TECHNICAL BULLETIN
NO. 171

THE BIOLOGY AND ECOLOGY OF THE WHITE RICE STEMBORER, IN NORTHERN AUSTRALIA

Agdex 116/622 $6.00 ISbBN 0 7245 2563 7

THE BIOLOGY AND ECOLOGY OF THE WHITE RICE STEMBORER, *SCIRPOPHAGA INNOTATA* (WALKER) (LEPIDOPTERA:PYRALIDAE), IN NORTHERN AUSTRALIA

C.S. Li

Department of Primary Industry and Fisheries, Darwin, N.T. 0800

May 1991

SUSTAINABLE AGRICULTURE

THE DEPARTMENT OF PRIMARY INDUSTRY AND FISHERIES IS COMMITTED TO THE PRINCIPLES AND PRACTICES OF SUSTAINABLE AGRICULTURE

Sustainable agriculture is the use of agricultural practices and systems which maintain or enhance:

- the economic viability of agricultural production;
- the natural resource base; and
- other ecosystems which are influenced by agricultural activities.

Principles:

1. Agricultural productivity is sustained or enhanced over the long term.
2. Adverse impacts on the natural resource base of agriculture and associated ecosystems are ameliorated, minimised or avoided.
3. Harmful residues resulting from the use of chemicals in agriculture are minimised.
4. The net social benefit (in both $ and non $ terms) derived from agriculture is maximised.
5. Agricultural systems are sufficiently flexible to manage risks associated with the vagaries of climate and markets.

CONTENTS

ABSTRACT

The biology and ecology of the white rice stemborer were studied primarily during 1960-68 in northern Australia.

Serious damage by the borer has been surveyed since 1960, a severe infestation being recorded in 1964-65.

From laboratory and field observations in the wet season crops, the borer passed through 3-4 overlapping generations. Oviposition sites, larval behaviour and aestivation sites are described in detail, especially larval migratory and aestivating behaviour. The duration of the first, second and third generations from egg deposition to moth emergence varied 48-63, 41-62, and 53-67 days respectively (duration from egg to adult: 2-7, 33-67, 7-8 and 3-6 days). The larvae of the residual third and fourth generations aestivated in the stubble, pupated and the moths emerged in early next wet season. Besides those larvae which aestivated, others continued to breed in the dry season crops. Seven or eight overlapping generations may occur if the rice is grown all the year round.

The seasonal fluctuations of the borer in the standing crop in 1962-63 at Humpty Doo and in the stubble from 1960 to 1967 at Humpty Doo and Tortilla Flats were monitored by light trapping, and by dissecting "dead hearts", "white heads" and stubble.

In the standing crop, four peaks of moth flights occurred at the end of November, of January, of February and in late March to early April. These were the peaks of moth flights of the aestivating, first, second and third generations respectively. Moth numbers of the first and third generations declined abruptly due to the late availability of the rice crop (late sowing) for most of the newly hatched larvae and a small number of moths emerged.

Four peak numbers of larvae and pupae occurred in early January, late January, mid March and early May. The peak numbers of larvae of the first and second, and of the third and fourth generations synchronized with the vegetative stage and reproductive stage of the crop respectively. The latter two generations of larvae may result in heavy yield losses by "white heads".

In the stubble, the numbers of larvae and pupae were much higher just after harvest or at the beginning of aestivation, declining abruptly in and after November due to moth emergence and very high mortality. Their numbers increased yearly until 1964 at Humpty Doo and 1965 at Tortilla Flats.

The onset of aestivation in maturing larvae is probably induced by changes of composition of food soon after heading.

The aestivation period which was terminated by the first rains of the next wet season varied from 4½ to 7½ months. Field observations and laboratory experiments were carried out to assess the effect of artificial and/or natural precipitation on termination of aestivation.

From the field data for the eight years 1960-67 at Humpty Doo and Tortilla Flats, the influence of differing amounts of opening rain on days to moth emergence was analysed. The relation between them was linear. The degree of correlation increased with increasing volume of opening rains up to 12mm, with only a slight increase for opening rains greater than 12mm.

Results from the laboratory experiments showed a similar linear response to precipitation volume; that is, time to moth emergence decreased as precipitation volume increased.

From the field and laboratory results the negative correlations found, which suggest that the longer the delay in the opening rains the earlier the first moths appear, were unreal.

INTRODUCTION

Rice, one of the staple food crops, has been grown for centuries under diverse ecological conditions in temperate, subtropical and tropical regions.

Australia lies on either side of the Tropic of Capricorn; its climate is tropical in the north and temperate in the south, and each region appears to be suitable for rice growing.

In southern Australia, rice growing is confined to the Murrumbidgee, Murray, Edwards and Coleambally Irrigation Areas (latitude 34° - 36°S) of New South Wales, where the crop is the largest and most highly productive in Australia. One crop a year is planted, in rotation with legume pastures. Normally the crop is sown from late September to mid-October by various methods of establishment such as drill sowing, aerial sowing and sod-seeding (McDonald, 1977).

Rice has been free from serious insect pests since the rice industry was founded in New South Wales in 1922. However, agronomic and other conditions have changed and some minor pests which formerly caused little injury such as the bloodworm (*Chironomus tepperi* Skuse), the common armyworm (*Mythimna converta* (Walker)) and the large cane moth-borer (*Bathytricha truncata* (Walker)) are now becoming important. In particular, both aerial sowing and sod-seeding of rice have provided optimum conditions for bloodworm to cause severe infestation (Jones, 1972).

In northern Australia, the rice industry is in its infancy and the growing areas are still small as compared with that in southern Australia. In Queensland, the industry is concentrated in the Burdekin and Tinaroo Irrigation Areas, and small areas at Ingham. In Western Australia, commercial rice was grown in the Camballin and Ord areas in the mid 1950's and 1960-61 respectively and discontinued in 1963 and 1983 respectively. In the Northern Territory, experimental rice began at Beatrice Hill near Humpty Doo and at the Sixty Mile near Tortilla Flats in 1952. Commercial rice production commenced at Humpty Doo in 1958-59 and at Tortilla Flats in 1964-65. Unfortunately the short-lived industry was eventually abandoned at Humpty Doo in 1963-64 due to unpredictable rainfall distribution, high salinity and other undesirable soil characteristics, unsuitable *indica* varieties and serious insect pests (Basinski, 1972). It was abandoned at Tortilla Flats in 1977-78 although experimental planting at the latter place continued for a further decade.

Rice insect pests in northern Australia are entirely different from those in southern Australia, and in the former region insect pest problems have partly contributed to difficulties in establishing a rice industry. The white rice stemborer (*Scirpophaga innotata* (Walker)), brown planthopper (*Nilaparvata lugens* (Stål)), whitebacked planthopper (*Sogatella furcifera* Horvåth), rice leaf rollers (*Cnaphalocrocis medinalis* Guenée, *Marasmia* sp.), and rice caseworm (*Nymphula stagnalis* Zell) have been recorded to cause considerable damage to rice; all are serious rice pests in southeast Asia so they have the potential to become important pests here in the near future. Of these the white rice stemborer is the most important insect pest (Koch, 1960; Li, 1961; Halfpapp, 1987; and see Appendix).

This study was conducted primarily during the period 1960-68 in the Northern Territory at Darwin laboratory; Berrimah Research Farm; the Coastal Plains Research Station (CPRS) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) at Humpty Doo some 72km south east of Darwin; and the Upper Adelaide River Experiment Station (UARES) (now called Tortilla Flats Research Farm) at Tortilla Flats 111km south of Darwin. Some investigations however were continued from 1972-1981.

Some results of the investigations, including integrated control, have been published (Li, 1961, 1970 and 1972), and this paper presents additional findings.

I. REVIEW OF THE DISTRIBUTION, BIOLOGY AND CONTROL OF THE WHITE RICE STEMBORER

Nomenclature and Taxonomy

The species was originally described by Walker in 1863 as *Tipanaea innotata* from Sarawak. In 1880, Snellen described the species again as *Scirpophaga sericea* from Sumatra and it was synonymized with *innotata* Walker by van der Goot (1925), which was transfered for *Scirpophaga* to the genus *Tryporyza* erected by Common (1960). Recently Lewvanich (1981) has revised *Scirpophaga* and placed *Tryporyza* as a synonym of *Scirpophaga*. Therefore *Scirpophaga innotata* (Walker) has been restored.

Geographic Distribution

S. innotata occurs in Asia, Australasia and Pacific Islands: East Malaysia; Indonesia; Philippines; Australia: Northern Territory (Bathurst Island, Berrimah, Humpty Doo, Sixty Mile, Sixty-seven Mile and Tortilla Flats), Queensland and Western Australia; Papua New Guinea and West Irian. Published records of *S. innotata* from India, Pakistan, Taiwan, Thailand and Vietnam require authentication (Common, 1960; Koch, 1960; Li, 1961, this paper; Lewvanich, 1981; Commonwealth Institute of Entomology, 1985; Halfpapp, 1987).

Biology, Life Cycle and Phenology

S. innotata is the most important insect pest of rice in Indonesia (van der Goot, 1925; van Halteren, 1979) and northern Australia (Koch, 1960; Li, 1961) and less serious in other countries. Besides rice, 2 wild rice species (*Oryza australiensis* Domin. and *O. perennis* complex (= *O. rufipogen* Griff.)), sugarcane and a wild sedge (*Cyperus rotundus* L.) are also affected (Common, 1960; Li, 1970; Oka, 1978; Lewvanich, 1981; Arvind, 1987).

The bionomics of *S. innotata* has been studied in four regions:

Adults. The adults are nocturnal, phototropic, and strong fliers. The mean fecundity is 142 or 160 eggs; sex ratio, 1.0 males/2.3 or 9.3 females; longevity, 4 days (van der Goot, 1925; Li, 1961; Rothschild, 1967, 1971).
Eggs. The eggs are laid in egg-masses at night on either surface of the leaf. The mean egg-mass contains 85 eggs arranged in 1-4 layers, covered by the hair scales from the female anal tuft. Incubation lasts 3-9 days (van der Goot, 1925; Otanes and Sison, 1941; Li, 1961).

Larvae. Newly hatched larvae bore into the stem directly or through the leaf sheath, severing the apical parts of the young plant and causing "dead hearts" or cutting the panicles off on the maturing plant and producing "white heads". They are usually gregarious in the first three instars and then disperse. The migration of the late instars, by making leaf cases, has been observed in the laboratory or in the field. The number of instars is six and larval duration is 19-61 days. The number of moults may increase by 1-3 in aestivating larvae (van der Goot, 1925; Otanes and Sison, 1941; Li, 1961; Rothschild, 1971).

Pupae. Pupation takes place in a white cocoon in the lower internode of the plant. The pupal period lasts 7-11 days. The aestivating larvae either move down to the underground stems of the stubble or penetrate into the soil itself, protecting themselves by a cocoon and pupating until the next season (van der Goot, 1925; Otanes and Sison, 1941; Li, 1961).

Phenology and Aestivation

S. innotata is multivoltine, but the number of generations per year depends on the varieties of rice cultivated, the length of planting period and availability of rice crops. In Indonesia, three generations can develop in early-maturing varieties (90 days) with short planting-periods. Four generations can develop in late-maturing varieties (120 days) with quick transplanting. The fourth aestivates. A small fifth generation appears in the youngest fields with longer transplanting period and 9-10 generations may occur in rice planted all the year around (van der Goot, 1925). In northern Australia, the borer passes through 3-4 overlapping generations. The fourth develops in early - or late-maturing varieties but a number of larvae can not reach maturity at the harvest time of the latter varieties. Larvae of the residual third and fourth generations aestivate (Li, 1961). In the Philippines, the borer has only 2-3 generations during the rice season (Otanes and Sison, 1941).

Field observation shows that aestivation is terminated by the first rain of 10mm in the wet season provided that aestivation has lasted at least 4½ months. The moths emerge about 4-6 weeks after the first rain. Under laboratory conditions, after the aestivation period of 4½-5½ months, the majority of moths will emerge 6-8 weeks after artificial rain, and somewhat sooner if the period has extended to 6 months or more (van der Goot, 1925, 1936).

Aestivation can only be terminated by direct water contact, not merely by exposure to higher humidity. Emergence follows artificial rain of 16mm or more and is accelerated by higher levels of rain, which has no influence on aestivation unless it has lasted a minimum of 3½ months. Water or artificial rain appears to dominate as a stimulus (Li, 1972).

Rainfall in the dry season is mainly responsible for damage in the next wet season because it has great influence over the borer population during aestivation. It indicates a correlation between the rainfall and the occurrence of the borer (van der Laan, 1959).

Parasites and Predators

Of the more than 20 species of natural enemies recorded, about 5 species of egg parasites (*Telenomus rowani*: (Gahan), *Tetrastichus schoenobii* Ferr., *Aprostocetus* sp. nov., *Trichogramma japonicum* Ashm., *T. Australicum* Gir.) are the most important and widely distributed. Reported percentages of parasitism vary extremely and fluctuate greatly depending on egg-mass densities. These indicate that egg parasites may be important regulating factors with high borer populations but less important at low or moderate population levels. Utilization of them may be limited but can be integrated with other control measures, especially chemical control and/or varietal resistance (van der Goot, 1925, 1948; Nickel, 1964; Li, 1970, 1972; Rothschild, 1970; Learmonth, 1980). In *T. rowani*, the life-cycle (the total duration being 9-12 or 12-14 days) and phoresy (adults being carried by the female moth, on the wing) have been observed (Rothschild, 1970; Li, this paper; Learmonth, 1981).

Cultural Control

Some sound cultural practices are still in use today in many countries. Late sowing has been practised successfully to evade the flight of moths from aestivating generation(s) and the first generation attack. In Indonesia, infestation is prevented until the flight of moths from the stubble is over, which is some 6-8 weeks after the first rain of 10mm. However, in northern Australia mid/late December is the optimal late sowing period in most years (van der Goot, 1925, 1936, 1948; Li, 1972). Harvesting at an optimal time and close to ground level can kill the majority of larvae. Ploughing and flooding effectively control the aestivating larvae (van der Goot, 1925; Li, 1961, 1972). Also ploughing in spring will destroy volunteer and/or wild rice before rice is sown and irrigation could be used to wet rice fields sufficiently to end aestivation; the moths will emerge and die before the hosts are available (Li, 1972). In some transplanted crops (overseas), clipping the seedlings before transplanting is recommended for *S. innotata*.

Varietal Resistance

Awned and poorly tillering varieties are more susceptible to *S. innotata* attack than are awnless varieties but field experiments show these differences to be of little importance. However a chemical difference may influence borer attack (van der Goot, 1925). Varieties resistant to *Chilo suppressalis*, *Scirpophaga incertulas*, *S. innotata* and *Sesamia inferens* are characterised by a narrow lumen, ridged stems, tight leaf-sheaths, tough tissues and high silica content, but none of these alone appears to be the main cause of resistance and a certain chemical composition of the rice plant appears to be important (Pathak, 1971). Also sixteen rice varieties have been tested and have shown a general similarity in their degree of susceptibility or resistance to the four species of borer listed above and the consistency of the resistance of five varieties to all four borers suggests that resistance is the result of a complex of factors (Das, 1976).

Insecticidal Control

For effective use of insecticides, the selection of the right application time, proper insecticide, correct formulation, and suitable application method is very important. The last has been improved and developed consistantly since World War II.

Conventional sprayings or dustings (with methyl parathion, fenthion, diazinon, phosphamidon, fenitrothion, CYP (Surecide) cartap etc.) (Soenardi, 1972; Custodio, 1972; van Halteren, 1979) are applied during the peak of egg hatching about 40 and 80 days after transplanting to control "dead hearts" and "white heads" respectively (Soenardi, 1972), one week before flowering (Rothschild, 1969) or during the preheading stage (Li, unpublished data) in order to reduce the infestation and increase yield.

Some systemic or potentially systemic insecticides whiuch have been used as seed, seedling or seed-bed treatments and paddy water/root zone application give effective control, longer residual period and no harmful effects on natural enemies, and certaily offer a great advantage over the conventional applications. Seed treatments (with diazinon, chlorpyrifos, chlorfenvinphos etc.), seedling dips (with carbofuran, trichlorfon, carbaryl, methy parathion, fenthion etc.) or seed-bed treatments (with phorate, lindane, carbofuran etc.) provide effective protection to the crop from early infestation during the seedling stage (Soenardi, 1967; Custodio, 1972; van Halteren, 1979). Because of inevitable losses by torrential rain/overflowing water which could decrease the effectiveness of paddy water application (with carbaryl, diazinon, lindare, carbofuran, chlordimeform, mephosfolan, cartap, chlorfenvinphos etc.) (Custodio, 1972; Li, 1972; Soenardi, 1972; vcan Halteren, 1979; Halfpapp, 1987), the more effective root-zone applications have been developed such as mud ball (with carbofuran, chlordimeform, mephosfolan, cartap, BPMC), gelatine capsule (with BPMC, carbofuran, cartap etc.), liquid applkicator (with carbofuran, BPMC) and soil incorporation (with carbofuran) methods. Any of these methods, requiring only one application to give protection until harvest, is superior to paddy water application. Of these, the soil incorporation method is an easier and more efficient way to control the borer because of the labour-saving, cheapness and no special equipment required (van Halteren, 1979).

The Rice Pest Complex

The pest complex in *S. innotata* occuring areas consists of several most destructive groups: stem borers, planthoppers and leafhoppers, rice gall midge, lepidopterous leaf-eating caterpillars and grain-sucking bugs. The occurence of these pests has been influenced by different cultural practices, rice varieties and control methods especially chemical control (Pathak, 1968; van Halteren, 1979). No information is available on development of insecticide resistance, insecticide-induced resurgance of secondary insects etc.. Hoiwever, in recent years the development/use of selective insecticides for more pests (such as Surecide, Salithion, carbofuran, chlordimeform, BPMC etc.) and the breeding of varieties resistant to major pests (such as Mudgo; IR 2755-E2-11-1-1 etc.) integrated with other control measures have been reported effective in controlling several groups of insects in the pest complex (Soenardi, 1972; Pathak and Dyck, 1973; Das, 1976; van Halteren, 1979).

II. LIFE CYCLE AND PHENOLOGY OF THE WHITE RICE STEMBORER IN NORTHERN AUSTRALIA

Introduction

In northern Australia, rice has been grown between Bathurst Island (latitude 11°S), Northern Territory and Burdekin Irrigation Area (latitude 19°-20°S), Queensland. In the main rice-growing areas where irrigation water is available throughout the whole year, two crops a year are planted. The wet season/summer crop and dry season/winter crop are sown in November - early January and June to early July respectively by drill sowing or aerial sowing (in experimental crop).

In the semi-arid tropical Northern Territory irrigation water is unavailable but the high rainfall is sufficient to permit one rainfed rice crop a year, with rainfall supplemented by water pumped from the Adelaide River at the beginning and/or the end of the wet season (the average annual rainfall, on the coast in the vicinity of Darwin, exceeds 1549 mm, of which more than 1514 mm falls in the period from November to April). Due to the unpredictable onset of the wet season, it is necessary to carry out drill sowing (or dry sowing) either before or between the first showers (September-October) and trust the rains to establish the crop. However, since 1962/63, late drill sowing in mid to late December has been adopted to reduce attack by the white rice stemborer. Aerial sowing (or water sowing) has also been tested experimentally in mid-wet season (January). After harvest, the fields are burned and/or ploughed or grazed as a means of fattening cattle.

Materials and Methods

Damage Surveys. Surveys to determine infestations were made for each generation at the late larval stage in experimental and commercial rice crops at Humpty Doo and Tortilla Flats. Three fields were selected more or less at random for each survey. In each selected field, three samples, each of which was composed of 100 tillers or stems, were taken near the opposite corners and at approximately the centre of the field. The first sample was obtained by walking 50 paces (or less) near the corner and along the margin of the field within the first 5 drill rows (or 5 paces), and 20 consecutive tillers or stems were examined for "dead hearts" or "white heads" along the observer's left side at 5 pace intervals. After finishing 100 tillers (or stems) of the first sample, the observer continued at 50 paces tyowards the centre of the field and another 50 paces to the right (or left) in the same way to examine the second sample, and then the third sample towards the opposite corner of the field.

Observations on Life Cycle. The rice variety, A36-3, was sown in 10 litre undrained plastic buckets containing soil from the field. Each bucket was placed in a 33 x 33 x 142 cm wire screen cage, all cages being kept outdoors at Berrimah Research Farm (ambient temperatures range approximately from 20°-35°C and 55-80% R.H.). Five to six caged buckets of plants were infested with newly hatched larvae of each generation. Each pair of moths was transferred separately to oviposition cages provided with rice leaves standing in water. In the laboratory, where temperature and relative humidity were similar to those of outdoors mentioned above, a series of newly hatched larvae were reared singly on cut stems that were replaced daily, in glass tubes plugged with cotton wool. Observations were recorded daily.

To examine the life cycle and abundance in the field, one hundred "dead hearts" or "white heads" were collected at random at weekly intervals from the rice fields at Humpty Doo and Tortilla Flats. Each "dead heart" or "white head" was dissected in the laboratory and a record was kept of the numbers of different instars and pupae found. In addition 2 light traps were operated from September to May to monitor the flights of moths.

After the harvest, two or three quadrats (each quadrat = 0.836 m^2 or 1 square yard) of stubble were sampled randomly. Each sample quadrat was excavated to the depth of 6-7 cm. The stubble sample was dissected and a record was kept of the numbers of tillers, live and dead larvae and pupae.

Termination of Aestivation by Precipitation. At the end of August, 1965, samples of stubble with soil were excavated from a heavily infested field, planted in eight wooden boxes (28 x 28 x 20 cm) at the same depth as in the field, and cut to a uniform length of 38 cm.

The boxes were grouped in two series, each series comprising four boxes. Each box was placed in an insect cage, all cages being kept in an opened screened insectary. The application of artificial precipitation to the stubble samples of the boxes (1) - (3) of the series I commenced on 30 August and to those of series II on 13 September. The fourth box (4) of each series was left untreated. Each series covered a period of four months.

A quantity of 500, 725 and 1000 ml of water, corresponding to 6.4, 9.3 and 12.8 mm of artificial precipitation, were applied by a watering can to the boxes (1), (2) and (3) of each series respectively every second day (except on weekends or when high antecedent rainfall has occurred).

All boxes of both series received rain (natural) between 28 September to 10 December.

The volumes of artificial and natural precipitation were measured, and the date and number of moths emerging were recorded.

Results

Damage Assessment

The major visible rice damage caused by borers is "dead heart" or "white head". Consequently all research workers agree to use "dead heart" and "white head" figures as a basis for estimating yield losses.

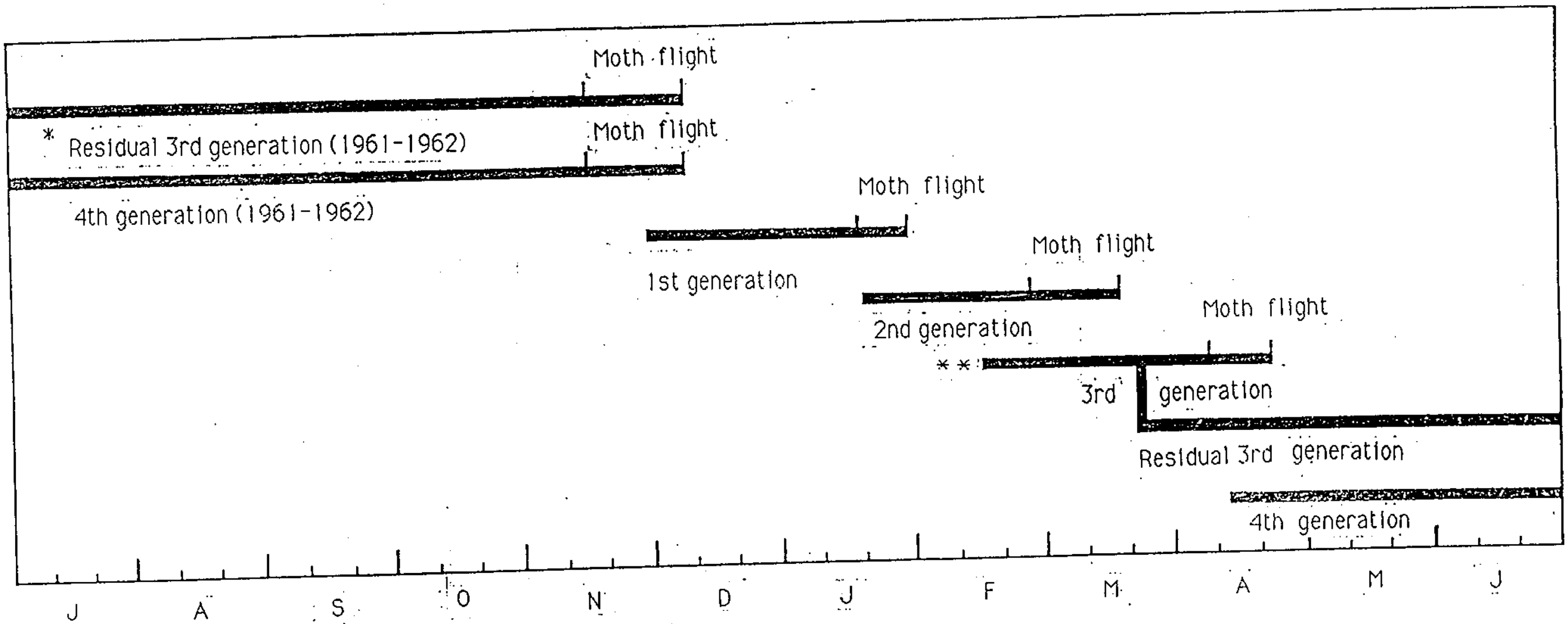

FIG. 1. Life cycle of S. innotata in the laboratory, 1962-63. *, the aestivating larvae collected from the field and kept in insect cages; **, the egg masses collected from the field.

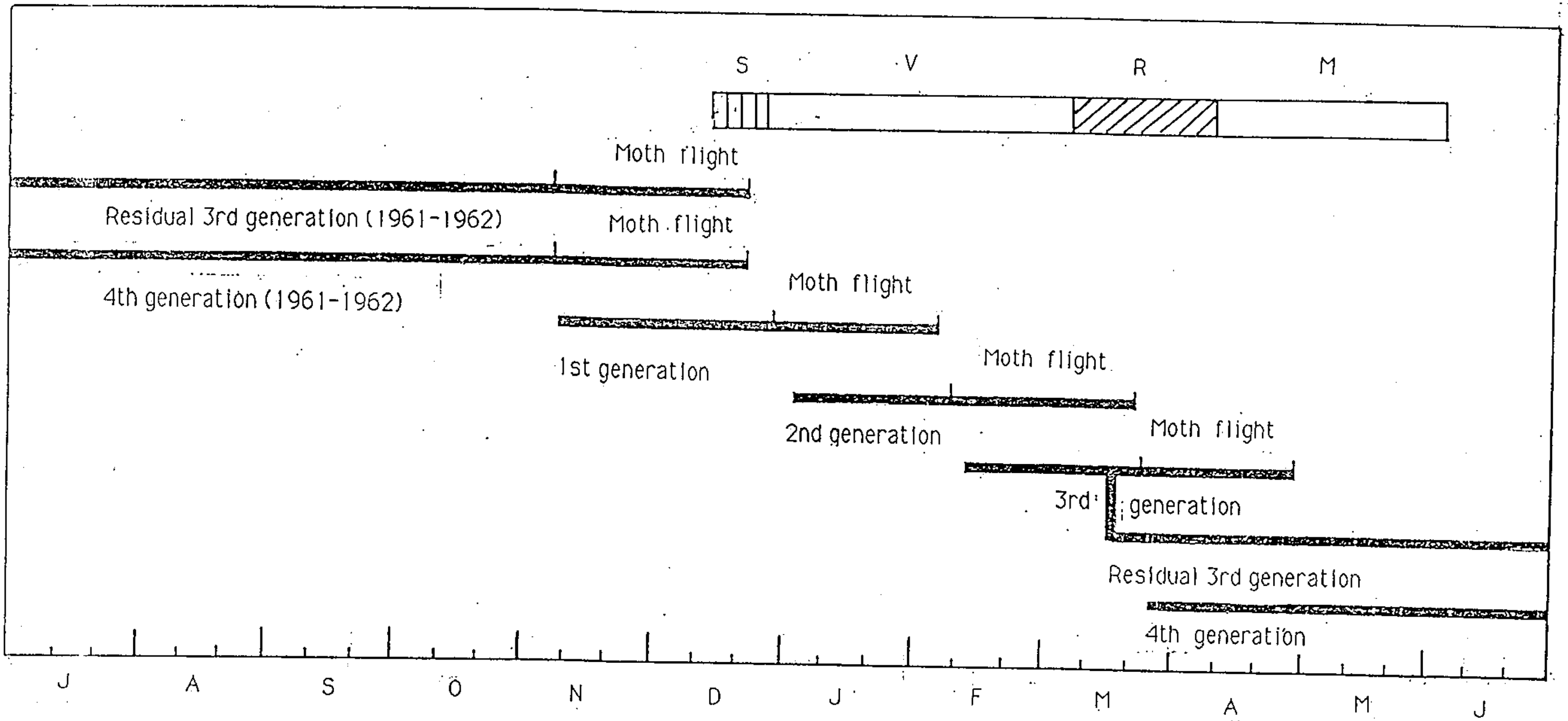

FIG. 2. Phenological relationship between the life cycle of S. innotata and the rice crop at Humpty Doo and Tortilla Flats, 1962-63. S, sowing; V, vegetative stage; R, reproductive stage; M, maturing stage.

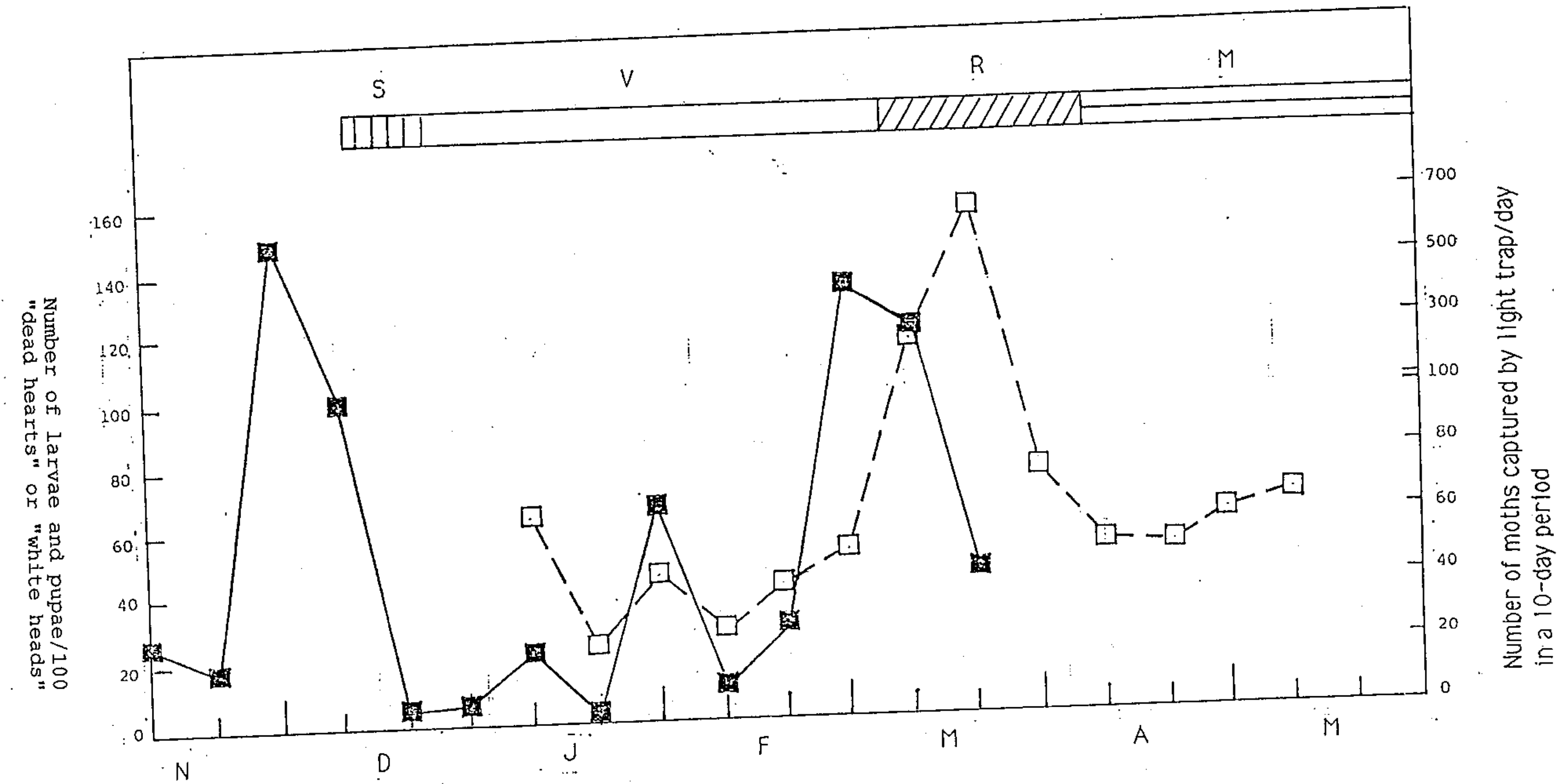

FIG. 3. Phenological relationship between the abundance of S. innotata and the rice crop at Humpty Doo, 1962-63. S, sowing; V, vegetative stage; R, reproductive stage; M, maturing stage; □-□, moths captured by light trap; ■-■, larvae and pupae from 'dead hearts' and 'white heads' dissected.

According to the damage surveys, the damage levels to wet season experimental crops between 1960/61 and 1980/81 were 0.1-12.0% "dead hearts" and 2.0-26.0% "white heads" at Humpty Doo, and 0-13.3% "dead hearts" and 1.9-45.7% "white heads" at Tortilla Flats. The damage levels to wet season commercial crops from 1960/61 to 1962/63 were 1.5-10.2% "dead hearts" and 1.7-16.8% "white heads" at Humpty Doo, and between 1964/65 and 1976/77 were 0.6-2.8% "dead hearts" and 1.6-14.9% "white heads" at Tortilla Flats. There was a serious infestation at Tortilla Flats in the 1964/65 experimental crop with an average of 13.3% (2-31) "dead hearts" and 45.7% (14-79) "white heads" being recorded.

Life Cycle, Behaviour and Phenology

Adults. The adult moths are nocturnal and positively phototropic. The longevity varied from 3-6 days. The ratio of male to female moths captured by the light trap from 1960 to 1963 was 1:1.7.

Eggs. The egg-masses were found on either the upper or lower surface of the rice leaf, usually near the tip and occasionally laid on the leaf sheath. The incubation period varied from 2-7 days.

Larvae. The larvae severed the young or bearing rice plants, causing "dead hearts" or "white heads" respectively. Occasionally the early instars also fed on the inside tissues of a leaf sheath causing death of the leaf blade. The first three instars were found in aggregations, most commonly containing 2-33 larvae in one "dead heart" or "white head". The larvae moulted six times. The 7th instar was the longest duration; 6th; 5th; 4th; 3rd; 1st; and 2nd instars had decreased in duration in that order. The total larval stage varied from 33-67 days.

The late instars were observed to have an interesting, migratory behaviour. Each larva emerges from the dying tiller and rolls a leaf to form a tube in which is enclosed. It then cuts off both ends of the leaf tube with the head and thorax protruding, carries this leaf tube wherever it goes, and drifts on the irrigation water until a suitable tiller is found. This leaf tube, filled with chewed rice tissue, is often found attached to the entrance tube where the migrating larva has bored into the suitable tiller.

The late instars reared in the laboratory have been observed to make stem tubes instead of leaf tubes.

Generally each larva migrates several times and in this way may destroy several tillers. Larvae become darker in colour over the migrating period.

Pupae. Pupation took place in a white cocoon usually in the basal internode but occasionally in th leaf sheath. A circular emergence hole was previously made in the stem wall near the top of the cocoon by last instars, and three silken septa laid down inside the emergence hole to prevent water entry. Pupal duration varied 7-8 days.

Laboratory observations during 1962-63 showed that the borer passed through 3-4 overlapping generations per year (Fig. 1). From the caged rice plants, the first generation commenced late due to difficulty in getting enough moths to emerge from the caged stubble. This might have some effect on the subsequent generation. The duration of the first, second and third generations, from egg deposition to moth emergence, was 48-63, 41-62, 53-67 days respectively. The larvae of residual third and fourth generations aestivated in the stubble and pupated and the moths emerged in mid-December, 1963.

Field observations during 1962-63 showed that the borer passed through 3-4 overlapping generations per year at Humpty Doo and Tortilla Flats (Fig. 2). Data on larvae were obtained through dissection of "dead hearts", "white heads" and stubble. Adult activity was monitored with light traps and by visual observations. The length of each generation at Humpty Doo was similar to that at Tortilla Flats. The 1962/63 wet season rice crops at Humpty Doo and Tortilla Flats, sown in mid to late December, escaped major attack by the first generation which bred mainly in volunteer and wild rice. The larvae of the residual third and fourth generations aestivated and pupated in the stubble and the moths emerged in late November to late December, 1963.

During the dry season, besides those larvae of the borer which aestivated, others continued to breed in 1962 dry season rice crop (sown in mid-July and harvested at beginning of December, 1962) at Tortilla Flats and in late sown rice (sown in March and harvested in mid-July, 1963) at Humpty Doo.

A similar observation was made in 1964 in April-sown rice at Humpty Doo and in the dry season rice crop at Tortilla Flats. Therefore, if rice is grown all the year round, seven or eight overlapping generations may occur.

Seasonal Fluctuations in Abundance

Numbers of Larvae and Pupae in the Standing Crop Observations were made on the numbers of the borer in the standing crop from generation to generation in 1962-63 at Humpty Doo (Fig. 3). These data were also extracted from the light trap captures and from the dissection of "dead hearts" and "white heads".

Peaks of moth flights occurred at the end of November, the end of January, the end of February and in late March to early April. A probable fourth flight may have resulted from previously observed larvae and pupae, but was not observed due to lack of electricity for operating the light trap. These were the peaks of moth flights of the 1961-62 aestivating first, second and third generations respectively. The moth flight of the first generation was in late December-early February and in this flight the peak in early January was from volunteer/wild rice and the peak in late January from volunteer/wild rice and rice crop. The higher peak from the rice crop is properly regarded as the moth flight of the first generation.

Moth numbers of the first and third generations declined abruptly. With the first generation this was due to the late availability of rice crop (or late sowing) for most of the newly hatched larvae; with the third generation only a small number of larvae pupated and emerged to produce the fourth generation (Figs 2 and 3.).

Peak numbers of larvae and pupae occurred in early January, late January, mid March and early May. These peaks represented respectively the majority of the first generation plus the minority of the second generation; the minority of the first generation plus the majority of the second generation; the third generation; and the residual third generation plus the fourth generation (Figs 2 and 3.).

Numbers of Larvae and Pupae in the Stubble Observations were made on the numbers of larvae and pupae in the stubble at Humpty Doo and Tortilla Flats from 1960 to 1967. After the harvest, the stubble were sampled and dissected each fortnight initially. This was then extended to monthly sampling in 1964, with only annual sampling (in June) for the three years 1965- 1967. The results are given in Tables 1 and 2.

In general, at both Humpty Doo and Tortilla Flats the number of larvae and pupae in the stubble was much higher just after harvest or at the beginning of aestivation, declining abruptly in and after November due to moth emergence and very high mortality. Numbers increased yearly until 1964 at Humpty Doo and 1965 at Tortilla Flats although some control measures had been applied.

Aestivation.

Onset of Aestivation. The full-grown larvae of the residual third generation and the fifth or older instars of the fourth generation aestivated during the dry season. The aestivating larvae might pass through 1-4 additional moults during aestivation. Near or at harvest time, larvae preparing for aestivation either moved down to the underground rice stems or penetrated into the soil itself, protecting themselves by a cocoon which had 2-4 silken septa inside the top.

With the latter, each aestivating larva bored a hole through the tip of the underground rice stem, and dug into the earth, pushed the soil particulkes into the hollow rice stem above ground and protected itself by a 1.6-5.4 cm lon cocoon, Very rarely, a cocoon in the osil had 2-3 branches built by the co-operation of 2-3 larvae.

An emergence hole was made by the larvae at the beginning of the wet season before pupation and a long silken tube with a silken septum connected the top of the cocoon to the emergence hole.

Of 1,181 aestivating larvae examined (852 from Tortilla Flats, 329 from Humpty Doo) 0.35%, 53.29% and 46.36% aestivated in the above ground rice stems, underground rice stems and soil respectively at Tortilla Flats; at Humpty Doo the figures were 0.30%, 56.84% and 42.86% respectively. (Tables 1 and 2)

The majority of aestivating larvae of the third generation were observed only in maturing rice plants. These were, however, unable to induce aestivation in a minority of larvae from the same generation which continued to breed the fourth generation. What the role of mature rice plants or other factors are in inducing the aestivation are still uncertain. This will be discussed later.

Table 1.
Numbers of larvae and pupae of *S. innotata* in the stubble at Humpty Doo, 1960-67.

a, pupal case; b, dead pupa; c, dead moth; d, pupa; *, not including pupae and moths; **, data unavailable after this month.

Sampling date	No. of stubble samples	Av. no. per sample (0.836m²)			Mortality * %
		Tillers	Live Larvae	Dead Larvae	
1960					
Nov	6	66.3	0.8	0	0
1961					
June	6	123.3	3.7	0.3	7.5
July	4	75.8	1.5	0.3	16.7
Aug	4	74.8	1.0	0	0
Sept**	2	85.5	4.5	0.5	10.0
1962					
June	2	102.5	4.5	0.5	10.0
July	6	99.2	3.7	0.3	7.5
Aug	4	113.0	2.5	0	0
Sept	4	136.3	3.8	0	0
Oct	4	105.8	2.3	0	0
Nov	4	102.8	0.8+1[a]	0.5	38.5
Dec	4	102.0	0.3+1.8[a]	0.8+0.3[b]+0.3[c]	77.7
1963					
June	2	193.5	6.0	1.0	14.3
July	6	177.5	3.0	0.2	6.3
Aug	4	188.0	5.0	0	0
Sept	4	196.3	12.5	0.3	2.3
Oct	4	142.8	5.5	0.5	8.3
Nov	4	115.5	3.5+0.8[d]	1.3	27.1
Dec	2	110.0	1.0	0	0
1964					
June	2	191.5	13.0	0	0
July	2	160.0	3.5	0	0
Aug	2	226.0	15.5	0	0
Sept	2	229.5	4.5	0	0
Oct**	2	142.0	2.5	0	0
1965					
June	3	105.3	2.7	0.7	20.6
1966					
June	3	220.7	1.0	0	0
1967					
June	4		9.8	3.5	26.3

Table 2.
Numbers of larvae and pupae of *S. innotata* in the stubble at Tortilla Flats, 1961-67.

a, pupal case; b, dead pupa; d, pupa; e, moth; *, not including pupae and moths; **, data unavailable after this month.

Sampling date	No. of stubble samples	Av no. per sample (0.836m²) Tillers	Live Larvae	Dead Larvae	Mortality * %
1961					
June	6	192.8	0.5	0	0
July	4	257.0	0	0.3	100.0
Aug	4	183.5	0	0	0
Sept**	2	190.5	0	0	0
1962					
June	4	167.3	4.8	3.0	38.5
July	4	151.0	7.0	0.5	6.7
Aug	2	176.5	5.0	1.0	16.7
Sept	4	188.8	2.3	1.0	30.3
Oct	6	172.7	6.3	1.2	16.0
Nov	4	156.0	0.8+0.3[d]+0.3[a]	1.8	69.2
Dec	2	138.5	0	1.5+0.5[b]	100.0
1963					
June	4	166.8	8.0	0.5	5.9
July	4	165.0	26.5	1.3	4.7
Aug	4	193.0	13.8	1.5	9.8
Sept	4	190.5	17.5	0.8	4.4
Oct	6	177.0	32.0	6.3	16.5
Nov	4	122.5	3.8+0.3[d]+0.3[e]	4.0	51.3
Dec	2	113.0	0	0	0
1964					
June	2	204.0	24.5	4.5	15.5
July	2	191.0	20.5	1.5	6.8
Aug**	2	185.0	12.0	0.5	4.0
1965					
June	2	192.0	30.0	10.5	25.9
1966					
June	3	117.0	4.7	3.7	44.0
1967					
June	4		27.0	10.0	27.0

Termination of Aestivation. The aestinvating larvae pupated and emerged soon after the first rains of the wet season. The aestivation period varied from 4½ to 7½ months.

Field observations and laboratory experiments were carried out to study termination as follows:

(1) Field Observations. Field data (Table 3) for the eight years 1960-1967 on the date of moth emergence (as monitored by moth traps) at Humpty Doo and Tortilla Flats was compared with rainfall records for the two sites to determine the effect of rain on aestivating larvae of *S. innotata*.

Table 3.
Amounts of initial rain, number of showers equal to or greater than 12 mm of rain and total number of showers up to moth emergence at Humpty Doo (H.D.) and Tortilla Flats (T.F.).

Site		1960	1961	1962	1963	1964	1965	1966	1967
H.D.	Initial rain (mm)	13.7	1.8	2.0	0.3	1.6	26.2	1.6	12.0
	No. showers								
	> 12 mm	4	4	1	4	6	3	3	3
	Total	7	16	15	10	15	8	5	8
T.F.	Intial rain (mm)	11.2	0.8	12.0	4.8	1.2	0.4	3.8	2.0
	No. showers								
	> 12 mm	2	3	2	2	6	0	2	4
	Total	11	13	12	12	18	6	4	10

Of the 16 records available 11 showed an initial rainfall of less than 5mm and it seems intuitively plausible that small amounts of rain will not wet the larvae, especially as they are somewhat protected by a silken cocoon.

From the available data, an assessment of the effect of differing amounts of initial rain was attempted by determining the regression for days to moth emergence (ME) from the day of occurrence of varying volumes of opening rains (ID). (Table 4)

Table 4.
Correlation and percent variance due to regression between days to moth emergence from the day of occurrence of varying amounts of opening rains.

ME, moth emergence; ID 0.25, any rainfall equal to or greater than 0.25mm; ID5, rain of 5mm or more spread over 3 days; ID12, first accumulation of 12mm or more rain for the season; ID20, first accumulation of 20mm or more rain for the season; ID25, first accumulation of 25mm or more rain for the season. **, *** significant at P = 0.01, and P = 0.001, respectively.

Relation	Correlation	% Variance due to regression
ME0.25 with ID 0.25	-0.50	20.0
ME5 with ID5	-0.70 **	45.0
ME12 with ID12	-0.76 ***	54.8
ME20 with ID20	-0.76 ***	55.3
ME25 with ID25	-0.77 ***	57.1

From the available data an assessment of the effect of differing amounts of initial rain was attempted by determining the regression for days to moth emergence (ME) from the day of occurrence of varying volumes of opening rains (ID) (Table 4)

At the same time the regression model included the effect of the magnitude of particular opening rain (IR), the total rainfall from the time of the opening rains to the time of moth emergence (TR) and the linear interaction effects ID.IR and ID.TR. The only significant effects found were due to ID. This relation between moth emergence (ME) and ID was linear and, it can be seen from Table 4 that the degree of correlation increases with increasing volumes of opening rains up to 12mm, with only a slight increase of opening rains greater than 12mm.

The negative correlations found suggest that the longer the opening rains are delayed the quicker the first moths appear.

A correlation between moth emergence from the day of occurrence of opening rains equal or greater than 0.25mm and the total rain falling up to the time of moth emergence was significant (0.60, $P<0.05$). However this correlation is considered to be spurious, because the longer moth emergence is delayed, the greater the volume of rain which can fall.

(2) Laboratory Experiments. In 1965 the termination of aestivation was studied in the laboratory (Darwin City) and under natural conditions to assess the effect of artificial and/or natural precipitation on pupation and moth emergence.

The results showed a similar linear response to precipitation volume; that is, time to moth emergence decreased as precipitation volume increased.

The regression of mean time of moth emergence on total 'rain' received accounted for 86.0% of the variance in time of moth emergence. The time at which precipitation commenced did not affect moth emergence, indicating further that the negative correlations referred to earlier, which suggest that the longer the delay in the opening rains the earlier the first moths appear, were unreal.

DISCUSSION

The migratory behaviour of the late instars has only been observed in the laboratory by van der Goot (1925) who does not believe it to be usual or useful in the field. This behaviour has been observed both in the field and in the laboratory in the present study. It seems that this behaviour is of particular significance in the insecticidal control of *S. innotata* and other *Scirpophaga* spp. which have the same behaviour, especially the insecticides applied in the paddy water on which the larvae drift and will be killed before finding suitable tillers.

No experiments were conducted to investigate the relationship between the infestation levels and yield losses in northern Australia. Estimation of yield losses caused by the borer is complicated because many factors (such as time of attack, rice variety, climatic conditions, soil fertility, cultural practice etc.) affect the relationship. In Indonesia, van Halteren (1979) has found that each unit percent "dead hearts" causes 0.5 percent yield loss and each unit percent "white heads" causes 1.2 percent yield loss in *S. innotata* studies. Indonesia and northern Australia have the same predominant borer species, similar climate and some introduced IRRI varieties in common so we may adopt van Halteren's results to assess the crop losses before our investigation(s) become available.

S. innotata is the most consistant and serious pest in wet season rice crops but its damage in dry season rice crops is negligible in the Northern Territory. In North Queensland and the Kimberley region of Western Australia, which have a similar climate to the Northern Territory, winter (dry season) crops are apparently not attacked (Halfpapp, personal communication; Koch, 1960) but it is possible that the few 'dead hearts' or 'white heads' present in winter (dry season) are not noticed. However, late sown dry season crops have been infested by the borer in the Ord area of Western Australia (Learmonth, personal comunication).

Since the early 1960's it has been suggested that delayed sowing and insecticide applications before or during preheading stage should be investigated and practised in order to escape attack by the first generation and to reduce heavy yield losses by the third generation respectively (Li, 1972; unpublished data). According to the present study in wet season crops moth flights of aestivating generations and of the second generation were always higher than the others and the peak number of larvae of the third generation occurred in mid March (Fig. 3). Although these key dates may have to be altered each year, the sowing date could be adjusted to avoid the coincidence between the preheading period and the peak number of larvae of the third generation which may result in heavy losses by "white heads".

There was only one severe infestation of *S. innotata* in the 1964-65 experimental crop at Tortilla Flats in the Northern Territory. Although the 1964/65 wet season experimental and first commercial crops at Tortilla Flats and the experimental crop at Humpty Doo all were sown late enough to escape attack by the first generation, the only experimental crop at Tortilla Flats was very seriously damaged as mentioned earlier. The severe infestation may be associated with high cutting of rice stems and failure to destroy stubble and volunteer rice by cultivation for a number of years before the 1964-65 wet season at Tortilla Flats. All these unfavourable practices may be responsible for the sudden increase of numbers of aestivating larvae year after year before the 1964/65 season at Tortilla Flats in comparison with

Humpty Doo where low cutting of rice stems and the destruction of stubble and volunteer rice have always been practised (see Tables 1 and 2). This has also been discussed in detail in the author's former paper (Li, 1972).

By contrast no severe infestation occurred in the first commercial crop, grown in 1964\65 on virgin soils at the Pilot Farm located a few kilometres' distance from the experimental crop at Tortilla Flats.

Major mortality factors included parasites (*Bracon* sp. and *Goniozus* sp.) at the beginning of aestivation; dessication in the long dry season; disease (unidentified); and rainfall at the beginning of the wet season (at the end of aestivation).

It was not possible to determine the extent of mortality caused by different factors because there were no visible symptoms on dead larvae except some emerged parasites or their remains. Therefore only the overall mortality is presented in Tables 1 and 2.

Aestivating larvae are the main source of infestation for the next rice crops. Control measures may best be effected in them during aestivation. It is also a critical period during which they may be susceptible to control. The assessment of their numbers and mortalities caused by key factors is very important in planning control to reduce the size of the aestivating generations affecting the next new crops.

Diapause in a state of developmental arrest as a response to unfavourable environmental conditions. It is expressed as hibernation in the temperate zone and as aestivation in the tropical and subtropical zones. The diapause of the rice stem borers, particularly of *Chilo suppressalis*, has been exhaustively investigated in temperate zone but poorly in tropical and subtropical zones.

In temperate areas, recent investigations have shown that diapause in *C. suppressalis* is induced by day length (photoperiod) (Inoue and Kamanos, 1957), temperature (Kukaya, 1950), or chemical composition of mature rice plants (Mikaye and Huziware, 1951). It is also influenced by inherited differences (Fukaya, 1948) or regulated by the endocrine system (Fukaya and Mitsuhashi, 1957).

S. incertulas larvae also enter diapause in winter in some temperate areas (Nakamura, 1955) or when they feed on mature rice plants (Ishikura and Nakatsuka, 1955). The species' two local races have different diapausing tendencies (Samezima, 1960). Although the inducing factors are not yet clarified, the photoperiod, or the maturity of the rice plant mentioned above, or both, may be related to the onset of diapause (Kiritani and Iwao, 1967).

In tropical and subtropical regions diapause has been studied only in *S. innotata*, in which it is induced by the different composition of food in the maturing rice plants (van der Goot, 1925; Li, 1972). In other species, the diapause is thought to be induced by low temperature in winter (Banerjee and Pramanik, 1967). In northern Australia, minority of *S. innotata* larvae of the third generation, which hatched out at an earlier date to reach maturity earlier and pupated before heading (or before changes of composition of food in the rice plants), continued to breed; while the majority of larvae from the same generation reached maturity later and underwent diapause induced by the maturing plants (see Fig. 2). This evidence is not yet sufficient to confirm that diapause is induced by maturing plants until other factors which induce diapause in *C. suppressalis* are also explored. There is indeed much more research required on these inducing factors in *S. innotata*.

In Surinam, van Dinther (1961) has studied the effect of artificial precipitation on the break of diapause of *Scirpophaga albinella* (Cr.) (= *Rupela albinella* Cr.). He has found that (1) the higher the precipitation the sooner the first moths appear; and (2) the longer the diapausing larvae have stayed in the dry stubble, the shorter the emergence period will be.

From the studies published by van der Goot (1936), van der Laan (1959) and Li (1972) mentioned earlier and just above (van Dinther, 1961) and the present study, it would be expected that the correlations are real. Assuming that some minimum volume of rainfall in a defined time period is required to terminate aestivation, the increase in the degree of correlation with increasing volume of initial rain may possibly be due to the increasing likelihood that the minimum opening rainfall required to terminate aestivation has been received.

The negative correlations found from the present results are similar to that of van der Goot (1925) and van Dinther (1961). The fact that no effect due to the volume of initial rainfall nor any interaction of the varying volume of opening rains and the magnitude of particular opening rain were detected requires an explanation. The only suggestion which can be offered is that the degree of shower activity and the length of records are too small. In future, records of the distribution of the numbers of moths caught in the light traps on different dates should be extended so that the significance of different amounts of rain in any one period could be assessed.

CONCLUSION

Scirpophaga innotata is distributed in the tropical regions of eastern Asia and Australia between the latitude 11°N (Iloilo, Philippines) and 17°S (Mareeba, Australia) where there are pronounced dry and wet seasons which favour the borer so that it is often the dominant borer species. In these regions temperature is not a limiting factor. Although it is multivoltine, the number of generations in a year depends on the varieties of rice cultivated, the length of the planting period and the availability of rice crops. *S. innotata* achieves 2-3 generations in the Philippines (Otanes and Sison, 1941), 3-5 generations in Indonesia (van der Goot, 1925) and 3-4 generations in northern Australia. If rice is grown all the year round, 7 or 8 overlapping generations may occur in northern Australia and 9 or 10 generations in Indonesia (van der Goot, 1925). However, during the dry season or off-season, the larvae of residual third and fourth generations in northern Australia and of the fourth generation in Indonesia (van der Goot, 1925) aestivate in the stubble. Besides these larvae which aestivate, others continue to breed in dry season rice. Both breeding in dry season rice crops or in ratoon rice and entering aestivation occur in northern Australia, Indonesia (van der Goot, 1925) and East Malaysia (Rothschild, 1971).

In northern Australia the occurrence of the borer in the standing crop was found to have four peaks of moth flights and four peaks of larvae and pupae. Moth numbers of the first and third generations declined abruptly due to the late sowing and a small number of moths emerged to produce the fourth generation. The peak numbers of larvae of the first and second, and of the third and fourth generations synchronised with the vegetative stage and reproductive stage of crop respectively. The latter two generations of larvae may result in heavy yield losses by "white heads".

The abundance of the borer in the stubble, the numbers of larvae and pupae increased yearly until 1964 at Humpty Doo and 1965 at Tortilla Flats where the markedly high number of aestivating larvae in the previous year could be one of the contributory factors in 1964-65 severe infestation.

The onset of aestivation in maturing larvae is probably induced by changes of composition of food soon after heading but this can not be confirmed until other factors are also explored.

In termination of aestivation, under field conditions the relation between moth emergence and day of occurrence of varying volumes of opening rains was linear. The degree of correlation increased with increasing volumes of open rains up to 12 mm, with only a slight increase for opening rains greater than 12 mm.

Results from laboratory experiment showed a similar linear response to precipitation volume; that is, time to moth emergence decreased as precipitation volume increased.

Under both field and laboratory conditions the negative correlations found, which suggest that the longer the delay in the opening rains the earlier the first moths appear, were unreal.

From the present study, it is suggested that the following programmes should be included in future research: (1) Study of yield losses associated with "dead heart" and "white head", as well as economic threshold studies to determine whether to apply control measures; (2) Assessment of the numbers of aestivating larvae and identification of key mortality factors; (3) Investigation of all factors inducing aestivation; (4) Extension of records of the distribution of moth numbers caught in light traps on various days in order that the significance of different amounts of rain in any one period may be assessed.

REFERENCES

Arvind, A. (1987). Host plants for yellow rice borer (YSB) *Scirpophaga incertulas* and white stem borer (WSB) *S. innotata*. Int. Rice Res. Newsl. 12 (3), 33.

Banerjee, S.N. and Pramanik, L.M. (1967). The lepidopterous stalk borers of rice and their life cycles in the tropics. In 'The Major Insect Pests of the Rice Plant', pp.103-124. (Johns Hopkins Press : Baltimore, Maryland).

Basinski, J.J. (1972). A review of rice growing in the Northern Territory and Western Australia. In 'Aust. Rice Res. Conf., Leeton, N.S.W., Feb. 1972', Working Papers, p. 1-7.

Common, I.F.B. (1960). A revision of the Australian stem borer hitherto referred to *Schoenobius* and *Scirpophaga* (Lepidoptera : Pyralida, Schoenobiinae). Aust. J. Zool. 8 (2), 307-347.

Commonwealth Institute of Entomology (1985). Distribution maps of pests. Series A (Agricultural), Map No. 253 (revised).

Custodio, H.A. (1972). Chemical control of insect pests and diseases of rice in the Philippines. Jpn. Pestic. Inf. No. 10, 39-59.

Das, Y.T. (1976). Cross resistance to stemborers in rice varieties. J. Econ. Entomol. 69 (1), 41-46.

Fukaya, M. (1948). On the local races of the rice stem borer [In Japanese]; Nogaku Kenkyu 37, 121-23.

Fukaya, M. (1950) On the factor inducing the dormancy of the rice stem borer *Chilo simplex* Butler. Proc. 8th Int. Congr. Entomol., Stockholm, 1948, 223-225.

Fukaya, M. and Mitsuhashi, J. (1957). The hormonal control of larval diapause in the rice stem borer *Chilo suppressalis*. I. Some factors in the head maintaining larval diapause. Jpn. J. Appl. Entomol. Zool. 1 (3), 145-154.

Halfpapp, K.H. (1987). Rice entomology in the Tinaroo Irrigation Area. In '4th Workshop on Tropical Agricultural Entomology, Darwin, N.T., May 1987', Working Papers, 4pp.

Inoue, H. and Kamano, S (1957). The effects of photoperiod and temperature on the induction of diapause in the rice stem borer, *Chilo suppressalis* Walker. Jpn. J. Appl. Entomol. Zool. 1, 100-5.

Ishikura, H. and Nakatsuka, K. (1955). 'A Review concerning the infestation and prediction of the paddy borer'. (Japanese Plant Protection Association, Tokyo).

Jones, E.L. (1972). Insect pests of rice in the Riverina. In 'Aust. Rice Res. Conf., Leeton, N.S.W., Feb. 1972', Working Paper, p.4 (c) - 21.

Kiritani, K. and Iwao, S. (1967). The biology and life cycle of *Chilo suppressalis* (Walker) and *Tryporyza* (Schoenobius) *incertulas* (Walker) in temperate-climate areas. In 'The Major Insect Pest of the Rice Plant', pp. 45-101. (Johns Hopkins Press : Baltimore, Maryland).

Koch, L.E. (1960) Rice stem borers at Kimberley research Station. J. Agric. West. Aust. 1 (12), 2-4.

Lewvanich, A. (1981). A revision of the old world species of *Scirpophaga* (Lepidoptera : Pyralidae). Bull. Br. Mus. (Nat. Hist.) Entomol. 42 (4), 185-298.

Learmonth, S.E. (1980). Rice insects and their management in the Ord River irrigation area of Western Australia. Int. Rice. Res. Newsl. 5 (1), 14.

Learmonth, S.E. (1981). Parasite 'hitch hikers' hit Ord rice pest. J. Agric. West. Aust. 22 (2), 68-69.

Li, C.S. (1961). Bionomics of the white rice borer, *Tryporyza innotata* (Walk.). Int. Rice Comm. Working Party on Rice Prod. Prot., New Delhi, pp. 1-13.

Li, C.S. (1970). Some aspects of the conservation of natural enemies of rice stem borers and the feasibility of harmonizing chemical and biological control of these pests in Australia. Mushi 44 (3), 15-23.

Li, C.S. (1972). Integrated control of the white rice borer, *Tryporyza innotata* (Walker) (lepidoptera : Pyralidae), in northern Australia. Mushi 45 (Suppl.), 51-59.

McDonald, D.J. (1977). Rice and its adaptation to world environments. Ricemill News, pp. 24-35.

Miyake, T. and Huziwara (1951). New factors inducing diapause in the rice stem borer (*Chilo simplex* Butler) and the green rice caterpillar (*Naranga aenescens* Moore). [In Japanese]; Spec. Rep. Hiroshima Agric. Expt. Sta. 4, 1-10.

Nakamura, S. (1955). Notes on the diapause of the rice paddy borer. [In Japanese]; Gensei, Kochi, 4 (1/2), 45-47.

Nickel, J.L. (1964). Biological control of rice stem borers : a feasibility study. Int. Rice Res. Inst. (Los Banos) Tech. Bull. No. 2.

Oka, H.I. (1978). An observation of wild rice species in tropical Australia. Report of trip, 1978. Natl. Inst. Genet., Misima, Japan. Contrib. No. 1216.

Otanes, F.Q. and Sison, P.L. (1941). Pests of rice. Philipp. J. Agric. 12 (1), 211-259.

Pathak, M.D. (1968). Ecology of common insect pests of rice. In 'Annu. Rev. Entomol.' Vol. 13, ed. Smith, R.F. and Mittler, T.E., pp. 257-294.

Pathak, M.D. (1971). Resistance to insect pests in rice varieties. Oryza 8 (2) (Suppl.), 135-44.

Pathak, M.D. and Dyck, V.A. (1973). Developing an integrated method of rice insect pest control. Pans 19 (4), 534-544.

Rothschild, G.H.L. (1967). Insect pests of rice in Malaysia. Part II Sarawak. In 'The Major Insect Pests of the Rice Plant', pp. 635-641. (Johns Hopkins Press : Baltimore, Maryland).

Rothschild, G.H.L. (1970). Parasites of rice stemborers in Sarawak (Malaysian Borneo). Entomophaga 15 (1), 21-51.

Rothschild, G.H.L. (1971). The biology and ecology of rice stem borers in Sarawak (Malaysian Borneo). J. Appl. Ecol. 8, 287-322.

Samezima, T. (1960). Report of the Miyazaki Agr. Expt. Sta. (mimeo). In Kiritani, K. and Iwao, S. (1967) (see above).

Snellen, P.C.T. (1880). Lepidoptera. Midden-Sumatra, Leyden 4 (1), 8, 79.

Soenardi, I. (1967). Insect pests of rice in Indonesia. In 'The Major Insect Pests of the Rice Plants', pp. 675-683. (Johns Hopkins Press : Baltimore, Maryland).

Soenardi, I. (1972). Results of some field experiments on the chemical control of the major rice insects in Indonesia. Jpn. Pestic. Inf. No. 10, 11-26.

van der Goot, P. (1925). Levenswijze en bestrijding van den Witten Rijstboorder op Java, Meded. Inst. PlZiekt, Buitenz. 66, 1-308.

van der Goot, P. (1936). Biologische grondslagen van de rijstboorderbestrijding. Landbouw 11 (11), 473-482.

van der Goot, P. (1948). Twaalf jaren rijstboorderbestrijding door zaaitijdsregeling in West Brebes (Res. Pekalongan). Meded. Alg. Proefst. Landb. Buitenz. No. 78, 1-32.

van der Laan, P.A. (1959). Correlation between rainfall in the dry season and the occurrence of the white rice borer (*Scirpophaga innotata* Wlk.) in Java. Entomol. Exp. Appl. 2 (1), 12-20.

van Dinther, J.B.M. (1961). The effect of precipitation on the break of diapause in the white rice borer *Rupela albinella* (Cr.) in Surinam (South America). Entomol. Exp. Appl. 4, 35-40.

van Halteren, P. (1979). The insect pest complex and related problems of lowland rice cultivation in South Sulawesi, Indonesia. Meded. Landpouwhogesch. Wageningen 79 (1), 1-111.

Walker, F. (1863). List of the specimens of lepidopterous insects in the collection of the British Museum. 28, 523.

ACKNOWLEDGEMENTS

Sincere thanks are extended to the specialists of the Commonwealth Institute of Entomology, London for identifying the rice insect pests and their natural enemies; to former officer(s)-in-charge of CPRS, CSIRO and former officer(s)-in-charge of UARES and their staff for assistance and co-operation; to CSIRO officers Mr K.P. Haydock, Dr D. Ractliff and Mr K.M. Cellier, Division of Mathematics and Statistics for statistical analyses; to my former assistants Messrs M.J. Dyer, S. Gardiner and K. Hodder, for their help in the field and in the laboratory; and to my colleagues Mr A.J. Allwood, Dr D.P. Drover and Dr R.J. Thistlethwaite for valuable comments and reading the manuscript.

APPENDIX. Rice insect pests in northern Australia.

H, heavy; L, low; M, moderate; **Niphadoses palleucus* Common erroneously recorded as a rice stemborer by Koch (1960).

Order and Family	Scientific Name	Incidence	Distribution
Coleoptera: Melyridae	*Laius major* Blackb.	L	NT
Hemiptera: Alydidae	*Leptocorisa acuta* (Thunb.)	L	NT, QLD
Cicadellidae	*Nephotettix apicalis* Motsch.	L	NT
	Nephotettix sp.	L	WA, QLD
	Recilia dorsalis (Motsch.)	L	NT, WA, QLD
	Tettigella spectra Dist.	L	NT
Delphacidae	*Nilaparvata lugens* Stål	L-M(in NT,WA) L-H(in QLD)	NT, QLD, WA
	Sogatella fieberi (Muir)	L	NT
	S. furcifera (Horváth)	M	NT, WA
Lygaeide	*Graptostethus diffusus* Wlk.	L	NT
	Pachygrontha austrina Kirk.	L	NT
Pentatomidae	*Eysarcoris trimaculata* Dist.	L(in NT), M(in WA, QLD)	NT, WA, QLD
Pseudococcidae	*Chorizococcus lii* Brookes	L	NT
Lepidoptera: Hesperiidae	*Borbo impar lavinia* Waterh.	L	NT
	Parnara amalia Semper	L(in NT), M(in QLD)	NT, QLD
	P. nasosida (Waterh.)	L-M	QLD
	Pelopodas lyelli lyelli (Roths.)	L-M	QLD
	Taractrocera ina ina Waterh.	L	NT
	Telicota augias argilus Waterh.	L	NT
Noctuidae	*Molis frugalis* Fabr.	L	NT, QLD
	Mythimna convecta (Wlk.)	H	QLD
	M. loreyimima (Rungs)	M	WA
	M. separata (Wlk.)	M	WA
	Mythimna sp.	L	NT
	Spodoptera exempta (Wlk.)	M	NT QLD
	S. mauritia (Boisd.)	L-M (in NT), H (in QLD)	NT, QLD
Nymphalidae	*Melanitis leda bankia* Fabr.	L	NT
Pyralidae*	*Chilo polychrysa* Meyrick	L	NT
	C. suppressalis (Wlk.)	L	NT
	Cnaphalocrocis medinalis Guen.	L-M	QLD
	Marasmia sp.	M	NT
	Nymphula stagnalis Zell.	L(in QLD)-M(in NT)	NT, QLD
	Scirpophaga innotata (Wlk.)	H	NT, QLD, WA
Orthoptera: Acrididae	*Austracris guttulosa* (Wlk.)	L	WA
	Bermiella acuta (Stål.)	L	NT, QLD
	Gastrimargus musicus (Fabr.)	L	WA
	Locusta migratoria (Linn.)	L	WA
Balattidae	*Ellipsidion Humerale* (Tepper)	L	NT
Tettigoniidae	*Euconocephalus? cornutus* Redt.	L	NT

A list of captions to figures:

FIG. 1. Life cycle of *S. innotata* in the laboratory, 1962-63. *, the aestivating larvae collected from the field and kept in insect cages; **, the egg masses collected from the field.

FIG. 2. Phenological relationship between the life cycle of *S. innotata* and the rice crop at Humpty Doo and Tortilla Flats, 1962-63. S, sowing; V, vegetative stage; R, reproductive stage; M, maturing stage.

FIG. 3. Phenological relationship between the abundance of *S. innotata* and the rice crop at Humpty Doo, 1962-63. S, sowing; V, vegetative stage; R, reproductive stage; M, maturing stage; , moths captured by light trap; ,larvae and pupae from 'dead hearts' and 'white heads' dissected.

Fig.1.

Fig. 2.

Fig.3.