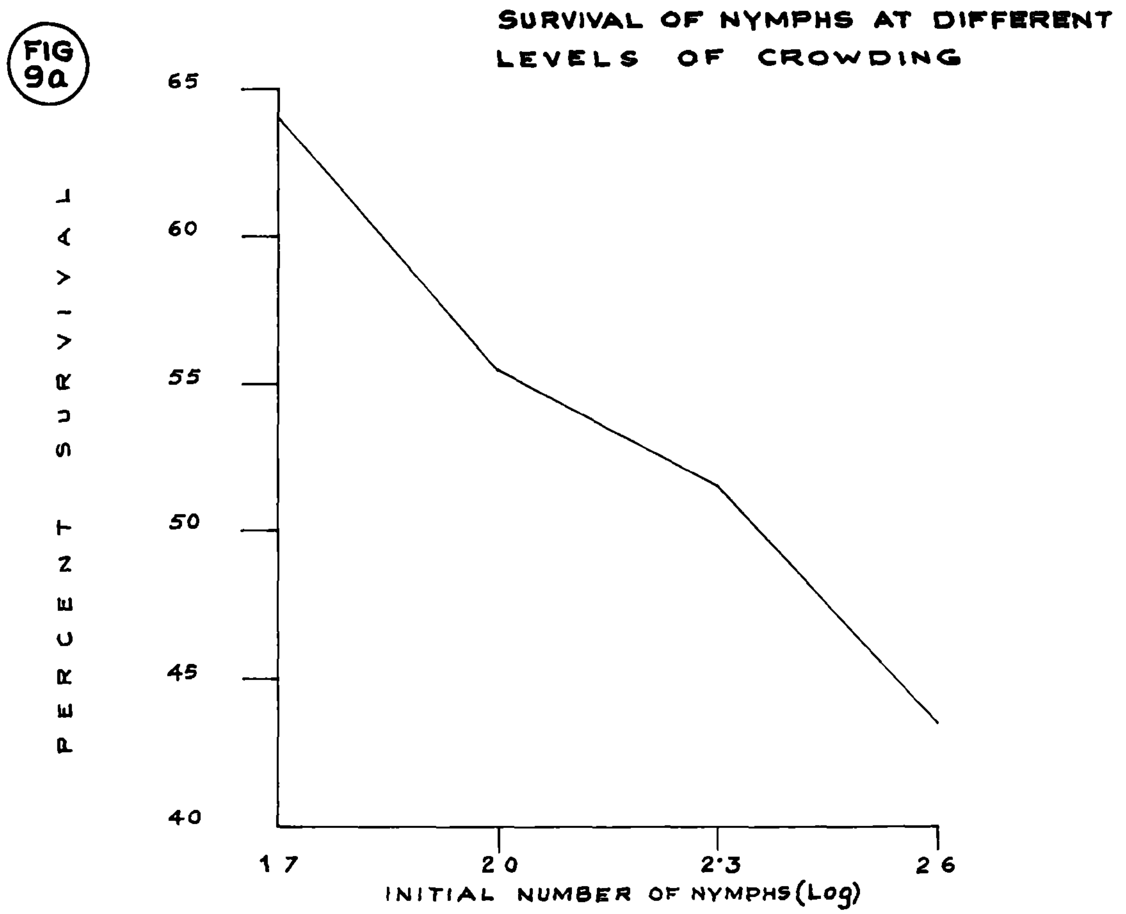


FIG 9a
SURVIVAL OF NYMPHS AT DIFFERENT LEVELS OF CROWDING
PERCENT SURVIVAL
65
60
55
50
45
40
1 7
2 0
2·3
2 6
INITIAL NUMBER OF NYMPHS (Log)

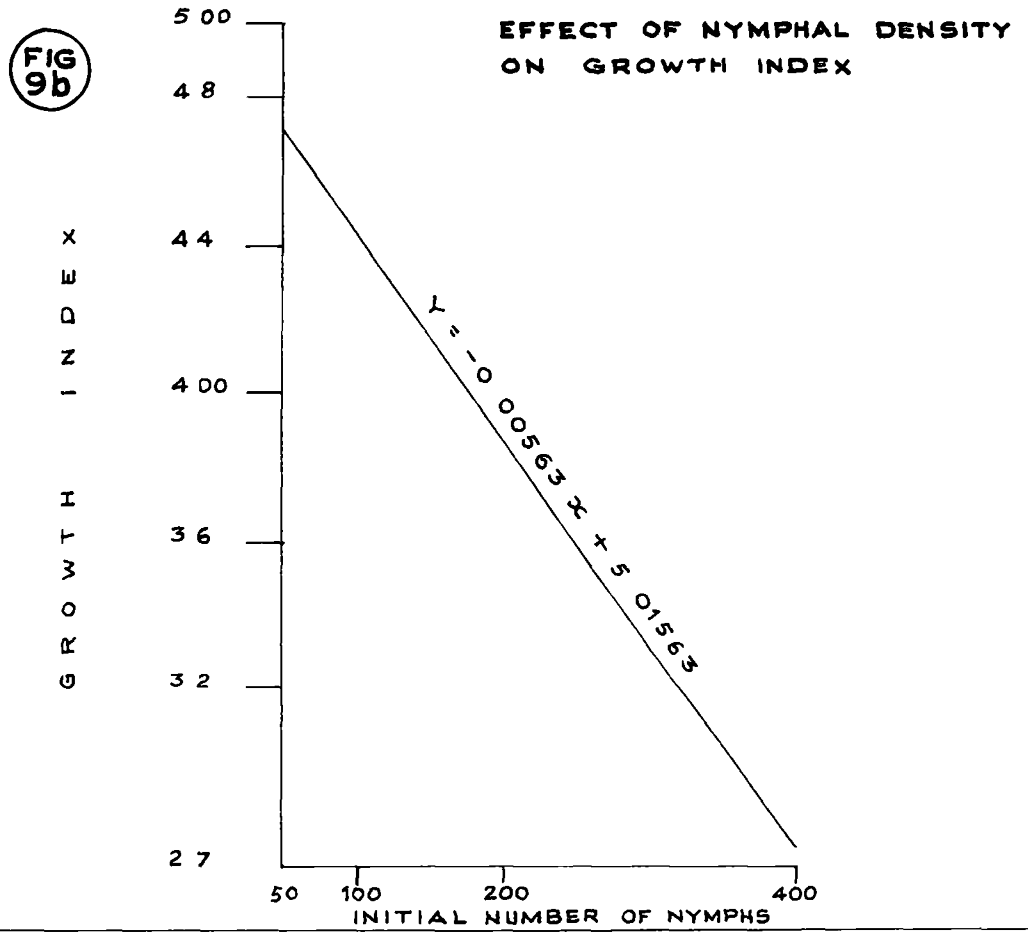


FIG 9b
EFFECT OF NYMPHAL DENSITY ON GROWTH INDEX
GROWTH INDEX
5 00
4 8
4 4
4 00
3 6
3 2
2 7
Y = -0 00563 X + 5 01563
50
100
200
400
INITIAL NUMBER OF NYMPHS

Table-16. Percent survival, duration and growth index of nymphs and sex ratio and weight of adults of N. lugens reared under different levels of crowding.*

Features	Initial number of nymphs per clump			
	50	100	200	400
Survival of nymphs (%)	79.60	67.40	61.20	47.15
Nymphal duration (days)	16.10	15.64	16.32	16.54
Growth index	4.94	4.31	3.75	2.85
Male : Female ratio	1: 1.62	1: 1.86	1: 1.39	1: 1.56
Percent brachypterous females	53.76	54.90	25.32	11.77
Mean weight of adult male (mg)	1.67	1.20	1.20	1.36
Mean weight of macropterous females (mg)	2.70	2.23	2.15	2.00
Mean weight of brachypterous female (mg)	2.90	2.95	2.90	2.55

* The values are the means of five replications.

Table-17. Analysis of variance of the nymphal survival at different levels of crowding.

Source	S.S.	d.f.	M.S.	F
Total	1688.707	19		
Treatment	1113.275	3	371.092	10.316**
Error	575.433	16	35.965	

** Significant at 1% level

Mean Table

Ranking	Level of crowding (Nymphs per clump)	Mean nymphal survival %
1	50	79.6 (64.11)
2	100	67.4 (55.34)
3	200	61.2 (51.50)
4	400	47.15(43.35)

Values in parentheses are angular transformation

C.D. (0.05) = 12.07

does not appear to be influenced by crowding of the nymphs.

Growth index

The growth index values computed were analysed statistically. The results of the analysis are given in Table 18.

The growth index of the nymphs is seen significantly affected by the variation in the crowding level. The growth index decreases as the crowding level increases from 50 to 400 nymphs per clump of rice.

The regression has been worked out using the formula $y - \bar{y} = \frac{c\ x\ y}{S^2_x} (x - \bar{x})$ where, x and y are the level of crowding and growth index values respectively. The equation for regression is $Y = -0.00563\ x + 5.01563$. This is a good fit to the data as indicated by the value of $r^2 = 0.961$. The regression line has been plotted and presented in Fig.9b.

Production of brachypterous females

The percentage of brachypterous females of N. lugens produced at the different levels of crowding are summarised in Table 16. The percentage of brachypterous females is high at the lower two levels of crowding of 50 and 100 nymphs per clump of rice. As crowding increases above 100 nymphs per clump, the percentage of brachypterous females decreases.

Table-18. Analysis of variance of the growth index of nymphs of *N. lugens* at different levels of crowding.

Source	S.S.	d.f.	M.S.	F
Total	15.412	19		
Treatment	11.816	3	3.939	17.507**
Error	3.595	16	0.225	

** Significant at 1% level

Mean Table

Ranking	Level of crowding	Mean growth index
1	50 nymphs per clump	4.936
2	100 "	4.312
3	200 "	3.746
4	400 "	2.846

C.D. (0.05) = 0.955

The data have been statistically analysed and the results are given in Table 19.

The effect of variation in crowding of nymphs on the production of brachypterous females is significant. Over-crowding of nymphs reduces the proportion of brachypterous females in the population.

Weight of adult insects

Weights of groups of freshly emerged adults of N. lugens were recorded as and when they emerged and the average weight per insect calculated. Results are given in Table 16. The weight of the insect is not seen to vary as a result of crowding.

Colour changes

A good number of the third instar nymphs under the higher two levels of crowding viz. 200 and 400 nymphs per clump are black in colour which is maintained till emergence of adults. The normal colour of third instar nymphs is light yellow which turns to yellowish brown and brown in later instars before adult emergence. The adult males emerging from the overcrowded lots (200 and 400 nymphs per clump) are ash coloured while those emerging from the other lots are brown which is the normal colour of the adult insect.

Table-19. Analysis of variance of the number of brachypterous females of *N. lugens* as affected by different levels of crowding.

Source	S.S.	d.f.	M.S.	F
Total	3729.469	19		
Treatment	2925.353	3	975.118	19.403**
Error	804.117	16	50.257	

** Significant at 1% level

Mean Table

Ranking	Level of crowding	% brachypterous females (average)
1	50 nymphs per clump	53.76 (46.974)
2	100 "	54.90 (47.746)
3	200 "	25.32 (27.790)
4	400 "	11.77 (19.878)

Values in parentheses are angular transformation

C.D. (0.05) = 14.267

Effect of Age of Host plant on the Biology of N. lugens

Effect of the age of the host rice plant on the biological features of N. lugens feeding and breeding on the different stages of growth was ascertained in laboratory experiments. The data are summarised in Table 20 and represented in Fig.10. The results are given below:-

Survival of nymphs

The mean percentages of survival of nymphs are 57, 69, 79 and 72 when reared on seedling, tillering, panicle initiation and flowering stages of growth respectively. It is thus seen that the survival of the nymphs is greater when reared on the two stages of the reproductive phase of the crop. Analysis of variance presented in Table 21 reveals that the treatment effect is significant. The percentage survival of nymphs on seedlings is significantly lower than that on the other stages. The survival percentages on the tillering and flowering stages do not significantly differ from each other. Similarly, the difference in survival between flowering and panicle initiation stages is also not significant.

Duration of nymphal period

The average duration of nymphal period varies from 14.059 days to 16.332 days. The nymphal period is completed

Fig. 10. Per cent survival, duration (days) and growth index of *N. lugens* nymphs when reared on different growth stages of rice

FIG 10

SURVIVAL, DURATION AND GROWTH INDEX OF NYMPHS ON DIFFERENT GROWTH STAGES OF RICE

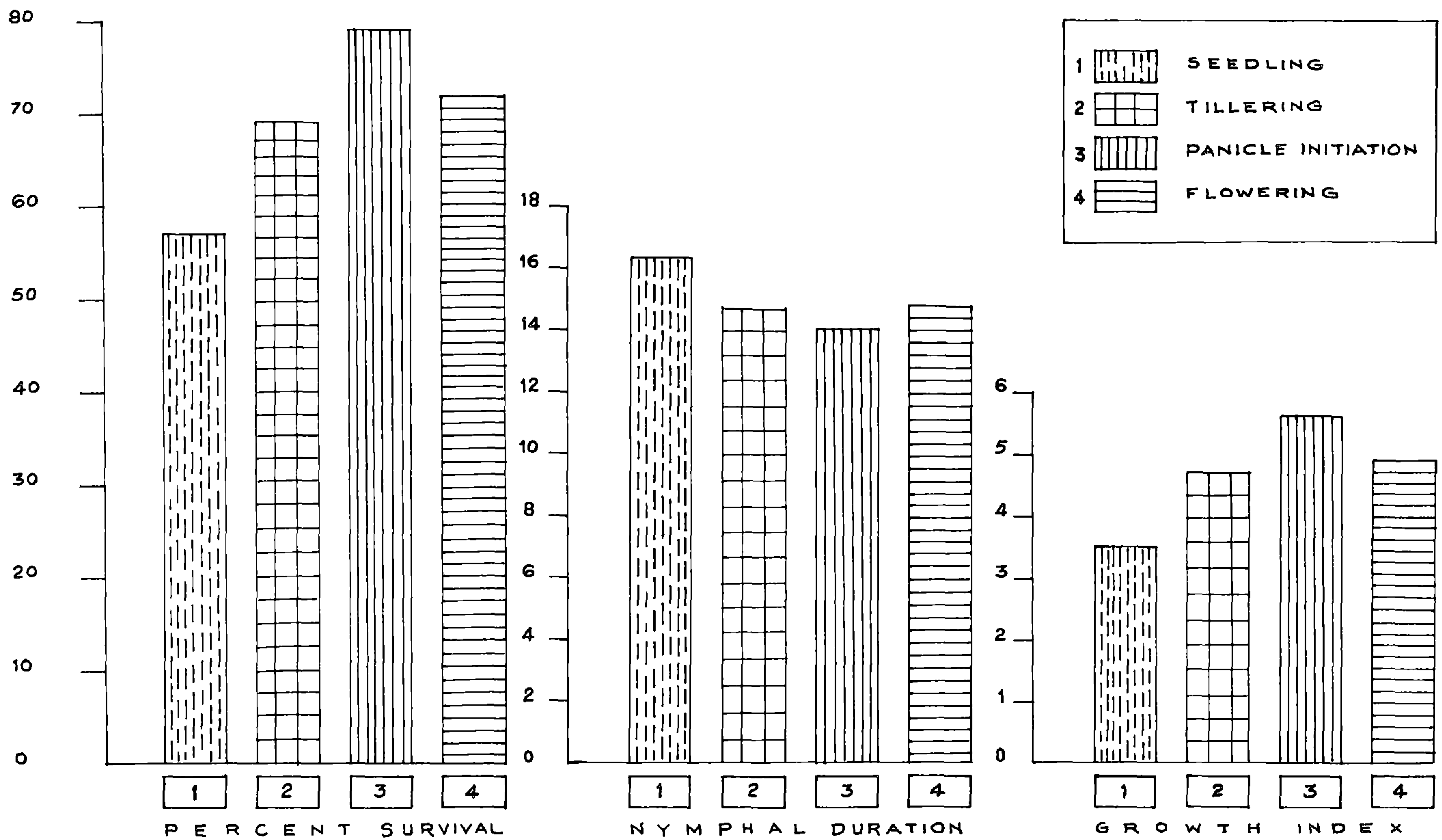


Table-20. Effect of age of the rice crop on the biological features of *N. lugens*

Stage of plant	Replication	Percent Survival of nymphs	Average nymphal duration (days)	Range of nymphal durations (days)	Growth index	Longevity of adult females *	No. of eggs laid by a female *
Seedling	I	52	16.231	13-17	3.204		
	II	60	16.000	15-17	3.750		
	III	60	16.667	16-18	3.600		
	IV	56	16.429	14-18	3.409		
	Mean	57	16.332		3.490	20.20	194.60
Tillering	I	68	14.176	13-17	4.797		
	II	72	14.278	13-17	5.043		
	III	72	15.500	15-17	4.645		
	IV	64	14.875	14.16	4.303		
	Mean	69	14.707		4.692	19.80	221.00
Panicle initiation	I	76	13.947	13-17	5.449		
	II	88	14.182	13-16	6.205		
	III	80	14.050	13-16	5.694		
	IV	72	14.056	13-16	5.122		
	Mean	79	14.059		5.619	20.60	236.00
Flowring	I	68	15.000	13-17	4.533		
	II	76	14.789	13-17	5.139		
	III	64	14.500	14-17	4.414		
	IV	80	14.800	13-17	5.405		
	Mean	72	14.772		4.874	20.20	210.80

* Mean of ten insects

Table-21. Analysis of variance of the survival of nymph of *N. lugens* on the different stages of rice plant.

Source	S.S.	d.f.	M.S.	F
Total	704.239	15		
Treatment	535.024	3	178.341	**12.647
Error	169.215	12	14.101	

** Significant at 1% level

Mean Table

Ranking	Stage of crop		% Survival
1	Panicle initiation	(T_3)	79 (62.72)
2	Flowering	(T_4)	72 (58.05)
3	Tillering	(T_2)	69 (56.17)
4	Seedling	(T_1)	57 (49.02)

Figures in parentheses are angular transformation

C.D. (0.05) = 5.79

Ranking : T_3, T_4, T_2, T_1

in the shortest duration of 14.059 days when reared on plants in the panicle initiation stage and in the longest duration of 16.332 days when reared on the seedlings. Analysis of variance of the data presented in Table 22 shows that the nymphal duration is significantly influenced by the age of the crop. There is significant difference between the treatments. Nymphal duration at the panicle initiation stage is significantly shorter than the rest of the treatments. Similarly, nymphal duration in the seedling stage is significantly longer than the rest of the treatments. The nymphal duration at the tillering and flowering stages are on par.

Growth index

The growth index of the nymphs is significantly affected by the age of the host plant (Table 23). The maximum growth index value of 5.619 is for the nymphs reared on plants at the panicle initiation stage and the lowest value (3.490) is for the nymphs reared on seedlings. These two values significantly differ from the growth index values of flowering and tillering stages which are on par with each other.

Longevity of females

The mean longevity of ten female macropterous insects

Table-22. Analysis of variance of the nymphal duration of *N. lugens* when reared on plants of different age.

Source	S.S.	d.f.	M.S.	F
Total	12.671	15		
Treatment	11.141	3	3.714	**29.016
Error	1.530	12	0.128	

** Significant at 1% level

Mean Table

Ranking	Stage of crop		Mean nymphal duration
1	Panicle initiation	(T_3)	14.059
2	Tillering	(T_2)	14.707
3	Flowering	(T_4)	14.772
4	Seedling	(T_1)	16.332

C.D. (0.05) = 0.551

<u>Ranking</u> : T_3, T_2, T_4, T_1

Table-23. Analysis of variance of growth index of *N. lugens* when reared on plants of different age.

Source	S.S.	d.f.	M.S.	F
Total	13.366	15		
Treatment	11.576	3	3.859	**25.899
Error	1.790	12	0.149	

** Significant at 1% level.

Mean Table

Ranking	Stage of crop		Growth index
1	Panicle initiation	(T_3)	5.619
2	Flowering	(T_4)	4.874
3	Tillering	(T_2)	4.692
4	Seedling	(T_1)	3.490

C.D.(0.05) = 0.597

Ranking: T_3, T_4, T_2, T_1.

emerging from each of the treatments are given in Table 20. The longevity of adults is lowest (19.8 days) in adults reared out on plants of the tillering stage and is highest (20.6) for adults reared on the panicle initiation stage. Analysis of variance of the data shows that the treatment effect is not significant. Thus there is no significant difference in the longevity of adults reared on the different stages of growth of the plant.

Fecundity

The mean number of eggs laid by ten macropterous females reared on the different stages of rice is presented in Table 20. Analysis of variance of the data has shown that there is no significant variation in the egg laying by the insects reared on the different stages indicating that the fecundity of the insect is not influenced by the nymphal feeding on different stages of growth of the crop.

Combined response of egg laying and nymph survival

Five pairs of macropterous adults were confined on potted plants of the different stages of growth, in cages for 48 hours for egg laying. The number of nymphs on each stage of the plant was counted, 17 days after exposure. The results are presented in Table 24. The mean number of progenies is highest (67) on the plants at the panicle initiation stage and is lowest (49) on seedlings. Statistical analysis of the data however, has shown that the effect of the treatment, is not significant.

Table-24. Population (number of nymphs) of *N. lugens* on plants at different growth stages resulting from eggs laid in 48 hours by five pairs of adults.

Replication	Stage of crop			
	Seedling	Tillering	Panicle initiation	Flowering
I	58	71	59	73
II	43	65	94	39
III	26	81	67	54
IV	69	42	48	81
Mean	49.00	64.75	67.00	61.75

Effect of Host Plant Nutrition on the Biology of *N. lugens*

Effect of varying the nitrogen and potash nutrition of rice plant on the biological features of *N. lugens* when used as its host was studied under laboratory conditions. The features studied are nymphal duration and survival, growth index, adult longevity, fecundity and oviposition and survival of nymphs.

Effect of Nitrogen Nutrition

The data on the biological features of N. lugens as influenced by graded doses of nitrogen applied to the host plants are given in Appendix V and summarised in Table 25. The results on the different features are given below:-

Nymphal duration

The average nymphal duration under the different levels of nitrogen varies from 14.02 days to 14.75 days. The shortest duration of 14.02 days is at the dose of 100 kg N/ha and the longest duration of 14.75 days is in the control, i.e. at zero level nitrogen. Analysis of the data (Table 26) shows that the nymphal duration is significantly influenced by the addition of nitrogen. All the treatments give singnificantly shorter nymphal duration compared to control. Among the different doses of nitrogen the variation in the nymphal duration is from 14.02 to 14.48 days.

Survival of nymphs

The survival percentage of nymphs varies from 66.25 to 75.00 at the different levels of nitrogen and the survival in the control is 71.25 per cent. Analysis of variance has shown that the effect of the treatment is not significant. Thus, the survival of the nymphs does not appear to be

Table-25. Biological features of N. lugens as influenced by host plant under different levels of nitrogen nutrition.

Biological feature	Doses of nitrogen (Kg N/ha)						
	N_0 0	N_1 20	N_2 40	N_3 60	N_4 80	N_5 100	N_6 120
** Mean nymphal duration (days)	14.75	14.40	14.48	14.32	14.06	14.02	14.28
** Percent survival of nymphs	71.25	73.75	68.75	75.00	66.25	71.25	73.25
** Growth index	4.83	5.12	4.76	5.23	4.71	5.08	5.17
* Mean adult longevity (days)	19.10	19.50	20.80	18.00	18.20	19.70	19.50
* Fecundity (No. of eggs per female)	182.8	187.6	207.3	180.7	189.7	206.2	203.4
@ Population build up (No. per plot)	910.3	735.5	1038.5	840.0	612.3	1111.5	991.0

** Mean of four replications

* Mean of ten insects

@ Mean of four replications, each consisting of four plants

Table-26. Analysis of variace of the nymphal duration of *N. lugens* reared on host plant under different levels of nitrogen

Source	S.S.	d.f.	M.S.	F
Total	3.370	27		
Treatment	1.489	6	0.248	*2.769
Error	1.882	21	0.090	

*Significant at 5% level

Mean Table

Ranking	Treatment	Mean nymphal duration
1	N_5	14.02
2	N_4	14.06
3	N_6	14.28
4	N_3	14.32
5	N_1	14.40
6	N_2	14.48
7	No (Control)	14.75

C.D.(0.05) = 0.42

influenced by the addition of nitrogen.

Growth index

The growth index values vary from 4.71 to 5.23 under the different levels of nitrogen. Analysis of variance shows that the variations in the values are not statistically significant.

Longevity of adults

Longevity of the adults that emerged from nymphs reared under different levels of nitrogen are given in Appendix VI and summarised in Table 25. There is very little variation in the longevity of adults as influenced by varying nitrogen nutrition. The results of the analysis revealthat the treatment effect is not significant.

Fecundity

Data on the number of eggs laid by ten females emerging from rearing under different nitrogen doses are given in Appenxix VII and summarised in Table 25. Analysis of the data have shown that the variation in fecundity is not statistically significant.

Oviposition and nymphal survival

The build up of population of N.lugens on plants under the different levels of nitrogen nutrition has been studied. Ten pairs of adults were confined on each plant for five days for egg laying. The number of nymphs were counted after 17 days and the data are given in Appendix V and summarised in Table 25. Analysis of variance of the data shows that the variations in the number of insects are not statistically significant. Thus, variations in nitrogen fertility levels do not influence the number of eggs laid and nymphal survival.

Effect of Potash Nutrition

Data on the biological features of N. lugens as influenced by the variations in the potash nutrition of host plants are given in Appenxix VIII and summarised in Table 27. The results are presented below:-

Nymphal duration

The mean duration of the nymphal period varies from 14.95 days to 15.40 days in the different levels of potash nutrition. These variations are not statistically significant. It is however, observed that at the three higher levels of potash, 75, 100 and 125 kg K_2O per hectare there is a prolongation in the nymphal duration to the extent of 1.79, 1.65 and 1.32 per cent over control respectively.

Survival of nymphs

The mean percentage survival of nymphs varies from

Table-27. Biological features of *N. lugens* as influenced by host plant under different levels of potash nutrition

Biological features studied	Doses of K_2O in Kg/ha					
	0 K_0	25 K_1	50 K_2	75 K_3	100 K_4	125 K_5
[a] Mean nymphal duration (days)	15.13	15.19	14.95	15.40	15.38	15.33
[a] Per cent survival	95.0	95.0	77.0	92.0	76.0	64.0
[a] Growth index	6.28	6.26	5.13	5.97	4.95	4.17
[b] Mean adult longevity (days)	17.90	17.70	18.90	17.50	19.00	17.70
[b] Mean fecundity (eggs/♀)	159.1	152.5	167.6	145.1	183.3	159.3
[a] Oviposition and nymphal survival (No. of insects per plant)	65.50	85.00	106.50	63.25	54.00	61.50

[a] Mean of four replications

[b] Mean of ten insects

64 to 95. The lowest survival of 64% is observed at the highest potash dose of 125 kg K_2O/hectare and the highest survival of 95% is observed at the lowest dose of zero level of K_2O.

The results of the statistical analysis of the data (Table 28) show that the variation in the survival is significant. The survival is significantly reduced (to 64%) at the dosage of 125 kg K_2O/hectare as compared to control and the other doses of potash (76 to 95%), they being on par among themselves.

Growth index

The growth index values of the nymphs computed for the different treatments was analysed and the results are given in Table 29. There is significant variation in the growth index values between the treatments. The index is highest in the control (6.28) closely followed by the lowest level of K_2O (6.26). The growth index decreases as the K_2O level increases and the lowest growth index value of 4.17 is seen at the highest level of K_2O. Growth index values at the highest two levels of K_2O viz. 100 and 125 kg/ hectare are significantly different (lower) from those in the control and other potash doses.

Adult longevity

Data on the longevity of the macropterous females

Table-28. Analysis of vatance of the survival percentage of N. lugens nymphs when reared on rice grown at different potash fertility levels

Source	S.S.	d.f.	M.S.	F
Total	4399.160	23		
Treatment	2162.770	5	432.553	*3.482
Error	2236.390	18	124.244	

*Significant at 5% level

Mean Table

Ranking	Treatment	Mean survival %
1	K_0	95(77.08)
2	K_1	95(77.08)
3	K_3	92(73.57)
4	K_2	77(61.34)
5	K_4	76(60.67)
6	K_5	64(53.13)

Figures in parenthesis are angular transformations
C.D.(0.05) = 16.56

Table-29. Analysis of variance of the growth index of *N. lugens* nymphs reared on rice grown under different levels of potash

Source	S.S.	d.f.	M.S.	
Total	26.474	23		
Treatment	14.375	5	2.875	** 4.277
Error	12.099	18	0.672	

** Significant at 1% level

Mean Table

Ranking	Treatment	Growth index
1	K_0	6.28
2	K_1	6.26
3	K_3	5.97
4	K_2	5.13
5	K_4	4.95
6	K_5	4.17

C.D. (0.05) 1.22

emerging from each of the treatment is given in Appendix IX. The mean longevity ranges from 17.7 days to 19.0 days. Statistical analysis of the data reveals that the variation in longevity due to the treatments is not significant. Thus, it appears that adult longevity is not significantly affected by the nymphal feeding on plants at dfferent potash fertility levels.

Fecundity

Number of eggs laid by ten macropterous females reared out at the different potash doses is given in Appendix X. The number of eggs laid per female ranges from 145.1 to 167.6. Statistical analysis of the data shows that the variation in fecundity is not significant. Thus, nymphal feeding at different levels of potash nutrition does not seem to affect the fecundity significantly.

Oviposition and nymphal survival

This was studied by confining five pairs of adults on each plant for five days and counting the number of nymphs on the 18^{th} day. The results of the statistical analysis of the data are presented in Table 30. There is significant variation in the number of insects. The highest three levels of potash, viz. 75, 100 and 125 kg K_2O/hectare have recorded significantly lower number of nymphs.

Table-30. Analysis of variance of the population build up of *N. lugens* on plants grown under different levels of potash.

Source	S.S.	d.f.	M.S.	F
Total	27212.63	23		
Treatment	12454.87	5	2490.98	*3.04
Error	14757.76	18	819.88	

*Significant at 5% level

Mean Table

Rauking	Treatment	Mean No. of insects
1	K_2	106.50
2	K_1	85.00
3	K_0	65.50
4	K_3	63.25
5	K_5	61.50
6	K_4	54.50

C.D.(0.05) = 42.53

Infestation Responses of *N. lugens* to Rice Varieties

Studies have been undertaken to ascertain the relative susceptibility of different strains of paddy to infestation by the native biotype of *N. lugens* with reference to different features of the insect on the one hand and of the rice strains on the other. The features of the insect studied are orientation, egg-laying, survival and duration of nymphs, adult longevity, growth index and fecundity. The features of the rice varieties studied are height of plants, width of leaves, thickness of stem and thickness of leaf blades. The susceptibility studies have been made at two stages of growth of the plants viz. the seedling stage and tillering stage. Results of studies made on these two stages are presented below.

Seedling Stage

Varietal susceptibility to infestation by *N. lugens*

A total number of 56 varieties including two cultures were screened for their susceptibility/resistance reaction to *N. lugens* nymphs at their seedling and tillering phases. The variety Annapoorna was the susceptible check. The mean susceptibility (damage) scores of these varieties are presented in Table 31. The mean damage score ranges from 3.0 to 9.0 on a zero to nine scale. At the seedling stage Ptb 33 is seen to be the only variety resistant to damage by the planthopper with a score of 3.0. The three varieties Ptb 12, Ptb 21 and Culture 57-5-1 are moderately resistant with damage scores of 3.4 to 4.5. Eleven varieties namely Ptb 4, Ptb 18, Ptb 19, Ptb 31, Bharathi, Ratna, Mashuri, IR 5, IR 20, IR 26 and IR 30 are moderately susceptible, the damage scores varying from 5.2 to 7.0. The remaining fortyone varieties are highly susceptible with damage scores ranging from 7.1 to 9.0.

Effect of insect orientation and plant characters on damage scores

The results are presented in Table 32. The average number of nymphs of *N. lugens* settling on the plants of different varieties ranges from 4.0 to 13.6. The mean height of the seedlings studied varies from 7.7 to 21.9 cm. The width and thickness of the leaf in the different varieties vary from 0.29 to 0.53 cm and 0.013 to 0.033 cm respectively. The thickness of the stem ranges from 0.094 to 0.144 cm. The influence of the different plant characters viz. height, width of leaf, stem thickness and leaf thickness on the damage score and on the number of insects settling on the plant was studied by taking the multiple regression models.

Table-31. Damage caused by N. lugens to different varieties of rice at the seedling and tillering stages. (Screened on a 0 to 9 scale)

Variety of rice	Seedling Stage Mean damage score	Seedling Stage Damage grade	Tillering Stage Mean damage score	Tillering Stage Damage grade
(1)	(2)	(3)	(4)	(5)
Ptb 1	8.2	HS	9	HS
" 2	7.9	HS	9	HS
" 4	5.9	MS	9	HS
" 5	7.2	HS	9	HS
" 8	7.1	HS	9	HS
" 9	7.5	HS	9	HS
" 10	7.2	HS	9	HS
" 12	4.5	MR	9	HS
" 15	9.0	HS	9	HS
" 16	9.0	HS	9	HS
" 18	6.5	MS	9	HS
" 19	5.2	MS	9	HS
" 20	8.8	HS	8	HS
" 21	4.4	MR	9	HS
" 22	8.1	HS	9	HS
" 23	7.9	HS	9	HS
" 26	9.0	HS	9	HS
" 27	8.9	HS	9	HS
" 28	9.0	HS	9	HS
" 29	9.0	HS	9	HS
" 30	9.0	HS	9	HS
" 31	6.6	MS	9	HS
" 32	7.9	HS	9	HS
" 33	3.0	R	3	R
Annapoorna	9.0	HS	9	HS
Rohini	7.4	HS	9	HS
Aswathy	8.9	HS	9	HS
Thriveni	8.1	HS	9	HS

Contd. on page 100

Table-31 Cond.

(1)	(2)	(3)	(4)	(5)
Jyothi	7.5	HS	6	MS
Sabari	9.0	HS	8	HS
Bharathi	6.0	MS	7	MS
Bala	9.0	HS	9	HS
Cavery	8.8	HS	9	HS
Jagannath	8.7	HS	9	HS
Kanchi	8.8	HS	9	HS
Padma	8.0	HS	9	HS
Ratna	6.0	MS	9	HS
Supriya	7.7	HS	8	HS
Mashuri	5.9	MS	8	HS
H_4	8.6	HS	8	HS
TN-1	8.6	HS	9	HS
Mudgo	7.3	HS	9	HS
Jaya	8.2	HS	9	HS
IR 5	6.6	MS	7	MS
IR 8	7.5	HS	9	HS
IR 20	6.0	MS	8	HS
IR 22	8.5	HS	9	HS
IR 25	8.0	HS	9	HS
IR 26	6.9	MS	9	HS
IR 28	7.9	HS	9	HS
IR 30	6.4	MS	9	HS
IR 32	8.1	HS	9	HS
IR 34	7.5	HS	9	HS
IR 68	8.1	HS	9	HS
Culture 57-5-1	3.4	MR	5	MR
Culture 26-4-2	8.6	HS	9	HS

R = resistant; MR = moderately resistant;
MS = Moderately susceptible; HS = highly susceptible

It is found that these regressions are not significant. The estimated regression models and the corresponding coefficients of determination are given below.

$$Y_1 = 9.914 - 0\ x_1 + 0.841\ x_2 - 101.758\ x_3 - 119.210\ x_4$$
$(R^2 = 0.0761)$

$$Y_2 = 10.183 - 0.047\ x_1 + 0.296\ x_2 - 29.658\ x_3 - 238.725\ x_4$$
$(R^2 = 0.0389)$

Where Y_1 = damage score

Y_2 = number of insects that settled on the plant

x_1 = height of the plant

x_2 = width of leaf

x_3 = thickness of stem

x_4 = thickness of leaf

R^2 = coefficient of determination

The simple correlation coefficients between the biometric characters and the damage score and number of insects have been worked out. There is a significant positive correlation between the damage score and the number of insects settled on the plant. The other correlation coefficients are not significant. The correlation coefficients obtained are given below.

	Y_1,	Y_2,	x_1,	x_2,	x_3,	x_4
Y_1		*0.4611	-0.1067	-0.0041	-0.2057	-0.0987
Y_2			-0.1704	-0.1213	-0.1456	-0.1840

* Significant at 1% level

Tillering Stage

Varietal susceptibility to infestation by *N. lugens*

At the tillering phase also Ptb 33 is seen to be resistant to brown planthopper damage with a score of 3.0. Culture 57-5-1 is the only strain which is moderately resistant with a score of 5.0. The varieties Jyoti, Bharathi and IR 5 show moderate susceptibility with scores varying from 6.0 to 7.0. All the remaining 51 varieties are highly susceptible to infestation and damage by *N. lugens* (Table 31). (See Plate III for hopperburn damage)

Effect of adult orientation and plant characters on damage scores

These were studied on 40 selected varieties, the results of which are given in Table 33. The mean number of adults which settled per plant ranges from 3.0 (on the variety Căvery) to 12.3 (on culture 26-4-2). The mean number of eggs deposited on different varieties ranges from 42 per plant (on Ptb 31) to 520 per plant (on IR 34).

Plate III - Manifestation of hopperburn symptoms on Jaya plants

(i) A healthy plant and a wilted plant

(ii) Stages of the development of hopperburn

A - Healthy plant

B - Yellowing of leaves and wilting of lower leaves

C - Leaves wilted, but the stem is partly green

D - Plant completely wilted.

PLATE - III (i)

PLATE - III (ii)

Table-32. Relation between damage score and nymphal settlement of N. lugens and some plant characters in different varieties of rice at seedling stage

Rice varieties	Damge score	Mean No. of nymphs per seedling	Mean height of seedling (cm)	Width of leaf (cm)	Thickness of stem (cm)	Thickness of leaf blade (cm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ptb 2	7.9	6.4	11.293	0.3 16	0.108	0.014
" 4	5.9	6.6	12.680	0.3 08	0.121	0.017
" 5	7.2	6.0	13.333	0.3 00	0.114	0.017
" 8	7.1	7.0	14.573	0.3 68	0.100	0.020
" 9	7.5	5.6	13.213	0.3 10	0.109	0.018
" 10	7.2	8.2	13.427	0.3 04	0.107	0.016
" 12	4.5	4.2	18.340	0.4 00	0.140	0.030
" 15	9.0	6.2	12.013	0.2 90	0.103	0.017
" 16	9.0	6.0	13.013	0.3 30	0.096	0.020
" 18	6.5	9.2	11.627	0.3 00	0.113	0.018
" 19	5.2	9.0	12.800	0.3 46	0.111	0.019
" 21	4.4	4.0	10.107	0.3 00	0.106	0.015
" 22	8.1	7.2	15.440	0.3 54	0.101	0.020
" 23	7.9	10.2	17.360	0.3 50	0.114	0.017

Contd.onpage 104

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ptb 26	9.0	4.4	11.440	0.3 14	0.111	0.017
" 27	8.9	6.0	13.773	0.3 76	0.119	0.021
" 28	9.0	12.0	8.200	0.3 06	0.102	0.015
" 29	9.0	5.8	11.640	0.3 69	0.100	0.017
" 30	9.0	10.4	8.640	0.3 95	0.094	0.018
" 31	6.6	6.4	20.413	0.4 76	0.138	0.028
" 32	7.9	11.2	14.907	0.3 10	0.111	0.016
" 33	3.0	5.2	12.200	0.3 14	0.120	0.019
Annapoorna	9.0	11.8	10.213	0.3 26	0.115	0.018
Rohini	7.4	10.4	13.187	0.3 34	0.115	0.017
Aswathy	8.9	6.8	12.813	0.4 16	0.130	0.023
Thriveni	6.4	6.8	8.173	0.3 46	0.113	0.015
Jyoti	7.5	6.8	12.720	0.3 92	0.125	0.022
Sabari	9.0	6.4	10.187	0.3 04	0.112	0.014
Bharathi	6.0	4.4	17.840	0.5 34	0.144	0.028
Cavery	8.8	11.2	11.330	0.3 24	0.104	0.018
Supriya	7.7	11.2	8.227	0.3 06	0.102	0.017
Mashuri	5.9	5.2	15.347	0.3 66	0.113	0.018

Contd. on page 105

(1)	(2)	(3)	(4)	(5)	(6)	(7)
H_4	8.6	8.6	21.973	0.4 70	0.138	0.033
TN-1	8.6	11.2	9.520	0.4 0 6	0.121	0.017
Jaya	8.2	11.2	11.560	0.4 04	0.134	0.019
IR 5	6.6	5.6	11.200	0.4 18	0.128	0.020
IR8	7.5	5.0	12.227	0.4 12	0.135	0.021
IR 20	6.0	6.8	11.240	0.3 96	0.108	0.021
IR 22	8.5	6.4	9.760	0.3 36	0.116	0.017
IR 26	6.9	5.4	7.987	0.3 28	0.114	0.015
IR 30	8.1	7.0	8.213	0.3 70	0.110	0.017
IR 32	8.1	8.8	9.493	0.3 04	0.120	0.017
IR 34	7.5	5.8	11.840	0.4 04	0.115	0.021
IR 68	8.1	9.0	8.733	0.4 25	0.113	0.023
Cult.57-5-1	3.4	4.0	7.707	0.3 22	0.107	0.013
Cult.26-4-2	8.6	13.6	10.653	0.3 48	0.122	0.017

Table-33. Relations between damage score, egg laying and adult settlement of N. lugens and some plant characters of different rice varieties at the tillering stage.

Rice variety	Mean damage score	Mean No. of adults settled per plant	Mean No. of eggs/ plant	Thickness of stem (cm)	Thickness of sheath (cm)	Thickness of culm (cm)
(1)	(2)	(3)	(3)	(5)	(6)	(7)
Ptb 1	9	10.0	127	0.914	0.191	0.432
" 2	9	7.0	107	0.876	0.203	0.396
" 4	9	9.0	172	0.914	0.191	0.417
" 10	9	9.6	79	0.610	0.132	0.241
" 12	9	7.3	109	0.795	0.165	0.384
" 15	9	4.0	86	0.991	0.203	0.391
" 21	9	8.6	167	0.902	0.191	0.381
" 22	9	8.3	218	0.940	0.191	0.254
" 23	9	7.6	69	0.762	0.152	0.328
" 26	9	5.7	132	0.945	0.191	0.417
" 27	9	8.7	107	0.914	0.178	0.394
" 28	9	8.6	131	0.762	0.152	0.284
" 29	9	8.7	112	0.483	0.102	0.287
" 31	9	4.7	42	0.851	0.160	0.442
" 32	9	8.7	137	0.635	0.152	0.216
" 33	3	3.7	52	0.978	0.203	0.373
Annapoorna	9	5.3	164	0.940	0.122	0.356
Rohini	9	8.3	164	0.559	0.140	0.330

Contd. on page 107

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jyothi	6	9.6	171	0.762	0.191	0.409
Sabari	8	5.3	148	0.813	0.140	0.508
Bharathi	7	7.3	92	0.841	0.147	0.452
Cavery	9	3.0	240	0.775	0.104	0.241
Padma	9	11.0	418	0.762	0.178	0.368
Mashuri	8	9.6	102	0.978	0.229	0.445
H_4	8	9.3	97	0.787	0.150	0.432
TN-1	9	11.3	432	0.564	0.152	0.330
Mudgô	9	6.7	60	0.584	0.127	0.381
Jaya	9	7.0	170	0.762	0.122	0.559
IR 5	7	5.0	114	0.762	0.152	0.610
IR 8	9	7.3	380	0.881	0.140	0.457
IR 20	8	7.3	176	0.635	0.114	0.419
IR 22	9	10.3	496	0.787	0.140	0.508
IR 26	9	4.0	82	0.792	0.084	0.394
IR 28	9	8.0	128	0.709	0.114	0.368
IR 30	9	7.0	168	0.660	0.114	0.356
IR 32	9	5.0	108	0.792	0.122	0.533
IR 34	9	12.0	520	0.864	0.140	0.483
IR 68	9	8.0	112	0.503	0.140	0.351
Cult.57-5-1	5	6.0	108	0.737	0.173	0.376
Cult.26-4-2	9	12.3	423	0.762	0.191	0236

The influence of stem thickness (0.483 to 0.991), sheath thickness (0.084 to 0.229) and culm thickness (0.216 to 0.610) on the damage score, number of adults settling and number of eggs laid was studied by taking the multiple regression models. It is found that the relationship between the number of insects on the one hand and stem thickness, sheath thickness and culm thickness on the other alone is significant. The influence of the above factors on the damage score and the number of eggs laid are not significant. The estimated regression models and the corresponding coefficients of determination are given below.

$Y_1 = 10.829 + 2.250\ x_1 - 32.150 x_2 - 7.133\ x_3$
$(R^2 = 0.113712)$

$Y_2 = 9.331 - 23.259\ x_1 + 94.090\ x_2 - 1.572\ x_3$
$(R^2 = 0.247245)^*$

$Y_3 = 139.661 - 83.586\ x_1 - 85.531\ x_2 + 93.362\ x_3$
$(R^2 = 0.001828)$

*Significant at the 0.05 level of significance.

Where, Y_1 = damage score

Y_2 = number of insects that settled per plant

Y_3 = number of eggs laid per plant

x_1 = thickness of stem

x_2 = thickness of leaf sheath

x_3 = thickness of culm

R^2 = Coefficient of determination

The simple correlation coefficients between the biometric characters of the plant and the damage score, number of insects settling and the number of eggs laid have been worked out. The correlation coefficient between the number of insects settling and the number of eggs laid alone is found to be significant. The correlation coefficients obtained are as given below

	Y_1	Y_2	Y_3	x_1	x_2	x_3
Y_1		0.262	0.245	-0.166	-0.283	-0.169
Y_2			0.581*	0.222	0.229	-0.189
Y_3				-0.033	0.300	0.015

*significant at 5 per cent level

Anatomical studies of leaf sheaths have shown that in Ptb 33 plants, there is more of sclerenchyma in the peripheral region, the parenchymatous cells being more silicified and devoid of chloroplasts. On the other hand in Annapoorna the scherenchymatous cells are few in the peripheral region; the parenchyma cells are not silicified, but succulent with chloroplasts present in abundance (Plate IV).

Host - biology relations of *N. lugens*

These studies were made with eight selected varieties of rice possessing graded degrees of resistance to infestation

Plate IV - Cross section of the stem of rice plant showing the anatomical differences in the leafsheaths of Ptb 33 and Annapoorna

A - Variety Ptb 33

B - Variety Annapoorna

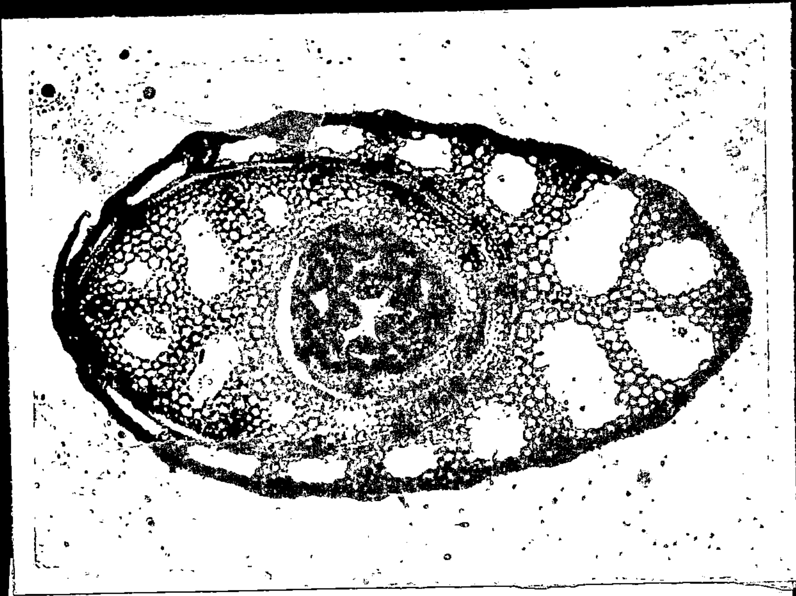


PLATE - IV A

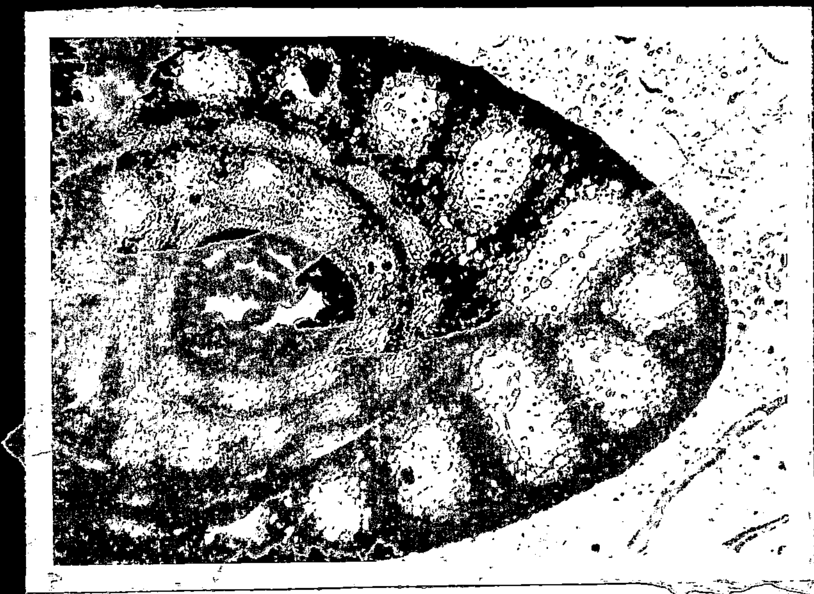


PLATE - IV B

and damage by *N. lugens*. The plants used were of the tillering stage. The varieties of rice and the degree of resistance of each are as under:

Ptb 33	:	Resistant
Culture 57-5-1	:	Moderately resistant
IR 5, Bharathi, Jyothi	:	Moderately susceptible
Jaya, TN-1, Annapoorna	:	Highly susceptible

Individual plants were exposed to adult hoppers and the number settling on each plant 48 hours after the release of the insects were counted. There were five replications. Results are presented in Table 34.

Orientation of adults on varieties

The mean number of adults settling on the individual plants varies from 7.87 to 9.73. Analysis shows that these variations are not significant indicating that the adults of *N. lugens* do not exhibit any significant preference or non-preference to the varieties studied.

Duration of nymphal period

The mean nymphal duration varies from 14.8 days (on Annapoorna and TN-1) to 18.2 days (on Ptb 33). Analysis of the data (Table 35) reveals that the variations in the duration are highly significant. The eight varieties appear to fall under three well defined groups with reference to

Table-34. Settlement of adult hoppers of *N. lugens* on different rice varieties and their biological features, when reared on the different varieties

Rice Variety	Mean adult settlement per plant	Mean Nymphal survival %	Average nymphal duration (days)	Growth index	Average longevity of adults (days)	Mean No. of eggs per female
Ptb 33	8.13	23.0	18.2	1.30	5.2	6.0
Culture 57-5-1	9.73	73.0	16.0	4.57	21.4	192.4
IR 5	7.87	71.0	15.5	4.58	19.6	215.0
Bharathi	8.93	79.0	15.6	5.06	20.2	197.6
Jyothi	8.33	70.0	15.8	4.43	21.0	208.0
Jaya	9.60	84.0	15.1	5.59	24.0	237.0
TN-1	8.93	83.0	14.8	5.60	24.6	211.2
Annapoorna	8.33	84.0	14.8	5.66	23.4	178.8

Table-35. Analysis of variance of the duration of *N. lugens* nymphs when reared on selected rice varieties.

Source	S.S.	d.f.	M.S.	F
Total	37.7947	31		
Treatment	33.9072	7	4.8439	**29.91
Error	3.8875	24	0.1620	

** Significant at 1% level of significance

Mean Table

Ranking	Variety		Mean nymphal duration (days)
1	TN-1	(V7)	14.83
	Annapoorna	(V8)	14.83
2	Jaya	(V6)	15.03
3	IR 5	(V3)	15.50
4	Bharathi	(V4)	15.63
5	Jyothi	(V5)	15.80
6	Culture 57-5-1	(V2)	16.00
7	Ptb 33	(V1)	18.20

C.D.(0.05) = 0.59

their nymphal duration. The variations in the nymphal duration between these groups are significant also. Thus Jaya, Annapoorna and TN-1 belong to one group with the shortest nymphal duration (14.83 to 15.03 days) there being no significant difference between them. The next group which shows a medium nymphal duration comprises of the varieties IR 5, Bharathi, Jyothi and Culture 57-5-1 with a duration range of 15.5 to 16.0 days. There is no significant difference between these varieties in nymphal duration. The third group which shows the longest duration of 18.2 days is represented by Ptb 33 (Fig. 11b).

Survival of nymphs

Survival of the nymphs is the lowest on Ptb 33(23%) and highest on Jaya and Annapoorna (84%). Analysis of variance presented in Table 36 shows that the varieties Jaya, Annapoorna and TN-1 are on par and shows significantly higher survival than the rest of the varieties. The varieties culture 57-5-1, IR 5 and Jyothi show no significant difference among themselves, but are significantly lower in nymphal survival than the former group. The variety Ptb 33 records a significantly lower survival percentage than the rest of the varieties. (Fig. 11 a)

Table-36. Analysis of variance of per cent survival of *N. lugens* nymphs when reared on selected rice varieties.

Source	S.S.	d.f.	M.S.	F
Total	5339.15	31		
Treatment	4508.52	7	644.08	**18.61
Error	830.63	24	34.61	

** Significant at 1% level

Mean Table

Ranking	Variety		Mean % survival	
1	(Jaya (Annapoorna	(V6) (V8)	84 84	(66.42) (66.42)
2	TN-1	(V7)	83	(65.65)
3	Bharathi	(V4)	79	(62.72)
4	Culture 57-5-1	(V2)	73	(58.69)
5	IR 5	(V3)	71	(57.42)
6	Jyothi	(V5)	70	(56.79)
7	Ptb 33	(V1)	23	(28.66)

Figures in parentheses are angular transformations
C.D. (0.05) = 8.65

Growth index

The mean growth index is lowest on Ptb 33 (1.30) and is highest on Annapoorna (5.66). Analysis of variance presented in Table 37 reveals that growth index on Ptb 33 is significantly lower than the index values on the other varieties. Growth index values on Annapoorna, TN-1 and Jaya are higher (5.59 to 5.66) than the others. The varieties Bharathi, IR 5, Culture 57-5-1 and Jyothi occupy an intermediate position with growth index varying from 4.43 to 5.06 (Fig.11 c).

Longevity of adults

The mean longevity of adults emerging from nymphs reared out on the different varieties varies from 5.2 days (Ptb 33) to 24.6 days (TN-1). Results of the Statistical analysis (Table 38) shows that the variation is significant only in the case of Ptb 33. All the other varieties are on par (Fig. 11 d).

Fecundity

The mean number of eggs laid per female reared out on the selected varieties together with the analysis of variance is given in Table 39. It is seen that the adult reared out on the variety Jaya lays the highest number of 237 eggs followed by that on IR 5 (215.0) and TN-1 (211.2).

Table-37. Analysis of variance of growth index of <u>N. lugens</u> when reared on selected rice varieties.

Source	S.S.	d.f.	M.S.	F
Total	65.587	31		
Treatment	58.180	7	8.31	**26.93
Error	7.407	24	0.31	

** Significant at 1% level

Mean Table

Ranking	Variety		Growth index
1	Annapoorna	(V8)	5.66
2	TN-1	(V7)	5.60
3	Jaya	(V6)	5.59
4	Bharathi	(V4)	5.06
5	IR 5	(V3)	4.58
6	Culture 57-5-1	(V2)	4.57
7	Jyothi	(V5)	4.43
8	Ptb 33	(V1)	1.30

C.D. (0.05) = 0.82

Table-38. Aaalysis of variance of longevity of *N. lugens* macropterous females reared out from selected rice varieties.

Source	S.S.	d.f.	M.S.	F
Total	2106.975	39		
Treatment	1537.375	7	219.625	**12.34
Error	569.600	32	17.80	

** Significant at 1% level

Mean Table

Ranking	Variety		Mean longevity (days)
1	TN-1	(V7)	24.06
2	Jaya	(V6)	24.0
3	Annapoorna	(V8)	23.4
4	Culture 57-5-1	(V2)	21.4
5	Jyothi	(V5)	21.0
6	Bharathi	(V4)	20.2
7	IR 5	(V3)	19.6
8	Ptb 33	(V1)	5.2

C.D. (0.05) = 5.23

The lowest number of 6.0 eggs is laid by the adult reared on Ptb 33 is significantly lower than all other varieties. There is no significant difference between the other varieties in fecundity though the fecundity varies from 178.8 to 237 eggs per female (Fig. 11 e).

Effect of silica/protein contents of rice plants on damage caused by *N. lugens*

Results of the chemical analyses of twenty varieties of rice at the tillering stage are presented in Table 40. The crude silica contents of the varieties under study range from 8.0 to 10.3 per cent. The correlation between the susceptibility score and the silica contents has been determined statistically and the correlation coefficient r = - 0.1599 which is not significant. The trend is of a negative correlation. It thus shows that the susceptibility of the plants to brown planthopper infestation is not related to the silica contents in the plant.

The total protein contents in the varieties vary from 4.13 to 4.56 per cent. The correlation between the protein contents and the damage score is positive, the correlation coefficient r = 0.1097 which is not significant. It shows that the susceptibility is not related to the protein contents in the plant.

Fig. 11. Biological features of *N. lugens* reared on selected rice varieties

(a) Nymphal survival (%)

(b) Nymphal duration (days)

(c) Growth index

(d) Adult longevity (days)

(e) Fecundity (No. of eggs laid per female)

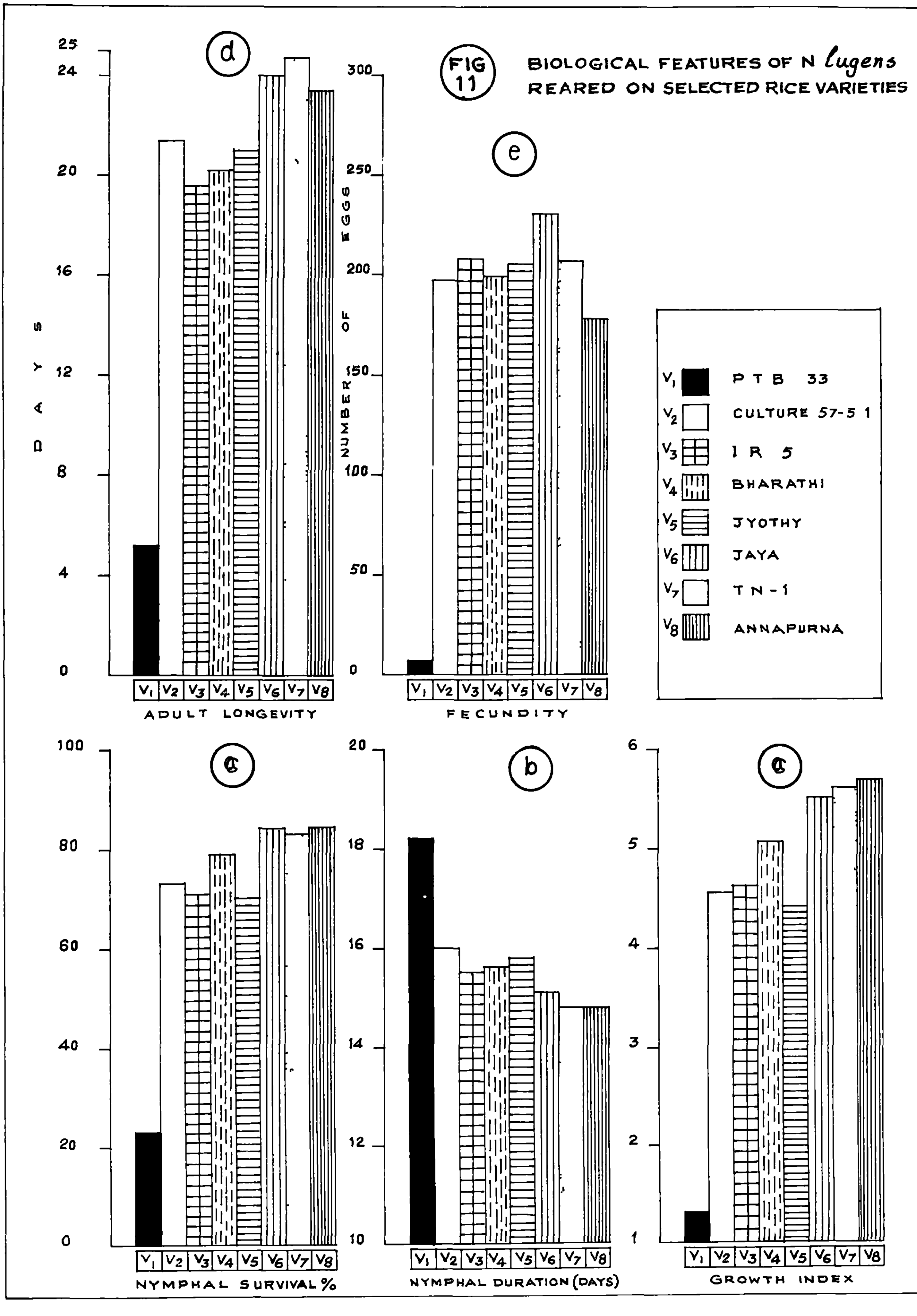


FIG 11
BIOLOGICAL FEATURES OF N lugens
REARED ON SELECTED RICE VARIETIES
d
DAYS
0
4
8
12
16
20
24
25
V1 V2 V3 V4 V5 V6 V7 V8
ADULT LONGEVITY
e
NUMBER OF EGGS
0
50
100
150
200
250
300
V1 V2 V3 V4 V5 V6 V7 V8
FECUNDITY
V1 PTB 33
V2 CULTURE 57-5 1
V3 IR 5
V4 BHARATHI
V5 JYOTHY
V6 JAYA
V7 TN-1
V8 ANNAPURNA
c
0
20
40
60
80
100
V1 V2 V3 V4 V5 V6 V7 V8
NYMPHAL SURVIVAL %
b
10
12
14
16
18
20
V1 V2 V3 V4 V5 V6 V7 V8
NYMPHAL DURATION (DAYS)
c
1
2
3
4
5
6
V1 V2 V3 V4 V5 V6 V7 V8
GROWTH INDEX

Table-39. Analysis of variance of the average number of eggs laid by macropterous female *N. lugens* reared out from selected rice varieties.

Source	S.S.	d.f.	M.S.	F
Total	257830.38	39		
Treatment	181116.38	7	25873.77	**10.79
Error	76714.00	32	2397.31	

** Significant at 1% level

Mean Table

Ranking	Variety		Mean No. of eggs laid per female
1	Jaya	(V6)	237.0
2	IR 5	(V3)	215.0
3	TN-1	(V7)	211.2
4	Jyothi	(V5)	208.0
5	Bharathi	(V4)	197.6
6	Culture 57-5-1	(V2)	192.4
7	Annapoorna	(V8)	178.8
8	Ptb 33	(V1)	6.0

C.D. (0.05) = 60.7

Table-40. Crude silica and protein contents of selected rice varieties.

Variety	Damage score (0-9 scale)	Crude Silica %	Total Protein %
Ptb 10	9	9.2	4.06
Ptb 33	3	9.3	4.13
Annapoorna	9	8.4	4.50
Sabari	8	8.8	4.50
Jyothi	6	9.3	4.38
Bharathi	7	9.1	4.56
Mudgo	9	9.1	4.13
Jaya	9	8.1	4.56
TN-1	9	10.0	4.31
Caveri	9	9.2	4.38
IR 5	7	10.3	4.25
IR 8	9	9.8	4.50
IR 20	8	8.4	4.56
IR 22	9	8.0	4.38
IR 26	9	8.2	4.50
IR 30	8	8.4	4.50
IR 32	9	9.0	4.38
IR 28	9	9.6	4.56
IR 68	9	8.2	4.50
Culture 57	5	8.6	4.56

Suitability of Some Weeds as Alternate Hosts for N. lugens

Ten species of weeds commonly seen in the rice fields were tested for their suitability as alternate host plants in terms of egg-laying, nymphal survival and adult survival.

Egg-laying

The number of eggs laid by macropterous females in a period of 24 hours is given in Table 41 and represented in Fig. 12. It is seen that the insect lays eggs on most of the weeds tested except on *Kallynga bulbosa* (nut grass) and *Cyanodon dactylon* (haryali grass). The mean number of eggs laid per female on different weed hosts ranges from 3.8 to 10.27. The lowest number of 3.8 eggs per female is on *Bracharia ramosa* and the highest number of 10.27 eggs per female on *Monochoria vaginalis*. This is closely followed by *Eliocaris atropurpurea* (9.93), *Fimbristylis miliaceae* (9.53) and *Panicum interruptum* (9.07). The mean number of eggs laid on these four species of plants is almost the same as that laid on rice plant (9.13) which is the principal host of the insect.

The analysis of variance of the data shows that there is significant differences between the host plants for

Table-41. Number of eggs laid by five macropterous females of *N. lugens* in 24 hours on different weeds

Sl. No.	Name of weed	No. of eggs laid			Mean	Mean No. of eggs per female
		Rep I	Rep II	Rep III		
1	*Monochoria vaginalis* P. (Pontederiaceae)	58	31	65	51.33	10.27
2	*Cyperus imbricatus* Retz (Cyperaceae)	18	29	37	28.00	5.60
3	*Eliocaris atropurpurea* K. (Eliocariaceae)	44	76	29	49.67	9.93
4	*Echinochloa crusgalli* L. (Gramineae)	26	37	14	25.67	5.13
5	*Bracharia ramosa* Staptf. (Gramineae)	27	11	19	19.00	3.80
6	*Fimbristylis miliaceae* V. (Cyperaceae)	61	47	35	47.67	9.53
7	*Panicum interruptum* W. (Gramineae)	49	36	51	45.33	9.07
8	*Paspalum longifolium* Roxb. (Gramineae)	38	47	41	42.00	8.40
9	*Kallynga bulbosa* Retz (Cyperaceae)	0	0	0	0	0
10	*Cyanodon dactylon* P. (Gramineae)	0	0	0	0	0
11	Rice (control)	47	51	39	45.67	9.13
	C.D.(0.05)				24.14	

Analysis of Variance Table

Source	S.D.	d.f.	M.S.	F
Total	6356.296	26		
Treatment	3396.296	8	424.500	*2.581
Error	2960.000	18	164.444	

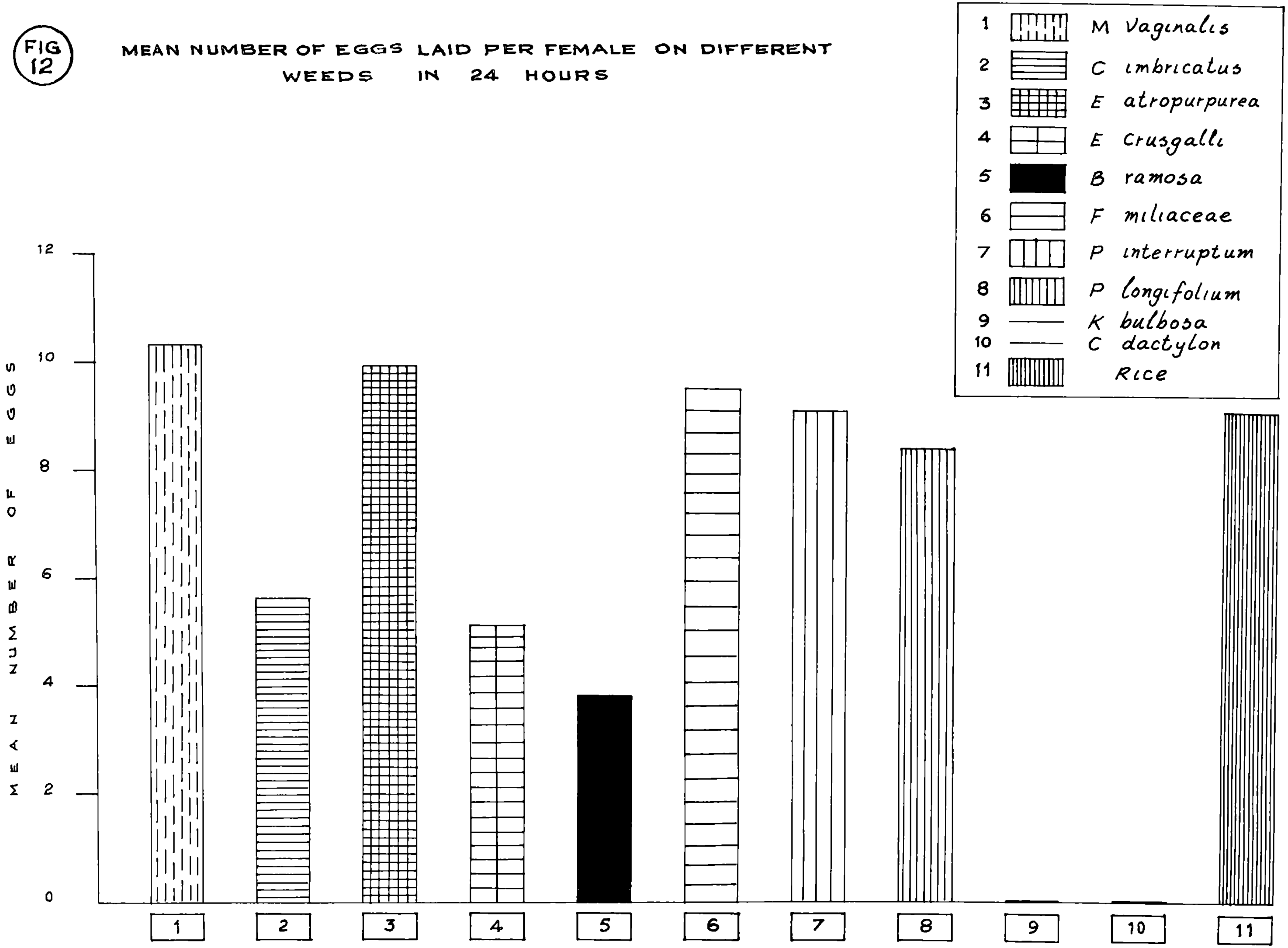
*Significant at 5% level

Ranking: 1, 3, 6, 11, 7, 8, 2, 4, 5

Fig. 12. Mean number of eggs
laid per female
N. lugens on different
weed plants and on
rice in 24 hours

FIG 12

MEAN NUMBER OF EGGS LAID PER FEMALE ON DIFFERENT WEEDS IN 24 HOURS



oviposition by the insect. Comparison of the means reveals that the number of eggs laid on Echinochloa crusgalli and Bracharia ramosa are significantly lower than those laid on other host plants.

The hatching of the egg has been noted on all the species of plants on which eggs have been laid. The incubation period of the egg on the different host plants do not vary, the period being 7 to 8 days.

Survival of Nymphs

The percentage survival of first instar nymphs on the above ten weeds and on rice plant for four days are given in Table 42 and represented in Fig. 13(a). It is seen that the nymphs do not survive for more than three days on the weeds except on Paspalum longifolium. The nymphs reared on this plant reaches adult stage in 15 to 16 days, the average survival percentage being 68 per cent as against 84 per cent on rice. The adults that emerge from this host are normal in colour and lay fertile eggs.

Survival of adult hoppers on weeds

The survival of adults of N. lugens when fed on different plants are summarised in Table 43 and representd in Fig. 13 (b). It is seen that the adult hoppers survive on most of the plants for one or two days. At 24 hrs. after

Table-42. Per cent survival of nymphs of N. lugens at different intervals on different weeds.

Name of plant	Survival percentage at				
	24 hrs.	48 hrs.	72 hrs.	96 hrs.	
M. Vaginalis	80.00	46.00	0	0	
C. imbricatus	84.00	54.00	12.00	0	
E. atropurpurea	70.00	42.00	0	0	
E. crusgalli	78.00	70.00	30.00	0	
B. ramosa	24.00	0	0	0	
F. miliaceae	92.00	60.00	58.00	0	
P. interruptum	20.00	0	0	0	
P. longifolium	92.00	80.00	80.00	80	68% reached adult stage
K. bulbosa	0	0	0	0	
C. dactylon	16.00	0	0	0	
Rice	90.00	86.00	86.00	84	84% reached adult stage

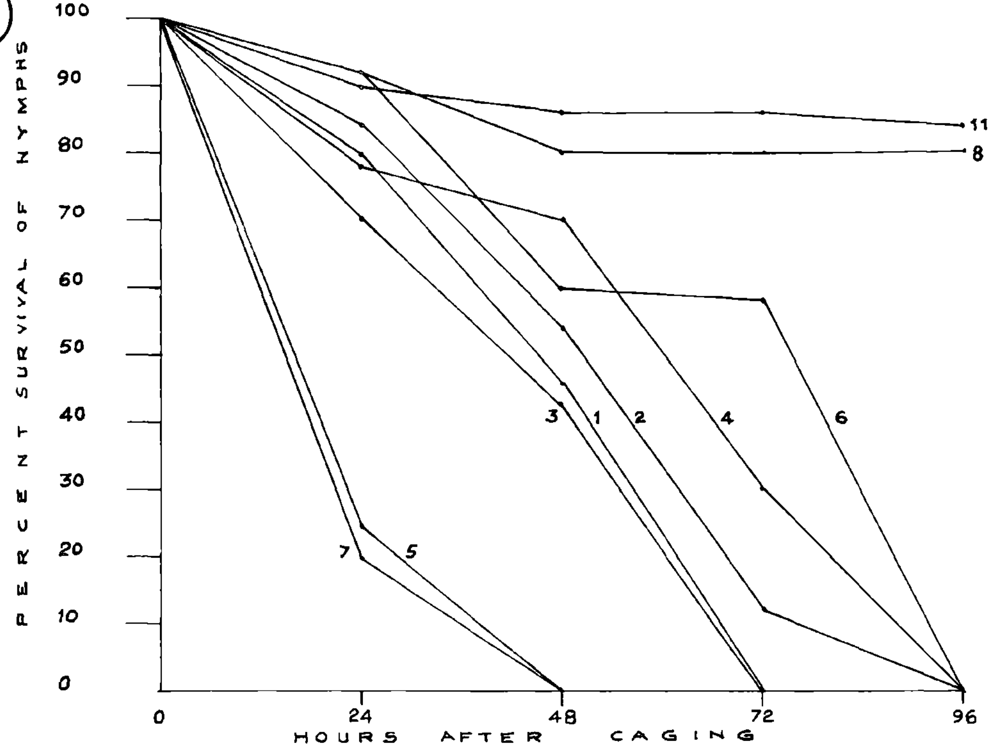
Fig. 13. Per cent survival of nymphs and adults of *N. lugens* on different weed plants and on rice

(a) Survival of nymphs

(b) Survival of adults

SURVIVAL OF NYMPHS AND ADULTS ON DIFFERENT WEEDS

FIG 13a



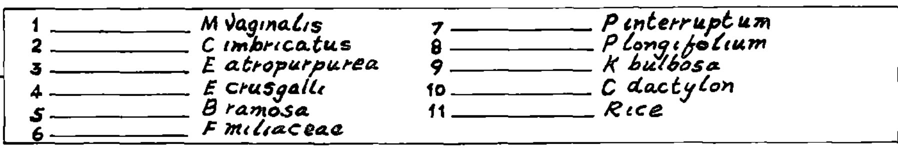


FIG 13b

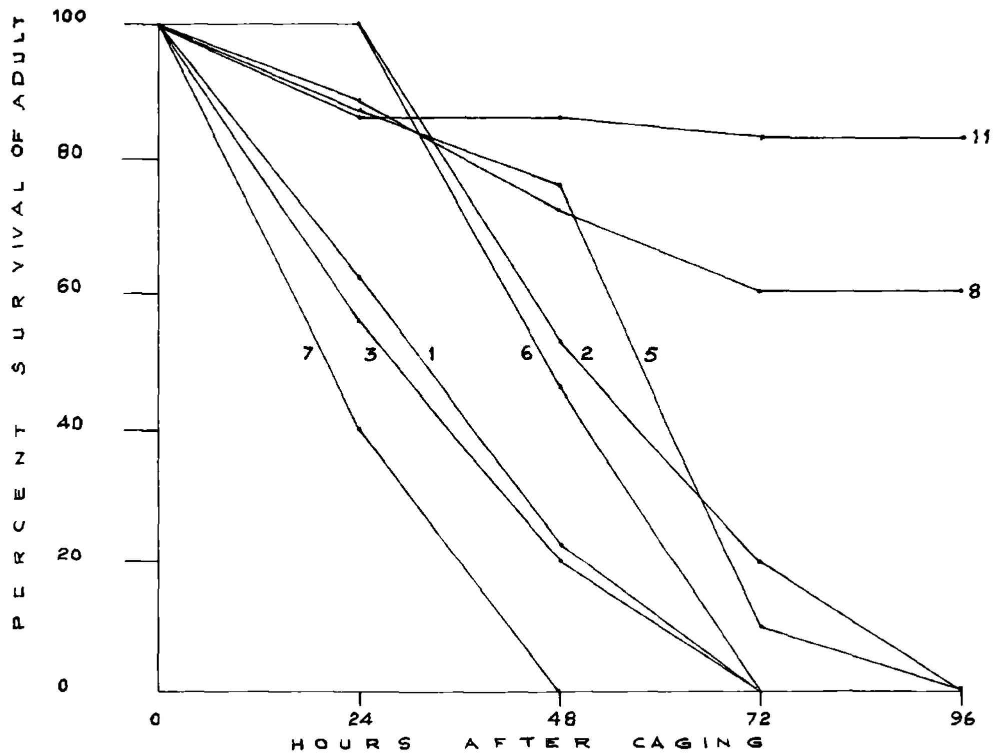


Table-43. Per cent survival of adult N. lugens on different weeds.

Name of plant	No. of insects intro-duced	Survival percentage at 24 hrs.	48 hrs.	72 hrs.	96 hrs.
M. vaginalis	50	56.00	20.00	0	0
C. imbricatus	30	100.00	53.33	20.00	0
E. atropurpurea	40	62.50	22.50	0	0
E. crusgalli	30	86.67	76.67	10.00	0
B. ramosa	50	60.00	0	0	0
P. miliaceae	30	100.00	46.47	0	0
P. interruptum	30	40.00	0	0	0
P. longifolium	50	88.00	72.00	60.00	60.00
K. bulbosa	50	72.00	0	0	0
C. dactylon	40	45.00	7.50	0	0
Rice	30	86.67	86.67	83.33	83.33

release the survival ranges from 40 to 100 per cent. At 48 hours the survival ranges from 0 to 76.67 per cent. But at 72 hrs. the insect survives only on three out of the ten species of weeds tested. On the fourth day (96 hrs.) the insect survives only on *Paspalum longifolium*.

DISCUSSION

DISCUSSION

Biology of N. lugens

The eggs of N. lugens are laid within the air spaces in the tissues of the rice plant. Air spaces are available more in the thicker succulent parts of the plants, and midribs of the leaf sheaths and the leaves are two regions where the air spaces are concentrated. Between these two regions, the maximum number of air spaces are located in the leaf sheaths. The present observations have shown that the females prefer the leaf sheaths to the leaves for egg-laying. The data presented show that the total number of eggs laid, the total number of egg masses deposited and the number of eggs per egg mass are much more on the leaf sheaths than on the leaves; these numbers are 78.3, 6.0 and 13.26 respectively on leaf sheaths and 21.9, 3.4 and 7.52 respectively on the leaf blades. Of the total number of eggs laid 77.59% are laid on the leaf sheaths (Table 1). These findings disagree with those of Mochida (1964 b) who observed that the number of eggs was more on the leaf blade than on leaf sheath. Nalinakumari (1973) on the other hand could not find eggs on leaf blade at all. The preference of N. lugens to the leaf sheaths over leaf blades for egg laying have been reported also by, Misra and

Israel (1968), Pathak (1968) and Bae and Pathak (1970).

Though there is no significant difference in the fecundity of the macropterous and brachypterous forms (228.3 and 209.6 eggs per female) there are differences in the egg laying behaviour of the two forms. Thus, when the oviposition period in the macropterous form is 18.2 days it is 13.7 days in the brachypterous form. The range of daily laying of eggs is zero to 60 in the former while it is zero to 99 in the latter. The average number of eggs laid per day by a macropterous female is 12.86 as against 15.69 eggs laid by a brachypterous female. The mean maximum number of 21.08 eggs laid per day is reached on the 9th day in the macropterous form and the mean maximum number of 43.9 eggs is reached on the 7th day in the brachypterous female. While the number of eggs laid per day by the macropterous female is very small in the beginning (it is 3.5 to 10.2 during the first four days) that laid by the brachypterous female is substantially high (14.8 eggs) even on the first day of egg laying (Table 44). The earlier records of fecundity of _N. lugens_ of 325 eggs by Suenaga (1963), of 244.2 eggs by Bae and Pathak (1970) and of 232.4 eggs by Nalinakumari and Mammen (1975) approximate with the findings of the present studies.

The shorter pre-oviposition and oviposition periods

Table-44. Comparison of some biological features of the macropterous and brachypterous females of *N. lugens*

Features	Macropterous females	Brachypterous females
Fecundity (No.of eggs/female)		
Range	151 - 308	131 - 319
Mean	228.3	209.6
No. of eggs laid per day/female		
Range	0 - 60	0 - 99
Mean	12.86	15.69
Pre.oviposition period		
Mean (days)	2.3	1.2
Oviposition period		
Mean (days)	18.2	13.7
Longevity of adult females		
Mean (days)	21.4	13.8

noted in the brachypterous females in comparison to the macropterous females also have been observed by Kisimoto (1965) and Pathak (1968). Nalinakumari and Mammen (1975) also found that the fecundity and pre-oviposition period of brachypterous females are much lower than those of macropterous females. Contrary to these findings Suenaga (1963) observed that the brachypterous females laid more eggs than macropterous females. The present studies indicate that though the pre-oviposition and oviposition periods of the brachypterous females are lower than those of macropterous forms, the fecundity is not substantially affected (209.6 as against 228.3). This is in agreement with the findings of Hirao (1972) that no significant difference exists in the fecundity of the two forms.

The hatchability of eggs of 84.83 per cent is high and helping a rapid build-up of the population. This and the average incubation period of 8 days are lower than those reported by Suenaga (1963) in Japan. But these are nearer to those reported by Bae and Pathak (1970) and Nalinakumari and Mammen (1975). The difference in the incubation period and hatchability may be due to the variations in the climatic features.

The average nymphal duration of 14.0 days of the present findings agrees with the duration reported by previous workers (Suenaga 1963, Mochida 1964b, Nalinakumari and Mammen 1975). The nymphal duration observed by Bae and Pathak (1970) is slightly longer (14.6 days) and that reported by Mochida is shorter (12.6 days). But all these observations are within the range of the nymphal duration (12 to 16 days) observed in the present studies.

The feeding habits of the nymphs and adults as well as the colour of the nymphs in the different instars observed are in conformity with the observations of previous workers. (Cresche 1933, Pathak 1968, Nalinakumari 1973). However, the migration of the nymphs to leaf tips and to other plants is not seem recorded by previous workers.

The total life-cycle of the insect from egg to adult ranges from 19 to 25 days, average being 22 days. This observation agrees with the findings of Nalinakumari and Mammen (1975).

Longevity of adult macropterous males and females averages 18 and 21.4 days respectively. The brachypterous females are short-lived, their average longevity being 13.8 days. Similar observations were reported by Bae and Pathak (1970) and Nalinakumari and Mammen (1975). But Kisimoto (1956) observed longer periods, the longevity of macropterous males, females and brachypterous females being 36.6, 30.7 and

26.1 days respectively. The extended longevity may be due to the difference in temperature and humidity conditions.

Effect of Temperature and Humidity on the Biology of *N. lugens*

Survival potential of the larva and its speed of development are two important factors which govern the population build-up of insects and both these are strictly controlled by the environmental factors, especially temperature and humidity. The results of the studies presented show that the survival and speed of development of nymphs in *N. lugens* are influenced by variations in temperature and humidity. In the case of survival of the nymphs the most favourable relative humidity is seen to be 70 per cent with a mean survival of 62.67 per cent. Increase or decrease from this humidity affects the survival of the nymphs adversely. As regards temperature, 29°C is the most favourable temperature for the nymphal survival with an average survival of 63.33 per cent. Temperatures below and above this decrease the survival of the nymphs. In general, temperatures around 29°C and relative humidities around 70 per cent are seen to favour the survival of the nymphs to the maximum (Table 7).

As regards speed of development of nymphs the most suitable temperature is 29°C giving a nymphal period of 14.63 days. The most suitable relative humidity for the development is 80 per cent with a nymphal duration of 15.75 days. Thus temperature around 29°C and relative humidities around 80 per cent offer favourable conditions for the development of nymphs. Apart from drawing circumstantial conclusions, critical studies on the relation between high humidities and the pest incidence have not been made in this country. Kulshreshtha _et al._ (1974) concluded that a relative humidity range of 70 to 85 per cent is optimal for the development of the insect which agrees with the present results. Experiments at Philippines have shown that constant humidities of 50 to 60 per cent are optimal for population growth (IRRI 1976). The present results do not conform to these findings.

The general conclusions made by previous workers regarding the effect of temperature on development of _N. lugens_ are that, atmospheric temperatures between 25 and 30°C are optimal (Pathak 1968, Bae and Pathak 1970, Kulshreshtha _et al._ 1974, Kalode 1976). Temperature over 30°C is thought to be unfavourable for the development of the insects (Ho and Liu 1969, Bae and Pathak 1970). These findings in general agree with the present results.

But the observation of Mochida (1977) that the nymphal survival is highest around 25°C and nymphal duration is shortest at 27°C do not agree with the present findings. The results reportēd from IRRI also show that temperature around 29°C is favourable for nymphal survival and development. The difference between the temperature preferundum reported by Mochida (1977) and that observed in the present studies may be due to the interaction of varying humidities and temperatures or due to the difference in the biotype or race of the insect. The interaction of temperature and humidity on nymphal survival and duration has been found to be statistically significant in the present studies.

Effect of humidity and temperature on the growth index of N. lugens has been studied for the first time. The growth index reflects the combined effects of speed of development and survival of the nymphs. This, infact gives a more precise picture of the survival potential of the insect as influenced by temperature and humidity than what is given by the two factors separately. The maximum growth index of 4.35 is at 29°C. The quadratic model for expressing the growth index (Y) in terms of temperature (x) is found to be $Y = -0.2039\,x^2 + 12.0855x - 174.8921$. From this model it is observed that growth index is maximum when the temperature is 29.64°C.

Similarly the quadratic model for expressing growth index (Y) on humidity (X) is found to be $Y = -0.0015\,x^2 + 0.2150\,x - 3.6900$. The most favourable relative humidity is 69.53 per cent.

Another feature which governs the population dynamics of insects is the proportion of males and females. While a 50 : 50 ratio is optimal, deviations on either side are unfavourable. In the case of *N. lugens* in which a female gets mated once or twice only and the male mates repeatedly, a preponderence of females will be more advantageous in population build-up. In the present studies the lowest percentage of 43.57 males is associated with a temperature of 29°C and the lowest percentage of 39.05 males associated with a relative humidity of 60 per cent. At 70 per cent relative humidity also it is significantly low, being 42.29 per cent. These observations are made for the first time.

The influence of climatic factors on the wing forms has not beem studied earlier objectively. Johno (1963) observed that high temperatures increased the percentage of brachypterous forms. Kalode (1976) stated that bachypterous forms develop under an optimal temperature regime. From the results of the present studies it is observed that at all the temperatures the percentage of brachypterous form increases with the increase in relative humidity and it reaches a high value (mean 27.05%) at 70 per cent relative humidity. The change thereafter is not appreciable. In the case of temperature, a constant temperature of 29°C gives the maximum percentage of brachypterous females. Thus a temperature of 29°C and a relative humidity of 70 to 100 per cent appear most favourable for the formation of brachypterous females (Table 11).

The incubation period of the eggs is not seen markedly influenced by the different temperatures and humidities studied. The mean incubation period over the different humidities varies from 7.33 to 8.00 days, while that over the different temperatures varies from 6.33 to 9.00 days. These differences are not statistically significant. However, the shortest mean incubation period is seen at 29°C and at 80 per cent relative humidity (Table 12). Though the nymphs develop at a low humidity of 40 per cent, the eggs do not seem to tolerate such a low humidity. On the other hand while the nymphs do not complete the development at 35°C, the eggs complete the development when kept at this temperature thus showing greater tolerance of eggs to higher temperature. The mean percentage of hatching of eggs is highest at 29°C than at 27°C, there being no significant difference between the two. Hatchability is significantly low at 35°C. As regards humidity the range of 70 to 80 percent is favourable for hatching of eggs. On the whole it appears that a temperature of 29°C and relative humidity 70 to 80 per cent are the most favourable for the incubation and hatching of eggs in N. lugens (Tables 13 and 14).

Suenaga (1963) has reported similar results on incubation and per cent hatching. He observed that the duration of the egg stage is shortest at 28°C and the percentage hatching highest around 25°C. Bae and Pathak (1970) also have reported the favourable effect of the temperature range of 25 to 29°C for the hatching of eggs. They further observed that the eggs have greater tolerance to high temperatures than nymphs as reported in the present investigations.

In Table 45 is compiled the information on the optimal temperatures and relative humidities indicated in the present studies as favouring the different biological processes which govern the population build-up of N. lugens. Higher levels of nymphal survival, growth index, percentage of females and hatching per cent and lower levels of nymphal duration, percentage of male and incubation period are the favourable features for rapid build-up of the population. The most favourable temperature for all these features is seen to be 29°C. The favourable relative humidity varies from 60 to 100 per cent.

Table-45. Optimal temperature and relative humidity for different biological processes of *N. lugens*.

Biological features		Optimal temperature (°C)	Optimal relative humidity (%)
Nymph survival	(H)	29	70
Nymphal duration	(L)	29	80-90
Growth Index	(H)	29	70-80
Male %	(L)	29	60-100
Brachypterous female %	(H)	29	90-100
Incubation period (days)	(L)	29	80
Hatching percent of eggs	(H)	29	70

H = Higher values favourable

L = Lower values favourable

Effect of Population Density on the Biology of *N. lugens*

Density of population is recognised as an important phenomenon in insect's ecology. It affects the ecology, physiology and behaviour of insects as exemplified in locusts. Fluctuation in population is to a great extent governed and patterned by the influence of crowding. In the present studies effects of crowding on such biological features of *N. lugens* as the survival and duration of nymphs, growth index, sex ratio and the weight of the adults have been studied for the first time. The mean nymphal survival varies from 47.15 to 79.60 per cent under the different graded crowding levels of 50 to 400 nymphs per clump. There appears to be an inverse relationship between the density of nymphs and their survival. The lower two levels of crowding namely 50 and 100 nymphs per clump give significantly higher survival rates. The nymphal duration is not seen substancially influenced by the degree of crowding. The growth index value which reflects the combined effect of survival and speed of development of the nymphs is significantly affected by the level of crowding and an inverse relationship is evident between growth index and level of crowding. The regression model for growth index (Y) on crowding (X) is represented as Y = - 0.0056 X + 5.0156.

The adult males and females emerging from the low density populations have comparatively more body weight than those emerging from high density populations. There is a significantly larger proportion of brachypterous females, about 54 per cent of the totals, in the low density population of 50 and 100 nymphs per clump. At the two high density levels of 200 and 400 nymphs per clump the population of brachypterous females is markedly low, the percentages being 25.32 and 11.77 respectively. The results presented clearly show that brachypterous females dominate in populations of low density and macropterous forms dominate in populations of high density.

Similar relations between the wing forms of N. lugens and population density have been reported by previous workers (Miyake et al. 1951, Kisimoto 1956, Johno 1963, Ho&Liu 1969, Kulshreshtha et al. 1974). The formation of the brachypterous forms is attributed to the quality and quantity of food by Kisimoto (1956). He observed a shortening of nymphal period at lower densities. However, in the present investigations, a significant change in nymphal duration is not registered.

Colour changes in nymphs and adults of N. lugens have also been seen associated with the changes in the population density. Thus a good proportion of nymphs in the third, fourth and fifth instars at the higher density levels of 200 and 400 nymphs per clump of rice, are black in colour while those at the lower levels of crowding are yellow or brown. Similarly, the adult males emerging from the high density populations are ash coloured as against the normal brown colour. Mammen (1971) and Nalinakumari (1973) also have noted the occurrence of differently coloured males. The changes in the colour observed may be due to a group - effect during the nymphal stage as suggested by Miyake et al.(1951) for the appearance of brachypterous forms.

Effect of Age of Host plant on the Biology of N. lugens

Though all stages of rice are susceptible to infestation by N. lugens only the late vegetative phase and the booting phase suffer greatly from the hopperburn damages. This is evidently due to the larger build-up of the population of the hopper on the late stages. According to the opinion of the previous workers the size of the population is due to the cumulative effect of the successive generations from the early infestations. (Bae and Pathak 1969, Ho and Liu 1969, IRRI 1969, 1971, Pathak and Dyck 1973, Soehardjan 1973, Kisimoto 1976). But the results of the present studies have shown for the first time that the age or stage of growth of the rice plant can influence the various biological activities of the insect. The survival of the nymphs, for example, is significantly influenced by the age of the crop. The highest survival is observed on plants of the panicle initiation stage followed by the flowering, tillering and seedling stages in that descending order. The reproductive phase appears to be better suited for the survival of the nymphs than the vegetative phases. A more or less similar trend is seen in the case of speed of nymphal development also. Thus the nymphal duration is shortest (14.059 days) on plants of the panicle initiation stage followed by tillering, flowering and seedling stages in that ascending order. In effect it is observed that the speed of development of the nymphs is significantly faster on the plants at the panicle initiation stage than on plants of the other stages. On the other extreme, the speed of development of the nymphs is significantly slower on the seedling stage of the plant than on the other stages (Table 20).

The response of growth index which reflects the combined response of survival and speed of development to age variations of the plant shows that it is significantly higher (5.619) at the panicle initiation stage, than at the other stages and significantly lower (3.490) at the seedling stage than at the other stages. The other two stages show intermediate effects. The rapid build-up of the hopper population at the boot-leaf stage is thus due to the suitability of the panicle initiation stage for the survival and development of the nymphs (Table 20).

The features like longevity of adult females and their fecundity are not significantly affected by the age of the crop. There is, however, a tendency for the females reared on rice plants of panicle initiation stage to lay more eggs (236 per female) and those reared on the seedlings to lay the least number of eggs (194.06 per female). This evidently indicates that the panicle initiation stage offers a better nutrition to the developing nymphs than the other stages (Table 20).

A comparison of the combined responses of egg laying, hatching and nymph survival to different growth stages as indicated by the resulting nymphal population of one generation has indicated (even though not significantly) that the panicle initiation stage facilitates the emergence of the largest population and the seedling stage the smallest population (Table 24). Even though the magnitude of the difference in the first generation is not significant, the cumulative effect in successive generations may bring about significant effects on the size of the population ultimately.

It has been reported from IRRI (IRRI 1974) that 70 to 90-day-old plants show a clear benefit in population build-up when continuously reared on them for three successive generations. The 70 to 90-day-old plants also are in the reproductive phase and is comparable to the panicle initiation stage in the present studies.

These studies have thus established that the age of the crop has governing influence on the life and activities of N. lugens. The panicle initiation stage appears to be highly favourable for the multiplication and build-up of the population of N. lugens and the seedling stage the most unfavourable; the other stages occupy intermediate positions.

Effect of Host plant Nutrition on the Biology of N. lugens

There have been many statements that higher populations of N. lugens are associated with application of higher doses of nitrogen in the field (Abraham 1957, Sogawa and Pathak 1970, Ngoan 1971, Das et al. 1972, Abraham and Nair 1975, Varca and Feuer 1976). These authors thought that the effect of nitrogen may be due to its indirect effect on the plant and the consequent changes in the micro environment. The results of the present studies have shown that the only one life process of the insect which is favourably affected at increased doses of nitrogen is the speed of development of the nymphs. The nymphal duration gets reduced by 4.7, 4.9 and 3.1 per cent over no nitrogen, at 80, 100 and 120 kg N/ha respectively and these are significant also. None of the other life processes including the growth index which contributes to the population build-up is influenced by the variations in the nitrogen nutrition of the host plants. So as suggested by the earlier workers (see above) the effect of the higher dose of nitrogen may be one of creating favourable micro environment suitable for the multiplication of the insect by providing thick and canopied growth of the plants.

Reports from IRRI (1972) and those of Kalode (1971) show that survival of the nymph is not affected by variations in nitrogen dosage. But Cheng (1975) has observed better survival of nymphs on nitrogen treated plants. All these workers have recorded higher fecundity for adults reared on plants under high nitrogen levels while the present findings do not support them. The nitrogen levels used by them are 150, 200 and 320 kg/hectare while in the present studies the maximum level is only 120 kg and this may explain the differences in the different findings. But under the usual practice of fertilization such high doses of nitrogen are not used at all.

The effect of potash nutrition of the plant has, however, some effect on the population-governing factors of the insect. Thus the survival of the nymph is reduced by 32.6 per cent over control (zero potash) at 125 kg K_2O which is significant. The lower doses also reduce the survival but not to any significant level. The growth index also shows a suppression at higher levels of K and the suppressions to the extent of 33.6 and 24.2 per cent over control at 120 and 100 kg K_2O/hectare respectively are significant also. But since the doses at which significant depressing effects on the population-building factors are seen are much higher than the recommended doses of K_2O, these findings may not have any immediate application. Vaithilingam (1975) and Subramanian and Balasubramanian (1976) have recorded that brown plant hopper incidence is low in plots treated with high doses of potash.

Infestation Responses of N. lugens to Rice varieties

Based on a zero to nine scoring with reference to susceptibility to damage by N. lugens the different varieties have been classified as resistant (R), moderately resistant (MR), moderately susceptible (MS) and highly susceptible (HS). The scoring for resistance has been done at the seedling stage (10-12 days old) and at the tillering stage (40-45 days old). The distribution of the different varieties within the four categories based on the scoring at seedling stage is 2, 5, 20 and 73 per cent respectively. Ptb 33 is the only variety with high resistance. Fortyone varieties constituting 73 per cent of the total are highly susceptible and others of intermediate ranges of resistance. At the tillering stage evaluation also Ptb 33 is resistant (Plate VI). The distribution of rice varieties under the different categories based on susceptibility scoring at the tillering phase is 2, 2, 6 and 90 per cent for R, MR, MS, and HS varieties. Thus at the tillering stage evaluation, more number of varieties are seen to be highly susceptible than at the seedling stage evaluation. Varieties like Ptb 12 and Ptb 21 which are moderately resistant at seedling stage show high susceptibility at the tillering stage. The one exception of a variety showing less susceptibility at the tillering stage than at the seedling stage is Jyothi which has a high susceptibility at the seedling stage and only a moderate susceptibility at the

Plate V - Symptoms of plant damage by *N. lugens* on resistant and susceptible varieties (Ptb 33 and Annapoorna)

PLATE - V

tillering stage. Varieties which maintain the different degrees of resistance to the insect at both the stages of growth are the resistant Ptb 33, the moderately resistant culture 57 and the moderately susceptible Bharathi and IR5. Even in these cases excepting Ptb 33 which maintains a low score of 3 at both the stages the others show a tendency to be more susceptible at the tillering phase. Thus the score of Culture 57 increases from 3.4 to 5 and those of Bharathi and IR5 from 6 to 7 and 6.6 to 6 respectively. In the case of highly susceptible varieties also an examination of the relative damage scores will show that in general the tillering phase records higher scores than the seedling phase. Examples of some values at the two stages are 7.1 and 9, 7.2 and 9, 7.4 and 9, 8.1 and 9 and 8.2 and 9 respectively. These results indicate on the one hand that the tillering stage of the plant is more susceptible to damage by the brown planthopper than the seedling stage and on the other that evaluation of resistance exclusively at the seedling stage may not give the correct picture about the relative resistance of the different varieties to infestation and damage by the brown planthopper (Table 31).

An analysis of the effect of different plant characters on insect orientation and plant damage by them was made by taking the multiple regression models. It is observed that such plant characters as height, stem chickness, leaf width and leaf thickness do not have any significant influence on the insect orientation and plant damage at both the stages of the plant. But at the tillering stage the correlation between the number of insects settling on the plants and the number of eggs laid is significant (r = 0.581). More the number of insects settling on the plants more is the number of eggs laid on them. There is also substantial positive correlation between the number of eggs laid and thickness of the leaf sheath (r = 0.300). This is also expected as the main site of egg laying is the leaf sheath and a thicker sheath will facilitate better egg laying on it. The susceptibility/ resistance reaction of different varieties has been studied by many workers and there is no general agreement of results due to the existence of biotypes (Varca and Feur 1976). At seedling tests Mashuri and Ptb 19 have been reported resistant by Parker et al. (1973) and Thomas (1976). But in the present studies these varieties are moderately susceptible. Mudgo and IR 26 reported to be resistant at Philippines are seen highly susceptible here. Similar observations on the susceptibility of these varieties have been reported by other workers also (IRRI 1976, Varca and Feuer 1976, Pathak and Kush 1977). Ptb 33 observed resistant in the present studies have been reported already as resistant to the three known biotypes of N. lugens. (Varca and Feuer 1976, Pathak and Kush 1977). The variation in the relative susceptibility of rice to N. lugens at different stages of growth as seen in the present findings has been recorded by Fernando et al. (1977) in Sri Lanka. They also have recorded similar observations in the carry over of resistance in Ptb 33 and loss of resistance in some other varieties at the different growth stages.

Earlier studies at IRRI (1969) also have indicated that plant characters are not correlated to resistance of varieties to N. lugens as is seen in the present investigations.

Even though higher silica contents in rice are positively correlated to resistance to stem borer and leaf roller pests (Pathak et al. 1971) no definite information is available on N. lugens. Crude silica contents of the plants are seen in the present studies not correlated with their resistance reactions. Anatomy of the leaf sheath of Ptb 33 shows the presence of sclerenchyma cells in the peripheral region and silicification and absence of chloroplasts in the parenchyma. Wan (1972) observed a significant correlation between total protein nitrogen of plants and hopper incidence in the field. But present studies do not indicate such a relationship in the susceptibility of varieties.

The susceptibility of a plant to insect infestation will depend upon various factors, of which those relating to the insect are the orientation of the insect to the plant for oviposition or feeding, feeding, development and survival of the nymphs, longevity and fecundity of the adults. Whether a variety is susceptible or resistant will depend upon how far these biological processes are facilitated by the variety. If the variety provides conditions favouring these processes then there will be a rapid build-up of the population of the pest on the plant and such varieties are said to be highly susceptible. If, on the other hand, the variety does not provide conditions favouring the different biological processes the insect is not able to build up its population on the host plants and such varieties are resistant.

The eight rice varieties studied in the present instance have graded susceptibilities to damage by N. lugens ranging from resistant to highly susceptible responses. There does not appear to be any preference in the insect for settling (orientation) on any one or selected ones of these different varieties. The speed of development of the nymph is seen to be highest in the susceptible varieties like TN-1 and Annapoorna in which the nymphal development is completed in 14.83 days. In the resistant variety Ptb 33 the speed of development is slow taking 18.20 days for the completion of the nymphal period. Further, the survival of the nymph is to the extent of 84 per cent in the susceptible varieties (Jaya and Annapoorna) as against 23 per cent in the resistant Ptb 33. The growth index which combines the effects of survival and speed of development is the lowest (1.3) in the resistant Ptb 33 and highest (5.66) in the susceptible Annapoorna. The adult is able to live for a much longer period (24.06 days) about 5 times more on the susceptible variety TN-1 than on the resistant variety Ptb 33 (5.2 days). The adult females bred on susceptible rice varieties (Jaya, IR5) lay forty times more eggs than those bred on the resistant variety Ptb 33.

The resistant variety of rice is thus seen to suppress to speed of development of the nymph, cause mortality among the nymphs, reduce the life span of the adult and suppress the egg laying capacity of the females. Ptb 33 thus exhibits clear indications of antibiosis to N. lugens.

Previous workers also have shown that on the resistant variety Mudgo the insect shows high mortality, slow growth rate, small body size and low fecundity. The resulting insects will be undersized and their ovaries contain few mature eggs (Sogawa and Pathak 1970, IRRI 1971, 1976, Pathak and Kush 1977).

Suitability of Weeds as Alternate Host plants for *N. lugens*

Alternate hosts play an important role in the ecology of phytophagous insects. A full knowledge of this will be helpful in fixing criteria for pest management. For the brown planthopper *N. lugens* the weeds of the rice fields may serve as alternate hosts. The part played by the weeds on the ecology of *N. lugens* was ascertained in terms of the suitability of the wet land weeds for oviposition, for feeding of nymphs and for feeding of the adults. Under obligatory conditions, the female lays eggs on eight of the ten species of weeds under study. The number of eggs laid on different weeds varies indicating the relative preference of the insect for egg laying. The eggs laid on these hosts hatch normally. These are highly significant findings. As regards the feeding of the nymph none of the weeds excepting *Paspalum longifolium* has been found to be suitable for the feeding and growth of the first instar nymph. The nymph dies on these weeds by the third day, indicating that it does not feed on them. The adults do not seem to feed on the weeds except on P.longifolium. The fact that even under forced conditions the nymphs and adults do not feed on the weeds proves that these weeds do not serve as alternate hosts for the insect at all. It is, however, interesting to note that all these weeds serve as oviposition hosts of the hopper. Most of these weeds grow together with the rice plant in the field. At a stage when population of the hopper goes high there will be keen competition among the females for egg-laying on its genuine host, rice. This problem is solved by the insect by ovipositing on weeds. These eggs are not wasted because they will hatch. Once they hatch, then the nymphs can move on to the rice plants. Thus the rice plants will be getting not only the nymphs hatching out of the eggs laid on them, but also the nymphs hatching out of the eggs laid on the weeds. The colonisation on the rice plants thus gets built up rapidly, thereby contributing to the population explosions and hopperburns.

One weed, Paspalum longifolium commonly found in the rice fields under waterlogged conditions, has been seen to be abundantly suited for the feeding and breeding of N.lugens. This is the first time that this weed is recorded as an alternate host of the insect. This is a weed which grows on the field bunds and along the fringes of the rice fields and can hence serve to sustain the hopper population during the off-season periods. Mochida and Okada (1971) listed 90 plant species as hosts or oviposition plants for N. lugens, but doubted whether all these are real hosts for the insect. Mochida (1977) considers Oryza sativa alone as the main host plant and some other species of Oryza and Echinochloa as alternate hosts. He has recorded Monochoria vaginalis as an oviposition host of the hopper as has been seen in the present studies also.

Echinochloa crusgalli has been listed as an alternate host by Mochida and Okada (1971) and as an egg laying host of N. lugens by IRRI (1976). Kim et al. (1975) however, reported that the nymphs cannot survive on this grass even for a few days and the plants do not suffer any damage. The present results show that the insect lays eggs on this weed, but the nymphs and adults cannot survive on the plant for more than three days. Cyanodon dactylon has been listed as an alternate host by Mochida and Okada (1971). But the present results show that the insect neither lays eggs on the plant nor is it suitable for feeding of the nymphs or adults. The variation in the response of N. lugens to different weeds may be attributable to the existence of different biotypes.

Many workers have observed higher population density of N. lugens towards the late stages of the crop in plots where weed growth is dense and have attributed this to the congenial micro climate created as a result of the weed growth

(IRRI 1974, Kulshreshtha et al. 1974, Fernando 1975, Varca and Feuer 1976). The results discussed thus indicate that the weeds constitute an important factor in the ecology of the brown planthopper. The importance of removal of weeds as a control measure is thus highlighted.

SUMMARY

SUMMARY

The female of the brown planthopper, *Nilaparvata lugens* Stål preferred leaf sheaths to leaves of rice for egg-laying. Of the total, 77.59 per cent of the eggs and 60.6 per cent of the egg masses were deposited on leaf sheaths. Average number of eggs per mass was 13.26 on leaf sheath and 7.52 on leaf blade.

The macropterous female had a pre-oviposition period of 1 to 3 days (average 2.3 days) and an oviposition period of 13 to 25 days (average 18.2 days). It laid a total of 151 to 308 eggs (average 228.3 eggs). The daily rate of egg laying was 0 to 60 (average 12.86). The maximum mean number of eggs laid per day was 21.08 laid onthe 9th day of oviposition.

The brachypterous female had a pre-oviposition period of 1 to 2 days (average 1.2), oviposition period of 10 to 17 days (average 13.7), fecundity of 131 to 319 eggs (average 209.6) and daily egg-laying of 0 to 99 eggs (average 15.69). The maximum number of eggs laid per day was 43.9 laid on the 7th day of oviposition.

Incubation period of eggs ranged from 7 to 9 days (average 8 days) and per cent hatching of eggs from 80.00 to 89.61 (average 84.83). The average durations of the 1st to

5th nymphal instars were 2.7, 2.8, 2.6, 3.1 and 2.8 days respectively, total nymphal duration being 14.0 days (range 12 to 16 days). Total life-cycle from egg to adult varied from 19 to 25 days average being 22 days.

Longevity of macropterous male, macropterous female and brachypterous female was on an average 18.0, 21.4 and 13.8 days respectively.

Maximum survival of nymphs of N. lugens was at the temperature of 29°C and relative humidity of 70 per cent, being 63.33 and 62.67 per cent respectively. The lowest nymphal durations of 14.63 and 17.75 days were at the temperature of 29°C and relative humidity of 80 per cent respectively. The growth index was highest at the temperature of 29°C (4.35) and relative humidity of 70 per cent (3.94). The percentage of male emergence was lowest at the temperature of 29°C (43.57 per cent) and at relative humidities of 60 and 70 per cent (39.05 and 42.29 per cent). Formation of brachypterous females was highest at a temperature of 29°C (31.27 per cent) and at a relative humidity of 70 per cent and above (25.17 to 28.67 per cent). Incubation of eggs was not affected by temperature and humidity variations. Percentage hatching of the eggs was significantly higher at 27 and 29°C (71.19 and 73.26 per cent) and at humidities of 70 and 80 per cent (77.47 and 72.10 per cent). It appeared that a temperature of 29°C and relative humidities above 70 per cent were optimal for the different biological processes of N. lugens.

Survival of nymphs of N. lugens was inversely proportional to their population densities, being 79.6, 67.4, 61.2 and 47.15 per cent at population densities of 50, 100, 200 and 400 nymphs per rice clump respectively. Nymphal duration was not affected by density variations. Growth index values were inversely related to the graded densities, being 4.94, 4.31, 3.75 and 2.85 respectively. The production of the brachypterous females at these densities, also was inversely related, being 53.76, 54.90, 25.32 and 11.77 per cent respectively. Weight of the adult was more at lower densities though not significantly. The 3rd instar nymphs under higher densities were mostly black in colour against the normal yellow colour. Adults of high density lots were ash-coloured against the normal brown colour.

Survival percentages of the nymphs were 57, 69, 79 and 72 when reared on seedling, tillering, panicle initiation and flowering stages of rice respectively. The average nymphal durations were 16.332, 14.707, 14.059 and 14.772 days respectively when reared on the four stages of growth. The growth index values of the nymph were 3.490, 4.692, 5.619 and 4.874 respectively when reared on the four stages. The adult lived for 20.20, 19.80, 20.60 and 20.20 days respectively when reared on the four growth stages of rice. Fecundity of the females was not affected by rearing on different stages of the pkant. In general the panicle initiation stage was the most suited stage for the build-up of the population of the insect and the seedling stage the least suited, the other two stages came in between.

Nymphal duration was decreased significantly to the extent of 1.8 to 4.9 per cent when reared on rice receiving 20 to 120 kg N/ha. Survival of nymphs, growth index, longevity of adults, fecundity and population build-up were not affected by variations in the nitrogen nutrition of the host plants. There was prolongation of nymphal duration to the extent of 1.79, 1.65 and 1.32 per cent at K_2O nutrition levels of 75, 100 and 125 kg/ha. Survival of nymphs was significantly reduced (by 32.6 per cent) at 125 kg K_2O/ha nutrition of the host plant. Growth index was singificantly reduced at 100 and 125 kg K_2O/ha, to the extent of 21.2 and 33.6 per cent. Longevity of adult and fecundity were not affected significantly by variation in potash nutrition. Potash at 75, 100 and 125 kg K_2O/ha levels suppressed the population build-up of the insect by 3.4, 17.6 and 6.1 per cent respectively.

Of the 56 varieties of rice tested for the degree of resistance to damage by N. lugens at the seedling and tillering stages, 2 per cent were resistant, 5 per cent moderately resistant, 20 per cent moderately susceptible and 73 per cent highly susceptible at the seedling stage and 2 per cent resistant, 2 per cent moderately resistant, 6 per cent moderately susceptible and 90 per cent highly susceptible at the tillering stage. The varieties were more susceptible at the tillering phase than at the seedling phase. Ptb 33 was the only variety resistant to the hopper damage. Variations in the plant characters like plant height, leaf width, leaf thickness and stem thickness of the rice varieties at their seedling stage had no effect on the settling of adults of N. lugens on them and on the damage caused by the hopper to the plants. At the tillering stage there was positive correlation between number of adults settling on the plants and number of eggs laid. The thickness of leaf sheath and number of eggs laid were positively correlated though not significantly. Leaf sheaths of the resistant Ptb 33 had more sclerenchymatous cells in the peripheral region and the parenchymatous cells were silicified and devoid of chloroplasts, while in the leaf sheaths of the susceptible Annapoorna there were fewer sclerenchymatous cells, less silicification and abundance of chloroplasts in parenchyma. Crude silica and total protein contents of the varieties were not correlated with resistance to N. lugens.

Adults of N. lugens did not show any distinction between resistant and susceptible varieties of rice for settling. Duration of nymph was longest in the resistant Ptb 33 (18.20 days) and shortest in the highly susceptible TN-1 and Annapoorna (14.83 days), the duration varied from 15.03 to 16.00 days in the other varieties. Survival of the nymph was lowest in the resistant Ptb 33 (23 per cent), highest in Jaya and Annapoorna (84 per cent) and 70 to 83 per cent in the other varieties. Growth index of the nymph was lowest (1.30) in Ptb 33 and highest (5.66) in Annapoorna and 4.43 to 5.6 in the other varieties. Longevity of the adult was significantly lower (5.2 days) in Ptb 33 than in the other varieties (19.6 to 24.06 days). The fecundity of adults reared on Ptb 33 was significantly less (6.0 eggs per female) than of those reared on other varieties (178.8 to 237.0 eggs per female). Thus Ptb 33 manifested antibiosis to _N. lugens_.

N. lugens laid eggs on 8 of the 10 wet land weeds studied. Eggs laid on weeds hatched, but the nymphs failed to develop on them for more than 3 days excepting on _Paspalum longifolium_. On _P. longifolium_ which was recorded for the first time as an alternate host of _N. lugens_, 60 per cent of the nymphs reached adulthood.

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APPENDICES

APPENDIX-I. The size and number of egg masses laid by N. lugens on leaf sheaths and blades of ten plants

Sl. No.	On leaf sheath: No. of eggs in each mass	No. of egg masses	Total No. of eggs	On leaf blade: No. of eggs in each mass	No. of egg masses	Total No. of eggs	Grand total: Egg masses	Grand total: No. of eggs
1.	12, 21, 6, 22, 8, 4, 8, 7	8	88	6, 6	2	12	10	100
2.	6, 7, 11, 3, 12, 32, 5	7	76	9, 4, 5, 8	4	26	11	102
3.	8, 8, 17	3	33	14	1	14	4	47
4.	10, 33, 5, 2, 4, 26, 18	7	98	2, 5, 2, 13	4	22	11	120
5.	11, 16, 17, 4, 8, 21	6	77	4, 2, 4	3	10	9	87
6.	7, 4, 11, 24, 5, 19	6	70	2, 30	2	32	8	102
7.	12, 2, 15, 30, 18, 7, 3, 13	8	100	4, 3, 8, 13, 3	5	31	13	121
8.	20, 8, 23, 6	5	61	5, 4, 3, 9, 4, 2	6	27	11	88
9.	16, 9, 2, 17, 26, 31	6	101	2, 5, 4, 11	4	22	10	123
10.	10, 18, 27, 24	4	79	8, 12, 3	3	23	7	102
	Total	60	783	Total	34	219	94	1002
	Mean	13.05		Mean	6.15			

Overall mean: 10.66

APPENDIX__ Number f eggs a d by m or pt s emal 1 ss s
s o eas e days

N g s aid day

8

8

2

36 0 8 2 5 6

2 3 2 6

6

2 2 5 6 3

V 0 8 23 9

6 39 5 34 3 7 2 3 9

2 39 8 3 8 5 2 9 0 3

VI 3 2 8 2 55 5 6 3

2 39 34 8 2 3

6 8 3 4 2 4 3 60 4

8 3 25 2 8 9

g 8 8 0 8 4 8 5 0 8 8 0 5 8 4

g s s day

1	8	9	2	2	2	23	34	25	26	27	28	al g s	Pr pos period
												72	
I												2 0	3
II	2	0	8	7		0		0	0	2	9	29	3
V												221	2
V	26	0	2									284	3
VI	2	3										203	2
VII		6	2	8	6							2 2	
V	4	3	0	0		9						23	3
IX	28	32	8		9	9		2	2	3		308	2
X	3		9									5	3
ra e	9 8	6 5	3 9		2 8	8		0 2	0 2	0 3	0 9	228 3	2 3

ao umbe g d au 228 3
ange 5 308
ag pr po al pe d = 2 3 days Range 3)

APPENDIX-III. Number of eggs laid by brachypterous females of N. lugens on successive days

Sl. No.	No. of eggs laid on each day																		Total eggs
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13	14	15	16	17	18	
I	0	19	63	0	0	99	21	12	7	39	16	12	8	0	8	3	9	3	319
II	0	13	0	73	61	8	49	00	0	2	2								208
III	0	48	0	0	21	9	39	47	0	0	0	0	11						175
IV	0	8	11	14	32	28	47	78	5	26	4	17	26	2					298
V	0	4	0	0	12	0	63	0	34	0	0	0	8	6	2	2			131
VI	0	0	39	16	9	21	69	0	9	12	5	4							184
VII	0	39	0	0	98	12	13	4	6	8	5	3	2	9					199
VIII	0	11	13	8	0	47	28	22	31	0	28	7	0	0	2	6	2		205
IX	0	0	18	2	11	7	41	21	18	3	27	13	6	12	2	8			189
X	0	6	13	0	0	59	69	14	4	2	2	4	8	3	0	2	0	2	188
Mean	14.2	14.8	15.7	11.3	24.4	29.0	43.9	19.8	11.4	9.2	8.9	6.0	6.9	3.2	1.4	2.1	1.1	0.5	209.6

Egg laying period - 11 to 18 days
Mean - 14.9 days
No. of eggs laid per female - 209.6

APPENDIX_IV Survival and de elopm nt of N lugens wh reared un e d f er nt levels of crowding

s ym h/ cmp	R	ul s em g d: g d al	Br yp- s ale	T al s ul s	Dur a ym s	M
				6)	( )	
50		9		8	96	39 58
		2	20	9	8	43 59
			28		82	3
		2	6	32	64	8 75
	V	5	20	39	8	9 23
		20	2 20 40	39 8	9 6	38 9
00		30	5	8	78	38 46
		2	2	9	59	40 68
		23	5 40	68	68	33 82
		2	8 3	58	58	20 69
			6 9			39 9
	M	6	6 8 37		6 4	35 0
200			8		6	39 35
			6		66	44 70
			37		62	4 90
		8	8	8	54	35 9
					57	4 37
					6 2	4 83
400		8	8	8	54 50	37 6
		3		97	49 25	42 3
			6		52 5	36 49
	V			2	43 0	39 53
	V			5	36 25	40 69
				88	5	39 02

ul als of nymph cmp	a-	Br hyp- er s emal s %	ex M	ti M	M an ymphal dur n days	Gr wth dex	Male	M cr p- erous female	Brachyp- rous female
		9		0		2	3	4	5
50		52 08		53	03	5 64			
		5 28		29	5 69	4 97			
	II	68 29	2	5	5 5	5 2			
	IV	43 75		6	6 00	4 00			
	V	5 28		60	6 05	4 86			
	Mean	53 76		62	6 0	4 94	67	2 70	2 90
00		57 69		60	5 5	5 02			
		38 98		6	22	3 88			
		58 82		96		4			
		6		8	6 5	6			
	V	52 0			5 96	4 64			
	M an	54 90		86	64	4 3	20	2 23	2 95
200		35 82		5	6 6	4.0			
		3 9		29	6 85	3 92			
		28 2		8	6 2	3 82			
	V			84	5 5	3 48			
	V	6 6		6	6 27	3 50			
	M an	25 32		3	6 32	3 5	20	2 5	2 90
400		8 27		69	8	3 17			
		0 5		37	6 40	3 00			
		8 00		4	0	3 10			
	V	8 3		5	5 66	2 75			
	V	8		6	6 43	2 21			
	M an	77		56	6 54	2 85	36	2 00	2 55

Appendix-V. Biological features of N. lugens as influenced by host plants grown under different levels of Nitrogen - Full data

	Levels of nitrogen KgN/ha)						
	0 N_0	20 N_1	40 N_2	60 N_3	80 N_4	100 N_5	120 N_6
Nymphal duration (in days)							
I	14.77	14.07	14.80	14.08	13.85	14.13	14.13
II	14.56	14.50	14.00	14.43	14.71	14.33	14.57
III	14.79	14.38	14.83	14.65	13.67	13.83	14.13
IV	14.86	14.64	14.29	14.13	14.00	13.79	14.29
Mean	14.75	14.40	14.48	14.32	14.06	14.02	14.28
Per cent survival							
I	65.00	70.00	75.00	65.00	70.00	80.00	75.00
II	80.00	90.00	70.00	70.00	70.00	75.00	70.00
III	70.00	65.00	60.00	85.00	60.00	60.00	80.00
IV	70.00	70.00	70.00	80.00	65.00	70.00	70.00
Mean	71.25	73.75	68.75	75.00	66.25	71.25	73.75
Growth index							
I	4.40	4.98	5.07	4.62	5.05	5.66	5.31
II	5.49	6.21	5.00	4.85	4.76	5.23	4.80
III	4.73	4.52	4.05	5.80	4.39	4.34	5.66
IV	4.71	4.78	4.90	5.66	4.64	5.08	4.90
Mean	4.83	5.12	4.76	5.23	4.71	5.08	5.17
Oviposition and nymphal survival							
I	980	812	1307	244	908	1420	577
II	620	703	971	1400	351	991	1290
III	1160	732	1067	966	613	931	1169
IV	881	695	809	752	577	1104	928
Mean	910.25	735.50	1038.5	840.00	612.25	1111.5	991.00

Appendix-VI. Longevity of adult macropterous females of <u>N. lugens</u> emerging from nymphs reared on rice grown under different levels of nitrogen - Full data

Rectification	Levels of Nitrogen KgN/ha						
	0 N_0	20 N_1	40 N_2	60 N_3	80 N_4	100 N_5	126 N_6
I	12	21	18	13	22	18	11
II	16	20	19	21	12	14	24
III	17	13	18	14	18	29	16
IV	27	11	12	11	26	25	14
V	24	29	21	25	24	12	18
VI	19	22	27	26	17	22	26
VII	13	18	16	18	13	20	25
VIII	26	18	29	17	10	17	25
IX	18	27	28	16	16	16	17
X	19	16	20	19	24	24	19
Mean	19.10	19.50	20.80	18.00	18.20	19.70	19.50

Appendix-VII . Number of eggs laid by macropterous females of N. lugens emerging from nymphs reared on rice grown at different nitrogen level - Full data

Replication	Levels of nitrogen kgN/ha						
	0 N_0	20 N_1	40 N_2	60 N_3	80 N_4	100 N_5	120 N_6
I	131	208	176	151	239	171	88
II	179	191	196	224	140	134	249
III	185	147	151	131	176	285	171
IV	260	88	128	126	269	271	153
V	206	249	280	225	199	139	207
VI	178	209	260	281	201	197	244
VII	132	168	157	189	139	203	220
VIII	224	187	284	181	118	197	271
IX	181	259	254	146	185	166	199
X	152	170	187	153	231	291	232
Mean	182.80	187.60	207.30	180.70	189.70	206.20	203.40

Appendix-VIII. Biological features of *N. lugens* as influenced by host plants grown under different levels of potash - Full data

		Levels of potash (kg K_2O/ha)					
		0 K_0	25 K_1	50 K_2	75 K_3	100 K_4	125 K_5
Nymphal duration (in days)	I	15.04	15.21	14.69	15.32	15.57	15.53
	II	15.27	15.28	15.39	15.58	15.43	15.24
	III	15.08	15.08	14.63	15.29	15.13	15.29
	IV	15.12	15.18	15.08	15.41	15.38	15.27
	Mean	15.13	15.19	14.95	15.40	15.38	15.33
Per cent survival							
	I	96.00	96.00	52.00	88.00	56.00	60.00
	II	88.00	100.00	92.00	96.00	92.00	68.00
	III	96.00	96.00	64.00	96.00	92.00	68.00
	IV	100.00	88.00	100.00	88.00	64.00	60.00
	Mean	95.00	95.00	77.00	92.00	76.00	64.00
Growth index	I	6.38	6.31	3.54	5.74	3.60	3.85
	II	5.76	6.54	5.98	6.16	5.96	4.46
	III	6.37	6.37	4.37	6.28	6.08	4.45
	IV	6.61	5.80	6.33	5.71	4.16	3.93
	Mean	6.28	6.26	5.13	5.97	4.95	4.17
Population build up per clump	I	77	119	130	65	50	56
	II	91	118	112	49	93	39
	III	59	37	105	86	42	64
	IV	35	66	79	53	31	87
	Mean	65.50	85.00	106.50	63.25	54.00	61.50

Appendix-IX. Longevity of adult macropterous females of *N. lugens* emerging from nymphs reared on rice grown under different levels of potash - Full data

Replication	Levels of potash (kg K_2O/ha)					
	0 K_0	25 K_1	50 K_2	75 K_3	100 K_4	125 K_5
I	21	27	11	21	15	18
II	22	16	18	17	22	16
III	18	14	18	16	19	27
IV	10	14	21	12	27	19
V	19	19	26	13	10	12
VI	12	23	24	27	18	20
VII	14	12	16	14	16	18
VIII	19	12	13	19	24	17
IX	26	14	20	18	18	16
X	18	26	22	18	21	14
Mean	17.9	17.7	18.9	17.5	19.0	17.7

Appendix-X. Number of eggs laid by macropterous females of N. lugens emerging from nymphs reared on rice grown at different levels of potash - Full data

Replications	Levels of potash (kg K_2O/ha)					
	0 K_0	25 K_1	50 K_2	75 K_3	100 K_4	125 K_5
I	209	198	94	197	131	163
II	177	203	126	188	208	159
III	160	161	179	120	187	220
IV	123	127	243	94	134	118
V	186	185	187	116	127	96
VI	131	124	231	218	133	195
VII	110	136	192	93	145	203
VIII	168	122	95	161	206	192
IX	235	109	119	109	173	148
X	92	220	210	155	219	97
Mean	159.1	152.5	167.6	145.1	166.3	159.3

BIOLOGY, ECOLOGY AND HOST PLANT RELATIONS OF THE BROWN PLANTHOPPER *NILAPARVATA LUGENS* STÅL

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ABSTRACT

The brown planthopper *Nilaparvata lugens* Stål is considered as the most serious pest of rice in Asia today. In India though the insect is known to occur in almost all the rice growing tracts, its ravages are heavy in the South. In Kerala severe outbreaks of this pest are experienced from 1972 onwards and the insect has gained considerable economic significance in rice cultivation. Though much work has been done elsewhere, knowledge on the basic features, such as biology, ecology and host plant relationships of the native biotype of the insect is lacking. With a view to contribute to the filling of this lacuna in our knowledge the present studies were taken up.

The studies were made in the laboratory and in field cages. Potted plants were used for the bulk rearing of the insect. Temperature variations required in the studies were maintained in an incubator and humidity variations in desicators using appropriate solutions. Relative susceptibility of rice varieties to damage by *N. lugens* was assessed in terms of a scoring on a zero to nine scale as perfected at the International Rice Research Institute.

Biological studies have shown that the hopper lays eggs in the leafsheaths and in the midribs of leafblades, the former being preferred for egglaying. Eggs hatch in a mean period of 8 days; the nymph undergoes five instars taking on an average 14 days. The life-cycle is completed in 22 days on an average. The macropterous male, female and the brachypterous female live for 18, 21.4 and 13.8 days respectively. The brachypterous female, though short-lived, lays on an average 209.6 eggs as against 228.3 eggs laid by the macropterous female during the life time.

The survival, speed of development and growth index of nymphs are significantly influenced by temperature and humidity. Changes in temperature significantly influence the sex-ratio and changes in humidity significantly influence the emergence of brachypterous females. The eggs can tolerate higher temperatures of 33°C to 35°C while the nymphs cannot. The overall effect is that temperatures around 29°C and relative humidities of 70 per cent and above are optimal for the life processes of the insect.

The influence of different densities of nymphal population on the biological features of the insect has been studied for the first time. The speed of development of the nymph is not significantly influenced by the degree of crowding. There exists an inverse relationship between the survival of the nymph and the level of crowding. Low nymphal densities favour the emergence of brachypterous females and high nymphal densities favour the formation of macropterous adults and also causes colour changes in the nymphs and adults.

The age of the host rice plant has governing influence on the life processes of the hopper. The panicle initiation stage appears to be highly favourable for the survival, multiplication and population build-up of the insect and the seedling stage the least favourable; the other stages occupy intermediate positions. The addition of higher doses of nitrogen significantly shortens the nymphal duration, but the other features like survival of nymphs and the longevity and fecundity of adults are not affected by it. Addition of higher doses of potash reduces the survival percentage of nymphs while the other features are not significantly influenced.

Of the 56 rice varieties studied, only one variety Ptb 33 is resistant to damage by the hopper. Majority of the others are highly susceptible. The plants are more susceptible at the tillering stage than at the seedling stage. Variations in plant characters like height, thickness of stem and sheath, and width and thickness of leaf in the different rice varieties are not correlated with susceptibility of varieties to damage by the insect. Host-biology relation studies on N. *lugens* have shown that the susceptible varieties exert marked favourable effects on the survival, speed of development and growth index of nymphs and on longevity and fecundity of adults. The resistant variety Ptb 33 suppresses the speed of development of the nymphs, causes mortality among them and reduces the life span and fecundity of the adults and thus exhibits clear indication of antibiosis.

The weed *Paspalum longifolium* has been recorded for the first time as an alternate host for N. *lugens*. Eight species of weeds serve as oviposition hosts for the insect. Eggs laid on non-host weeds hatch successfully but, the nymphs do not survive on them for more than three days.

The original contributions in the present studies relate to oviposition behaviour of N. *lugens*, effect of the factors of temperature, humidity, population density, nitrogen and potash nutrition of the host plant and different rice varieties on the biology of N. *lugens*, factors affecting formation of the wing forms and role of weeds on the ecology of the insect.

The world literature on the different aspects of the brown planthopper has been reviewed.