DETERMINATION OF KEY FACTORS AFFECTING THE POPULATION DYNAMICS OF *DIOPSIS LONGICORNIS* AND *D. APICALIS* (DIPTERA: DIOPSIDAE), PESTS OF RICE IN THE REPUBLIC OF GUINEE, WEST AFRICA

by

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ABSTRACT

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Pest status of the rice stem-borers, *Diopsis longicornis* and *D. apicalis* was not well known in the Republic of Guinée.

In the present study, adult and immature populations of both species were monitored under various local cultural practices, i.e., planting methods (direct and transplanted), different planting dates and seasons (wet and dry). As previously observed in other West African countries, *D. apicalis* did occasional damage to rice in Guinée. However, contrary to findings elsewhere, *D. longicornis* was not an important pest of Guinean rice, infesting 4 % of stems over the five seasons studied.

Regulators affecting population size and behaviour of *D. longicornis* were determined, focusing on factors controlling the fly's quiescent period in aggregation sites during the dry season, and the insect's movement to and from these refugia. Availability of cultivated and wild rice was found to interrupt or prevent quiescence of *D. longicornis*. Abiotic factors, (relative humidity, rainfall and photoperiod) influenced time of dispersal of *D. longicornis*.

RESUME

Doctorat | Hélène Chiasson | Entomologie

L'importance de *Diopsis longicornis* et *D. apicalis*, ravageurs du riz était peu connue en République de Guinée.

Dans cette étude, les populations imaginales et pré-imaginales des deux espèces ont été dénombrées sur riz cultivé sous différentes dates et méthodes de semis, en saison pluvieuse et sèche. Comme déjà observé dans plusieurs pays ouest-africains, *D. apicalis* a causé peu de dommage sur le riz guinéen. Par contre, en Guinée, *D. longicornis* n'a pas occasionné les dégats signalés ailleurs, détruisant seulement 4% des tiges au cours des cinq saisons étudiées.

Certains facteurs déterminant la taille et le comportement des populations grégaires de *D. longicornis* pendant leur periode de dormance en saison sèche ont été précisés. Egalement définis ont été les facteurs initiant la dispersion de l'insecte vers les sites d'aggrégation. La présence du riz cultivé et sauvage a empêché ou interrompu la dormance de *D. longicornis* tandis que certains facteurs abiotiques, (humidité relative, précipitation et photopériode) ont paru initier la dispersion saisonnière du diptère.

Suggested short title:

Population dynamics of rice pests *Diopsis longicornis* and *D. apicalis*

Hélène Chiasson

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ORIGINAL CONTRIBUTIONS

1. Our knowledge of *D. longicornis* and *D. apicalis* on dry and wet season rice crops in the Republic of Guinée was considerably increased and reliable conclusions were reached.
2. Transplanted rice was found to be significantly more damaged by *D. longicornis* than direct seeded rice. This has practical implications for rice farmers in Guinée.
3. First comprehensive description of *D. longicornis*' dry season quiescent period.
4. First study of *D. longicornis* dispersal to and from dry season aggregation sites or refugia.
5. *D. longicornis* dry season refugia were described for the first time, e.g., plants encountered, size of diopsid aggregations, sex ratios of individuals, determination of female reproductive state.
6. First description of *D. longicornis* pre-aggregation sites.
7. First comparison of abiotic factors, such as rainfall, temperature. photoperiod and relative humidity, with *D. longicornis* dispersal to and from dry season aggregation sites.

The following activities and findings are also being reported for the first time:

8. Marking, release and recapture of *D. longicornis*.
9. Specific techniques for monitoring *D. longicornis* were developed, e.g., marking with paints and by spine-clipping.
10. Use and effectiveness of interception traps for collecting *D. longicornis* and *D. apicalis*, e.g., sticky coloured traps and double-entry window traps.
11. Exact records and controlled study of *D. longicornis* larval infestation of wild rice, *Oryza longistaminata*.

12. First record of *D. longicornis* adult feeding on weeds, *Panicum* nr. *laetum* and *Commelina diffusa*.
13. *D. apicalis* was found not to be a major pest of rice in coastal Guinée since infestation was low and very inconsistent.
14. *D. longicornis* is not presently a major pest of rice in coastal Guinée, but it may become one by increasing the cropping season i.e., double and triple-cropping. Increasing rice acreage during the wet season instead of multiple cropping as a means of increasing rice production is preferred to prevent pest build-up.
15. Beginning of the rains, along with an increase in relative humidity at the onset of the wet season, are important signals to *D. longicornis* departure from dry season refugia and initiation of egg-laying on wet season rice. These abiotic factors either act directly on *D. longicornis* or indirectly through renewed growth of secondary hosts such as *Oryza longistaminata*.
16. Decrease in photoperiod, and in quality of the rice plant, seem to trigger *D. longicornis* departure from the wet season rice crop to dry season refugia.
17. Observations suggest that *D. longicornis* are attracted to dry season refugia by visual cues.
18. First records of pathogens infecting *D. longicornis* and *D. apicalis*.

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INTRODUCTION

Diopsid flies are major pests of rice in West Africa. There has been little research on rice pests, and especially on *Diopsis* spp. in this sub-region of Africa. Most studies on diopsids have focused on levels of infestation and effects on yield. The present study, in the Republic of Guinée, relates level of infestation by *D. longicornis* Macquart and *D. apicalis* Dalman to certain local cultural practices. In addition, I examined the ecological factors affecting population size and dispersal of the more important pest, *D. longicornis*. I chose this subject because the life-cycle of *D. longicornis*, which extends from an active reproductive stage in the wet season to a period of quiescence in the dry period, was not well understood. Furthermore, my studies, while contributing to the enrichment of fundamental knowledge on the flies, could also help in predicting the effects that *D. longicornis* might have on rice cultivation if government plans for intensification (e.g., increased acreage and multiple cropping) are implemented.

Although matters more pressing to the agricultural realities of Guinée, such as crop loss assessments, might have been addressed, logistical support for such research were unavailable. To evaluate properly *Diopsis longicornis*' and *Diopsis apicalis*' impact on local cropping systems, extensive studies involving several fields and representing several farming practices were necessary. Inadequate infrastructure - poor roads, and communication systems with areas within and outside the country, little laboratory space and equipment and few active local researchers and technicians - prevented the carrying out of research that depended on sophisticated resources and of trained personnel. The work was nevertheless attempted because it met the following challenges: it was an opportunity to fill a research gap, to contribute to Guinée´s agricultural development and, more personally, it answered the curiousity of a researcher fascinated with some of the ´strangest flies on earth´ (van Bruggen 1962).

To provide a perspective on the area in which this work was conducted, I have included background information on the agricultural base of the Republic of Guinée as it relates to rice production (Chapter 1). This section is followed by a thorough literature review of work done on *Diopsis longicornis* and *Diopsis apicalis* in West Africa, including the findings of this study (Chapter 2). I have given particular attention to the review because most reports on West African entomological research are hidden in obscure journals or in unpublished research summaries of local research stations, and generally unavailable. The research results are presented in two main chapters. Chapter 3 reports on experiments that were designed to determine the influences of local farming practices, such as time and method of planting, on the size of *D. longicornis* and *D. apicalis* populations during both the dry and wet seasons. Five seasons were studied in all, the 1987, 1988 and 1989 dry seasons and the 1987 and 1988 wet seasons. Chapter 4 describes *D. longicornis*´ dispersal behaviour to and from dry season aggregation sites and examines the factors regulating the fly´s quiescent period.

Notation and style. The name *Diopsis longicornis* was used throughout this study, as recommended recently by Feijen (1985), to refer to the larger stalk-eyed rice stem-borer. Common synonyms include *D. macrophthalma* Dalman or *D. thoracica* Westwood.

I have followed the notation and style conventions given in the CBE style manual (1983) and in the Publications Guide of the Entomological Society of America.

CHAPTER 1

SOCIOECONOMIC DESCRIPTION OF THE REPUBLIC OF GUINEE

IMPORTANCE OF RICE IN THE REPUBLIC OF GUINEE

Rice is the main staple food for the people of Guinée, both urban and rural. Consumption fluctuates from region to region, but 1985 estimates based on domestic production (500-640,000 tons of paddy per year) and imports (90,000 t/yr) gives a general average between 60 and 70 kg per person per year. This per capita consumption is well below that of the heavy consumers, such as Sierra Leone and Liberia (more than 100 kg per person per year), but comparable to Guinée s other neighbours, Sénégal, Côte d'Ivoire and Guinea-Bissau (60-80 kg per person per year; Hirsch, 1986). The Republic of Guinée is within the West-African Rice Zone (Figure 1).

With a new government in 1984, and a general opening to and acceptance of foreign aid and investment, along with a change in outlook concerning the development of agricultural systems, intensification of the rice crop has become a government priority. Self-sufficiency in rice would provide a staple for the peasant population, remove the burden of having to buy it, and, by lowering rice imports, would significantly reduce cash flow out of the country (Hirsch 1986, Min. Plan et Coop. Int. 1987, Min. Dev. Rural 1986 1987, Salomon 1987).

The Republic of Guinée should be able to attain self-sufficiency in rice, or at least significantly reduce its dependence on rice importation, because Guinée has a strong and ingenious agricultural base and favourable conditons for rice production. For example, in 1974, after three years of poor rainfall, famine was widespread in Africa, however, the nationwide effects of the drought in Guinée were mild compared to conditions in some other West African countries (Nelson et

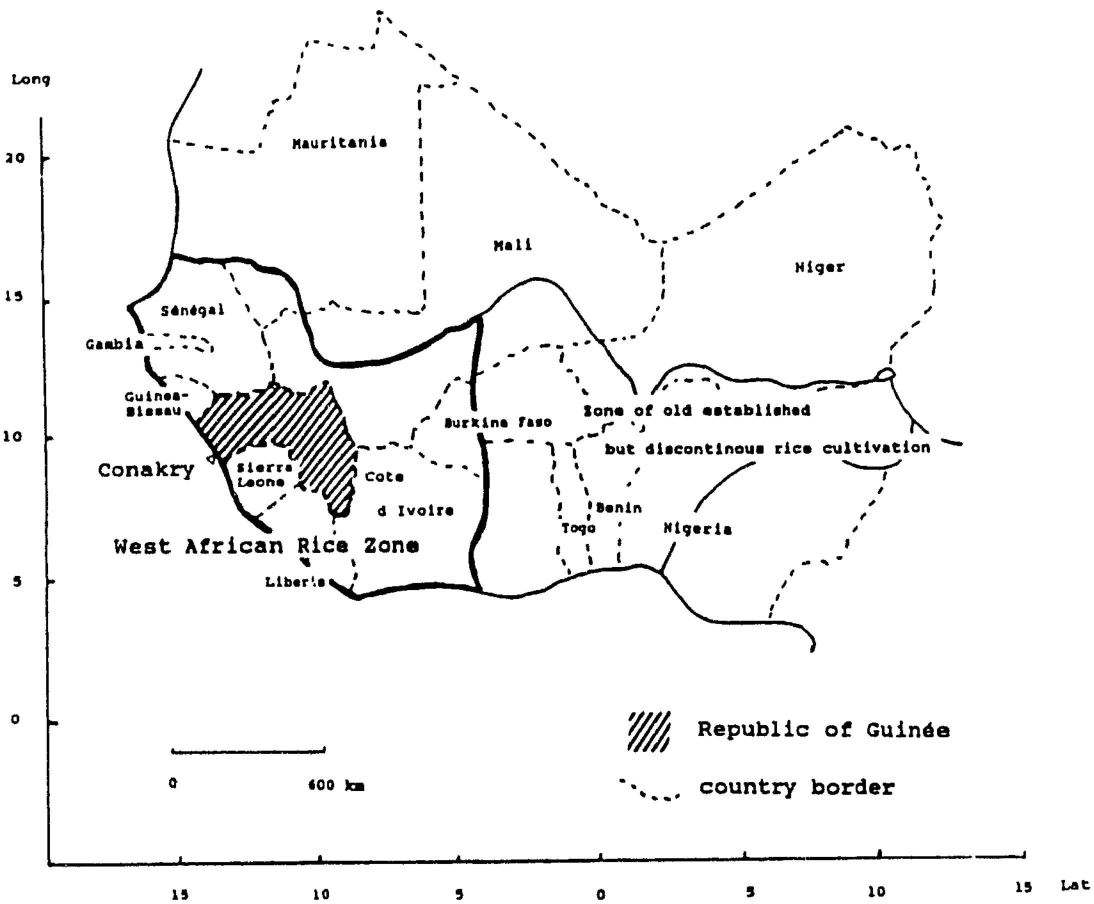

Fig. 1 THE REPUBLIC OF GUINEE AND THE WEST AFRICAN RICE ZONE (adapted from Richards, 1986)

al. 1975). With an increase in burning of forests and brush for agricultural land, and a change in overall African climatic conditions, Guinée's potential for feeding its growing population has declined since the 1970's. After independence in 1958, until the early 1980's, despite the government's emphasis on industrialization and collective effort, Guinée's agricultural production progressively declined. This may be attributed to the increase in civil service and other urban activities, compounded by a lack of economic incentives to producers (prices were fixed lower than production costs), the disruption of the distribution system, and rapid inflation and loss of confidence in the currency. Other constraints are lack of awareness and vision, disempowerment, and those aspects of the cultures, religions and social structures that act as barriers to achieving sufficient production. In the long term these are probably more important than science, technology and politics.

The Guinean farmer's response to this situation was to reduce his crop acreage to a minimum (Nelson et al. 1975, Min. Plan et Coop. Int. 1987), and rice production dropped from near self-sufficiency to almost strict local subsistence.

However, with proper management, by offering real incentives to farmers, and with the growing knowledge of sustainable intensification of food crops, the country can greatly increase its production (Min. Rel. Ext. 1986, Min. Dev. Rural 1987, Thai 1987).

CONSTRAINTS TO PRODUCTION

The main constraints to rice production are a stagnating low-quality institutional environment, technical deficiencies, and a lack of organized markets (Hirsch 1986). Present yields are rarely above 1.5 t/ha and are often closer to 900 kg/ha. This contrasts with 3.3 t/ha and 5.8 t/ha yields obtained under intensive production in China and Japan respectively (FAO, 1979). Although most Guinean farmers are competent technicians, and are familiar with the particular needs of the local varieties of rice, they are often hampered by difficult climatic conditions (too dry or too wet), an unfavourable topography and inadequate surface water supply to permit inexpensive irrigation, and severe pressure from weeds and pests of rice such as crustaceans (in mangrove areas), swamp rats, birds, diseases and insects.

CHAPTER 2

LITERATURE REVIEW

PESTS OF RICE IN WEST AFRICA

Although Africa's rice growing area is 35% of the world's total area in this crop, and about only 2% of its total production, rice production in this continent has seen a steady increase from 1965 to 1982. However, the per hectare yields have remained generally low (Alam et al. 1985). In 1967, Cramer evaluated yield loss of rice in Africa caused by insects, diseases and weeds at 34%, of which insects accounted for 14%. Barr et al. (1975) argue that these figures are too conservative and that Cramer based his estimates on insufficient data. These authors, using Cramer's and FAO (1972) estimates, evaluate losses caused by insects, disease and weeds at 51%. Pests of rice in West Africa are either cosmopolitan, or closely related to pest species found in other rice-producing continents, or restricted to Africa. The main pests are stemborers, and of these, *Diopsis* (Diopsidae: Diptera) is one of the genera that is restricted to Africa. Several species have been found throughout Africa on rice, i.e., *Diopsis longicornis* Macquart (=*D. thoracia* Westwood, *D. macrophthalma* Dalman), *D. apicalis* Dalman (=*D. tenuipes* Westwood), *D. collaris* Westwood, *D. affinis* Adams, *D. circularis* Macquart, *D. curva* Bertoloni, and *D. servellei* Macquart. However, only *D. longicornis* and *D. apicalis* do much damage to rice (Descamps 1957a, Grist & Lever 1969).

PEST STATUS OF *D. LONGICORNIS* and *D. APICALIS*

D. longicornis is believed to cause more damage to rice than *D. apicalis* because of its almost exclusive affinity for this crop (Descamps, 1957a). Studies have not succeeded, however, in quantifying its relationship with yield. Phrases such as ´serious pest´ and ´severe damage´ have been commonly used in the literature to describe *D. longicornis* and its effect on rice, but there has been little research to back up these statements. In Malawi, research by Feijen (1979) seems to show that because of compensatory tillering, *D. longicornis* may not have much effect on yield. How *D. longicornis* damages a rice plant is well documented and will be treated thoroughly later.

TAXONOMY OF *D. LONGICORNIS* AND *D. APICALIS*.

D. longicornis and *D. apicalis* are classified in the family Diopsidae of the Superfamily Nothyboidea, section Acalyptratae, Division Schizophora, Suborder Cyclorrhapha, of the Order Diptera (Borror, De Long & Triplehorn 1981). There is controversy over the names of both *D. longicornis* Macquart and *D. apicalis* Dalman. In 1817, Dalman described *Diopsis macrophthalma* and *Diopsis apicalis*. Macquart (1835) later described a *macrophthalma*-like specimen as *D. longicornis* and subsequently this species was again described as *D. thoracica* by Westwood (1837). This name became well used thereafter in rice entomology. Feijen (1985) has recently challenged it and has chosen *D. longicornis* as being the more correct name, because upon examining Dalman´s *macrophthalma* specimen, Feijen discovered that it belonged to the genus *Diasemopsis* because it bore a hair on the scutellar spine, as in *Diasemopsis signata*. Therefore, priority was given to the name *D. longicornis* Macquart to describe the economically important stalk-eyed rice stem-borer.

The nomenclature of *D. apicalis* is more problematical. The status of many *apicalis*-like specimens with an apical wingspot are being revised by Feijen (in preparation). He has already confirmed the synonymy of *D. tenuipes* as *D. apicalis*, and has redescribed *D. apicalis* (1987). However, much work still has to be done to elucidate the *apicalis* complex. This will probably add an additional 35 species to the genus. Feijen (personal communication) believes that species in Guinée are most likely the true *D. apicalis* Dalman, as well as *D. lindneri* Feijen and *D. occidentalis* Feijen (manuscript species).

MORPHOLOGY AND LIFE-CYCLE

Useful descriptions of the diopsids attacking rice can be found in Descamps (1957a), Abu (1972), Akinsola (1979), Tran (1981), Brenière (1983), and Feijen (1984). Tran provides excellent illustrations in his paper. More general descriptions are to be found in Brenière (1969), Agyen-Sampong (1978) and Hill (1983). The stages in the life-cycle of *D. longicornis* are illustrated in Figure 2 and those of *D. apicalis* are shown in Figure 3.

Egg. Eggs of *Diopsis* spp. are white, elongated, longitudinally striated and measure from 1.3 mm to 2 mm long. The extremities bear minute structures, the anterior one, differentiated according to species. A female can lay from 30 to 60 eggs according to Descamps (1957a). Brenière (1983) and Feijen (1984) give lower estimates of 30 and 48 respectively. Hatching occurs after 24 to 72 h.

Larva. Upon hatching, the larva enters the rice stem and feed, damaging from 3 (Descamps 1957a) to as many as 10 stems (Brenière 1983), before pupating in the last one visited. First instar larvae are 3 mm long and reach 17 mm by the last instar. Larvae are cylindrical to subcylindrical, comprising 12 segments, the last bearing two

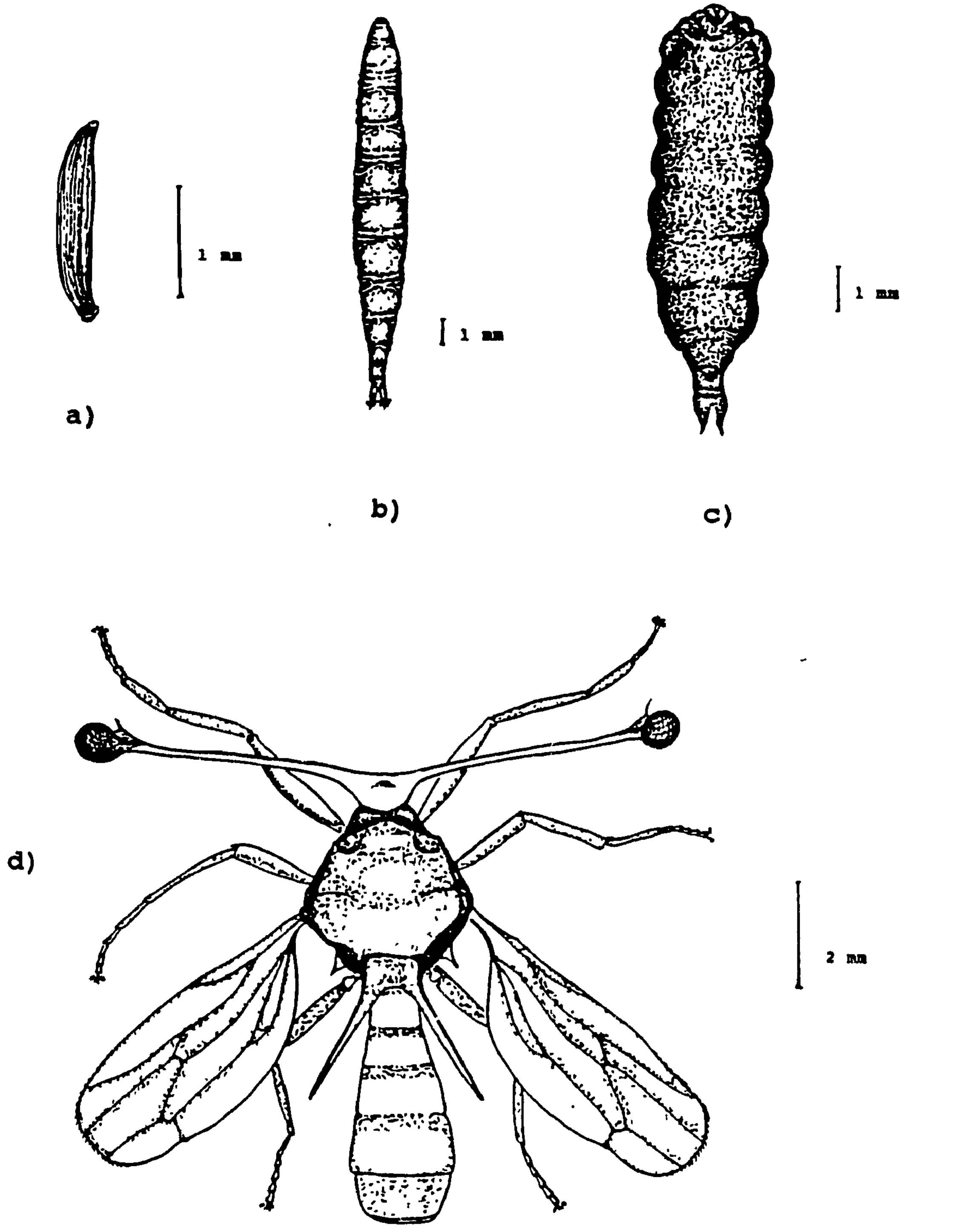

Fig. 2 LIFE CYCLE OF DIOPSIS LONGICORNIS

a) egg b) larva c) pupa d) adult

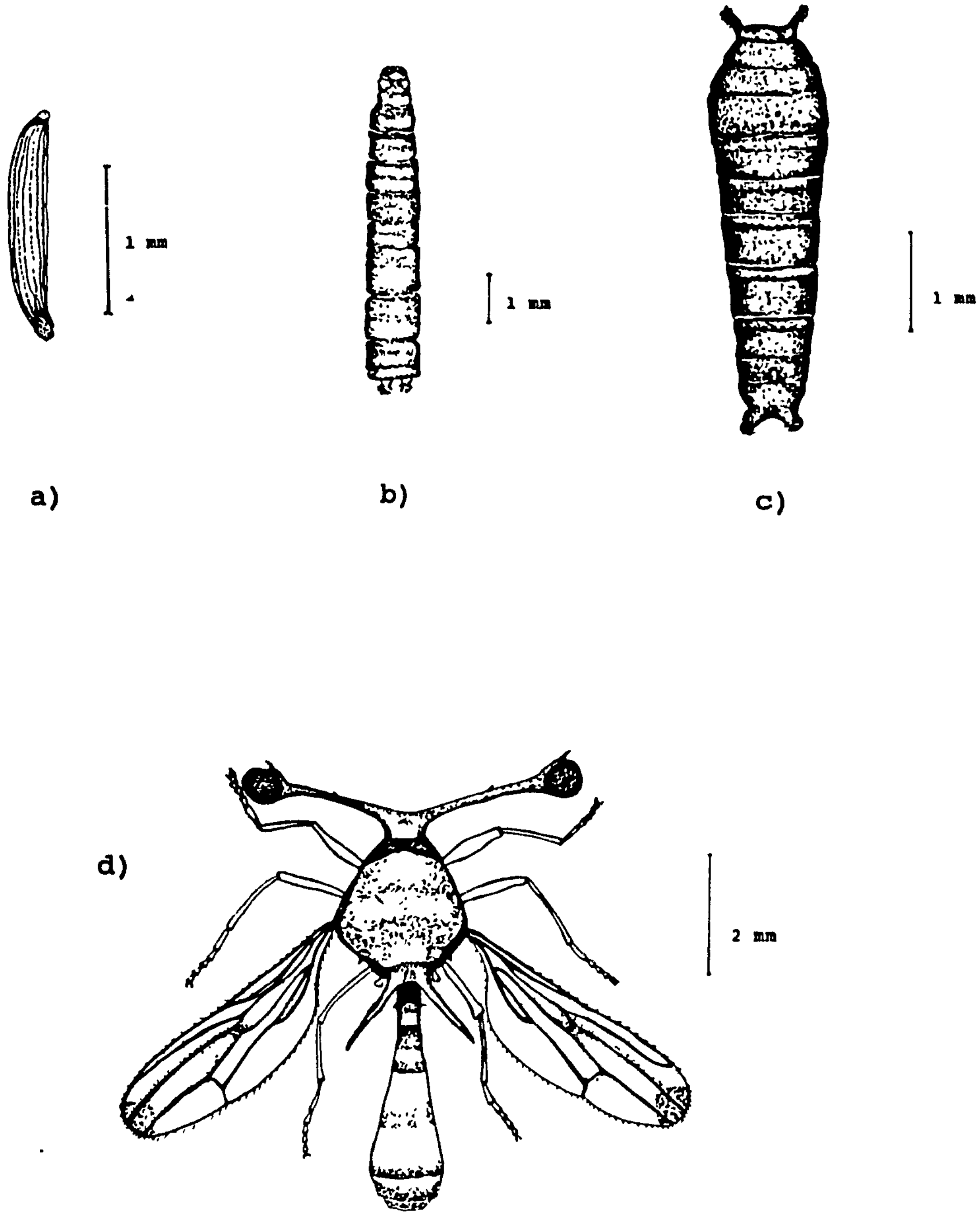

Fig. 3 LIFE CYCLE OF <u>DIOPSIS</u> <u>APICALIS</u>

a) egg b) larva c) pupa d) adult

prolongations; these prolongations or tubercles are long and narrow in *D. longicornis* and short and stubby in *D. apicalis*. At the apex of each tubercle is a spiracle surrounded by four groups of five sensorial hairs (Descamps 1957a, Lavigne 1962). Prothoracic stigmata of the genus *Diopsis* spp. are described as indented spatulae, the number of identations, being constant within a species. Descamps determined the duration of larval period at 25 to 33 days for *D. longicornis* and from 6 to 20 days for other diopsids (apparently including *D. apicalis*). Vercambre (1982) found that the larval period lasted from 28 to 35 days under relatively controlled temperatures (25-30^0 C), whereas Feijen (1984) found a duration of 30 to 40 days with a possible length of 75 days under field conditions. Alghali and Osisanya (1982a) showed that developmental time was not only a function of temperature, but also of the variety of rice on which the larva feeds.

Larvae of *D. longicornis* are apparently the only diopsid species to feed exclusively on undamaged stems. Females of *D. apicalis* deposit their eggs on damaged or undamaged stems (Descamps 1957a), or just on damaged stems (Scheibelreiter 1974); in contrast to my findings in which they were found mainly on undamaged stems. Upon hatching, *D. apicalis* larvae start feeding on the stems whether they are damaged or not. Whereas *D. longicornis* larvae are obligate phytophages, those of *D. apicalis* are facultative phytophages, feeding on decaying plant material as well as on healthy tissue. *D. apicalis* has been recorded also as a predator of *D. longicornis* and of lepidopterous larvae. Because of this, Scheibelreiter (1974) considers that *D. apicalis* should be regarded as a beneficial species rather than as a pest of rice. Cochereau (1985a) reached similar conclusions from his studies in Côte d'Ivoire.

Pupa. The pupa of *D. longicornis* measures 10 mm long and 2.8 mm wide and is slightly flattened dorso-ventrally (Figure 2). The anterior end is bulkier than the posterior and the colouring is reddish brown. The first segment is small and invisible on the dorsal side, but all other segments have accentuated margins. The posterior stigmata are more distinct than in *D. apicalis*. The pupa of *D. apicalis* (Figure 3) is smaller than that of *D. longicornis* (4 mm long by 1.1 mm wide), of a lighter colour and with rounder posterior stigmata (Descamps 1957a, Tran 1981). Pupation occurs in the stem, but not always at the site of larval damage. In the present study, pupae were most often found lodged between enfolding leaf sheathes of a healthy stem. Pupae found near damaged stems were usually parasitized. According to Descamps (1957a), pupation of *D. longicornis* lasts an average of 10 to 12 days depending on the temperature. Vercambre (1982) found that it took 7 or 8 days at 25^0 and 30^0 C and Feijen (1984) recorded 11 to 17 days at 25^0 C.

Adult. Adult *D. longicornis* and *D. apicalis* are distinguished by their characteristic stalked eyes. The small head of the fly is extended laterally into two long stalks each bearing a compound eye at their extremity. The minute antennae are born on these stalks just below the eyes. Many hypotheses have been proposed concerning the possible function of the eyestalks: a) binocular vision, b) a periscopic view, being able to see beyond and around the leaf or plant part on which the insect is resting (Feijen 1984), c) excessive organs (van Bruggen 1962), d) balancing organs, e) structures for monitoring of head movements and positions, f) structures involved in behavioural displays, g) a source of sexual dimophism, or h) for mimicry of wasps (Townes 1972).

The periscopic vision theory, favoured by Feijen, is supported by my own observations. Diopsids take flight quickly if disturbed. Following this flight, they each alight on different leaves and often different tillers, a behaviour, if continued in absence of disturbance, which would assure evenly-spaced egg deposition by well-dispersed females.

Adults of *D. longicornis* and *D. apicalis* have been described recently and illustrated by Descamps (1957a) and Feijen (1978 1984 1987). General descriptions are provided by Hill (1983), Heinrichs et al. (1985), Brenière (1969 1983), Shillito (1971a, b) and Steyskal (1972, cited by Feijen 1984).

Besides the eye stalks, other morphological features of the one cm long adult *D. longicornis*, include a globular, black thorax with lateral sculpturing. The scutellum bears two long, rigid spines measuring up to three times the length of the scutellum. I believe that these spines, along with a pair of smaller metapleural spines, probably render the insect unpalatable to predators, an asset especially useful during the dry season, when adults are found in swarms. The wings are hyaline with a slight pollinosity along the margins and microtrichia on the rest of the wings. The halteres are globular and white. The legs are pale brown and the 10-segmented abdomen is reddish-brown and covered with a fine, dense pollinosity.

D. apicalis is similar to *D. longicornis*, but it is smaller (about 6.5 mm), and the wings bear a characteristic apical wingspot covering the submarginal cell and the first and second posterior cell (Figure 3).

Few studies have been made of the internal organs of diopsids. Kumar and Nutsugah (1976) have described the alimentary and reproductive organs of *D. longicornis*. Vercambre (1982) described the ovarian development in *D. longicornis* in order to relate fecundity to infestation of the rice crop. Alghali and Osisanya (1982a) made similar observations in order to relate development time to preference for rice variety.

Development time in the field from egg-to-adult stage is 37 to 48 days according to Descamps (1957a), 34 to 45 days according to Vercambre (1982), and 44 to 54 days according to Feijen (1984). Feijen notes that Descamps´ calculation of 60 days for egg to egg development does not take into account the extended lifespan of the adult during the dry season, which can be as long as 9 months.

Alghali and Osisanya (1982a) observed *D. longicornis* development on different varieties of rice and found that the life cycle from egg to adult ranged from 29 to 44 days depending on both environmental conditions and rice variety. It is interesting that they found that the local species of rice, *Oryza glaberrima*, consistently provided the least suitable medium for development. Consequently, these varieties should been taken into consideration in rice-breeding programmes.

NATURAL ENEMIES

Information on natural enemies of *D. longicornis* and *D. apicalis* is limited to research done in neighbouring countries. No reports have been issued from Guinée.

Egg. Eggs of *D. longicornis* and *D. apicalis* have few known predators. Feijen (1984) considers, however, that 25% to 45% of the eggs are destroyed by predators. These might include, the pirate bug, *Orius punctaticollis* Reuter (Descamps 1957a) and carabids (Brenière 1983).

Egg parasitoids of *D. longicornis* and *D. apicalis* are more well documented. Descamps (1957a) estimates that 50% of the first generation and up to 75% of the second generation of *D. longicornis* are parasitized by the parasitic wasp *Trichogramma (Xanthoatomus) ethiopicus* Risbec (Trichogrammatidae) in Cameroon. Feijen and Schulten (1981) believe that this parasitoid was misidentified and that more than one species of *Trichogramma* were present in Descamps´ study. Four species of egg parasitoids have been recorded in Malawi, the two most important species being *Trichogramma kalkae* and *T. pinneyi*, which were described by Schulten and Feijen (1978, cited by Feijen 1984). Of less importance were *Trichogramma simmondsi* Nagaraja and a *Paracentrobia* species (Trichogrammatidae). From 1971-75, average rate of parasitism was between 43% and 73%, with peaks as high as 100% at the end of oviposition period of *D. longicornis*. Rates of parasitism were recorded in the 1972-73 season as 41% by *T. kalkae*, 16% by *T. pinneyi*, 0.3% by *Paracentrobia* sp. and 0.2% by *T. simmondsi*. In Zanzibar, *T. simmondsi* was a more important parasitoid of *D. longicornis* eggs (23%) than were *T. kalkae* and *T. pinneyi* (6% and 0.2% respectively). Sciomyzid flies are important alternative hosts of *Trichogramma* spp. that are parasitic on the eggs of stem-borers (Nishida & Torii 1970). *T. kalkae*, which parasitizes eggs of the *apicalis*-complex, has also been recorded from a sciomyzid.

It is important to note that no pathogen has been reported from any stage in the *D. longicornis* and *D. apicalis* life-cycle, i.e., egg, larva, pupa and adult.

Larva. Records of larval predators are few. Based on his attempts at rearing *D. longicornis*, Vercambre (1982) concluded that spiders and ants prey on the larvae as they move from one rice stem to another. Jordan (1966) found stems with holes of 3 to 5 cm in length, having the appearance of bird damage. She believed that predacious birds could be attacking the larvae. In Zanzibar, these holes were also found, but were attributed to tenebrionids preying on larvae (Feijen 1984). Feijen also saw a small carabid larva preying on *D. longicornis* larvae. Descamps (1957a) had also observed predation by carabid and tabanid larvae.

Larval parasites were found by Descamps (1957a). *Steleocerus lepidopus* Becker (Chloropidae) parasitized *D. longicornis* at a rate of 30% for 1st and 2nd generation and up to 80% by the end of the rice growing season. Brenière (1983) recorded *Steleocerus predatoria* Ferr as a larval parasite of *D. longicornis*, and Feijen (1984) collected larvae parasitized by nematodes (Rhabditata).

Pupa. Among pupal predators are the larvae of *Chilo zacconi* Blesz., (Pyralidae) (Descamps 1957b, cited by Feijen 1984), *D. apicalis* and of certain tabanids and carabids, but these were observed only occasionally by Descamps (1957a).

Tetrasticus (Aprostocetus) diopsisi Risbec (Eulophidae) is considered by Descamps (1957a) to be an important pupal parasitoid of *D. longicornis*, destroying up to 72% of the pupae throughout the year. Feijen (1984) considers that these counts are unusually high. His figures for pupal parasitism in Malawi were, on average, 15.5% over several years. Jordan (1966) observed a rate of 6.8% parasitism by *Prostocetus* sp. (Eulophidae), and Vercambre (1982) noted low level parasitism by *Tetrastichus diopsisi*. Pollet (1977) collected one pupa with an unidentified hymenopteran parasite. Other pupal parasites include *Aprostocetus brevistylus* Masi (Eulophidae) and *Eupelmella predatoria* Ferrière (Eupelmidae) (Brenière, 1983), *Aprostocetus* sp. and *Trichopria* sp. (Proctotrupidae) (Scheilbelreiter and Apaloo 1972, cited by Feijen, 1984), *Tetrastichus (Aprostocetus) brevistylus* Masi (Eulophidae), *Pleurotropis dipterae* Risbec (Eulophidae), *Eurytoma diopsisi* Risbec (Eurytomidae), *Eupelmella predatoria* Ferrière (Eupelmidae), *Opius annulicornis* Granger (Braconidae), *Trichopria oriphila* Ashmed (Proctotrupidae), *Galesus silvestrii* Kaeffer (Proctotrupidae), *Dirrhinus garouae* Risbec (Chalcididae), *Tetrastichus sesamiae* Risbec (Eulophidae), *Diourbelia diopsisi* Risbec (Pteromalidae), *Opius* spp. (Braconidae), *Bracon antennatus* Granger (Braconidae) (Descamps 1957a).

Adult. Descamps (1957a) , in Cameroon, observed the asilid *Omnatius variabilis* and two species of *Microstylum* (Descamps 1957b, cited by Feijen 1984) as predators of adult *D. longicornis*. Predators of stalk-eyed flies in Malawi include crabspiders (Thomisidae), various web-constructing spiders, dragonflies and praying mantids (Feijen 1984). Dragonflies and spiders are also mentioned by Brenière (1983) as predators of adults of *D. longicornis*.

In the course of my experiments with caged adults of *D. longicornis* and young rice plants (Chapter 4), I noticed that the diopsids died or disappeared quickly. Because adult dragonflies were emerging regularly from an abundant nymphal population in the water, I observed them on several occasions in order to check their possible predatory behaviour towards the stalk-eyed flies. The dragonflies showed no interest in the diopsids, flying away from them rather than towards them. Dissection of twenty dragonflies showed no diopsid remains in the gut. According to Dr. Raymond Hutchinson from the Biosystematics Research Centre in Ottawa (personal communication), emerging adult Odonota may not be predators because the rigid thorax and strong scutellar spines of the diopsids would be unpalatable to them. He suggested, however, that the dragonfly nymphs were the unsuspected predators. The nymphs are known to be very active searchers, and diopsids would be accessible especially during their evening and night rest period on rice leaves and on the side walls of the cage. In addition, the strong mandibles of the nymph could easily chew the rigid body of the adult flies.

Adult *D. longicornis* and *D. apicalis* are sometimes parasitized by fungi, especially by members of the Laboulbeniales (Feijen 1984), which appear as stalked leaf- or globular-shaped exvaginations of the cuticle. These fungi are host specific and, although they can appear on various parts of the body, they are also often position-specific and occasionnally sex-specific. On *D. longicornis*, Feijen found a rate of parasitism in females of 12% and in males, 30%. According to Feijen, rate of parasitism increases with age.

Other fungal parasites found on *D. longicornis* by Feijen (1984) are *Rhizomyces ctenophorus*, *Stigmatomyces porrectus* and undescribed *Stigmatomyces* sp.

ETHOLOGY AND ECOLOGY OF *D. LONGICORNIS* AND *D. APICALIS*

Major work on this topic has been scarce except for Descamps´ research in Cameroon (1956, 1957a & b) and Feijen´s in East Africa (1979, 1984). Vercambre (1982), in Sénégal, followed the phenology of *D. longicornis* and *D. apicalis* on rice crops from 1969 to 1977. Jordan (1966) added a short account of her observations of these two species of diopsids in Sierra Leone while pursuing her main interest, which was lepidopterous stem-borers. Brenière (1969, 1983) provided general descriptions that seem more to summarize Descamps´ and Feijen´s work than to record his own observations.

Pollet (1977, 1978) and Cochereau (1978, 1985a, 1985b), as part of their studies of the economic importance of diopsids in Côte d´Ivoire, have both described the phenology of *D. longicornis* and *D. apicalis* in relation to the different stages of rice. Scheibelreiter (1974) did similar studies in Ghana.

From those studies, it is clear that *D. longicornis* females are gravid at the onset of the rainy season, which coincides with the beginning of the rice growing season. The females lay their eggs on the young plants, perhaps even on nursery seedlings (Feijen 1979, Cochereau 1985a), and continue to do so until the end of the vegetative stage. Once hatched, the larva enters the stem at the ligule, then descends along the central whorl to the base of the stem where it begins feeding. The larva makes a diagonal cut in the heart tissue, which then withers and dies, thus preventing panicle formation and production of grain. Once the tissue begins to decay, the larva of *D. longicornis* leaves the stem and searches for a healthy one, which it will damage in the same way. The average larva destroys three stems before pupation (Descamps 1957a). Jordan (1966) says six stems are damaged, although she claims to be quoting from Descamps. Brenière (1969) estimates larval damage at 10 stems per larva. In Malawi, Feijen (1979) found, that a larva would remain in the same stem until pupation, damaging several hearts, except when attacking small seedlings. I consider that the differences in results between Feijen's and the others' mentioned, lie in interpretation. What Feijen calls 'stem', others refer to as 'plant'.

A larva of *D. longicornis* pupates in the tiller, sometimes in the stem after having damaged it, or more often in between the leaf sheathes enfolding the stem. Soon after emergence, adults reach sexual maturity, mate, and, if the rains and the rice crop are still present, begin laying. If the rains have stopped and if rice is no longer present in its vegetative stage, the flies remain sexually immature, swarm with other freshly emerging adults and search for humid and shaded refuges. These swarms, which may contain several thousand individuals, remain in a dormant state until the beginning of the rains and the rice growing season. The quiescent period can last from three to eight months depending on the region.

D. apicalis has similar behavioural traits and ecological requirements to *D. longicornis* except that *D. apicalis* females sometimes lay their eggs on damaged stems.

Distribution of *D. longicornis* and *D. apicalis*

West Africa. Because high humidity is a determining factor for the presence of diopsids, these insects, even though present in all parts of West Africa, are seen most commonly in the more humid zones. If they are to be found in more arid zones, such as Mali or Niger, they are concentrated along major water bodies like the Niger River. The distribution of *D. longicornis* in West Africa is illustrated in Figure 4. In his article on the influence of climatic factors on the population dynamics of rice pests, Agyen-Sampong (1982a) underlines the lack of research in this area. He adds that little is known of factors that influence presence or absence of diopsids in a particular locality.

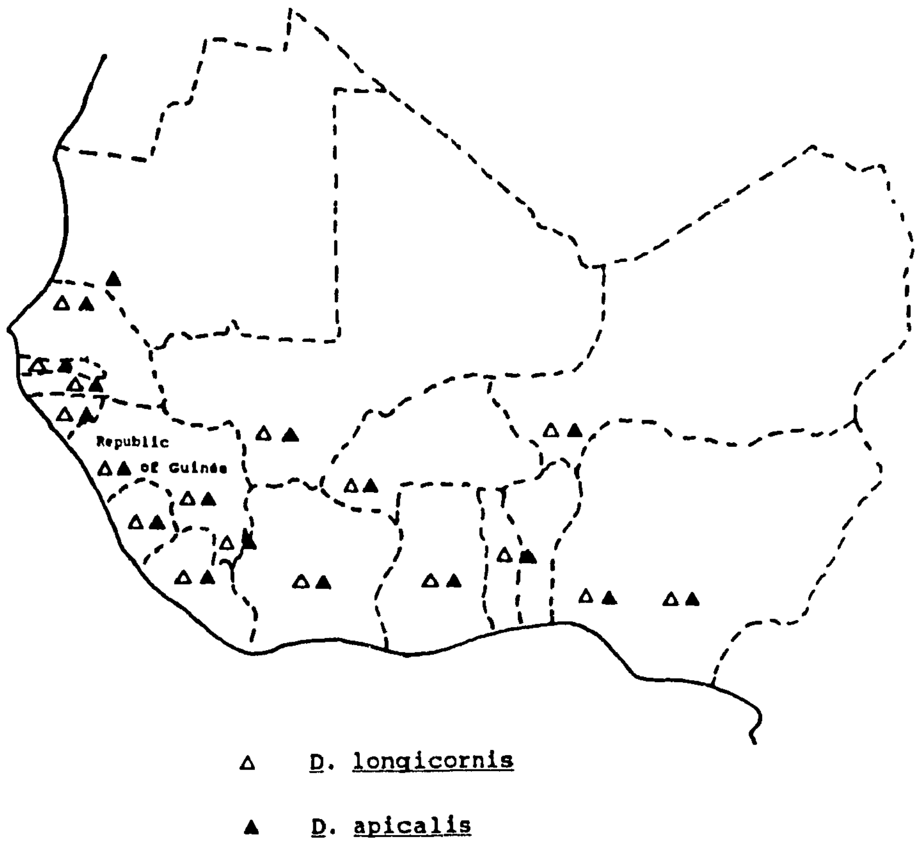

Fig. 4 RECORDED COLLECTIONS OF DIOPSIS LONGICORNIS AND DIOPSIS APICALIS IN WEST AFRICA

(from Agyen-Sampong 1978 & Brenière 1983)

Spatial distribution in the field. Although *D. longicornis* and *D. apicalis* visit many different types of rice (mangrove, upland, lowland and irrigated rice), the flies prefer well-watered sites. Therefore, these diopsids are usually considered pests in lowland and irrigated rice rather than in the more precarious conditions of upland rice. Since diopsids' tolerance to salt is not great, they are less abundant in mangrove rice fields (Agyen-Sampong 1982a, Vercambre 1982, Litsinger et al. 1987, Alam 1988). Sampling in mangrove rice fields in Guinée during my study confirm these reports.

D. longicornis is found almost exclusively on rice. Searches for secondary plant hosts have generated few results. Alghali and Domingo (1982) collected eggs from *Rottboellia exaltata* L.F. (Gramineae), a common weed associated with mangrove swamps in Sierra Leone. It is not known, however, if the eggs would be able to continue their development on this plant. After rearing over 100 larvae of *Diopsis* sp. collected from shoots of wild grasses with the characteristic dead heart symptoms, Deeming (1982) found that three species arose from his experiment: *Diopsis apicalis*, *D. collaris* , *D. macquartii* Guerin-Meneville. No specimens of *D. longicornis* were reared, even though this species was commonly found in the research area where rice is not grown. Thus, *D. longicornis* must have had an alternative host, but it was not found. Jordan (1966) claims that even though wild rice, *Oryza barthii* Chev., was plentiful around her experimental plots, no *D. longicornis* were seen infesting it. Records of weed hosts of *D. apicalis* are more frequent. Deeming (1982) reared *D. apicalis* larvae from *Cyperus* sp. (Cyperaceae), and the Gramineae, *Paspalum* sp., *Sporobus pyramidalis* and *Pennisetum purpureum*, *Oryza barthii*, *Echinochloa* sp., and from sorgum and millet. Morgan and Abu (1972) found *D. apicalis* eggs on the upper leaf surface of *Echinochloa colonum* (=*colona* L.?) in Ghana. Vercambre (1982) mentions that *Oryza barthii* and *O. longistaminata* Chev. & Roehr, are alternative hosts of *D. apicalis* (as *tenuipes*). Brenière (1969) found *Echinochloa* sp. as a weed host of *D. apicalis*, but he does not mention the country where this was observed. Alghali (1979) gives a list of weed hosts for rice stem-boring diopsids found in Nigeria, but he does not specify which species of diopsids were found. Cochereau (personal communication) claims that in Côte d'Ivoire, *D. longicornis* was seen infesting *Oryza barthii*, *O. longistaminata* and even a species of *Leersia* if cultivated rice was close by.

Although cultivated rice is the main host of *D. longicornis*, it is unknown how a population of this species of fly can maintain itself in the absence of rice. My study has attempted to provide answers.

It is important to note that there is a controversy concerning the nomenclature of the wild rice species mentioned above. For this study, Clayton's (1968, cited by Oka, 1988) nomenclature will be used to designate the African common perennial species of wild rice, *Oryza longistaminata* Chev. & Roehr.. Clayton gives the name *barthii* Chev. to the annual wild rice species, the distant relative of the African cultivated rice, *O. glaberrima* Steud.. Since *barthii* has been used by various authors to designate either the perennial or annual species, the older name, *O. breviligulata* Chev. & Roehr. is used here to name the annual species as suggested by Oka (1988). During the present research, plants were identified with the use of keys found in Hutchinson and Dalziel (1954).

The plants studied during the present study were identified with the use of keys found in Hutchinson and Dalziel (1954).

Spatial distribution on the plant. Descamps (1957a), Brenière (1969), Vercambre (1982) and Feijen (1984) claim that eggs of *D. longicornis* are laid mainly on the upper side of the subterminal leaf. Their studies were done mainly on the wet season crop. Egg-laying behaviour on irrigated rice during the dry season was studied by Scheibelreiter (1977). He determined that 48% of eggs laid were on the stem or base of the tiller from the root collar or water level to the base of the first leaf. Another 20 % were found on the stem from the base of the first leaf to the base of the second leaf. A remaining 25% were deposited on the leaves, and 7% on the root collar. Alghali (1984b) and Alghali and Osisanya (1982b) confirmed Scheibelreiter's observations.

As mentioned previously, larvae enter the stem at the level of the ligule and feed on the delicate central tissue. During my present study, I observed that *D. longicornis* larvae occur approximately 10 cm (between 8-12 cm and up to 17 cm when the plant is full grown) from the root collar or the water level, whereas *D. apicalis* are found closer to or at the collar or water level. Because *D. longicornis* infest only healthy stems, one can find only one larva per stem. *D. apicalis* invades healthy and infested stems (Descamps 1957a, Brenière 1983), or only infested stems (Scheibelreiter 1974). Alghali and Osisanya (1982b) note that frequency in oviposition is related to rice varieties, some being favoured more than others by gravid females. During my experiments, *D. apicalis* were found on undamaged stems rather than on damaged ones.

Most pupae are found on the outer leaf sheaths rather than closer to the heart of the tiller. Alghali (1984c) found that 96% of the *D. longicornis* pupae were found on the first three outer leaf sheathes; he also determined that the pupae preferred healthy tillers as opposed to damaged ones, and he claimed that movement of the larvae, just before the pupal stage to a healthy tiller would either avoid or delay parasitism, since parasites are often attracted to the frass or decaying material caused by the feeding larva (Ingram 1983 and Seabrook 1977, cited by Alghali 1984c).

Adult diopsids, when in refuge sites during the dry season, occur in groups of up to 200 on a single leafblade. On rice, however, *D. longicornis* disperse to different leaves, with rarely more than one insect per leaf. This behaviour permits better dispersion of eggs and thus better survival of ensuing larvae.

Temporal distribution. There has already been mention of the difference in behaviour and ecological requirements for *D. longicornis* from the rainy season to the dry season. Oviposition time coincides with the tillering stage of the early rice crops at the beginning of the rainy season. This first generation produces a second generation, which remains and reproduces on later rice crops (Pollet 1977 1978, Cochereau 1978). Pollet (1977) studied population densities of *D. longicornis* and *D. apicalis* in a field where plots were sown at intervals of 15 days in order to make rice available at different phenological stages at all times. Over the year, the population of *D. longicornis* was fairly constant, with peaks in July, August, October and December (Figure 5 in Pollet 1978). Pollet (1978) found that *D. apicalis* attacked the seedlings, and then *D. longicornis* attacked the tillering stage after transplanting, an observation that has not been confirmed by other authors. Pollet´s colleague, Cochereau (1985a) makes the opposite claim that *D. longicornis* infests the rice crop at the beginning of the plant´s cycle, with *D. apicalis* following later. Pollet (1978) concludes that, under continuous cropping, populations of *D. longicornis* would persist throughout the year, and that intercropping (with non-host plants of rice pests) should be employed to lower the population and to prevent pest build-up.

Cochereau (1978, 1985a) studied population fluctuations of *D. longicornis* in the 1976 and 1977 wet seasons to test several sampling methods: water traps, visual counts, and sweep-nets for adults, stem dissection for larvae and leaf and stem examination for eggs. From these, he concluded that a) *D. longicornis* wase more numerous during the tillering stage than *D. apicalis*, and that the inverse was true at the ripening stage, b) sex ratio of *D. longicornis* changed from the tillering to the ripening stage (M to F 1:0.81 to 1:1.25) in favour of females, whereas the inverse is true for *D. apicalis*, with more females at tillering (1:2.75) than at ripening (1:0.74); for both species there is an increased proportion of immature females from the tillering to the ripening stage, but, the change is more pronounced for *D. longicornis*, c) the population of *D. longicornis* rose to a peak at the middle of the tillering stage, and to a smaller but noticeable peak at the stem elongation stage. For the 119-day variety of rice used, Cochereau claims that the first peak was composed of diopsids emigrating from the surrounding vegetation (dry season refuge sites), and that the second peak represented the generation of *Diopsis* spp. issuing from the rice crop. This two peak pattern was consistent regardless of the time of the year, and the amount of precipitation received by the crop. Cochereau adds that early or late dates of planting most likely will increase or decrease diopsid infestation respectively, since egg development is concentrated early in the wet season.

Past studies of *Diopsis longicornis* and *D. apicalis* have been concentrated during the rainy season when rice is grown (Cochereau 1978, 1985a, Pollet 1977, 1978, Feijen 1979, Brenière 1969). Little research has been undertaken to study the flies on rice during the dry season (except by Cochereau, 1985b). The biotic and abiotic requirements of the diopsid population in the dry season and in the absence of cultivated rice are not well known. Only Descamps (1957a) and Feijen (1984) provide a brief description of *D. longicornis* and *D. apicalis* behaviour in refugia during the dry season.

Quiescence.

Although it is known that *D. longicornis* enters a period of quiescence (Descamps 1957a, Feijen 1984), no work has been done on this long period of partial inactivity. We do know that during the dry season the insect remains reproductively immature and aggregated in dense populations. At the onset of the following wet season it disperses onto the new rice crop. Many questions come to mind when one looks at this unusual phenomenon. Are the same individuals found from the beginning to the end of the dry season, and also in the same place? How does this population maintain itself in the absence of cultivated rice? What are the relationships between *D. longicornis* and the plants in the refuge sites? What is the behaviour and life cycle of the fly during the dry season? How did this species live before the widespread planting of rice?

Insect quiescence, or direct inhibition of development by adverse environmental conditions (Danks, 1987), has been studied by few entomologists in the tropics. In his review of the topic, Denlinger (1986) uses the term ´dormancy´ to describe the period of arrested development in tropical insects, since information is still too incomplete to confidently use the more defined terms ´diapause´ and ´quiescence´. Environmental regulators of arrested development are still not well known, even though it is clear that there are limiting factors that prevent year-round development of many species of insects.

Denlinger (1978, 1980, 1986) has shown that even in the tropics, though not as marked as in the temperate zones, factors such as daylength, temperature, rainfall, relative humidity, and quality and quantity of food, can have significant effects on the development of tropical insects.

In some insects, differences in daylength of as little as one half hour can be an important cue for dormancy induction and termination. Photoperiod is the primary regulator of adult diapause termination of the fungus beetle *Stenotarsus rotundus* Arrow (Endomychidae) at 9^0 N (Tanaka, Denlinger & Wolda 1987, Tanaka, Wolda & Denlinger 1987). Dubreka, where my present research was undertaken, is at the same latitude; thus a change in photoperiod may also influence *D. longicornis* behaviour.

Temperature is another major environmental cue. The high rise in temperature during the mid-season of the dry period may greatly affect the metabolism of insects that rely on a moist environment for survival. From eight years of observation, Tanaka, Wolda and Denlinger (1988) conclude that, in dense aggregations, *S. rotundus* are able to lower their metabolic rate. This permits survival during a 10-month period of diapause in a tropical environment in which energy reserves are in short supply. The higher R.H. within the aggregation may also contribute to the lowering of metabolic rate. *D. longicornis* do not cluster in as dense masses as do *S. rotundus*. However, their choice of moist refuge sites during the dry season may permit them to lower their metabolic rate and thereby increase their chances of survival.

According to Denlinger (1986), there is little evidence that lack of rainfall is a regulator of tropical dormancy since insects may enter diapause or quiescence long before rains have ended. Onset of rainfall does seem to stimulate normal development. Restoration of reproduction in the fungus beetle, *Stenotarsus rotundus*, involves a complex relationship between the coming of the rainy season, egg maturation and flight muscle development on the one hand, and on the other, mating and dispersal from the aggregation site.

The grouping of *D. longicornis* individuals in refuge sites, and their later dispersal from these sites to rice fields, seem to be related to a combination of environmental changes. These include the relative humidity of the micro-habitat, the quality of the food plant, and rainfall patterns. Lack of rainfall does not, however, prevent *D. longicornis* from infesting rice fields in the dry season (Pollet 1977 1978, Cochereau 1985b, Lafleur 1988, Chiasson in press). Also, an occasional rain during the dry season does not alter the aggregation behaviour of the clustering flies. In 1989, in Dubreka, an early rain occured on March 21, four weeks earlier than the regular period of rainfall, and no immediate change was seen in the swarming behaviour of the *D. longicornis* populations found in the refuge sites.

Although chemical changes in the host plant or food source is known to provide a trigger for larval diapause in the lepidopterous stem borers *Busseola furca* Fuller (Noctuidae) (Usua 1973, cited by

Denlinger 1986) and *Chilo partellus* (Swinhoe) (Pyralidae) (Scheltes 1976, cited by Denlinger 1986), there is no evidence yet that such changes in host plant initiates aggregation or dispersal of *D. longicornis*.

ECONOMIC IMPORTANCE

Pest status of *D. longicornis* and *D. apicalis*

The earliest records of *D. longicornis* or *D. apicalis* as agricultural pests were of *D. apicalis* attacking maize in South Africa (Mally 1920, cited by Feijen 1981), but attacks were considered low in comparison with lepidopteran borers. Risbec (1947, 1950, cited by Feijen 1984), from his field studies in West Africa, first recorded three *Diopsis* spp. infesting rice: *Diopsis servillei* Macquart (=*affinis* Adams), *D. collaris* Westwood and *D. apicalis* Dalman.

In the first major work on West African *Diopsis* spp., Descamps (1957a) lists *D. longicornis* as an important stem-borer pest of rice, but does not consider *D. apicalis* as a pest because of its facultative saprophagous and phytophagous nutritional requirements. Descamps first established *D. longicornis*´ importance as a potential pest by claiming that this species almost exclusively infests cultivated rice, feeds only on healthy tissue, and attacks several stems during its development. Roger and Commun (1959) report *D. longicornis*´ and *D. apicalis*´ importance on rice in their review of rice pests in French West Africa.

Brenière (1966, 1969, 1982a, 1983, 1986) was the next to publish material on the economic importance of *D. longicornis* and *D. apicalis*, from his work in Côte d´Ivoire and in Madagasgar. His review on *D. longicornis* and *D. apicalis* in 1966 updated Roger and Commun´s work, which in turn was based on Descamps´ research. Brenière´s main research interest at that time was the white stem borer, *Maliarpha separatella* Rag.. Brenière´s later reviews (1969, 1982a, 1983) contained results from his own research in Côte d´Ivoire as well as from other authors. His evaluation of the pest status of *D. longicornis*, *D. apicalis* and *D. collaris* was based on pest density and level of infestation.

Following Brenière's work, the major publications comprised two Ph.D. theses that treated the bionomics and economic importance of diopsid flies (Alghali 1981c, cited by Alghali and Osisanya 1982b; Feijen 1984). Alghali's comprehensive work on the susceptibility of rice varieties to *D. longicornis*, and Feijen's in-depth treatise on the systematics, ecology and economic importance of the family Diopsidae, were the first important attempts at determining the pest status of the diopsids in general, and of *D. longicornis* and *D. apicalis* in particular. Alghali treated rice varietal resistance in several subsequent works (Alghali 1981b, 1981c, 1983, 1984b, 1984c, Alghali and Osisanya 1982a, 1982b), and reported his research on the influence of plant spacing and of plant age on the level of infestation by *D. longicornis* (Alghali 1980, 1981a, 1984a). Feijen studied the economic importance of *D. longicornis* in Malawi (1976, 1977, 1979) and then concentrated his efforts on the systematics of the Diopsidae, and on the parasitoids of *D. longicornis* eggs (Feijen 1978, 1981, Feijen & Schulten 1981, Schulten & Feijen 1983, Schulten & Feijen 1978, cited by Feijen 1984).

In addition, in the 1970's, Morgan and Abu (1973) determined the seasonal abundance of *Diopsis* spp. on the rice crop in Ghana. Scheibelreiter, also in Ghana, determined the relative importance of *D. longicornis* and *D. apicalis* in rice fields (1974), as well as making a very thorough study of the distribution of *D. longicornis* eggs on the rice plant (1977). During this time entomologists at WARDA (West Africa Rice Development Asssociation), in Sierra Leone, were beginning to conduct general inventories (Akibo-Betts & Raymundo 1976, Agyen-Sampong 1976, 1979a 1982a and b, Agyen-Sampong & Fannah 1979), ecological studies (Agyen-Sampong 1978 1979b), and integrated pest management experiments in mangrove swamp rice systems (Agyen-Sampong 1979a 1982b). In these systems, *Maliarpha separatella* is a more serious pest than *D. longicornis* (WARDA reports 1980, 1982-1987).

During this period, WARDA (=ADRAO: Association pour le développement de la riziculture de l´Afrique de l´Ouest) scientists also conducted pioneer work in rice research in the French-speaking countries of Sénégal (Casamance) and Mali (Mopti). They made an inventory of rice insects, and recorded *Diopsis apicalis*, *D. collaris* and *D. longicornis*, as well as a study of seasonal fluctuations of the populations of major pests (WARDA-ADRAO 1978, 1981).

Researchers from France continued Brenière´s 1960´s efforts in Sénégal and Côte d´Ivoire. Roudeillac (1974, cited by Vercambre, 1982) and Vercambre (1970 & 1979, cited by Vercambre, 1982) evaluated the relative abundance of *D. longicornis*, *Diopsis apicalis* and other *Diopsis* spp. on irrigated rice. Vercambre conducted studies on the chemical control of *Diopsis* spp. and other rice pests. He also published a brief report on his studies of the bionomics and ecology of *D. longicornis* (1982). His suggestions for control were either chemical insecticides or cultural methods, i.e., choosing appropriate planting dates, sowing by transplanting instead of by direct seeding, and by using resistant rice varieties. Vercambre recommended the use of insecticides, either on swarms found in refuge sites during the dry season, or on the rice crop a few days after transplanting at the beginning of the rainy season. This author also suggested out that the abundance of *Diopsis* spp. in the field does not necessarily translate into a corresponding high level of damage on rice, but he published no data on to support this claim.

Near Bouaké, in Côte d´Ivoire, during extensive ecological studies, Pollet (1977, 1978) concluded that *D. longicornis* was a secondary pest, and *M. separatella* the primary pest, which occured at a frequency of 90% compared to other pests.

From their research, Descamps (1957a), Brenière (1966, 1969), Scheilbelreiter (1974, 1977), Morgan and Abu (1973), Pollet (1978) and Cochereau (1978) claim that although *D. apicalis* is not particularly harmful to the rice crop, *D. longicornis* is a major pest. Terms such as ´severe damage´ (Descamps 1957a, Brenière 1969) and ´important losses´ have been used in the literature, but little conclusive research had been done to verify the relationship between pest presence and level of infestation in relation to yield.

Methods used to assess crop losses caused by *D. longicornis*

Studies of assessment of crop losses on rice were made by several researchers in West Africa. Vercambre (1979, cited by Vercambre, 1982) found that a mixed application of lindane and diazinon (3kg AI /ha) increased yields by 1 t/ha. He concluded that insect pests had reduced yield by about 25%. With insecticide protection, crops yielded from 25 to 30% more in Nigeria (Agyen-Sampong 1988). Similar experiments in Sénégal gave yield increases of 3.3 and 5.7 t/ha (WARDA 1978), and in Ghana, yields of irrigated rice were increased by 30% (Agyen-Sampong 1977, cited by Agyen-Sampong 1988). Under insecticide protection in Mali, deep-flooded rice yields increased by 35% and, in Sierra Leone, mangrove swamp rice yielded 10 to 20% more under insecticide protection (WARDA 1980). Agyen-Sampong (1978) estimated that in Dawhenya in Sierra Leone, there was 30 to 40 kg loss in yield for every 1% stem-borer infestation. Brenière (1969) reported a loss of 1 t/ha, but did not provide total yield data; these are enormous losses considering that total yield in peasant farms equal that amount.

Akinsola (1980) stated that *D. longicornis* infestation caused yield reductions of 5% to 19%, but no methods of assessment were mentioned. Etienne (1981, cited by Brenière 1981) found that losses in farmers´ fields caused by attack by this insect were 3%, whereas losses on agricultural stations were as high as 20%. Yields in farmers´ fields are generally much lower than yields in experimental stations, therefore methods to increase production (e.g., fertilizers) used in research centres, could be making the crop plant more attractive to insect pests.

The need for informative estimates of the effect of stalk-eyed fly infestation on yield generated several methods to attempt these evaluations. The following is a review of methods that have been used to assess crop losses from *D. longicornis.*

Number of eggs laid in relation to *D. longicornis* damage and yield. In Nigeria, Alghali (1981c, cited by Alghali & Osisanya 1982b), and in Ghana, Morgan and Abu (1973), obtained a positive correlation between the number of eggs laid and the amount of damage done by *D. longicornis* on rice stems. They showed nevertheless that the number of dead hearts caused by *D. longicornis* may not be in direct correlation with yield loss because of the ability of the plant to produce secondary tillers. Alghali studied the compensatory ability of several rice varieties in order to establish their susceptibility or resistance to damage by stalk-eyed flies. In Alghali's study, crop losses ranged from 2% to 54%.

Percentage infestation. These calculations were determined by counting dead hearts and white panicles (Morgan and Abu 1973, Agyen-Sampong 1978, Brenière 1982a, Alghali and Osisanya 1984, Akinsola and Agyen-Sampong 1984, Lafleur 1988, Chiasson, in press). Percentage infestation studies have given valuable results on the effect of plant spacing on diopsid infestation (Alghali 1980, 1984a). Cochereau (1985b) determined that not all dead hearts result in death of the meristem. He estimated that one third of the dead hearts observed in his studies continued to develop and produce a panicle.

Compensatory tillering. Frossard (1971, cited by Vercambre 1982) noticed that during insecticide trials, untreated (and therefore more damaged) plants had 82% more tillers compared to the average number in the treated fields. Cochereau (1985b) reported similar results, but added that even though untreated plants had more tillers during the vegetative stage, numbers of tillers were similar in untreated and treated plots at the flowering stage.

The problem of compensatory tillering was investigated by Feijen (1979), who determined the effect of simulated damage (pulling out the central shoot of the tiller) on the ability of the plant to develop secondary tillers and its effect on yield. He found that: a) when damage was done four weeks after transplanting, number of stems in all damaged hills had increased after two weeks compared to controls. The extent of stem increase varied markedly, with rice variety, the short season variety (116 days), showing less of an increase than the long season variety (198 days). Yields were only significantly higher, however, with the damaged short-cycle variety.

b) number of tillers was significantly higher at a high fertilizer level (twice the recommended level) than at a lower level (recommended amount), although yield was still negatively affected at both fertilizer levels.

c) the positive effect of injury on tiller increase was stronger in younger and smaller hills than in older and larger hills. Injury at 28 d after transplanting generally gave a higher tiller and yield increase (though not significant) than at 45 d after transplanting.

d) effects of simulated injury and real *D. longicornis* damage on yield were compared and shown to be similar.

Feijen concluded that attack by *Diopsis* spp. larvae can have either negative or positive effects on a rice hill, depending on intensity, time of attack, and general growing conditions, including soil type, amount of fertilizer, spacing of hills, hill size, and rice variety. Feijen believes that the influence of diopsid larvae is positive or neutral under usual conditions, and that only under poor growing conditions with a late and heavy attack will the rice be negatively affected by *Diopsis* spp.. This is an important point because most African farmers work with poor quality soils.

As most published investigations have been done in experimental stations, where rice yields are high (4 t/ha), it is necessary to repeat these tests in farmers´ fields where yields rarely reach 2 t/ha.

Yield in insecticide-treated and in untreated fields. It is important to relate pest numbers to yield in both treated and untreated fields. Several tests have been done with *Maliarpha separatella* by WARDA researchers (WARDA 1978, 1980, 1982, 1983), but few with *D. longicornis*, (Brenière 1982a, Alghali and Osisanya 1984). The latter authors found that protection with carbofuran against damage by diopsids generally significantly increased the number of panicles produced (both total and mature), the percentage tillers with panicles, the 1000-grain weight, and the total grain yield. The extent of increase depended on rice variety. For most varieties, unprotected and thus damaged plants produced more tillers than did protected plants. These secondary tillers were able to produce panicles, but, with many varieties, compensatory panicles were lighter in weight and therefore did not produce an important gain in yield. Alghali and Osisanya (1984) claim that reduction in grain weight and amount of starch, is related to the amount of carbohydrates accumulated in the leaves and culms before and during heading. The longer the vegetative stage, the more carbohydrates the plants can accumulate. Furthermore, with some varieties, where injury occurs in the early stages of growth, there was a significant decrease in rice yield. These results contradict those of Feijen (1979).

Cochereau (1985b), during his studies of the relationship between pest damage and yield, found that the systemic insecticide carbofuran gave unsatisfactory results. He claims that the high dosage necessary to eliminate the insects negatively affected the physiology of the plant and significantly reduced the weight of grain per panicle.

Screening different varieties of rice with or without *D. longicornis*. Akinsola (1980) compared the growth of caged plants with and without *D. longicornis*. He obtained the following results: a) infested plants initially (20 and 40 d after tillering) had fewer tillers, but later in the season, numbers were equal to or higher than for uninfested plants, b) uninfested plants were taller than infested plants, c) although numbers of productive tillers were higher in infested plants, uninfested plants produced a higher grain yield than did infested plants, d) uninfested plants had heavier panicles than did infested plants. These results were later corroborated by those of Alghali and Osisanya (1984), discussed above. Akinsola calculated that yield losses caused by *D. longicornis* ranged from 5 to 19%, depending on rice variety and time of injury in the phenology of the plant. Unfortunately, Akinsola does not mention the size or other details of his cages. Experiments conducted in cages, particularly small cages, are subject to error because, based on my own observations, the microclimatic conditions inside the cage can diminish plant growth. After assessing the results from his caged experiments, Cochereau (1985b) also claims that this technique may be unreliable.

Methods of managing populations of *D. longicornis*

The use of synthetic insecticides. Early recommendations for controlling rice pests in West-Africa mainly emphasized the use of synthetic insecticides (Brenière 1969). Although insecticides can still be useful in an integrated management system, and are still recommended by some researchers (Vercambre 1982, Brenière 1986), it is generally recognized that responsible methods of pest control must be based firmly on cultural and biological means, as well as on the choice of resistant varieties, and that pesticides be reserved for emergency measures if needed. This point was made in West Africa by Taylor 1977, Brenière 1986, Agyen-Sampong 1979a & b, 1982b, Cochereau 1981, 1982, Alghali and Osisanya 1982a & b, Brenière and Bordat 1982, Akinsola 1985 as well as by others elsewhere (van den Bosch 1978, Brader 1979, Pimentel & Andow 1984, Hill 1984, Philogène 1985, Kenmore 1987). The high cost of synthetic insecticides makes them unavailable to resource-poor farmers. Their use is also frequently hazardous because most farmers do not have access to the proper application and safety equipment. Even if appropriate application and safety equipment are available, lack of knowledge concerning pesticide use and misuse, and associated hazards, are such that accidents are common. Paul Harrison (1986) in his informative commentaries on African agriculture points out that, contrary to a common assumption, because of the unpredictable climate and poor soil, the African environment is very fragile. To improve African agricultural systems, he recommends methods that would strengthen their basic features, such as increasing soil fertility and stability, and that would augment the inherent capabilities of the crop to resist or recover from enemies and other stresses. Increased dependence on external inputs, such as synthetic insecticides, only weaken an already fragile situation.

Alam et al. (1985), Philogène (1985) and Agyen-Sampong (1988) add that because reliable estimation of crop losses caused by insect pests are rare, and that grain yield loss data have been inconsistant, the use of insecticides can often be wasteful and that instead, other methods requiring less external inputs should be emphasized. These views are shared by many other researchers and rice specialists in other areas of the tropics where there is a greater tendency to encourage cultural methods of control, the use of resistant varieties, and ways to augment natural enemies (Kiritani 1979).

Cultural controls. FAO (1979) presents a comprehensive review of cultural practices used for rice cropping in the tropics. I will review only methods tried and tested in West Africa.

a) Fertilizer and pest incidence. In Sierra Leone, Akibo-Betts and Raymundo (1976) state that "high incidences and infestation of insect pests appear to be associated with the use of high levels of fertilizers, and the practice of continuous cropping. No specific studies have been conducted on the effects of added nitrogen on *D. longicornis* attacks, but results from studies with *M. separatella*, the pyralid stem borer, are contradictory. With added nitrogen, infestation by the pyralid increased in the mangrove rice swamps of Sierra Leone (WARDA 1983, 1985, 1987). In the WARDA 1986 report, it is said that there is "higher infestation in unfertilized fields and relatively lower yield losses in fertilized fields than in unfertilized fields". In a study in India there was a positive correlation between N level and stem borer incidence (Saroja & Raju 1981). These reports do not specify, however, if yields are lowered in absolute terms.

b) Continuous cropping. Continuous cropping is believed to increase pest incidence, especially for a monophagous pest such as *D. longicornis*. In 1966, Jordan's observations of *D. longicornis* seem to point out that continuous cropping would augment *D. longicornis* infestation on rice because of its lack of true diapause and its specialization on rice. Loevinsohn and Litsinger (1989), based on their work in the Philippines where problems of continous cropping have become evident, have recommended that rice should be grown non-intensively (on larger areas) rather than intensively (multiple cropping), with other crops being grown during the fallow period.

c) Date of planting. Vercambre (1982) states that the date of planting or transplanting can influence *D. longicornis* abundance by avoiding the peak period of *D. longicornis* reproduction. He followed ovarian development of *D. longicornis* over time. Choice of planting date is an effective method of avoiding pests in temperate climates, but it is debatable whether this method can be applied to the tropics because the insect has time to adapt its development to changes in planting dates of the crop (Loevinshon 1987, personal communication). Vercambre mentions that synchronous planting dates among farmers would best prevent pest build-up. Loevinshon (1984) studied synchronous planting extensively (through several years of light trap monitoring in rice fields of over 30 farmers in the Philippines) and its effect on pest abundance, and his conclusions support synchronous planting as an important regulator of pest build-up in areas where rice production is intensive.

It is difficult to apply the results of rice research in the Philippines to West Africa where rice is not grown as intensively. However, as government policies in most West African countries now encourage intensified rice production, it will be necessary to develop guidelines when intensifying production to keep pest numbers at benign levels. Farmers in Sierra Leone may understand the importance of synchronous planting, at least against rodent and bird damage, they tend to sow the same varieties of rice, or varieties of similar duration at the same time (Raymundo 1984). Bird populations are spread out over a larger area of mature grain, and therefore the effect on individual fields is lessened.

d) Plant spacing. Alghali (1984a) studied egg deposition by *D. longicornis* on leaf blades and leaf sheaths and recorded percentage deadhearts, 30 and 60 days after transplanting, using two varieties of rice at spacings of 15 X 15 cm, 20 X 20 cm, 25 X 25 cm and 30 X 30 cm. In both varieties, and for the two recording dates, number of tillers per hill, number of eggs, and percentage deadhearts increased with increase in spacing. Alghali believes that a high number of tillers (a mean of 20 per hill in the 30 X 30 treatment as opposed to 7 per hill in the 15 X 15 treatment) permits easier access to larvae of *D. longicornis* searching for healthy tillers on which to feed, because diopsids attack all tillers of one plant before moving on to another. He cites Isreal (1964), who observed that the relatively higher temperatures and humidities found at stem bases of high-tillering varieties favour the development of diopsid eggs and of the newly-hatched larvae that descend to the base of the tillers.

Resistant varieties. Alghali concentrated his efforts on the selection of varieties resistant to *Diopsis longicornis*. His group screened a large number of local and improved varieties of rice and studied such parameters as percentage infestation (Alghali and Osisanya 1984), number of eggs laid per variety (Alghali 1984b, Alghali and Osisanya 1982b), selection of pupation site (Alghali 1984c), level of parasitism, to the effects of lignification and silica contents of the varieties on the extent of damage by *D. longicornis* (Alghali 1981b). These studies showed that resistance was based on number of tillers per hill, leaf angle, plant height, stem diameter, leaf colour, plant age, plant spacing, and plant quality. Furthermore, Alghali provided data on the effect of *D. longicornis* damage on compensatory tillering and on the contribution of these tillers to grain yield. Those authors also made valuable contributions to our understanding of the general biology of the pest (Alghali 1984b, Alghali and Osisanya 1982a).

Rice varietal resistance to *D. longicornis* has also been studied at the International Institute of Tropical Agriculture at Ibadan, Nigeria (Alam 1982, 1984, Alam et al. 1983). In an elaborate 21m X 24m screenhouse, Alam tested over 1 300 rice cultivars (*O. sativa* and *O. glaberrima*), selected from 40 rice growing countries in the world. Over 80% originated from Africa. Infestation ranged from 1% to 67%. Alam noted that under natural conditions maximum infestation is about 15%. Cultivars coming from Africa and, in particular, cultivars of *O. glaberrima*, the rice species indigenous to West Africa, were found to be more resistant than others. Alam's method of rearing *D. longicornis* under controlled conditions is the only effective one tried so far. It has been included in the International Rice Research Institute's comprehensive text on methods of evaluating the genetic basis of rice resistance to insect pests (Heinrichs et al. 1985).

Natural enemies. As mentioned previously, Descamps (1957a) in Cameroon, and Jordan (1966) in Sierra Leone, had identified several parasites of *D. longicornis*. Besides the list of parasites of rice pests compiled by the WARDA Rice Research Station at Rokupr, Sierra Leone (Agyen-Sampong & Fannah 1986), little work has been done elsewhere in West Africa on the collection and identification of these parasites, or on their biology, level of parasitism and on possibilities for their use in a biological control program. Hymenopterous parasites of *D. longicornis* are being carefully documented in East Africa (Feijen 1977, Feijen & Schulten 1981, Schulten & Feijen 1983, Schulten & Feijen 1978, cited by Feijen 1984), and results from this work should prove to be very valuable. L'I.R.A.T. (Institut de Recherches en Agriculture Tropicale) in Montpellier, France, are presently establishing a program of introduction of natural enemies for lepidopterous rice stem borers (Brenière 1981, 1982b, Brenière and Bordat 1982) and perhaps the same could be done if necessary, for diopsids. Planting beneficial nectary plants on the bund might attract parasitic wasps that would keep pests at minimum densities (S.B. Hill, personal communication). Alley-cropping with leguminous trees has been used successfully in the Philippines to augment soil fertility, create a windbreak, provide a barrier for dispersing pests, and to provide a habitat for natural controls (R. Maclean, personal communication); it could be attempted in Africa as well.

Botanical insecticides. There is only one record of a botanical insecticide used on the stalk-eyed fly. Lafleur (1988) regularly applied extracts of both the seed and the fruit (seed and pulp) of the neem tree, *Azadiracta indica*, on the rice crop from 28 days after transplanting to the flowering stage in the rainy season. He found that although both applications repelled *D. longicornis* from the rice plant, they did not result in decreased pest damage. Lafleur therefore does not recommend the use of neem during the rainy season because the rain washes away the extracts, which must remain on the plant to be effective. His experiments have not yet been tried in the dry season, when persistance of the insecticide may be better assured.

Traditional methods of control. Entomologists at the Rokupr Rice Research Station in Sierra Leone have accumulated information on this topic through extensive visits and surveys of rice farms in West Africa. The three methods that could reduce *D. longicornis* numbers are: a) intercropping of rice with other food crops, b) synchronization of varietal maturity, and c) higher seeding rates to discourage seedling pests (Raymundo 1984).

It is possible that with the extensive local knowledge of medicinal plants, some farmers may also be using preparations from indigenous plants as insecticides.

BASIS FOR THIS STUDY

As the present review points out, little research in rice entomology in Guinée has been done; *D. longicornis* and *D. apicalis* have been studied only superficially in Guinée by the Foulayah Agricultural Institute (Institut de Recherches Agro-Zootechniques de Foulayah, Kindia, République de Guinée), and the Rice Research Centre in Kilissi (Centre de recherches agronomiques, Kilissi, République de Guinée).

Preliminary studies at these centres indicate that *Diopsis* spp., and especially *D. longicornis* and *D. apicalis* are important pests of lowland rice in Guinée. Furthermore, before this study was undertaken, preliminary sampling of rice fields in the Dubreka area in 1986, as well as conversations with local rice farmers revealed that these two diopsid species were present in great numbers on the rice crop and were considered by the farmers to be pests.

The present study was therefore conducted to determine the effect of *D. longicornis* and *D. apicalis* presence on Guinée's coastal rice crops, and to identify key factors that regulate the abundance of the more important pest, *D. longicornis*. To achieve this the following objectives were established:

1. (Chapter 3) to determine and compare the population size of *D. longicornis* and *D. apicalis* from seeding to harvest, and to determine the level of infestation by *D. longicornis* and *D. apicalis* on the rice crop under the following conditions:

   a) different planting methods, i.e., direct sowing (broadcast) and transplanting from a seed bed,

   b) different climatic conditions, i.e., rainy and dry season,

   c) different planting dates, i.e., successional planting dates with a 14 d or 21 d interval between dates.

2. (Chapter 4) to determine environmental factors (both biotic and abiotic) that influence the ecology and behaviour of *D. longicornis* on a year round basis. Determining factors chosen were: influence of cultivated rice on reproductive activity, the importance of secondary plant hosts, conditions of dry season refugia, and conditions for diopsid dispersal to and from the refugia.

CHAPTER 3

POPULATION DENSITY, DEVELOPMENT AND BEHAVIOUR OF *DIOPSIS LONGICORNIS* AND *D. APICALIS* ON CULTIVATED RICE IN RELATION TO DIFFERENT CULTURAL PRACTICES AND DIFFERENT SEASONS.

INTRODUCTION

Experiments were undertaken to determine adult and larval *Diopsis longicornis* and *D. apicalis* population size under different cultural practices: different planting dates and planting methods (direct, by broadcast sowing and indirect, by transplanting) in both the wet and dry seasons. The purpose was to identify a planting date and planting method during both seasons that would prevent or diminish diopsid infestation. After the first season, it became evident that it would be difficult to demonstrate diopsid preference for either a particular planting date and/or planting method by sampling the adult population, since the plot size and arrangement used permitted drift of the mobile population from one treatment to another, regardless of preference. Although plot size was increased, the possibility of plot to plot interaction could not be eliminated. Even though the experimental design and sampling programme were not changed, the objectives were redefined.

Sampling of the adult population was undertaken in order to:

a) determine the overall population size, sex ratio and number of gravid females over time. Successive planting dates would permit sampling over a longer period of time.

b) select a time of planting that would avoid infestation by diopsids at the onset of both the dry and wet periods. To minimize risk of damage by diopsids, planting during the dry season should occur after *D. longicornis* and *D. apicalis* have moved to refuge sites where they undergo a period of quiescence for the duration of the dry season; and in the wet season, planting should occur several weeks after dispersal from dry season refugia to alternative host sites in order to avoid diopsid movement to the rice crop.

The immature stages of *D. longicornis* and *D. apicalis* were sampled to determine the peak time of larval infestation during both seasons, as well as determine diopsid preference for oviposition sites between plants sown either by direct or indirect planting methods.

A comprehensive description of the study site, the experimental design, the sampling programme, the type of analysis used to meet the above objectives, and then discussion of results will follow.

DESCRIPTION OF EXPERIMENTAL AREA

The experimental field was situated in the prefecture of Dubreka, which lies in the maritime region of the Republic of Guinée, approximately 45 km north of the capital of Conakry. Dubreka is part of a continuous band of coastal plains of varying width (50-150 km) reaching from the Casamance area in Sénégal to Liberia. The plains, which extend from the sea to the liberian-guinean highlands, are characterized by two distinct morpho-ecological land types and a corresponding transition zone. Along the immediate coast lie the mangrove swamps, which are under the constant influence of bimodal tides. Vegetation is limited to a few salt-tolerant species of *Rhizophora* and *Avecennia*. Succeeding the mangrove is a band of hygromorphic soils composed in part of deposits left by the receeding tidal influence, and by sedimentation from rivers flowing down from the inland range (Salomon 1987). The prefecture of Dubreka ($9^{o}50$ N, $13^{o}7$ and $13^{o}23$ W) is typical of the coastal region of Guinée in that both land types are well-represented.

The area chosen for the study lies well beyond the mangrove swamps in the region of lowland hygromophic soils at the base of the foothills of the Fouta Djallon highlands. The vegetation is herbaceous (e.g. *Panicum* spp., *Pennisetum* spp., *Imperata cylindrica*) dotted with coconut palm (*Cocos mucifera*) and oil palm (*Elaeis guineensis*). Human activities, such as burning and cutting of trees to clear farmland and to obtain firewood, as well as general climatic changes, have transformed the original tropical deciduous and broadleaf evergreen forest into an area of savannah and brush.

The climate is under the influence of the seasonal rhythm of alternating dry (December to May) and wet seasons (June to November). Rainfall in the Conakry-Dubreka-Coyah triangle exceeds that of all other regions of West Africa (almost 5 000 mm per year in Conakry). Heavy rainfall has been a key factor in the accumulation of alluvial deposits in the lowlands as it is concentrated in a few months (1400 mm in July alone in Conakry).

Temperature remains high throughout the year (23^{o} to 27^{o}C), as does relative humidity (average of 76%, based on 1986, 1987, 1988 readings taken by CERESCOR[1]).

Despite a prolonged dry period of approximately six months, many plains remain engorged with water throughout this time because of a high water table. The present socio-economic activities of the inhabitants of Dubreka are agriculture and fishing. At last census (1983), population density was 87 inhabitants per km^2. The experiments were done in the Néguéah district of the Sub-prefecture of Dubreka and in a sector called Biff, five km from the village of Dubreka. Mount Kakoulima (1007 m) towers above lowlands used for banana plantations, rice fields and vegetable gardens, which are tended by nearby villagers.

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MATERIALS AND METHODS

Preparation of the experimental site

The choice of site for these experiments was based on availability of water throughout the dry period, a history of use without the addition of chemical pesticides, an area where local rice cropping systems were well represented, and an area where co-operation with landowners and farmers was possible. All these criteria were met in the Biff sector of Dubreka.

The site was prepared at the end of the 1986 wet season (November - December, 1986). The field was cleared, ploughed and canals were dug throughout the area in order to assure adequate irrigation. The area was divided into 32 plots, each measuring 5 m X 2 m, the size of experimental plots used by researchers at the Kilissi Agricultural Research Centre (Centre de recherches agronomiques de Kilissi, Guinée), 150 km to the east of Dubreka.

Experimental design

The variety of rice chosen was Nankin I, a short cycle (3 months) variety of *Oryza sativa* var. *indica*. This variety was introduced into Guinée by the Chinese over 25 years ago, and has since then been tested extensively by the Foulayah Agricultural Institute (Institut des Sciences Agro-Zootechniques de Foulayah-Kindia, Guinée), 30 km northwest of Kilissi and the Kilissi Agricultural Research Centre. The variety has also been distributed to farmers in many localities in Guinée. It is characterized by a low tillering potential, medium height (1 meter), and a potential yield of 4.2 - 4.5 t/ha (Soumah, 1984).

The first 'direct seeded' date was December 24, 1986. The first seed bed was prepared eight days earlier (December 6) to synchronize the later stages of both the direct and indirect rice crops, as recommended by Dobelmann (1976). He claimed that rice grown from transplanted see-transplanted seedlings is delayed approximately eight days in relation to direct seeded rice. This did not prove to be correct in our situation; the transplanted rice had to be started 14 days before the direct seeded date, and this was done in the following seasons.

The second, third, and fourth direct seedec dates were fixed at 14-day intervals in the 1987 dry season and the same was done for the preparation of the second, third and fourth seed beds. Seedlings were transplanted after 25 days. Treatments (two sowing methods X four planting dates), were replicated four times and were arranged in a Randomized Block Design (Gomez and Gomez 1984).

Direct seeded rice was sown by the broadcast method at a rate of 80 kg/ha on puddled and saturated soil; rice grown for transplanting was first sown at the same rate as for the direct seeded rice, in a seed bed, and transplanted 25 days after planting, two plants per hill and with 20 cm X 20 cm spacing between hills. Seeds were soaked in the fungicide, Thioral® before planting. Mineral fertilizers were used following recommendations of local agricultural bulletins, i.e. 100 kg/ha of urea, 400 kg/ha $CaH_2(PO_4)_2$ and 180 kg/ha KCl.

Changes in the experimental design in subsequent seasons

While measuring adult populations, it became evident that plot size was far too small to prevent plot-to-plot interaction, preventing valid estimation of the effects of each treatment on the adult population. To avoid these interactions plot size would need to be more than 10 times the present size and only the centre of each plot sampled, or plots could be isolated from each other by non-target plants (G. Lafleur, formerly of the 'Projet de Protection des Végétaux', Bobo-Dioulasso, Burkina Faso, personal communication). Even though such important changes in plot arrangement were not possible, plot size was nevertheless increased to 5 m

X 4.5 m in the 1987 wet season, and again to 9.5 m X 5 m in the 1988 dry and wet seasons and the 1989 dry season. The layout of the experimental field in the latter seasons is illustrated in Figure 5.

After the 1987 wet season, the interval between dates of planting was increased to 21 days. The 14-day period was thought to be too short a difference for valid interpretation and the sampling load was also concentrated in too short a period. Because of this change, the fourth date of planting was eliminated. The experimental design then consisted of six treatments (three planting dates X two planting methods).

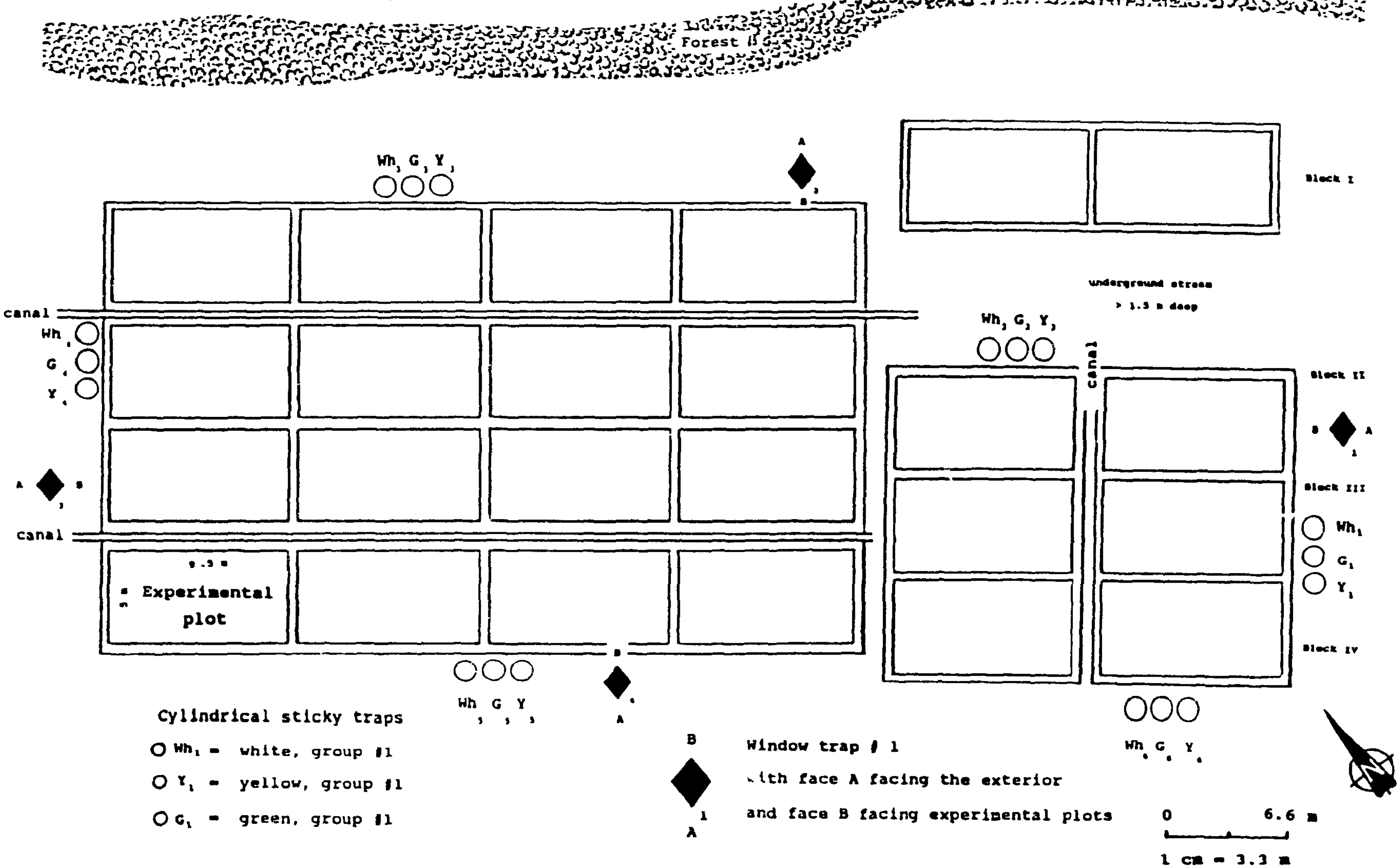
During the 1988 and 1989 dry seasons and the 1988 wet season, rice blast, *Magnaporthe grisea* (Hebert) M.E. Barr (=*Pyricularia oryzae* (Cooke) Sacc.) was a general problem in the field. A foliar spray with lopsin^R was applied twice during the vegetative stage.

Sampling procedure.

Sweep net. Adults of *D. longicornis* and *D. apicalis* were collected with a standard sweep net as recommended by Pollet (1978), Cochereau (1978, 1985a) and Nishida and Torii (1970). Ten sweeps (one sweep per step) were taken weekly, in a diagonal line across each plot and total number of insects were counted per plot. After the 1987 dry season, the sex of each fly collected was determined, as well as the presence or absence of eggs within each female. Rice sown in seed beds in preparation for transplanting were also sampled for presence of adult diopsids. Because none were collected, results only represent samplings from plots after the rice had been transplanted.

Plant dissections. From the seedling to the flowering stage, which corresponds to 55 days after transplanting (DAT) or 65 days after seeding (DAS), 10 plants from every plot were randomly harvested and dissected for the detection of eggs, larvae and pupae. Dissections were done every 14 days during the 1987 dry season and every 7 days during the subsequent seasons.

Fig. 5 Experimental Field. Dubreka. Dry and Wet Seasons 1988 and Dry Season 1989 (including positions of interception traps)



During the first two seasons of the study (1987 dry and wet seasons), plants were dissected weekly until the ripening stage to confirm the observations of Pollet (1978), Brenière (1983), and Cochereau (1985a) that *Diopsis* are not known to infest rice beyond the flowering stage. Upon confirmation, plants were dissected only until the flowering stage during the subsequent seasons.

At the end of the 1987 wet season, after harvest, a sample of rice stalks left in the field, were randomly harvested (10 per plot) and dissected in order to detect presence of *Diopsis* spp. larvae or pupae. Larval diapause in rice stubble is seen with other stemborers such as *Marliarpha separatella* (Agyen-Sampong 1979a). *M. separatella* as well as *Chilo* spp. were found, but no *Diopsis* sp. larva or pupa was collected. This further confirms the exclusive affinity of *Diopsis* spp. for living plant tissue.

Identification of eggs, larvae, pupae and adults was done with the aid of keys provided by Brenière (1983) and Tran (1981). Adult identifications were confirmed by sending specimens to H.R. Feijen of the Rijksmuseum van Natuurlijke Historie in Leiden, Holland.

Sweep net sampling and plant dissections generated results on adult, pupal and larval parasites and pathogens. The information that was gathered is reported in Appendix 1.

Visual observations for eggs. During the first season, eggs were not seen during plant dissections, therefore, in the following seasons, sampling was done by visual observation of the plant in the field. According to Descamps (1957a), Brenière (1983) and Feijen (1984), eggs are laid on the upper surface of terminal and sub-terminal leaves. Visual observation of these plant parts from 100 plants or 50 hills were made in each plot every second week. Even though eggs were found, counts were low during the two seasons when these observations were made, (1988 dry and wet seasons: Appendix 2.0). Because larval presence did not reflect such low egg numbers, egg counts are invalid. Although most researchers agreed with Descamps and Brenière on the egg-laying strategy of *Diopsis* spp., Scheibelreiter (1977)'s conclusions are probably more reliable and they may explain why so few eggs were found in the present experiment. He determined that 68% of *D. longicornis* eggs are deposited on the stem, 7% on the root collar and only 25% are to be found on the leaves, during the various stages of the rice crop. In addition, Cochereau (1985a) noted that eggs are difficult to find after 30 DAT (Days After Transplanting) because they are hidden in the folds of the dense rice plant.

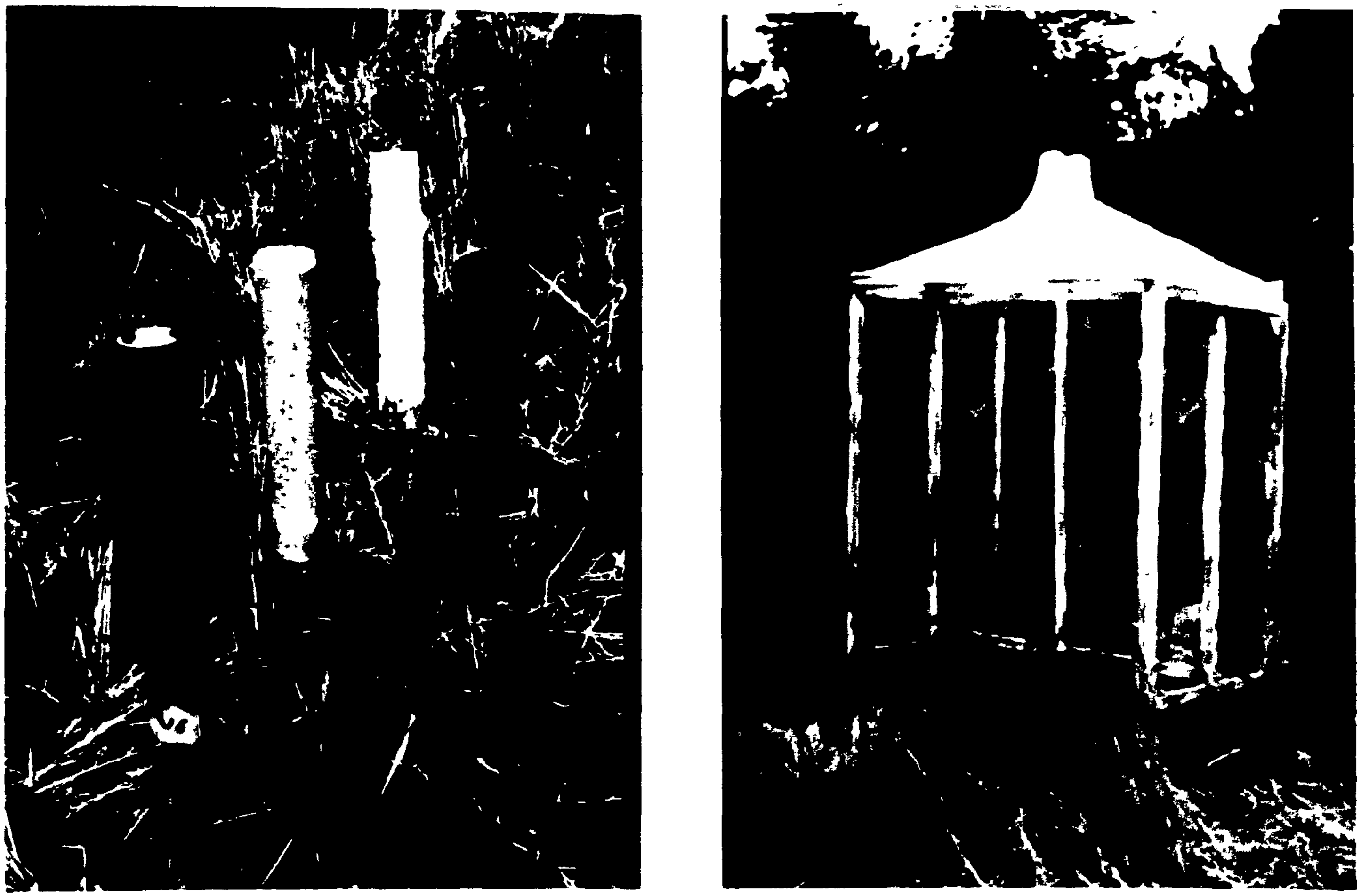
The following information was also noted from weekly plant samples before dissection: number of tillers infested with eggs, larvae and pupae per plant, number of dead hearts or white panicles per plant and the stage of the plant.

Interception traps. Two types of interception traps were used during the last three field seasons (the 1988 dry and wet seasons and the 1989 dry season). These traps were designed to monitor insect activity around the experimental field, i.e., movement in and out of the field and direction of movement. This study was designed to determine whether the diopsid population remained on the rice field once established and if there was continual invasion from the exterior onto the field during the season.

The first type of trap used was a cylindrical sticky trap made with a piece of bamboo (8 cm diameter by 50 cm long). Cylindrical traps have been used by Lewis (1959) to sample mobile insects in cereal fields. The traps were painted either white, dark green or bright yellow to test the colour preference of diopsids (Figure 6a). Tangletrap was used as an adhesive. Six groups of traps of each of the three colours were placed at the periphery of the field of study.

Catches with the sticky traps were low in the first season and upon consultation with R. Vernon (Vancouver Agriculture Canada Research Station), the trap was changed from a cylindrical to a flat rectangular

Fig. 6 Interception traps.



a) cylindrical sticky traps b) double-entry window trap shape. Vernon mentioned that the fly would more likely land on a shape with an edge than one without one. Rectangles, measuring approximately 20 cm X 15 cm were painted the same colours as the cylinders and were used in the place of the latter during the 1988 wet season and during the 1989 dry period.

The second trap was an adaptation of the window and malaise traps described by Martin (1978), with an additional two-directional feature (Figure 6b). The double entry was suggested to me by M. Loevinshon (International Development Research Centre) and R. Vernon. Four traps were placed at each of the four sides of the field. Positions of both cylindrical sticky and window traps are illustrated in Figure 5.

Evaluation of percentage infestation (level of damage). Oñate's formula (1965 cited by FAO 1979) is still widely used for the evaluation of the level of infestation or damage of the rice crop by stem borers. Data are collected either at the maximum tillering (MT) stage or at the flowering (FL) stage.

$$\text{Percentage infestation} = \frac{\text{No. of damaged plants}}{\text{No. of plants sampled}} \times \frac{\text{No. of damaged tillers}}{\text{Total no. of tillers in the damaged plants}} \times 100$$

Damage is measured as the number of dead hearts at the maximum tillering stage, or of white panicles at the flowering stage.

Gomez (1972, cited by FAO 1979) adjusted Oñate's formula for the determination of damage at flowering in order to account for possible compensatory tillering, by including numbers of tillers from both damaged and undamaged plants.

$$P = \frac{I}{nx + (N-n)y} \times 100$$

where:

P = % infestation

I = Total number of damaged tillers in all damaged plants taken from the sample.

n = Total number of damaged plants.

x = Total number of tillers per damaged plants.

N = Total number of plants (damaged or not damaged) in the sample.

y = Mean number of tillers per plant for a sample of 10 undamaged plants.

In these experiments, to achieve the greatest accuracy, Oñate´s formula was used for the calculation of percentage infestation at MT and Gomez´s for the calculation of infestation at FL. FAO (1979) recommends that concurrent with the evaluation of percentage damage, a sample of plants should be taken at random from the plot to determine the species of insects causing the damage. During this study, weekly plant dissections revealed that very few Lepidoptera larvae, the other major rice stem borers, were found in rice stems and only after the MT stage had been reached. During the 1987 dry season, only 2 larvae were found in 1320 plant samples; in 1988, 1 larva was found in 1920 plant samples; and in 1989, no larvae were found in 2200 plant samples. Lepidoptera larvae were slighlty more numerous during the wet season: 21 larvae were collected in 1987 in 2680 plant samples, and 4 were collected in 1988 in 2000 plant samples. Species found were: *Sesamia calamistis* Hamps (Noctuidae), *Chilo zacconius* Blesz. (Pyralidae), *Chilo* sp., *Maliarpha separatella* Rag. (Pyralidae), and a few species not described in either Tran (1981) or Breniere (1983).

Statistical analysis

The SAS statistical programme (1988) was used to analyse variance using the General Linear Models Procedure, and to calculate difference between treatment means, using Tukey´s Studentized Range Test. Treatments tested were method and date of planting; block effect was also tested to verify whether proximity to the forest edge had an influence on numbers of diopsids. The 0.05 level of significance was accepted.

Raw data were first checked for normality with SAS and for homogeneity of variance using Hartley's F_{max}-test (Sokall and Rolf 1981). When standard deviation was proportional to the mean (data are whole numbers covering a wide range of values) data were transformed to a logarithmic scale. When variance was proportional to the mean (data contained many zeros) data were transformed by means of the square root equation $(X+0.5)^{1/2}$.

A Chi-square test was used to check weekly sampling data for seasonal homogeneity of sex ratios and of ratios between gravid and non-gravid females (Gomez and Gomez 1984).

Sampling of farmers' fields adjacent to the experimental plots

As mentioned previously, local farmers sow rice almost exclusively during the wet season. As a means of simple comparison of adult diopsid numbers collected on the experimental plots with numbers present in local rice fields, farmers' fields bordering the experimental area, were sampled with a sweep net during the 1987 and 1988 wet seasons.

Contrary to management practices followed in the experimental area (use of fertilizers and of fungicides), farmers chosen for this study, do not use these products or any other on their fields.

In both seasons, the area surrounding the experimental plots was divided into three sections. The sections, measuring close to 120 m^2 each, were tended individually by three farmers. In 1987, two sections were planted with the 120-day variety, Dewankhé and the other with the 120-day variety, Khorkhori. In 1988, the three sections were planted each with a different variety: Khorkhori, Kaoulaca bélè and Kaoulaca fikhé. Section I, where Kaoulaca bélé had been planted, was subdivided and Khorkhori was planted in an area measuring 45 m^2.

Sweep net sampling was done every 7 days, starting 14 days after transplanting. Instead of tracing plots within the sections, starting points were selected and marked with a bamboo pole. From these points, the investigator would walk 20 paces (always in the same direction) and take one sweep with each step. Areas were sampled during the vegetative stage of the rice plant.

RESULTS AND DISCUSSION

DRY SEASON EXPERIMENTS

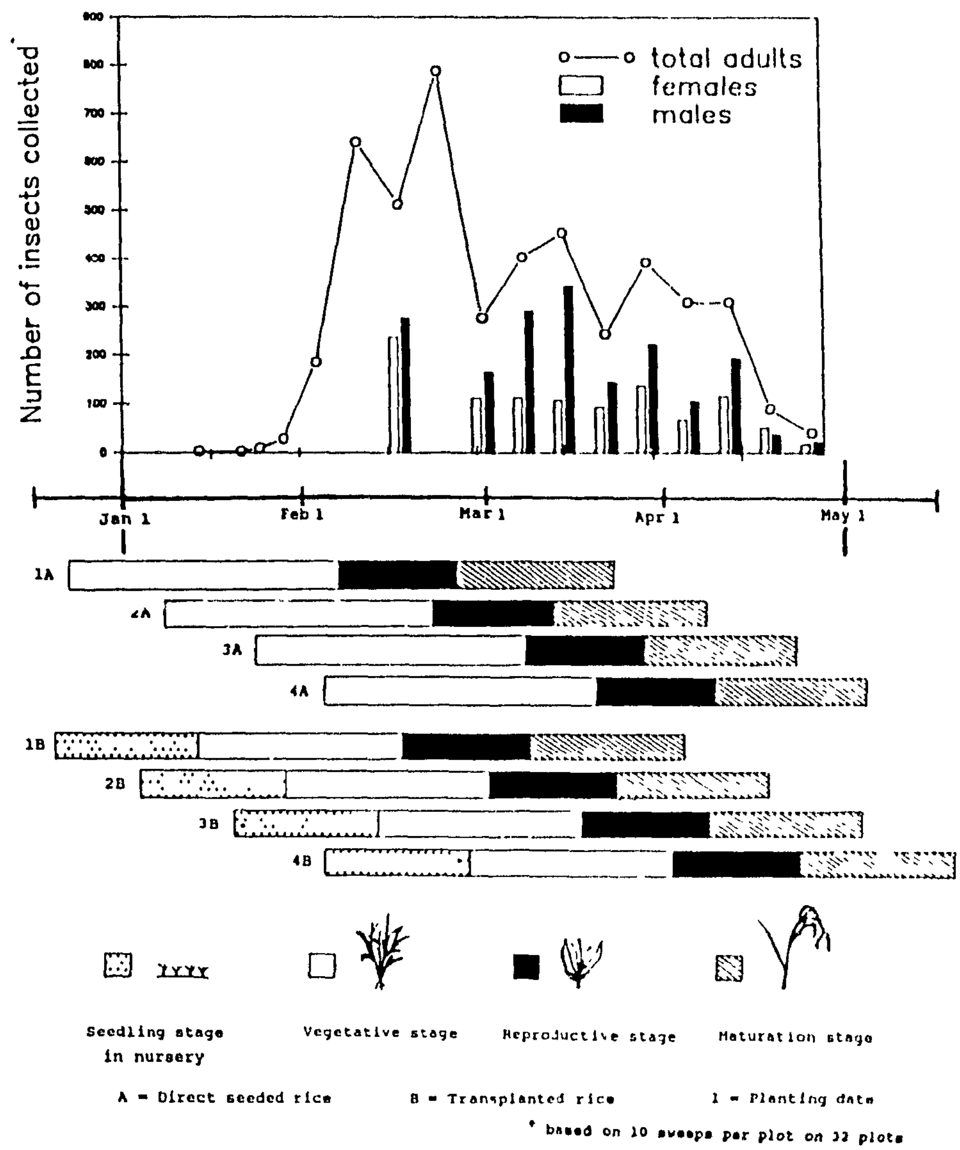
Data not included in the Figures or Tables of this chapter are reported in Appendix 2.

Dry Season 1987 (December 1986 to May 1987)

There was an experimental error with treatment 4A (direct seeded rice, fourth planting date) for the 1987 dry season. Seeds from a 120-day variety, ´Dewankré´, were sown instead of ´Nankin I´. The error was detected several weeks later, too late to correct it by replacing with ´Nankin I´. Even though sampling was continued on the 4A plots, these data were removed from all results presented here, except for total number of adults collected in the experimental field (Figures 7 & 8).

Adult population of *D. longicornis*. Plotting of total numbers of adult *D. longicornis* collected (Figure 7) provides an indication of the size and dispersion of the adult population on the experimental field throughout the dry season. It was assumed that adults were not present in plots that were not sampled, i.e., during the first week after sowing or transplanting, and later after the beginning of the maturation stage. Periodic sampling at these times confirmed this assumption. The curve shows an initial high peak from February 10 to March 3, when rice was at the vegetative stage, and thus attractive to *Diopsis* spp. in all plots. The population declined from March 3 to March 24, when the first and second crops were beyond the maximum tillering stage. Adult numbers were high again from March 31 to April 14 even though rice was beyond the vegetative stage in all but 8 plots at this time. This two-peak pattern had been recorded previously during wet season experiments by Cochereau (1978 1985a).

Fig. 7. Total number of Diopsis longicornis adults collected from all plots during weekly sweep net sampling Dry Season 1987



Even though sampling units were too close together to effectively evaluate treatment effects (date and method of planting and block) on the adult population, means were nevertheless tested for significance (Table 1). There was no significant difference in mean numbers of *D. longicornis* collected from plots sown on different planting dates, and from plots sown by either direct seeding and by transplanting, but there was a difference in numbers between blocks. Adults of *D. longicornis* were sampled in higher numbers in Block 1 than in the other three blocks. This suggests an edge effect associated with the forest canopy, which was adjacent to Block 1 (Figure 5). The forest probably offers a humid and shaded refuge for diopsids in the dry period.

Sex ratio of *D. longicornis*. Of the 4694 adult *D. longicornis* sampled, 2850 were sexed and of these 37% were females (Figure 7). Number of gravid females were counted from a small sample of females: out of 121 females only 9 carried eggs. This small percentage of laying females (7% of total females) confirms findings from the literature that report that diopsids are reproductively inactive during the dry period (Descamps 1957a, Brenière 1983). Females were in a higher proportion in February (46%), decreased in March (33%), then rose again in April (46%). A Chi-square test confirned this lack of homogeneity in sex ratio over the season (Table 2). Reasons for this variability were not clear at the time, and it was surprising to see that numbers of gravid females rose in April when the population was expected to be mainly composed of immature adults just emerging from the crop (as previously observed by Cochereau (1985a) and B. Camara (Centre de recherches agronomiques de Kilissi, personal communication) in their wet season studies. An explanation will be put forth later in the study.

Adult population of *D. apicalis*. Adults of *D. apicalis* were collected in as high numbers as for *D. longicornis* at the beginning of the season (February 10: Figure 8) and decreased significantly after March 1, as did

Table 1. Variation in mean numbers of *D. longicornis* and *D. apicalis* adults collected with date, method of planting and block. +
Dry Season 1987

	Mean number of *D. longicornis*	Mean number of *D. apicalis*
DATE OF PLANTING		
1	178.4a	134.6a
2	147.9a	88.4ab
3	87.9a	32.0b
4	165.3a	31.3b
METHOD OF PLANTING		
Direct seeded	118.1a	114.3a
Transplanted	159.8a	49.6b
BLOCK		
1	257.0a	64.1a
2	99.0b	59.7a
3	94.0b	69.9a
4	117.7b	115.6a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

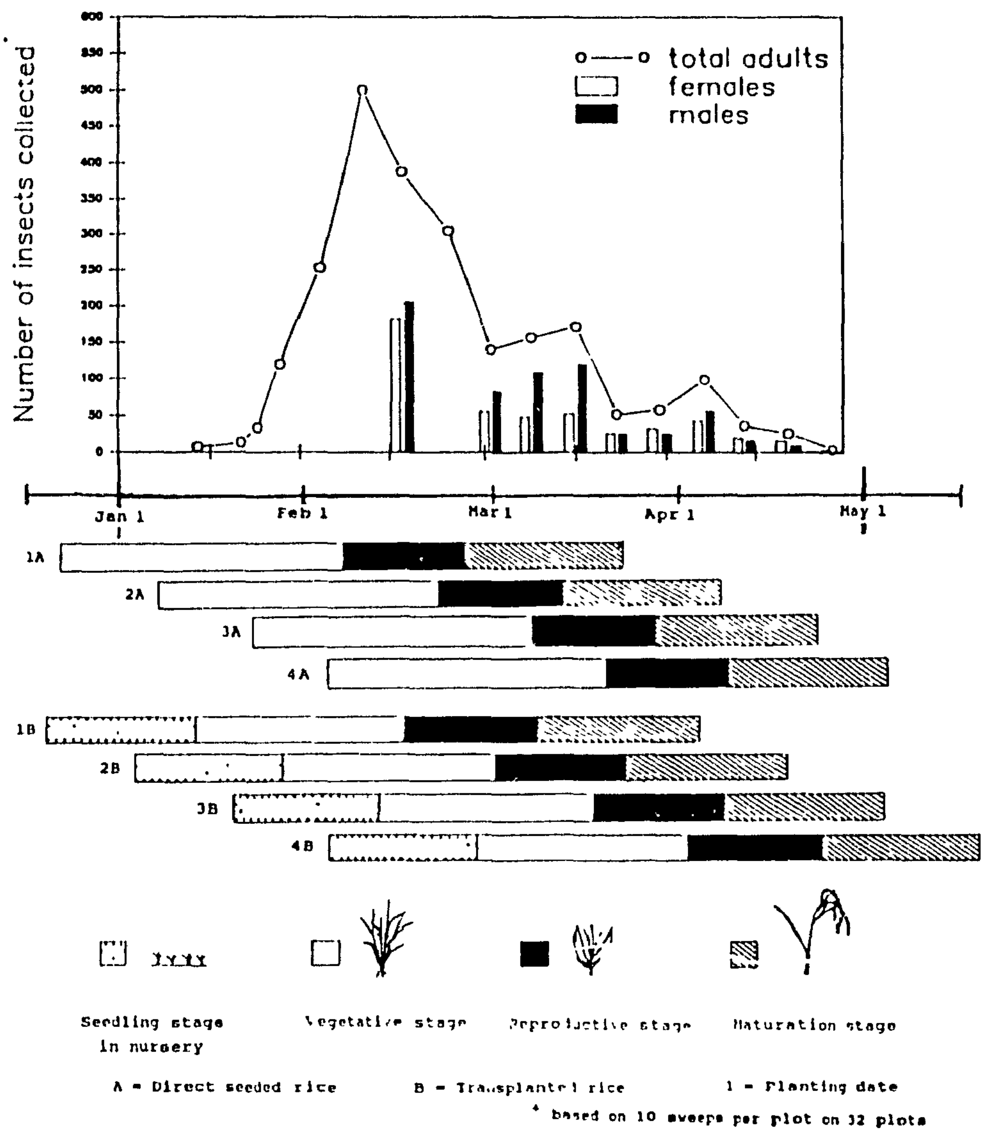
+ data based on weekly sweep net sampling (10 sweeps per plot in 32 plots)

Table 2. Variation in numbers of *D. longicornis* and *D. apicalis* males and females collected weekly. Dry Season 1987

	Total	♂♂	♀♀	Cal. X_2	Tab. X_2	H_o Acc/Rej*
D. longicornis	2850	1800	1050	85.2	16.9	Rej.
D. apicalis	1130	653	477	35.8	16.9	Rej.

* where H_o = proportion of males and females are constant throughout the season (independent of date) ($P < 0.05$)

Fig. 8. Total number of Diopsis apicalis adults collected from all plots during weekly sweep net sampling Dry Season 1987



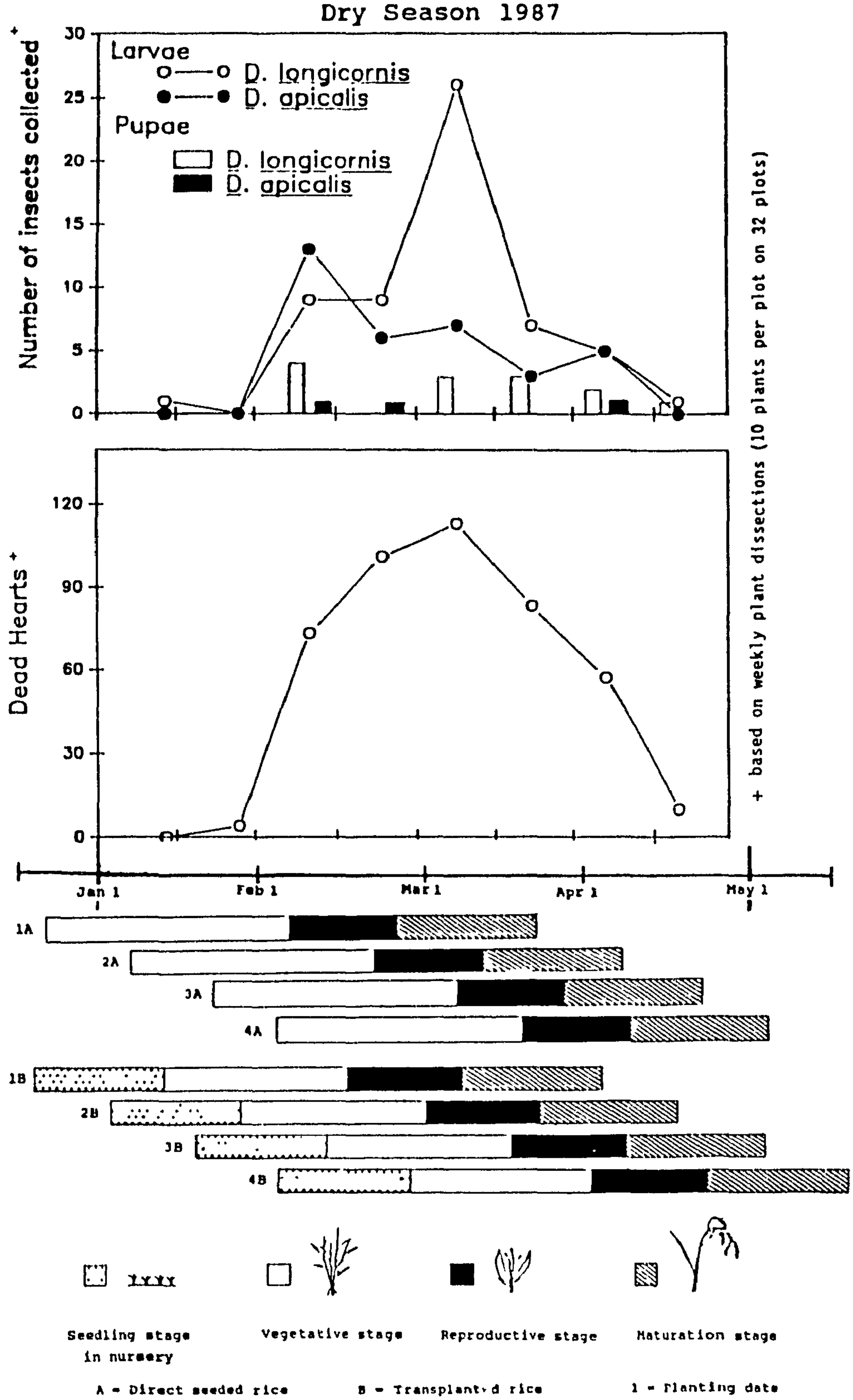
gicornis. Unlike *D. longicornis*, however, *D. apicalis* numbers did not rise again to a second peak at the beginning of April. Total *D. apicalis* adults collected (2368) were lower than those of *D. longicornis* (4694). Adult *D. apicalis* means were also compared according to date and method of planting (Table 1). *D. apicalis* were collected in significantly higher numbers from plots sown on the first planting date than from plots sown on other dates. Direct seeded rice was visited by a higher number of adult *D. apicalis*, but no block was favoured over any other.

Sex ratio of *D. apicalis*. Of 2368 individuals collected, 1130 were sexed and of these 42% were females (Figure 8). Only 3 of the 99 females examined (3%) carried eggs. Thus, there were probably 71 gravid females amongst the 2368 adults collected. This suggests that relatively few larvae would be produced. A chi-square test for homogeneity of ratios over the season showed that sex ratio varied significantly during the season, as with *D. longicornis* (Table 2). *D. apicalis* and *D. longicornis* ratios followed a similar trend (Table 2 & Figures 7 & 8). Female numbers were almost equal to males in February, dropped in mid-March, rose again to 50% at the end of March, and continued to rise to outnumber males after April 14 (from 54% to 75%).

Larval and pupal populations of *D. longicornis*. Total numbers of *D. longicornis* larvae and pupae found during plant dissections are shown in Figure 9. These numbers were considered to be representative of the population of immatures during the season, even though not all plots were sampled at each sampling date. Sampling was not done in plots during the 14 day-period after planting or when rice was beyond the flowering stage. This is because during frequent random sampling, no *Diopsis* spp. larvae were found at these times. A peak in *D. longicornis* larval presence on March 10 corresponded with the peak in adult population found between February 10 and March 3 (Figure 7), suggesting that the larvae developed from eggs laid by these adults. The total number of immatures found

Fig. 9. Total number of Diopsis longicornis and D. apicalis larvae, pupae and dead hearts collected from all plots

Dry Season 1987



from eggs laid by these adults. The total number of immatures found throughout the season was low in proportion to the adult population (larvae=58; pupae=6), but it was consistent with the low percentage of gravid females (7%). The preference for transplanted over direct seeded rice was significant (Table 3), with mean numbers collected on transplanted rice more than four times as high as numbers taken on direct seeded rice. Whereas adults had gathered in greater numbers on the plots from the first block, larval presence was distributed more or less equally amongst all blocks. Date of planting did not affect larval population density.

Larval and pupal populations of *D. apicalis*. Total numbers of *D. apicalis* larvae and pupae found were similar to those of *D. longicornis*, except for the high numbers obtained on March 12 for the latter species (Figure 9). The small increase in *D. apicalis* larvae on February 10 may correspond with a rise in adult numbers at this time. The low total numbers of larvae (34) and pupae (3) were consistent with the extremely low proportion of gravid females present (3%). *D. apicalis* larval infestation was more or less equal on crops sown on either dates of planting (Table 3), even though adults were seen more abundantly on the crops sown on the first date (Table 1). Infestation was higher in the transplanted rice than in the direct seeded rice; this does not correspond with adult numbers, which were higher in the direct seeded rice. As with the adults, there was no block effect on larval infestation. Broadly similar patterns of infestation by larval *D. apicalis* and *D. longicornis* were found. Larvae of both species were more numerous in stems of transplanted rice than in direct seeded rice; neither dates of planting nor blocks had an effect on larval presence for both species. As mentioned above, results of larval presence provide a more accurate indication of diopsid preference than do results of adult presence because of the drifting behaviour of the mobile adults.

Table 3. Variation in mean numbers of D. longicornis and D. apicalis larvae and of dead hearts collected with date, method of planting and block.+ Dry Season 1987

	Mean number of D. longicornis	Mean number of D. apicalis	Mean number of Dead hearts
DATE OF PLANTING			
1	1.0a	1.1a	11.6b
2	2.5a	1.5a	18.0a
3	2.8a	0.9a	16.4ab
4	2.3a	1.5a	18.3ab
METHOD OF PLANTING			
A	0.7b	0.3b	6.6b
B	3.1a	1.9a	22.6a
BLOCK			
1	2.9a	2.0a	19.9a
2	1.7a	0.4a	14.9a
3	1.7a	1.0a	13.3a
4	2.0a	0.9a	15.0a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

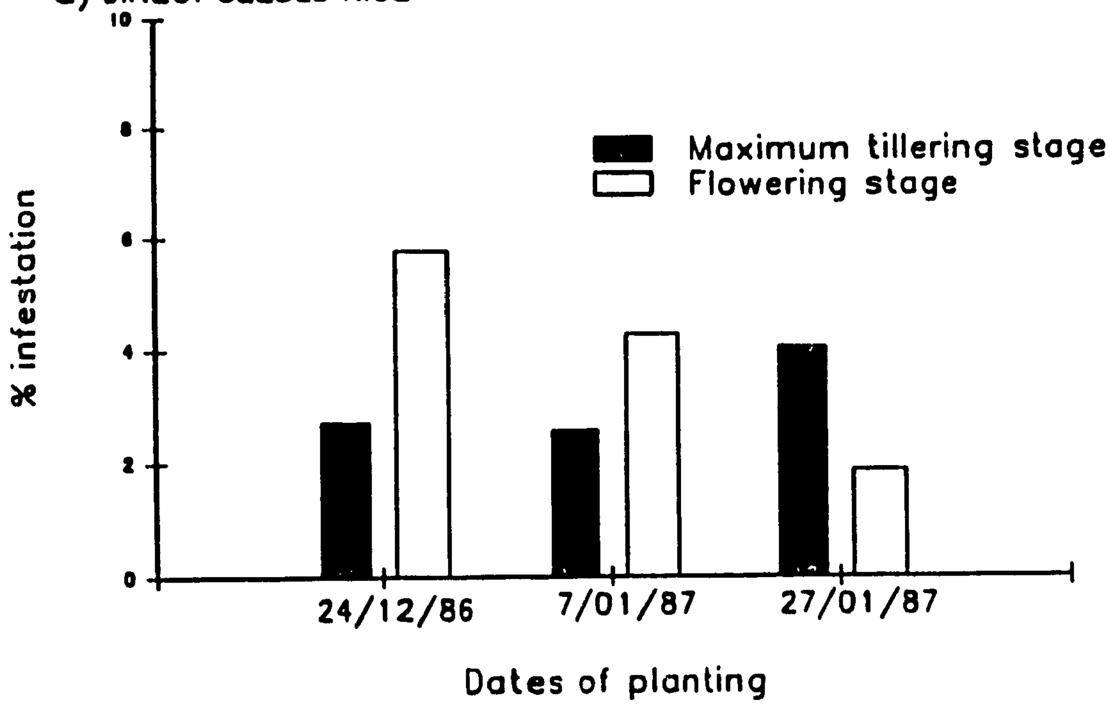
+ data based on weekly plant dissections (10 plants per plot on 32 plots)

Number of dead hearts (DH) and percentage infestation. Even though larval numbers of both *D. longicornis* and *D. apicalis* were low, number of DH were high (Figure 9). For example, although only 33 larvae (26 *D. longicornis* and 7 *D. apicalis*) were collected on March 10, as many as 113 DH were counted from the same samples (240 plants), averaging 4 DH per larva. A significantly higher number of DH were observed on the second date of planting than the first, and transplanted rice was more damaged than direct seeded rice (Table 3). There was no block effect on mean number of DH. These results relate well to those obtained with larval numbers, except for the significantly higher presence of DH among the plants sown on the second planting date.

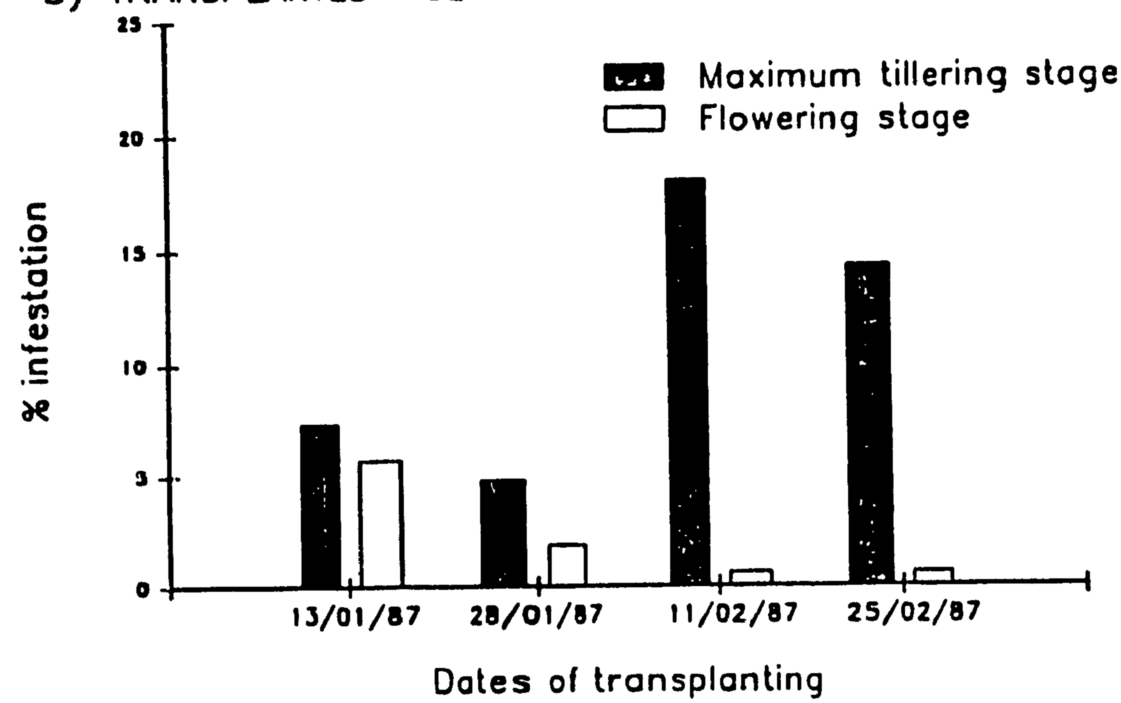
Percentage infestation at maximum tillering (MT) and flowering (FL) stages are illustrated in Figures 10a & b. The highest percentage infestation in direct seeded rice was 6% at FL (meaning that 6% of the tillers observed had a dead heart counted at the flowering stage). Highest infestation (18% at MT) in transplanted rice occured on the crop planted on the third date, contrary to results from weekly plant dissections for larvae and DH; these latter findings showed more damage on the crop sown on the second date of planting. Results for the MT stage are more dependable than those taken at FL because damage observed at MT was caused exclusively by diopsids, whereas some of the damage at FL may be caused by lepidopterous larvae, wind and poor germination. In summary, results both from DH counts and percentage infestation calculations show a preference by diopsids for transplanted rice over direct seeded rice.

Fig. 10.
Percentage infestation of direct seeded vs transplanted rice by diopsid larvae[1] – Dry Season, 1987

a) DIRECT SEEDED RICE



b) TRANSPLANTED RICE



[1] based on numbers of dead hearts (at MT) or of white panicles (at FL) in 100 plants/plot

Dry Season 1988 (December 1987 to May 1988)

During this season, it was hoped that interception traps would increase the precision of the sampling programme, as well as provide additional information on dispersal behaviour and pattern of infestation of both *D. longicornis* and *D. apicalis*. Unfortunately diopsid presence proved to be low; therefore results are inconclusive for most tests. The following is nevertheless an interpretation of the data collected.

First dry season planting began later in the 1988 season than in the 1987 season, although it had been intended to start earlier. Seeds prepared for the first seed bed were initially planted on December 10, however, because they did not germinate a replacement seed bed was prepared three weeks later on December 30.

Adult population of *D. longicornis*. The curve of the total population (Fig. 11) did not resemble that of the previous dry season (Figure 7). Total numbers were lower (735 in 1988 vs. 4694 in 1987) and the population rose slowly and gradually to one small peak on March 8 and to somewhat larger peaks on March 29 and April 6. Whereas in 1987, high numbers occured in February when most rice plants were at the vegetative stage, the highest peak in 1988 occured at the end of March and beginning of April, when only 8 plots out of 24 were at this stage. Our hypothesis, that the adult population sampled at the end of the season was derived from immatures coming from adults present earlier in the season, did not hold because adult numbers were too low early in the season. There may be another reason for an increase in numbers of adult *D. longicornis* late in the season. Perhaps April is the time when most *D. longicornis* leave the refuge sites and disperse into neighbouring fields.

As with the 1987 dry season results, adult population means were tested for effect of date and method of planting, and of block (Table 4). Neither date, method of planting nor blocks had a significant effect on mean numbers of adult *D. longicornis* collected. These results are similar

Fig. 11. Total number of *Diopsis longicornis* adults collected from all plots during weekly sweep net sampling Dry Season 1988

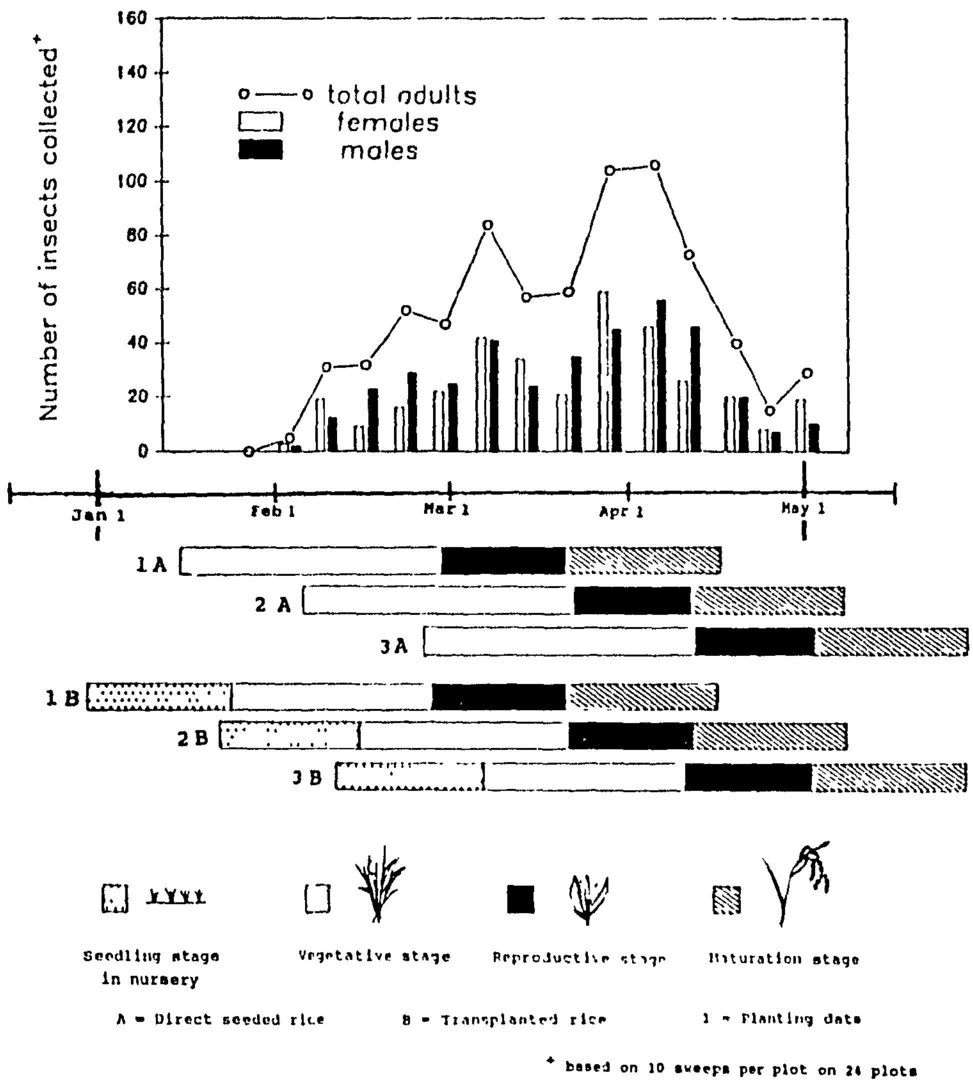


Table 4. Variation in mean numbers of *D. longicornis* and *D. apicalis* adults collected with date, method of planting and block. +
Dry Season 1988

	Mean number of *D. longicornis*	Mean number of *D. apicalis*
DATE OF PLANTING		
1	28.0a	6.0a
2	29.1a	4.6a
3	34.6a	1.5a
METHOD OF PLANTING		
Direct seeded	32.3a	4.3a
Transplanted	28.8a	3.8a
BLOCK		
1	37.0a	6.8a
2	35.5a	5.0a
3	31.3a	2.8a
4	18.5a	1.5a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+data based on weekly sweep net sampling (10 sweeps per plot in 24 plots) to those obtained in 1987. In this year, however, Block 1 had a significantly higher number of *D. longicornis*, suggesting an edge effect from the forest; in 1988, this situation was not evident.

Sex ratio of *D. longicornis*. During this dry season, 344 (47%) of the 735 adult *D. longicornis* collected were female and 145 (42%) of these females were gravid (20% of the total population: Table 5). As in the previous season, sex ratio varied significantly over the season with an important rise in the proportion of females at the end of the season (66% on May 3). The percentage of gravid females collected was much higher (42% of total females) than in 1987 (7%), but results from this season may not be representative because they are so low. However, to ensure survival, one might expect a higher number of gravid females when population density is low.

Adult population of *D. apicalis*. Overall *D. apicalis* population was low (Figure 12). The largest sample was taken on March 8 (a total of 18 *D. apicalis* adults or 4 flies per 40 sweeps). Means were tested nevertheless, and results showed no significant difference in mean insects collected between either dates or methods of planting, or between blocks (Table 4). Means may be too low to show significance.

Sex ratio of *D. apicalis*. Of the 98 adult *D. apicalis* collected, 53 (54%) were female (Table 5). Only eight females (15%) of the 53 adults carried eggs (8% of the total population). This ratio is slightly higher than that obtained in 1987, but it is still low. Sex ratios and ratios between gravid and non-gravid females remained constant during the season (Table 5). Because of low numbers of gravid females, *D. apicalis* larvae were totally absent from plant dissections. Note that *D. apicalis* adults will visit other hosts besides cultivated rice.

Fig. 12. Total number of <u>Diopsis</u> <u>apicalis</u> adults collected from all plots during weekly sweep net sampling Dry Season 1988

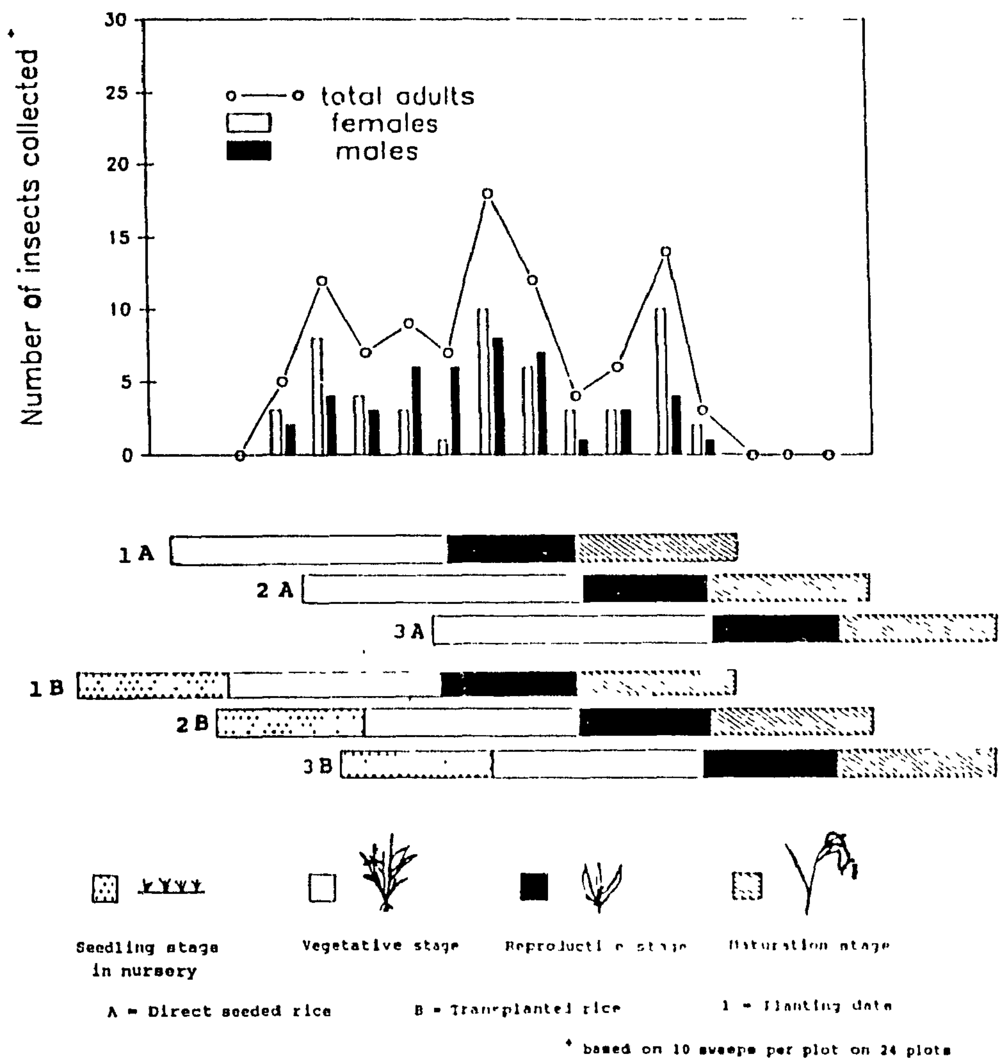


Table 5. Variation in numbers of D. *longicornis* and D. *apicalis* males and females and in gravid and non-gravid females collected weekly. Dry Season 1988

Male vs Female

	Total	♂♂	♀♀	Cal X_2	Tab X_2	H_o Acc/Rej*
D. *longicornis*	735'	373	344	30.0	22.3	Rej
D. *apicalis*	98	45	53	9.9	18.3	Acc

' 18 insects were damaged and could not be sexed

* where H_o = proportion of males and females is constant throughout the season (independent of date) ($P < 0.05$)

Gravid vs Non-gravid

	Total ♀ dissected	Gravid	N-gravid	Cal X_2	Tab X_2	H_o Acc/Rej*
D. *longicornis*	342	145	197	70.0	22.4	Rej
D. *apicalis*	53	8	45	11.4	18.3	Acc

* where H_o = proportion of gravid to non-gravid females is constant throughout the season (independent of date) ($P < 0.05$)

Larval and pupal populations of *D. longicornis*. Number of *D. longicornis* larvae and pupae found during weekly plant dissections are given in Figure 13. All were very low. The average number of *D. longicornis* larvae collected from one treatment (a sample of 40 plants) per sampling date never rose above 1. These figures indicated very low infestation by diopsids during this dry period. No significance was found between means from the different dates and methods of planting, or from the different blocks (Table 6).

Number of dead hearts (DH) and percentage infestation. There were 6 times more DH than larvae found this season, but numbers were lower than observed in the previous dry period (a total of 136 in 1988 compared to 441 in 1987: Figure 13). There was no difference in damage between crops sown on different dates of planting and between crops sown in different blocks (Table 6). Contrary to the 1987 findings, direct seeded rice was more damaged than transplanted rice, however, one must keep in mind that this season's figures may be too low to draw any conclusions.

Percentage infestation results were also lower this season than in the previous year. In 1988, highest infestation occured in transplanted rice (over 5%) at MT (on March 22) in the second crop (Figures 14a & b).

Interception traps. Cylindrical sticky traps. The six groups of sticky traps placed around the experimental field caught only 6 *D. longicornis* and no *D. apicalis* during this season; one insect was found on a green trap (G_2) whereas the other 5 were on yellow traps (two on Y_1; one on Y_2; two on Y_6: Figure 15). With relatively few adult *Diopsis* spp. sampled with the sweep net, it was not expected that many individuals would be captured by the traps. However, their numbers were so low that the efficiency of the trap was questioned. To test the trap, and also the attractiveness of each colour to diopsids, a simple experiment was made during this season:

Fig. 13. Total number of *Diopsis longicornis* larvae, pupae and dead hearts collected from all plots

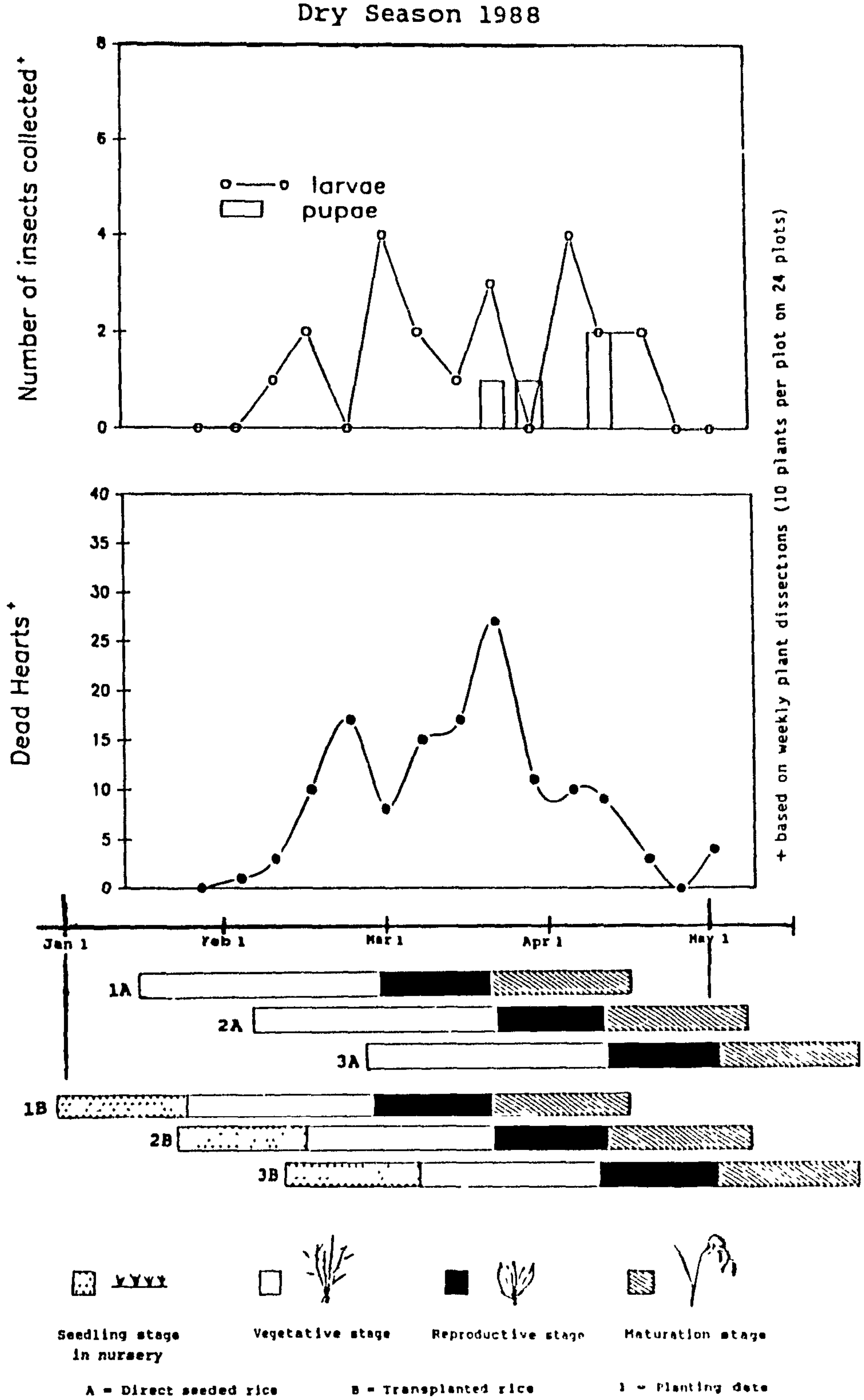


Table 6. Variation in mean numbers of *D. longicornis* larvae and dead hearts collected with date and method of planting and block.[+] Dry Season, 1988.

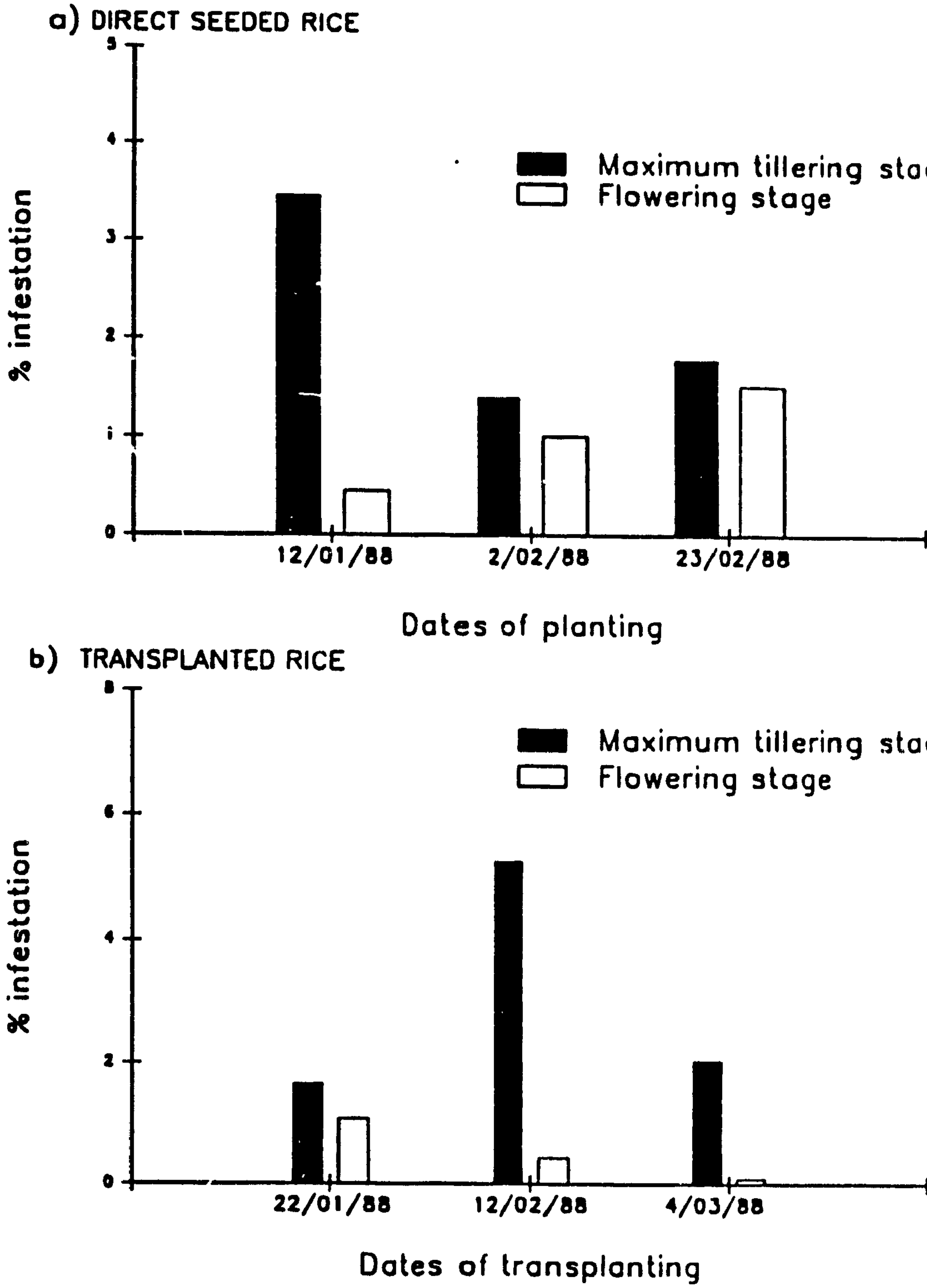
	Mean number of *D. longicornis*	Mean number of dead hearts
DATE OF PLANTING		
1	1.1a	6.8a
2	0.9a	4.6a
3	0.6a	5.5a
METHOD OF PLANTING		
Direct seeded	0.9a	7.3a
Transplanted	0.8a	4.0b
BLOCK		
1	0.7a	5.2a
2	0.8a	7.3a
3	1.5a	5.7a
4	0.5a	4.3a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

[+]data based on weekly plant dissections (10 plants per plot on 24 plots)

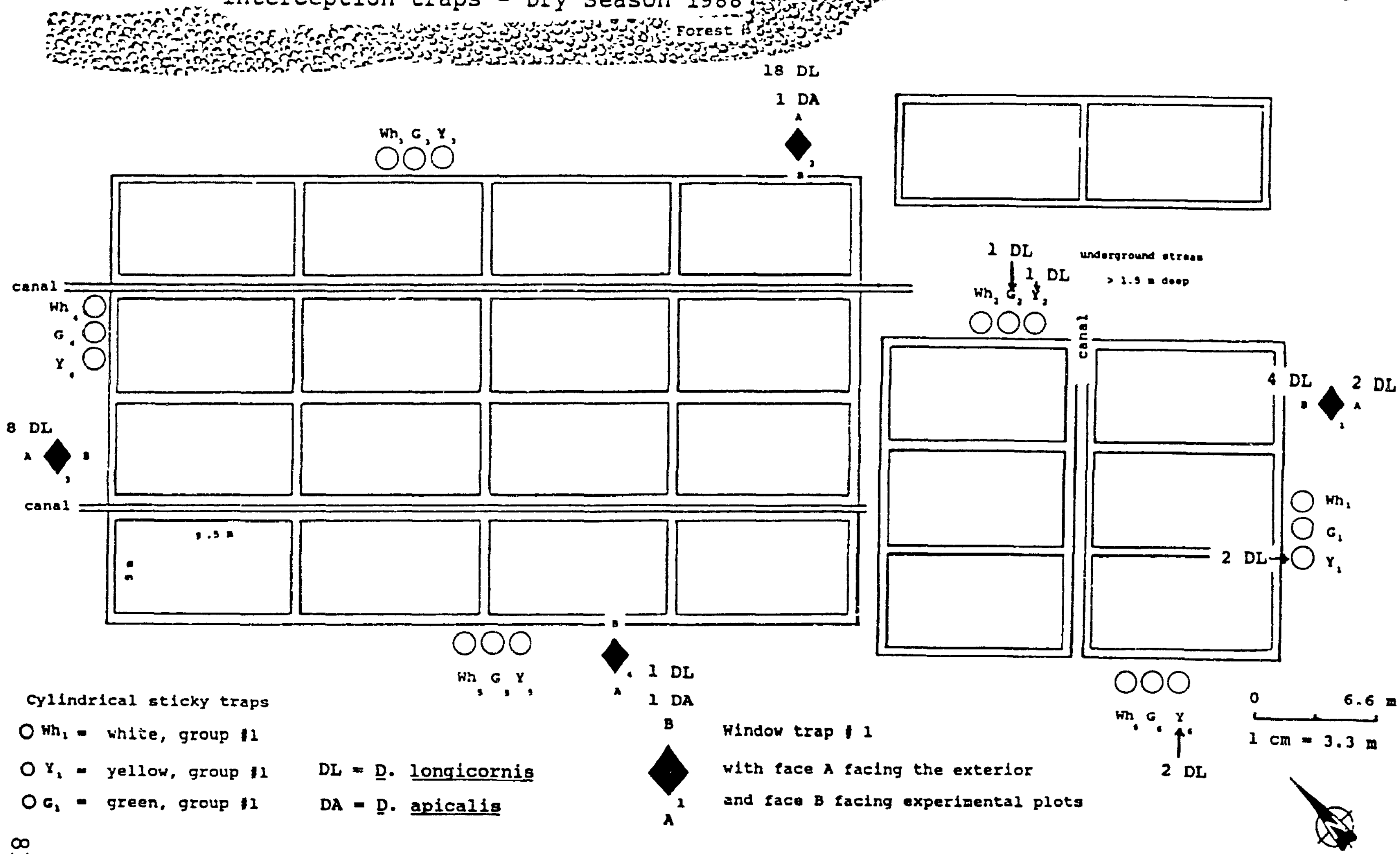
Fig. 14.

Percentage infestation of direct seeded vs transplanted rice by diopsid larvae[1] – Dry Season, 1988



[1] based on numbers of dead hearts (at MT) or of white panicles (at FL) in 100 plants/plot

Fig. 15. Total number of Diopsis longicornis and D. apicalis adults collected from weekly monitoring of interception traps - Dry Season 1988



Three other groups of traps of the same colours were placed in three refuge sites of *D. longicornis* where several thousands of these insects could be found per square meter. After 10 days in these sites, observations were taken of the number of diopsids captured. The yellow trap captured more diopsids than the other three colours; 27 compared to 4 by the green trap and one by the white trap. It was surprising that only 32 insects were captured in an area where so many mobile diopsids were present.

Observations of behaviour of *D. longicornis* around the traps placed in the refuge sites revealed interesting phenomena. When encouraged to move towards the traps (by pushing the swarm of diopsids with a sweep net), the insects appeared to land briefly on the traps, choosing to land on yellow over all other colours, but then took off. The fly seemed to sense through its tarsi that the quality of the substrate was undesirable.

It is likely that sticky traps, placed in the experimental field, were also visited by many more diopsids than the results show.

Window traps. These traps caught more diopsids than did the sticky traps, but numbers were low. A total of 33 *D. longicornis* and 2 *D. apicalis* were collected evenly throughout the experiment. The exterior face of window trap #2 collected by far the most insects (18 *D. longicornis* and 1 *D. apicalis*: Figure 15). This can be explained by its proximity to the forest edge, which offers the conditions of shade and high humidity that are characteristic of diopsid dry season refugia. The fact that the diopsids were found on the exterior face of the trap implies that they had left the refugia and were moving towards the rice field.

It is difficult to evaluate the efficiency of both types of traps because of the overall low population density in the field during the season.

Dry season 1989 (December 1988 to May 1989)

Adult population of *D. longicornis*. Adult numbers were higher (total 1138) than those obtained in 1988, but still much lower than in 1987. The 1989 total adult population curve shows a gradual increase to a small peak on February 21, then dips down in early March to rise again on March 21 and 28 (Figure 16). The second peak might suggest that these insects came from, at least in part, the adults of the first peak. In comparing figures from the 3 dry seasons (1987, Figure 7; 1988, Figure 11; 1989, Figure 16), there are few similarities between the *D. longicornis* adult population curves. Statistical analysis of 1989 weekly sweep net sampling results show a significantly higher number of adults collected from the crops sown on the third planting date than from the crops sown on both the first and second planting dates. There is no difference in means between the two methods of planting, or between the different blocks (Table 7).

Sex ratio of *D. longicornis*. Of 1133 adult *D. longicornis* collected, 490 (43%) were female. Of these females, 121 were gravid females (25% of total females or 11% of the total population) (Table 8). This ratio is close to that found in 1987 and, as in 1987, larval presence was very low in proportion to the total adult population. Sex ratios remained constant throughout this dry period, but ratios between gravid and non-gravid females varied continuously during this time (chi-square test, Table 8).

Adult population of *D. apicalis*. *D. apicalis* numbers were low in 1989. The total population curve shows an earlier peak on January 31 (44 flies) decreasing to two insects on March 14, then rising again to 40 insects on April 4 (Figure 17). This curve is different from both the 1987 or 1988 curves. *D. apicalis'* polyphagous nature may explain the lack of consitency in numbers collected during these experiments.

Fig. 16. Total number of Diopsis longicornis adults collected from all plots during weekly sweep net sampling

Dry Season 1989

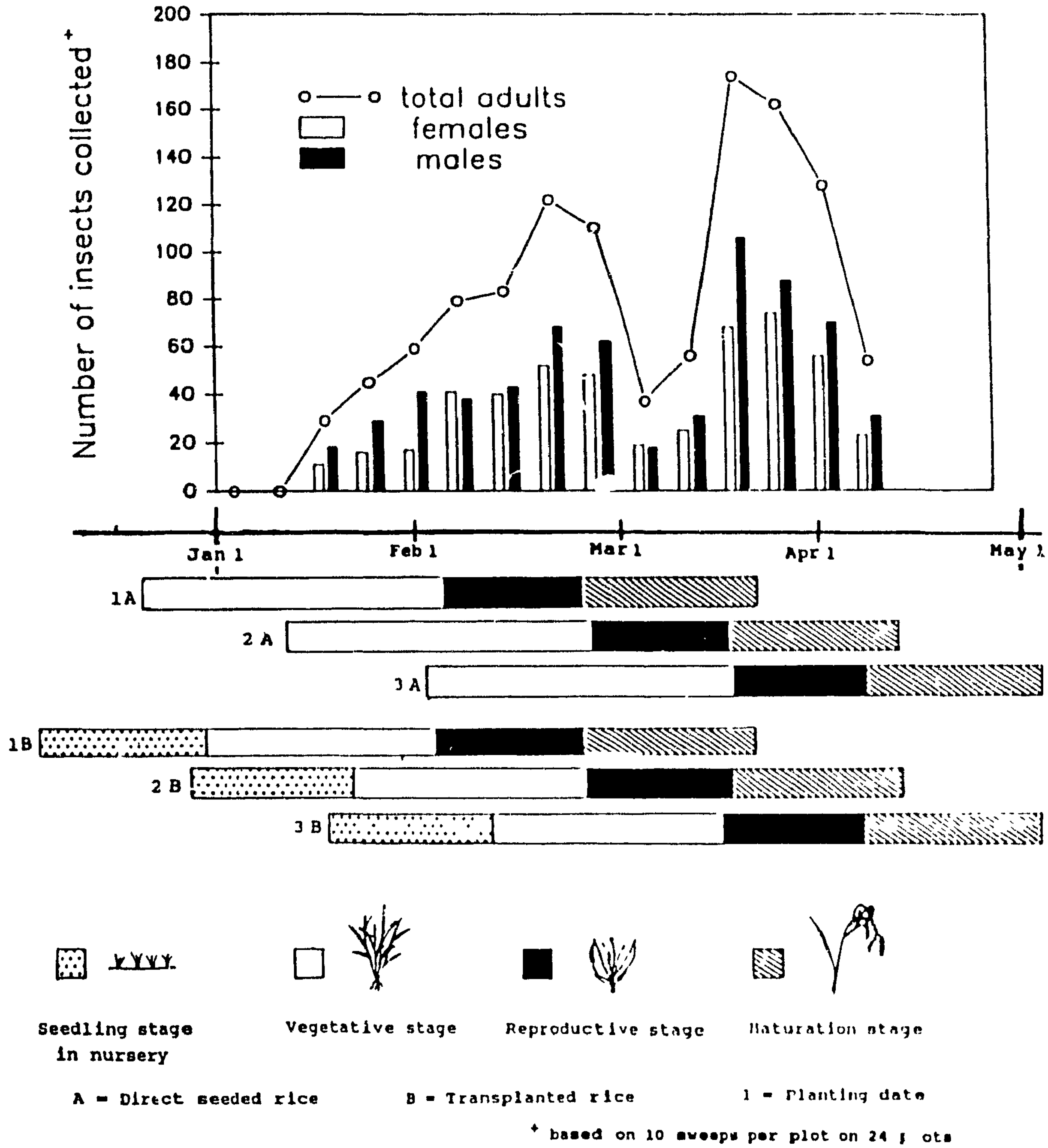


Table 7. Variation in mean numbers of *D. longicornis* and *D. apicalis* adults collected with date, method of planting and block.[+]
Dry Season 1989

	Mean number of *D. longicornis*	Mean number of *D. apicalis*
DATE OF PLANTING		
1	34.8b	11.6a
2	22.6b	4.0a
3	84.9a	14.5a
METHOD OF PLANTING		
Direct seeded	51.6a	9.5a
Transplanted	43.3a	10.6a
BLOCK		
1	93.7a	18.0a
2	32.8a	7.0a
3	35.0a	4.7a
4	28.2a	10.5a

Note: Any two means in one column and within one section followed by different letters differ significanlty at $P < 0.05$

[+] data based on weekly sweep net sampling (10 sweeps per plot in 24 plots)

Fig. 17. Total number of *Diopsis apicalis* adults collected from all plots during weekly sweep net sampling Dry Season 1989

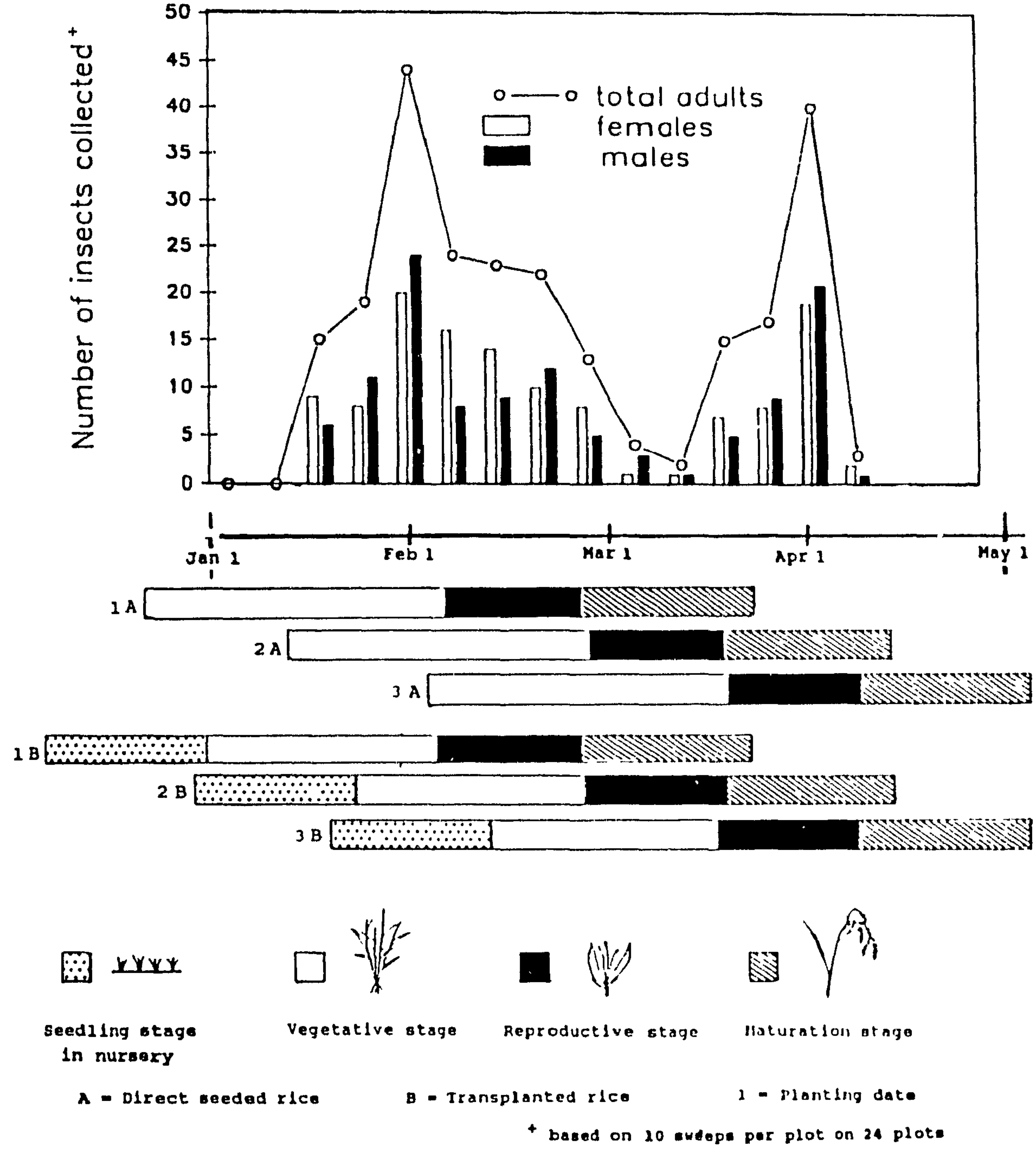


Table 8. Variation in numbers of *D. longicornis* and *D. apicalis* males and females and in gravid and non-gravid females collected weekly. Dry Season 1989

Male vs Female

	Total	♂♂	♀♀	Cal X_2	Tab X_2	H_oAcc/Rej*
D. longicornis	1133	643	490	12.0	21.0	Acc
D. apicalis	238	115	123	7.6	21.0	Acc

* where H_o = proportion of males and females is constant throughout the season (independent of date) ($P < 0.05$)

Gravid vs Non-gravid

	Total ♀	Gravid	N-gravid	Cal X_2	Tab X_2	H_oAcc/Rej*
D. longicornis	490	121	369	30.6	21.0	Rej
D. apicalis	123	11	112	12.9	21.0	Acc

* where H_o = proportion of gravid to non-gravid females is constant throughout the season (independent of date) ($P < 0.05$)

Mean numbers of *D. apicalis* were tested for significance and results showed no effects of date and method of planting or of block (Table 7).

Sex ratio of *D. apicalis*. There were almost equal numbers of female (52%) and male (48%) *D. apicalis*. Numbers of gravid females were very low, as were values obtained in previous dry seasons, with only 11 gravid females obtained from 123 females collected (9% of total females or 5% of the total population: Table 8). Sex ratios and ratios of gravid to non-gravid females remained constant throughout the study period.

Larval and pupal populations of *D. longicornis* and *D. apicalis*. Early in the season, larval counts were very low; no more than two larvae each of *D. longicornis* and *D. apicalis* were found in up to 240 weekly plant dissections from the beginning of the sampling period (December 27) until February 14. At this time all plots were at the vegetative stage (Figure 18). On February 21, until the end of the sampling programme, diopsid numbers increased. Contrary to results obtained in the other dry seasons, *D. apicalis* larvae were collected in higher numbers (44) than *D. longicornis* (40).

Effect of date and method of planting and block on mean numbers of larvae collected was tested (Table 9). *D. longicornis* and *D. apicalis* larvae were collected in significantly higher numbers from the crops sown on the third date of planting, and the transplanted rice was damaged by more larvae of both species than the direct seeded rice. Similar results were obtained in the 1987 dry season when *D. longicornis* and *D. apicalis* larvae showed a preference for transplanted rice.

Eggs were searched for weekly from January 1 to March 14, but since none were found this activity was discontinued.

Fig. 18. Total number of Diopsis longicornis and D. apicalis larvae, pupae and dead hearts collected from all plots Dry Season 1989

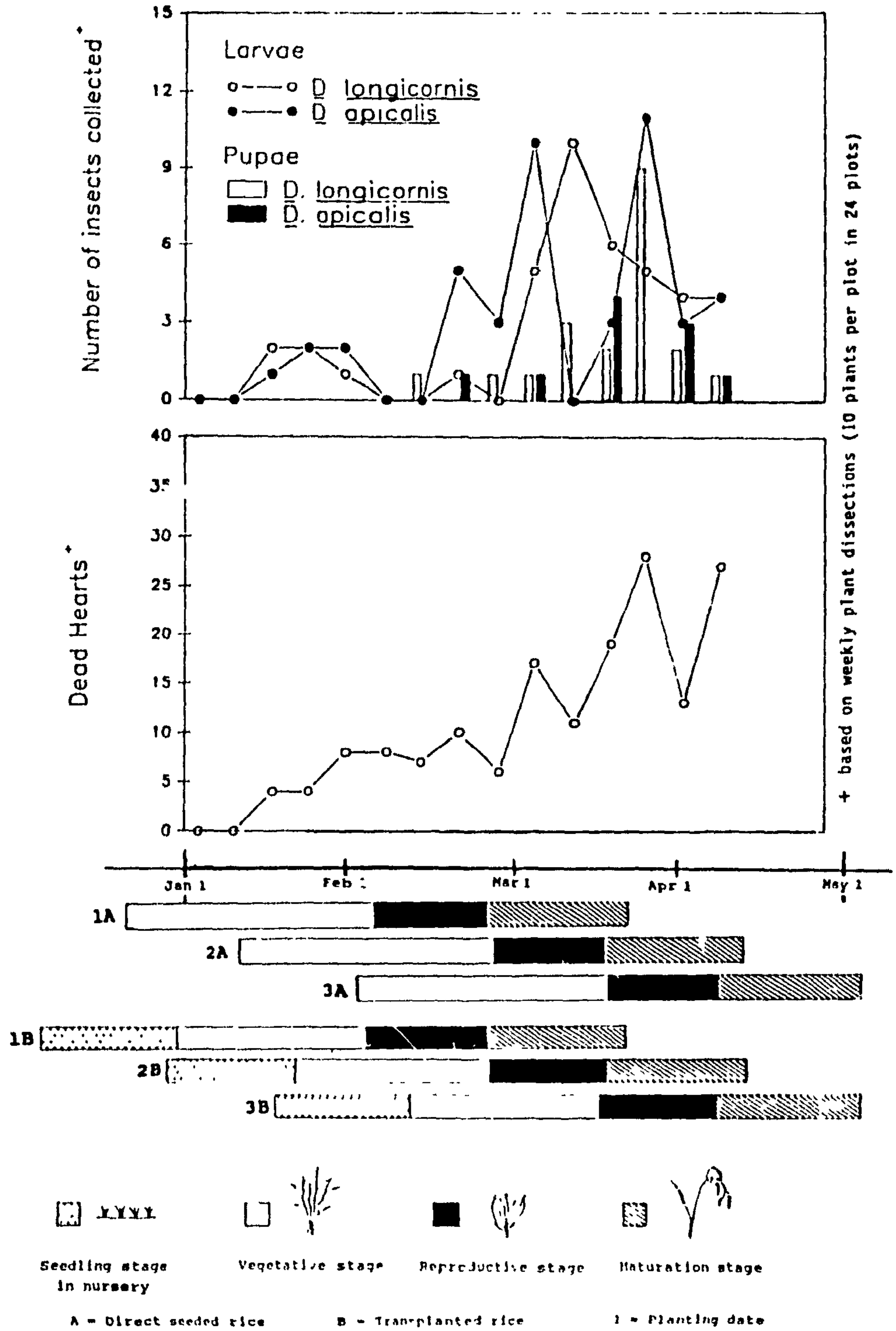


Table 9. Variation in mean numbers of *D. longicornis* and *D. apicalis* larvae and of dead hearts collected with date, method of planting and block. Dry Season 1989+

	Mean number of *D. longicornis*	Mean number of *D. apicalis*	Mean number of dead hearts
DATE OF PLANTING			
1	0.6b	0.8b	4.1b
2	1.4b	1.8ab	4.8b
3	3.4a	2.6a	11.4a
METHOD OF PLANTING			
Direct seeded	1.0b	0.3b	4.0b
Transplanted	2.6a	3.1a	9.5a
BLOCK			
1	2.3a	2.5a	9.5a
2	2.0a	1.7a	6.7a
3	1.3a	2.2a	6.2a
4	1.5a	0.5a	4.7a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+ data based on weekly plant dissections (10 plants per plot in 24 plots)

Number of dead hearts (DH) and percentage infestation. During this season (Figure 18), number of DH (162) were twice the number of larvae (84) found, a smaller proportion than in previous years (in 1987 and 1988, there were 5 and 6 times more DH than larvae respectively). The higher number of *D. apicalis* larvae present may be responsible for this difference. *D. apicalis* may be a less active searcher and pest than *D. longicornis*.

There was a significantly higher number of DH in the crop sown on the third planting date (Table 9). There was more than twice as many DH in transplanted rice as in direct seeded rice, which corresponds with 1987 data for this test. There was no block effect on the distribution of DH.

Percentage infestation is illustrated in Figures 19a and b. Results taken at maximum tillering on direct seeded rice follow results obtained in 1987 (Figure 10a), with a gradual increase in infestation from the first date of planting to the third. Results from the transplanted rice (Figure 19b) do not resemble results obtained either in 1987 (Figure 10b) or 1988 (Figure 14b). In 1989, infestation was slightly higher in the direct seeded rice than in the transplanted rice; in the two previous seasons, infestation was higher in the transplanted rice.

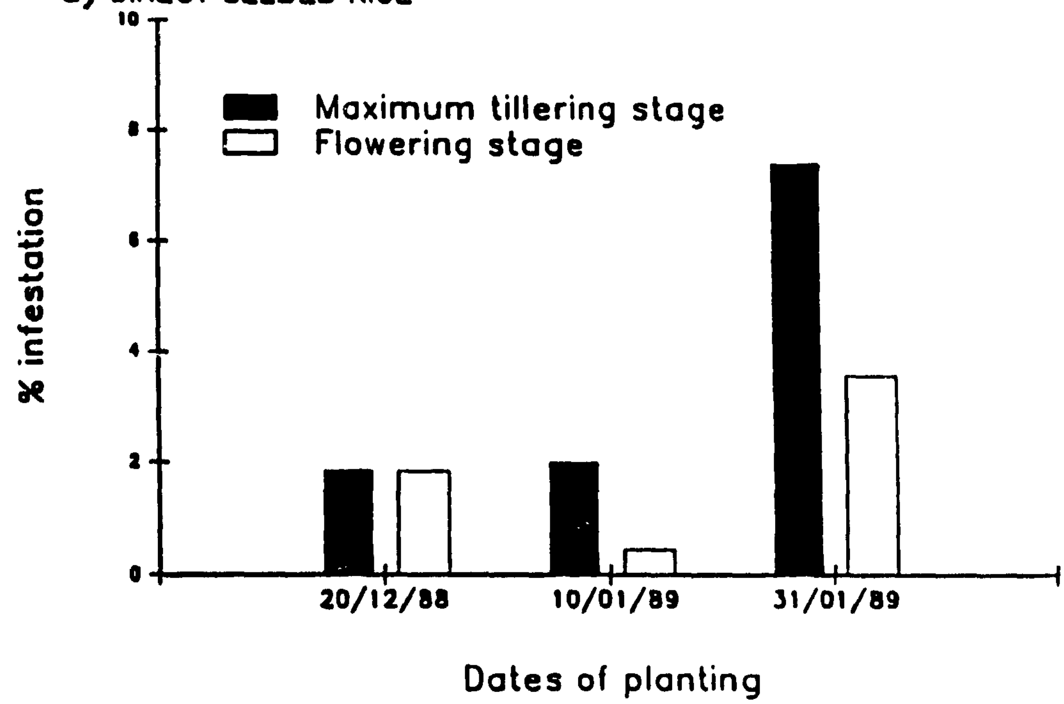
This season's percentage infestation results using Oñate's (1965, cited in FAO 1979) and Gomez's (1972, cited in FAO 1979) formulae, do not compare with results of DH numbers observed during weekly plant dissections. The latter results are most likely more dependable than those obtained using Oñate's and Gomez's methods since weekly plant dissections generate more data.

Interception traps. Sticky traps. The green coloured trap was removed from all groups of traps because no trap of this colour had captured diopsids during the previous season. As with the past two seasons (1988 dry and wet seasons), the yellow traps captured most diopsids: 8 *D. longicornis* and 16 *D. apicalis* (Figure 20). White traps did not capture any

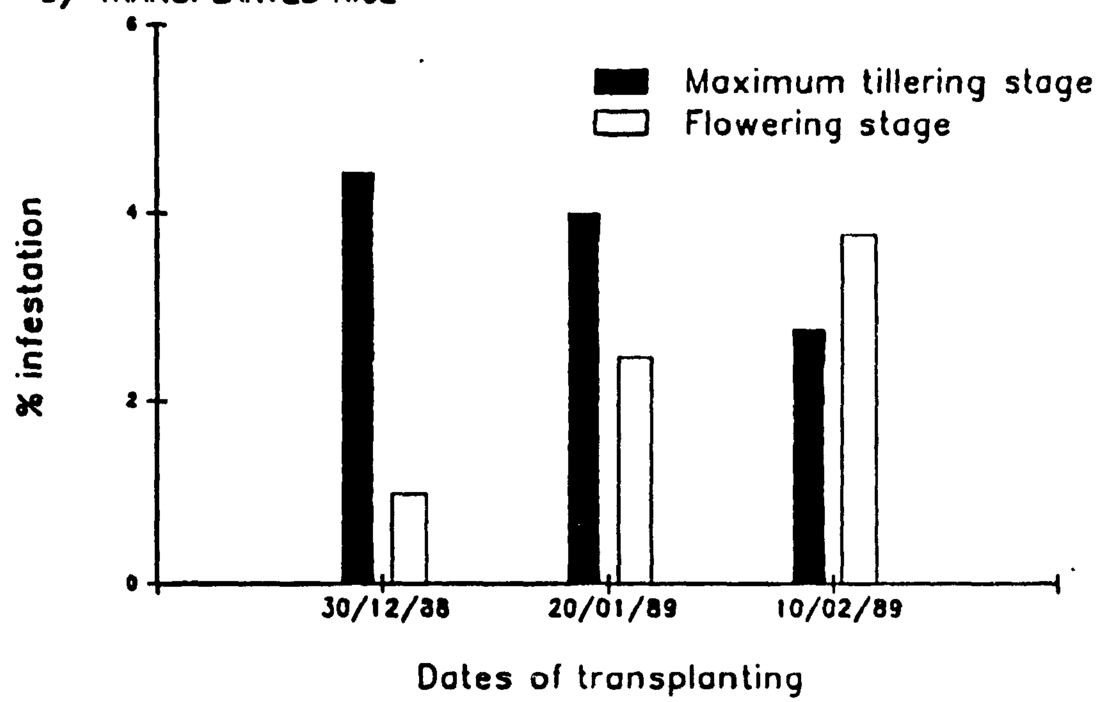
Fig. 19.

Percentage infestation of direct seeded vs transplanted rice by diopsid larvae[1] – Dry Season, 1989

a) DIRECT SEEDED RICE

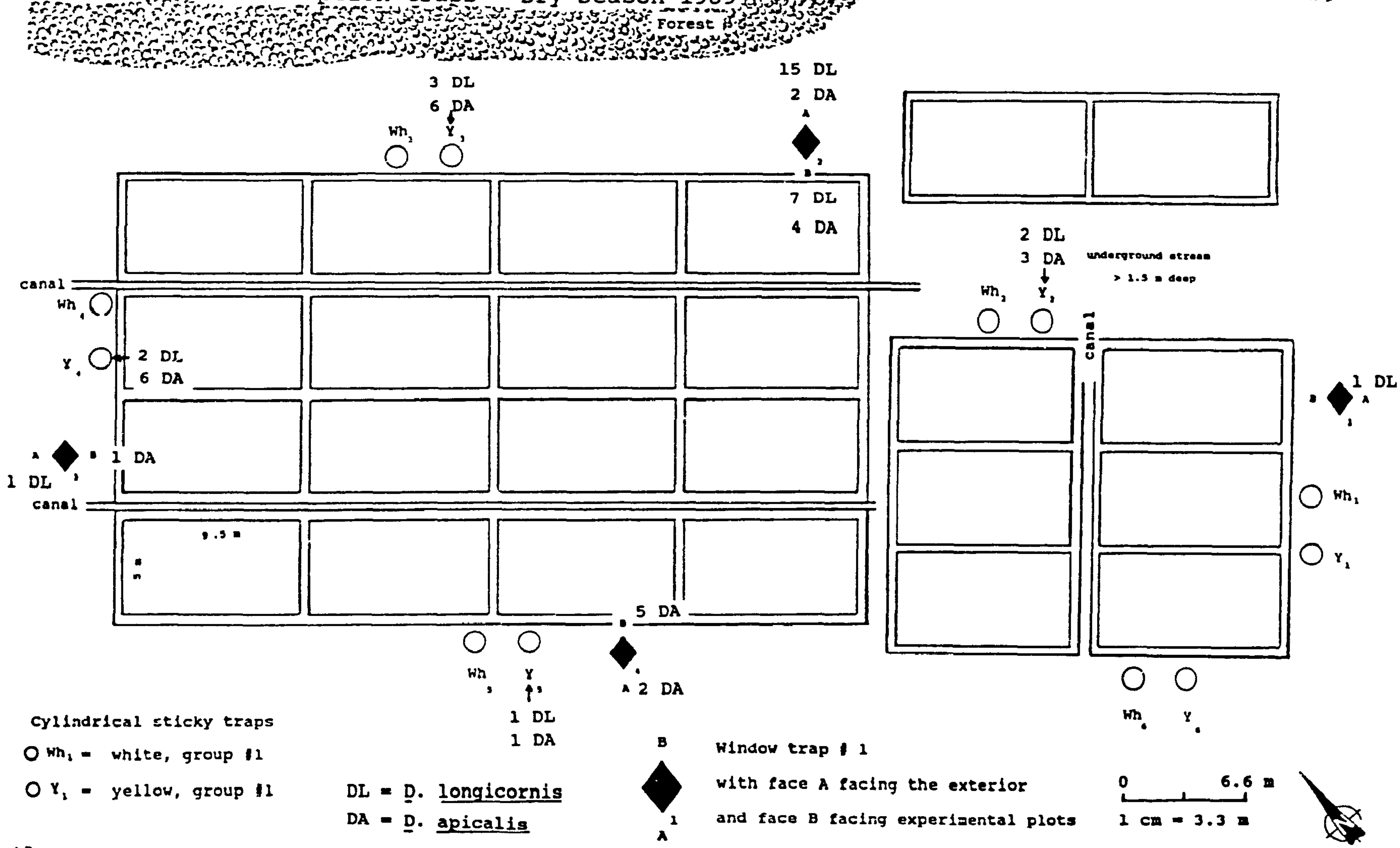


b) TRANSPLANTED RICE



[1]based on numbers of dead hearts (at MT) or of white panicles (at FL) in 100 plants/plot

Fig. 20. Total number of Diopsis longicornis and D. apicalis adults collected from weekly monitoring of interception traps - Dry Season 1989



flies. More *D. apicalis* were captured than *D. longicornis* even though the latter insects were more numerous in the field. It is possible that *D. apicalis* is more easily trapped by the adhesive than *D. longicornis*. Problems in capturing *D. longicornis* were mentioned earlier under the results from the 1988 dry season tests. Diopsids were trapped at a constant rate of one or two insects per week. The two groups of traps on the North side of the field and the group on the West side captured more insects than the others probably because of the proximity of these traps to the forest.

Window traps. As in 1988, the exterior face of the trap closest to the forest edge collected more *Diopsis* spp. (15 *D. longicornis* and 2 *D. apicalis*) than all the other traps (Figure 20). The interior face of this trap captured 7 *D. longicornis* and 4 *D. apicalis*. The proximity of the forest edge permited continual movement of diopsids from the shaded and humid refugia to the field, since the insects were captured continuously throughout the dry season. It appears that diopsids are not confined to their quiescent state or to their refugia.

As with the sticky traps, more *D. apicalis* were captured with the window traps in this season than in the previous dry season (1988). This corresponds with the higher number of *D. apicalis* collected in the field during this season (total of 241) compared to the 1988 dry season (total of 97). Whereas the *D. longicornis* found were taken mainly from the trap placed on the edge of the forest, as many *D. apicalis* specimens were collected in the trap across the field and in the open (trap #4) as in the trap closest to the forest (trap #2). These results, along with the fact that few *D. apicalis* were found in the humid and shaded refugia along witn *D. longicornis*, indicate that *D. apicalis* do not have the same ecological requirements as do *D. longicornis* during the dry period, being able to withstand a much drier environment than *D. longicornis*.

Results of Pooled Dry Season Data

To better compare effects of method of planting and of block, data from all three dry seasons were pooled and submitted to the same statistical tests, i.e., General Linear Models Procedure, Tukey's Studentized Range Test, and tests for Normality and for Homogeneity of Variance.

Dates of planting were not included in the tests since they were not the same from year to year.

Adult *D. longicornis* and *D. apicalis*. Whereas in 1987, *D. longicornis* had been present in significantly higher numbers in Block 1, tests with pooled data showed no significance with blocks nor with method of planting (Table 10).

Whereas the first two dry season results (1987 and 1988) showed that *D. apicalis* were collected in higher numbers in direct seeded rice than in transplanted rice, pooled data eliminated this significance (Table 10). There was no significance between blocks as well.

Larval *D. longicornis* and *D. apicalis* and presence of dead hearts (DH). As with individual seasons, when the data werepooled, method of planting had a significant effect on larval numbers of both *D. longicornis* and *D. apicalis*, and on presence of DH. Transplanted rice was a preferred site for larval infestation over direct seeded rice. There was no block effect on larval numbers of both species, or on numbers of DH (Table 11).

Table 10. Variation in mean numbers of *D. longicornis* and *D. apicalis* adults collected with method of planting and block. Pooled Data.+ Dry Seasons 1987 1988 1989

	Mean number of *D. longicornis*	Mean number of *D. apicalis*
METHOD OF PLANTING		
Direct seeded	67.3a	42.7a
Transplanted	85.6a	24.2a
BLOCK		
1	136.0a	31.5a
2	56.2a	25.8a
3	57.4a	28.1a
4	58.1a	46.4a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+data based on weekly sweep net sampling over the three seasons

Table 11. Variation in mean numbers of *D. longicornis* and *D. apicalis* larvae and of dead hearts collected with method of planting and block. Pooled data.+ Dry Seasons 1987 1988 1989

	Mean number of *D. longicornis*	Mean number of *D. apicalis*	Mean number of dead hearts
METHOD OF PLANTING			
Direct seeded	0.9b	0.3b	5.9b
Transplanted	2.3a	2.3a	13.1a
BLOCK			
1	2.0a	2.2a	11.9a
2	1.5a	0.9a	9.9a
3	1.5a	1.3a	8.6a
4	1.4a	0.7a	8.3a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+ data based on weekly plant dissections over the three seasons (10 plants per plot)

GENERAL DISCUSSION -DRY SEASON EXPERIMENTS

Method of Planting

From these results, it appears that during the dry season, larvae of both *D. longicornis* and *D. apicalis* were present in greater numbers in transplanted rice than in direct seeded rice. As Scheilbereiter (1977) has pointed out, eggs are more likely to be deposited at the base of the stem; it is possible that the diopsid female can reach the lower part of the plant more easily in a transplanted plot, where rows separate individual plants or hills, than in a plot of densely packed direct seeded rice. Similarly, Alghali (1980) had found that wider spaced hills had significantly more eggs than closer spaced hills; percentage dead hearts was also higher in the wider spaced hills, though not significantly.

The microclimate (e.g., higher relative humidity) within an area of transplanted rice may be more favourable to diopsids. Furthermore, stress experienced during transplanting (e.g., with reduction of root area and associated nutrient losses) also can contribute to increased pest damage.

Planting date in relation to abundance of *D. longicornis*.

The effect of planting date on diopsid numbers and on numbers of dead hearts (DH) could not be compared from year to year because of varying planting dates. However, the relationship between first planting date in each dry season and date of last rainfall in the previous wet season may be relevant. Whereas in 1987, the first crop of direct seeded rice was sown on December 24 and transplanted rice was planted on January 13, in 1988, these planting dates were delayed by three weeks. In 1987, rice was at the vegetative stage by the first week of January, whereas in the 1988 dry season, rice was not at an attractive stage to diopsids until the third and fourth weeks of this month. It is possible that most immature diopsid adults that developed from the wet season crop had already aggregated in refuge sites by the time rice was available at the end of January 1988. On the contrary, in 1987, the immature adults encountered the rice crop before their establishment in dry season refugia. The first date of planting was 20 days after the last rain in late 1986 and 46 days in late 1987 and early 1988 (Figure 21a and b). These results indicate that the time for *D. longicornis* swarming into refugia is correlated with the last rainfall, occuring in a more or less specific time period after the last rain. Results from the following experiments and observations (Chap. 4) support this.

The first planting date occured on December 20, 1988 at the onset of the 1989 dry season, 23 days after the last rainfall (Figure 21c). Planting was at about the same time as in the 1987 dry season (December 24, 1986). *D. longicornis* numbers were not as high, however, at the beginning of the 1989 season as they were at the beginning of the 1987 dry period. There was, however, an increase over 1988 dry season numbers and my hypothesis that dispersing diopsids are attracted by an early dry season crop may still hold. Lower numbers found at the beginning of the 1989 dry period may have been caused by the unusually heavy rains in the 1988 wet period. These may have considerably diminished the diopsid population that would have carried over to the dry period. In summary, the first planting date should occur after diopsids have aggregated into dry season refugia, which generally corresponds to over 45 days after the last rainfall.

In the 1987 dry season, it appears that there was an initial population of *D. longicornis* that became established on the rice at the onset of the season (Figure 7). This is supported by the high peak early in the growing period. Subsequently, numbers fell, but later returned to higher levels. It seems likely that the second peak population were the offspring of the first peak population.

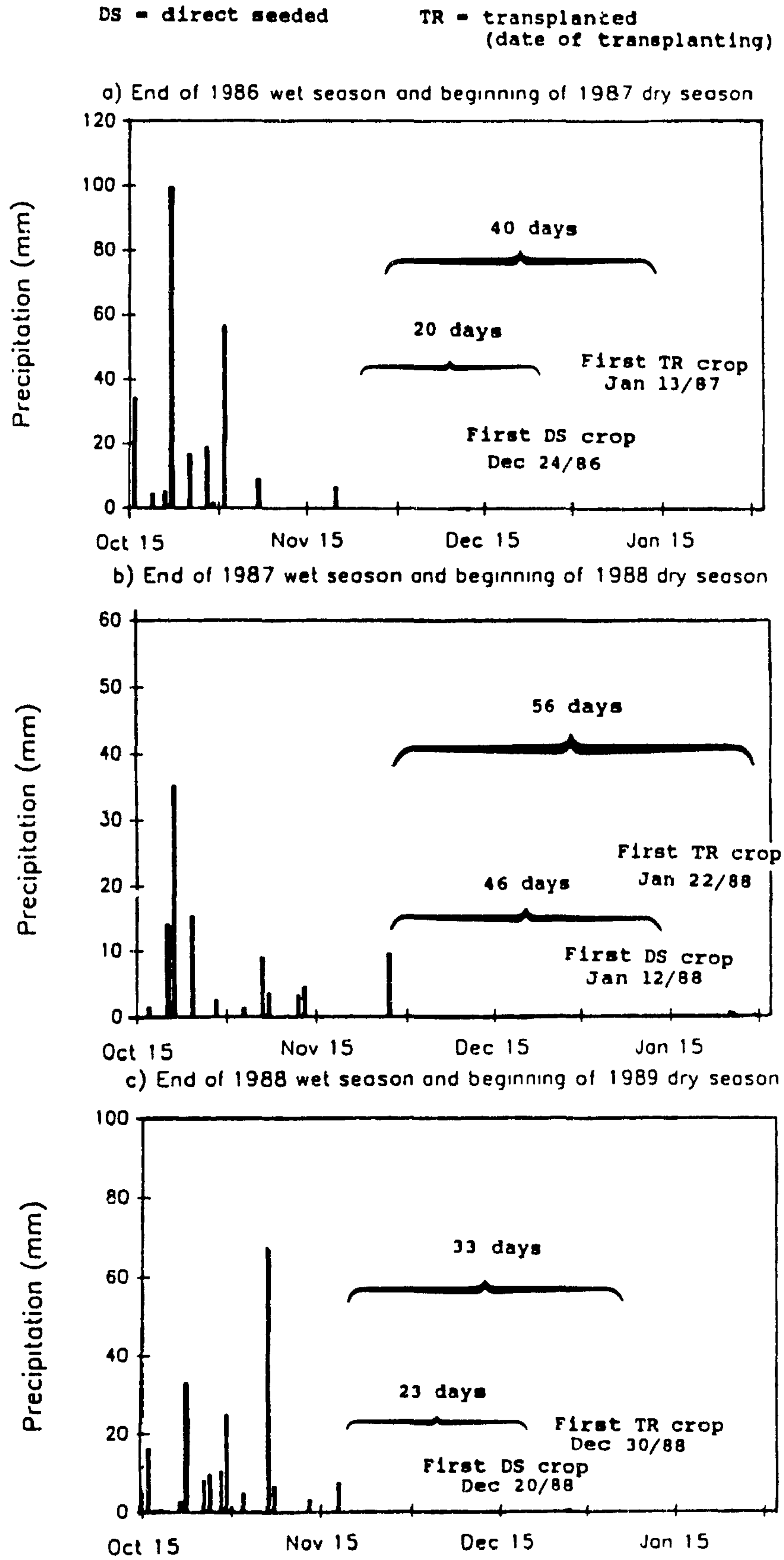


Fig. 21. Time between last rainfall and first dry season planting dates

This curve did not follow the same trend in either 1988 or 1989. As in 1987, there were two main population peaks during the 1988 and 1989 seasons, but in contrast to 1987, the second peak was largest in 1988 and 1989. Whereas numbers collected at the beginning of the season were much lower in these latter years than at that time in 1987, there was a substantial population of *D. longicornis* towards the end of March and at the beginning of April. These adults may have come from eggs laid on the rice earlier in the season but, with so few gravid females present, not all adults present in April can be accounted for this way. In 1988, 9 gravid females were collected out of a total of 69 females (13%) from January 25 to March 1; in 1989, 54 gravid females were collected out of 225 females (24%) from December 27, 1988 to February 28, 1989.

The increase in fly population at the end of the rice growing period suggests that there was movement of *D. longicornis* to the rice field from outlying areas especially at this time. It may be that, even though the larger part of the population is aggregated in forested refugia, away from the open rice field, some individuals begin dispersing before the end of the dry season. Experiments described in Chapter 4 were designed to monitor *D. longicornis* dispersal behaviour during the dry period.

Planting date in relation to abundance of *D. apicalis*

In 1987, as with *D. longicornis*, adults of *D. apicalis* were present in large numbers early in the season. Unlike *D. longicornis* though, numbers of *D. apicalis* did not exhibit a second peak. Low fecundity (3%) may explain this, as well as the fact that this species readily chooses other hosts besides rice. As with *D. longicornis*, because of the early presence of rice in 1987, *D. apicalis* may have moved from the late wet season rice crop onto the dry season rice instead of entering forested refugia. The ecology and behaviour of *D. apicalis* during the dry period is not as well known as that of *D. longicornis*. Aggregations of large numbers of *D. apicalis* in refugia were not observed during this study. Only a few *D. apicalis* specimens were collected near the *D. longicornis* aggregations.

As with the *D. longicornis* adult population, numbers of *D. apicalis* adults were much lower in 1988 and 1989. During 1988, a maximum of 18 insects were collected per sampling date. These low numbers may indicate that, as with the *D. longicornis* population, the delay in planting may have avoided invasion by dispersing *D. apicalis* adults.

In 1989, an initial high number of *D. apicalis* adults was recorded on the rice. The first planting date probably occured during the diopsid period of dispersal. The second peak in April may reflect an invasion from other areas since numbers of gravid females sampled on the crop during the season (11 out of 123 females collected) were very low, and would unlikely cause a rise in the *D. apicalis* population.

The choice of a later date for planting the dry season rice crop (generally over 45 days after the last rain) is likely to avoid both *D. longicornis* and *D. apicalis* adult dispersal from the late wet season rice crop. Nevertheless, *D. apicalis* does not seem to be a threat to the rice crop during the dry season regardless of the planting date, because *D. apicalis* larval infestation remained low throughout the study.

Sex ratio and female fecundity of *D. longicornis*

Sex ratios varied significantly within the 1987 dry season (between 28% and 57% females) and within the 1988 dry period (between 28% and 66% females), but remained constant during the 1989 dry period. For the first two seasons, results show that males outnumbered females (63% and 53% respectively) whereas in 1989 females were slightly more numerous (51%). This may not be representative of the actual situation, according to Cochereau (1985a). He observed that the effectiveness of sweep net sampling of adults varies with the vertical movement of the fly on its host plant. It may be that females, especially gravid females are concentrated at the base of the plant and are therefore less likely to be collected with a sweep net. A suction apparatus may be a more efficient sampling method for diopsid adults.

Nevertheless, although a portion of gravid females may have evaded the sweep net, it can be concluded that their presence was low, and larval counts confirm this.

Sex ratio and female fecundity of *D. apicalis*

Sex ratio of *D. apicalis* varied significantly only during the first dry period, but not in the two subsequent seasons. Results from the 1987 season are more representative than the others because of the much larger sample obtained during this year. Fecundity of *D. apicalis* was very low (one or two gravid females per sampling period) and numbers remained at this level throughout the three dry seasons.

WET SEASON EXPERIMENTS

Wet Season 1987 (June to November 1987)

Adult population of *D. longicornis*. Total numbers of *D. longicornis* were much lower in this season than during the previous dry season. Rainfall, which was very heavy during the months of July, August and September, was an important deterrent to insect presence. Total number of adults collected during this season showed a slight peak at the beginning of the season (on July 21: Figure 22). Numbers collected per sampling date varied between 26 and 59 flies until mid-September when they decreased to as low as 10, when rains were particularly intense. As the rains subsided, *D. longicornis* density increased until the end of the sampling programme (October 20), when rice in the experimental plots had gone well beyond the vegetative stage for all dates of planting.

Much higher numbers of *D. longicornis* were collected on the direct seeded rice sown on the first planting date than from all other crops (Table 12). This is probably because rainfall was intermittent at this time (early July), whereas it was continuous after this period for two months. Therefore the direct seeded rice sown on the first date of planting was at the vegetative stage and available to diopsids when they were most active. The first crop of transplanted rice and all other crops were planted later (after July 14) when rainfall was heavy. This may also explain why *D. longicornis* adults were collected more from direct seeded rice than from transplanted rice (Table 12).

Edge or block effects was not apparent in this season (Table 12). Conditions that favour *D. longicornis* presence, such as high humidity and relatively low temperatures, were met throughout the experimental area and in the adjoining fields. Consequently, the *D. longicornis* population was well dispersed.

Fig. 22. Total number of *Diopsis longicornis* adults collected from all plots during weekly sweep net sampling
Wet Season 1987

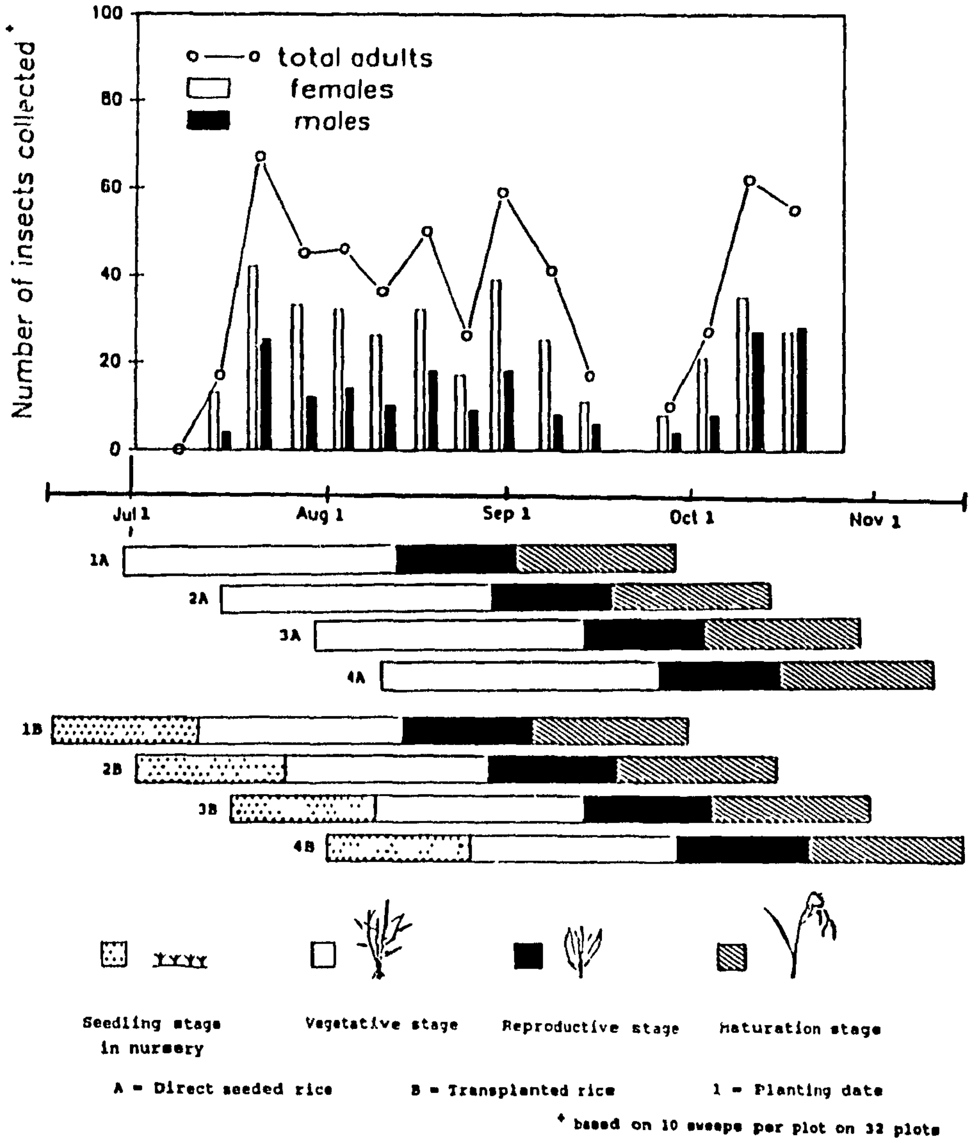


Table 12. Variation in mean numbers of *D. longicornis* and *D. apicalis* adults collected with date, method of planting and block. +
Wet Season 1987

	Mean number of *D. longicornis*	Mean number of *D. apicalis*
DATE OF PLANTING		
1	27.9a	3.9a
2	13.1b	2.3ab
3	16.3b	0.6b
4	19.1ab	0.3b
METHOD OF PLANTING		
Direct seeded	27.9a	2.2a
Transplanted	10.6b	1.5a
BLOCK		
1	19.0a	1.0a
2	21.1a	2.0a
3	18.5a	2.0a
4	15.2a	2.5a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+ data based on weekly sweep net sampling (10 sweeps per plot in 32 plots)

Sex ratio of *D. longicornis*. Of the 552 adults collected, 361 (65%) were female (Table 13), a higher ratio than obtained in the previous dry period (37%). Percentage of gravid females also increased in this wet period since 36% of females (19% of the total population) were gravid. These results confirm Descamps´ observations (1957a) that *D. longicornis*´ reproductive stage occurs during the wet period. Both sex ratios and ratios between gravid and non-gravid females were fairly constant throughout the wet season (Table 13). This is contrary to Cochereau´s results (1985a) that showed an increase in percentage of *D. longicornis* females towards the end of the wet season.

Adult population of *D. apicalis*. The *D. apicalis* populations were low and data were therefore difficult to interpret. Only 54 individuals were collected during the entire season (Figure 23). As with results of *D. longicornis* sampling, more *D. apicalis* were collected on the first planting of direct seeded rice. Tests showed that there were no differences in mean numbers collected with methods of planting or with blocks (Table 12).

Sex ratio of *D. apicalis*. Percentage females was slightly higher (50%) than during the 1987 dry season (42%) (Table 13). The proportion of gravid females significantly increased during the wet period (48% of total females) compared with the previous season (3% of total females). Sex ratios and ratios between gravid and non-gravid females remained constant throughout the wet season (Table 13). This contradicts with Cochereau´s observations (1985a) that showed a decrease in percentage of female *D. apicalis* over the season.

Table 13. Variation in numbers of D. *longicornis* and D. *apicalis* males and females and in gravid and non-gravid females collected weekly. Wet Season 1987

Male vs Female

	Total	♂♂	♀♀	Cal X_2	Tab X_2	H_o Acc/Rej*
D. *longicornis*	552	191	361	14.6	22.4	Acc
D. *apicalis*	54	27	27	3.6	15.5	Acc

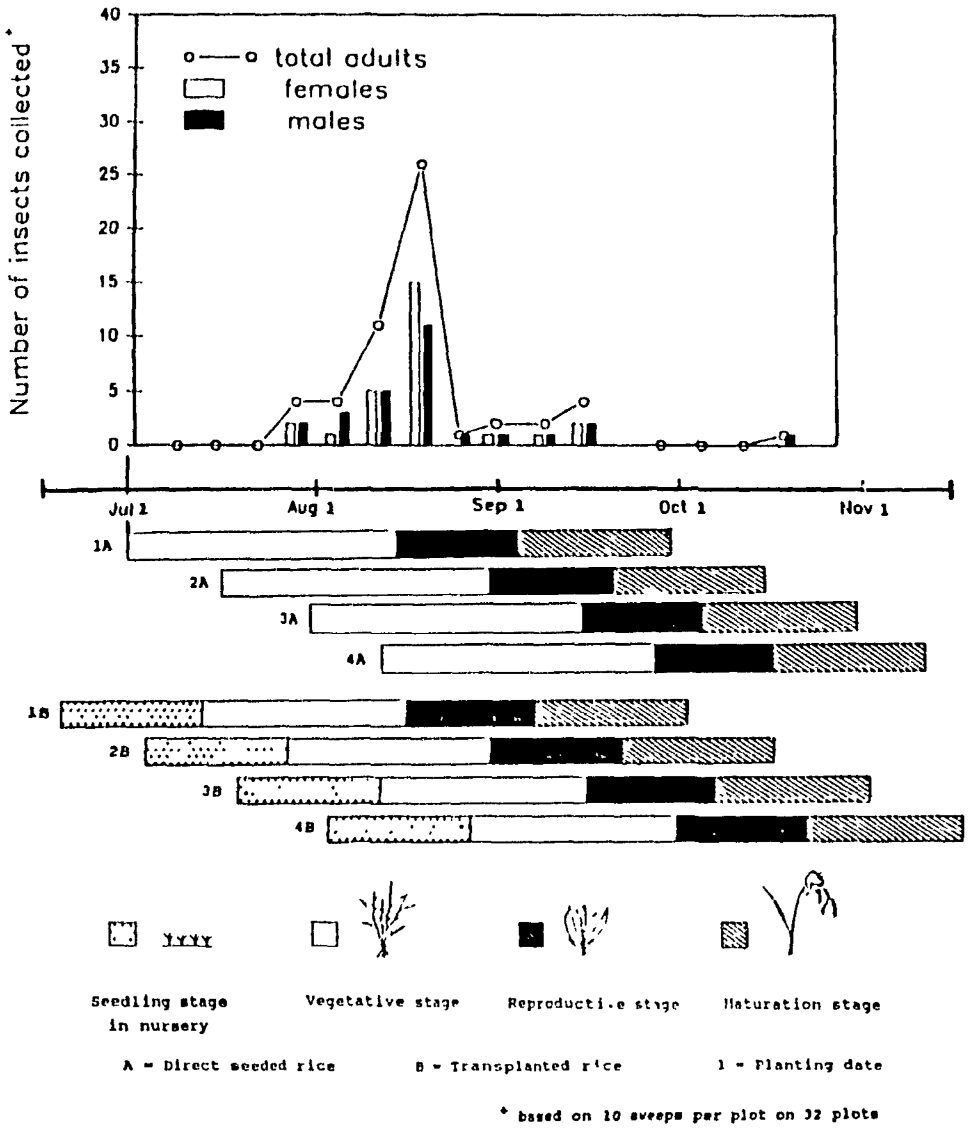
* where H_o = proportion of males and females is constant throughout the season (independent of date) ($P < 0.05$)

Gravid vs Non-gravid

	Total ♀	Gravid	N-gravid	Cal X_2	Tab X_2	H_o Acc/Rej*
D. *longicornis*	286	104	182	17.3	18.3	Acc
D. *apicalis*	27	13	14	5.2	12.6	Acc

* where H_o = proportion of gravid to non-gravid females is constant throughout the season (independent of date) ($P < 0.05$)

Fig. 23. Total number of Diopsis apicalis adults collected from all plots during weekly sweep net sampling Wet Season 1987



Larval and pupal populations of *D. longicornis*. Even though the adult population of *D. longicornis* was lower during the dry season, total number of larvae collected during the wet season (66) was relatively higher than during the dry season (58) when more adults were collected. Infesta tion was concentrated in the first part of the season: numbers collected dropped by the end of August, probably because of the abundant rainfall from mid-July onwards reducing insect activity (Figure 24). Eleven pupae were collected from dissected plants, mainly in August.

Rice sown on the first and second dates of planting was infested more than rice sown on the third and fourth dates of planting (Table 14). When the latter two crops were at the vegetative stage, rain was too heavy and too constant to permit insect activity.

Damage to direct seeded and transplanted rice was similar during this season. There was no block effect on *D. longicornis* larval numbers.

Larval and pupal populations of *D. apicalis*. Only 3 *D. apicalis* larvae and no pupae were found during weekly plant dissections. *D. apicalis* infestation remained low throughout the experiments; most likely *D. apicalis* females chose a variety of hosts besides cultivated rice for oviposition.

Number of dead hearts (DH) and percentage infestation. As found in the 1987 dry period, number of dead hearts (DH) were three times the number of larvae and pupae found. Number of DH were tested for significant difference according to date and method of planting, and to block (Table 14). The first planting date had significantly more DH than the crops sown on other dates and numbers decreased significantly with later dates. Direct seeded rice was more infested than transplanted rice. There was no block effect on numbers of DH present.

Fig. 24. Total number of *Diopsis longicornis* larvae, pupae and dead hearts collected from all plots - Wet Season 1987

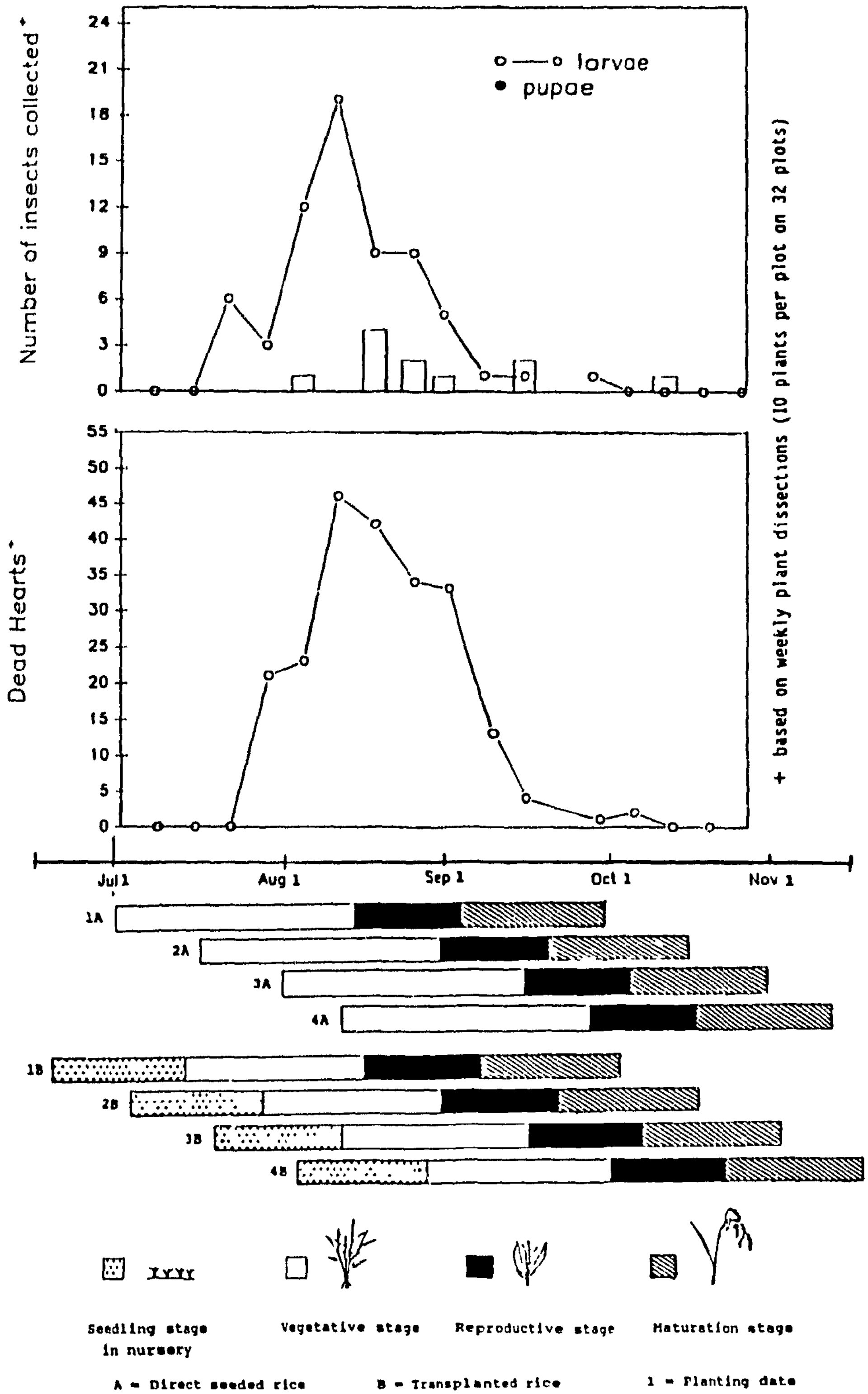


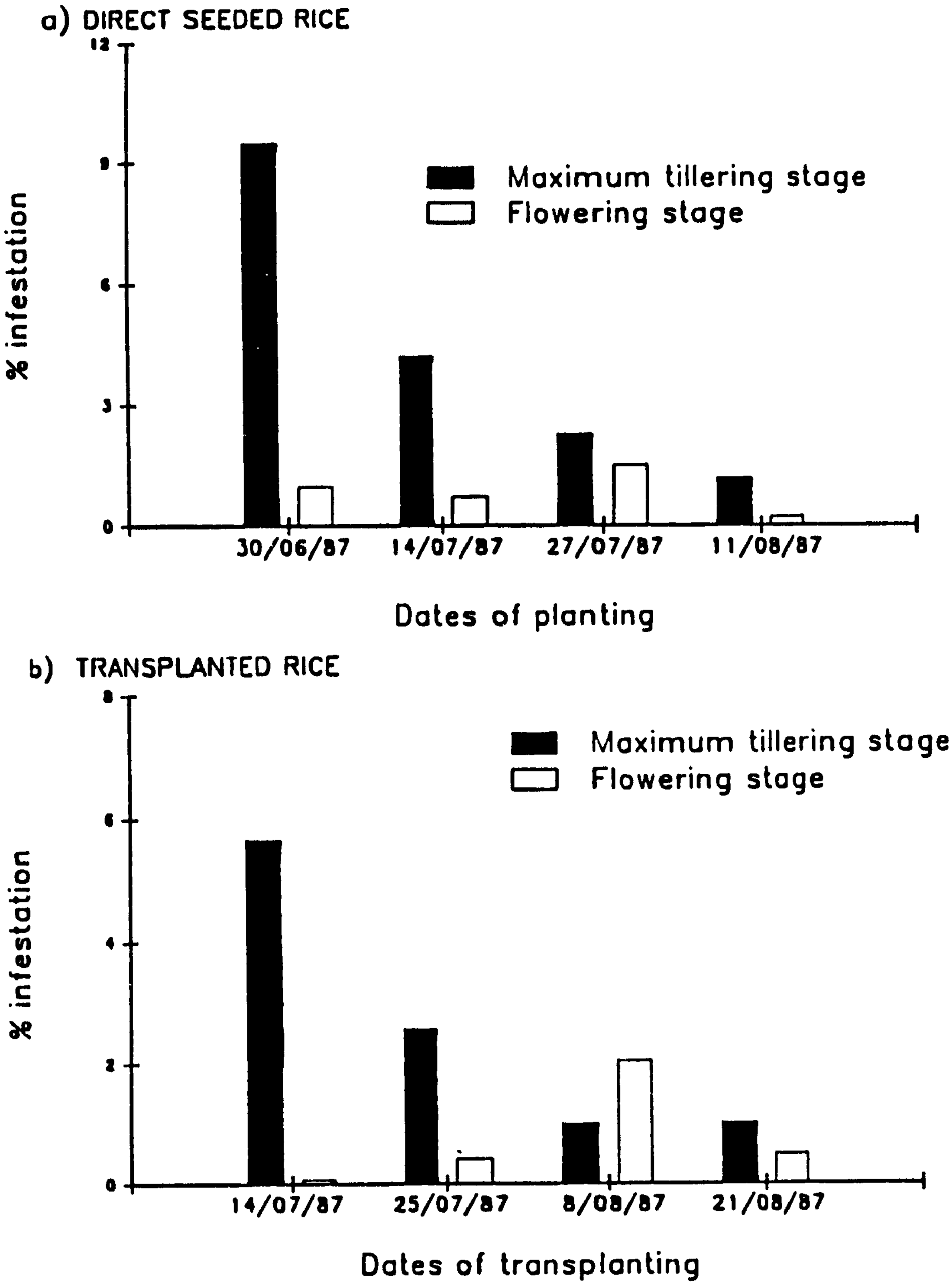
Table 14. Variation in mean numbers of *D. longicornis* larvae and of dead hearts collected with date, method of planting and block. +
Wet Season 1987.

	Mean number of *D. longicornis*	Mean number of dead hearts
DATE OF PLANTING		
1	4.0a	16.6a
2	3.6a	8.3b
3	0.5b	2.8c
4	0.3b	0.7c
METHOD OF PLANTING		
Direct seeded	2.5a	11.5a
Transplanted	2.0a	4.3b
BLOCK		
1	1.6a	8.9a
2	2.6a	7.3a
3	2.1a	6.3a
4	2.7a	4.8a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+ Data based on weekly plant dissections (10 plants per plot in 32 plots)

Fig. 25. Percentage infestation of direct seeded vs transplanted rice by diopsid larvae[1] — Wet Season, 1987



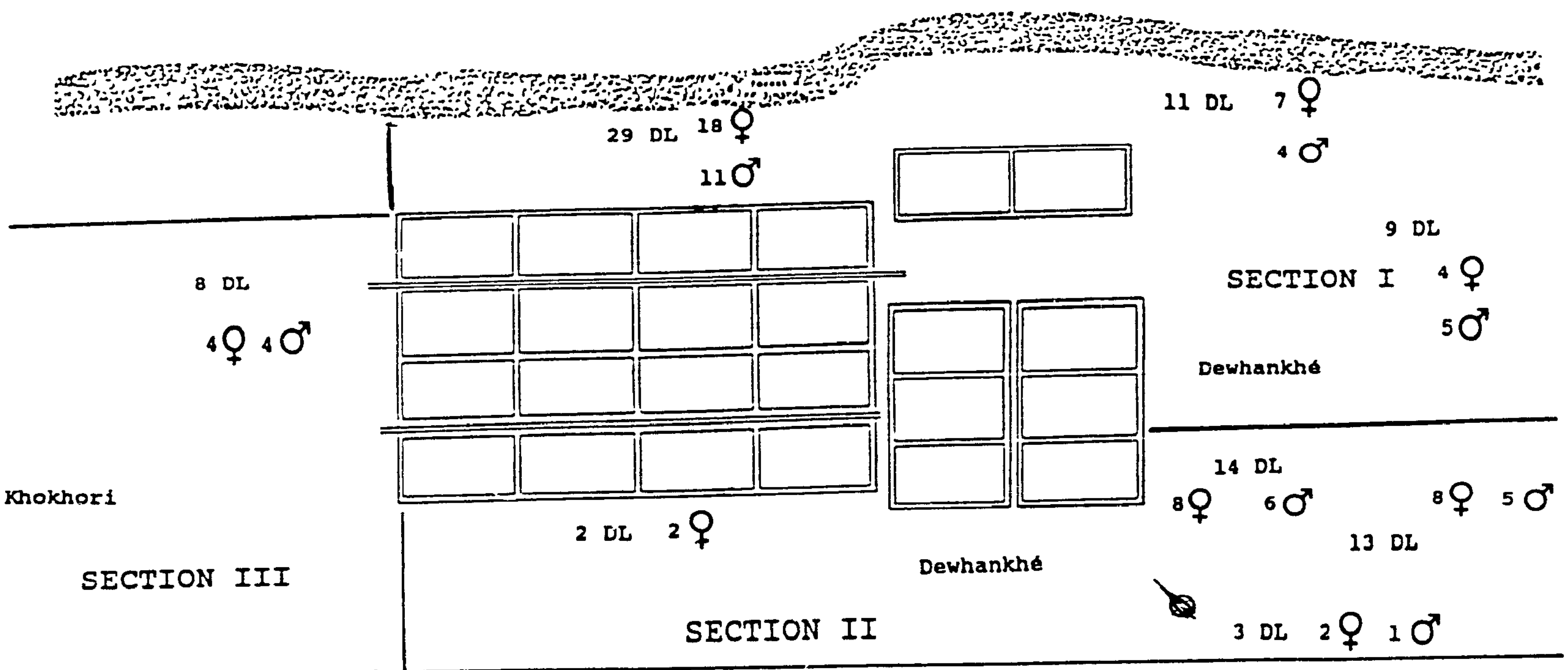
[1]based on numbers of dead hearts (at MT) or of white panicles (at FL) in 100 plants/plot

Monitoring of infestation at maximum tillering (MT) and at flowering (FL) gave results similar to those obtained from weekly plant dissections. Rice was significantly more damaged in the crop sown on the first date of planting than rice sown on other dates (Figures 25a & b). Infestation continously decreased from the second crop onwards probably be cause of the controlling effect of rain on infestation. Direct seeded rice was more infested than transplanted rice, and damage was more evident at the maximum tillering stage than at flowering.

Sampling of farmers´ fields adjacent to the experimental plots.

Numbers of insects collected from the various points within the three field sections were low during the season. Less than 4 *D. longicornis* adults were collected per 20 sweeps throughout the study period (Figure 26). These numbers were much lower than those obtained in the experimental plots, which averaged 16 *D. longicornis* per 20 sweeps. Only one *D. apicalis* was collected during the entire season.

Fig. 26. Total number of *Diopsis longicornis* collected from farmers' fields[1]- Wet Season 1987



[1] Based on weekly sampling of 20 sweeps per plot

DL = *D. longicornis*

Khorkhori = Rice variety

<u>Wet season 1988 (June to November 1988)</u>

Adult population of *D. longicornis*. Contrary to results from the 1987 wet season, *D. longicornis* were found in very low numbers, especially at the beginning of the 1988 wet period (Figure 27). In 1987, the first crop was planted one week sooner (June 30) than in 1988 (July 5), offering rice to the active and searching gravid diopsid females as early as the second week of July. This one week difference was probably not the reason for the difference in numbers collected in the two wet seasons. Rainfall was much less intense in July 1987 than in July 1988. In July 1987, the highest amount of rainfall in one day was 57 mm, and, in the same month in 1988, the highest daily accumulation rose to as high as 243 mm, with several other days with more than 100 mm of rain. Rainfall in 1988 was excessive, being a definite limiting factor in insect activity, and therefore in infestation. Before the end of September, when rains had begun to diminish, no more than one adult *D. longicornis* was collected per 10 sweeps per sampling date, and only two adults of *D. apicalis* were collected during all of July, August and September.

There was no significant difference in numbers of adults of *D. longicornis* between methods of planting (direct seeded and transplanted) and dates of planting, nor between blocks (Table 15). Efficiency in adult sampling was largely dependent on whether rain had recently fallen before the sampling date or not. For example, on August 30, adult numbers rose in both direct seeded and transplanted rice plots, and for both first and second planted crops; then, on the next sampling date a week later (September 6), numbers for all crops dropped. Before the August 30 morning sampling, only 5 mm of rain had fallen on the previous 2 days, whereas a few hours before sampling on September 6, 69 mm of rain had fallen. Heavy rains force *D. longicornis* to move down the rice plant and hide, making sweep net sampling inefficient (as discussed in the dry

Fig. 27. Total number of Diopsis longicornis adults collected from all plots during weekly sweep net sampling
Wet Season 1988

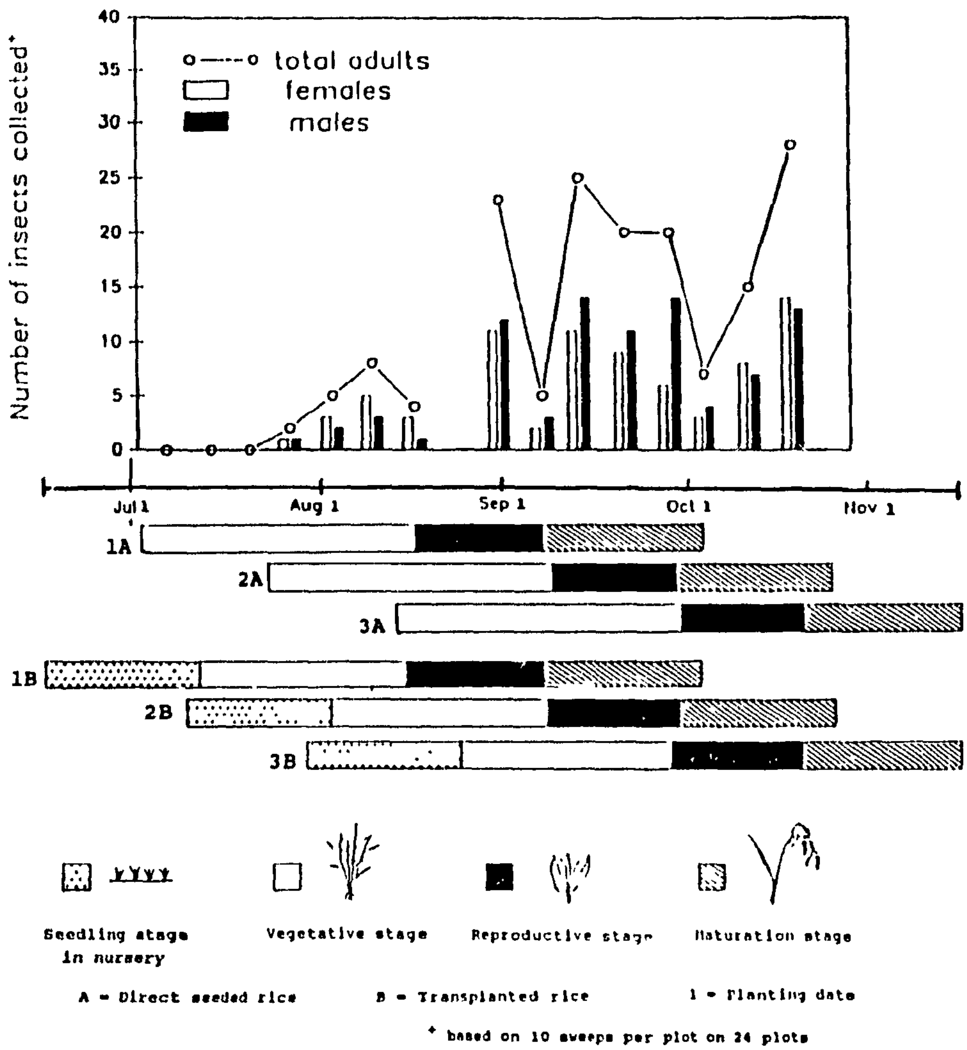


Table 15. Variation in mean numbers of *D. longicornis* adults and of dead hearts collected with date, method of planting and block. +
Wet Season 1988

	Mean number of *D. longicornis*	Mean number of dead hearts
DATE OF PLANTING		
1	5.3a	3.6a
2	5.3a	0.9b
3	9.5a	1.4b
METHOD OF PLANTING		
Direct seeded	7.5a	2.3a
Transplanted	5.8a	1.6a
BLOCK		
1	6.3a	1.8a
2	7.5a	1.3a
3	5.5a	2.0a
4	7.3a	2.7a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+ data based on weekly sampling (adults = 10 sweeps per plot in 24 plots and dead hearts = 10 dissected plants per plot in 24 plots) season section above). Thus, rainfall makes sweep net sampling inefficient during the wet season, when sampling of larvae by plant dissections is a more useful population monitoring method.

Sex ratio of *D. longicornis*. Almost equal numbers of females and males were captured this season. Thirty-three percent of females collected were gravid, a ratio close to that obtained in the 1987 wet period. Chi-square tests showed that sex ratios remained constant during the growing season, but the ratio of numbers of gravid to non-gravid females fluctuated during this time (Table 16). At the beginning of the season, percentage of gravid females was very high. Up to 100% of females collected were gravid at the beginning of August. This percentage dropped to 18% by the end of August, but then rose and remained between 33 and 55% throughout the rest of the season. The 18% value on August 30 is suspected to be an error related to diopsid females being concentrated at the base of the rice plant at the time of sampling. The decrease in gravid females is most likely related to an increase in immatures emerging from the crop.

It is important to note, and will be discussed later, that dissected females collected in late October and in November had an important fat body in their abdomen, a condition that may have been present at this time during the 1987 wet season but had not been noticed.

Adult population of *D. apicalis*. As mentioned previously, only 2 *D. apicalis* adults were collected during the 1988 wet season; no larvae or pupae were found during regular plant dissections. It is possible that the polyphagous *D. apicalis* visited other hosts or other rice fields during this period.

Table 16. Variation in numbers of *D. longicornis* males and females and in gravid and non-gravid females collected weekly. Wet Season 1988

Male vs Female

	Total	♂♂	♀♀	Cal X_2	Tab X_2	H_o Acc/Rej*
D. longicornis	161	85	76	5.5	19.7	Acc

* where H_o = proportion of males and females is constant throughout the season (independent of date) ($P < 0.05$)

Gravid vs Non-gravid

	Total ♀	Gravid	N-gravid	Cal X_2	Tab X_2	H_o Acc/Rej*
D. longicornis	76	25	51	32.8	19.7	Rej

* where H_o = proportion of gravid to non-gravid females is constant throughout the season (independent of date) ($P < 0.05$)

Larval population of *D. longicornis*. Most larvae were found during the first part of the season: six of the eight larvae were collected on and before August 16, and five of these six were collected on the first crop of direct seeded rice. Other crops were infested by a total of only three larvae. One pupa was found during weekly dissections. Even though these figures are very low, they correspond with previous results, which indicated that the first date of planting of direct seeded rice is the most damaged crop of the wet period. Numbers were too low to analyse statistically.

Number of dead hearts (DH) and percentage infestation. This season, almost six times as many DH were found as *D. longicornis* larvae. This is a higher proportion than in the 1987 wet period when three times as many DH as larvae were recorded.

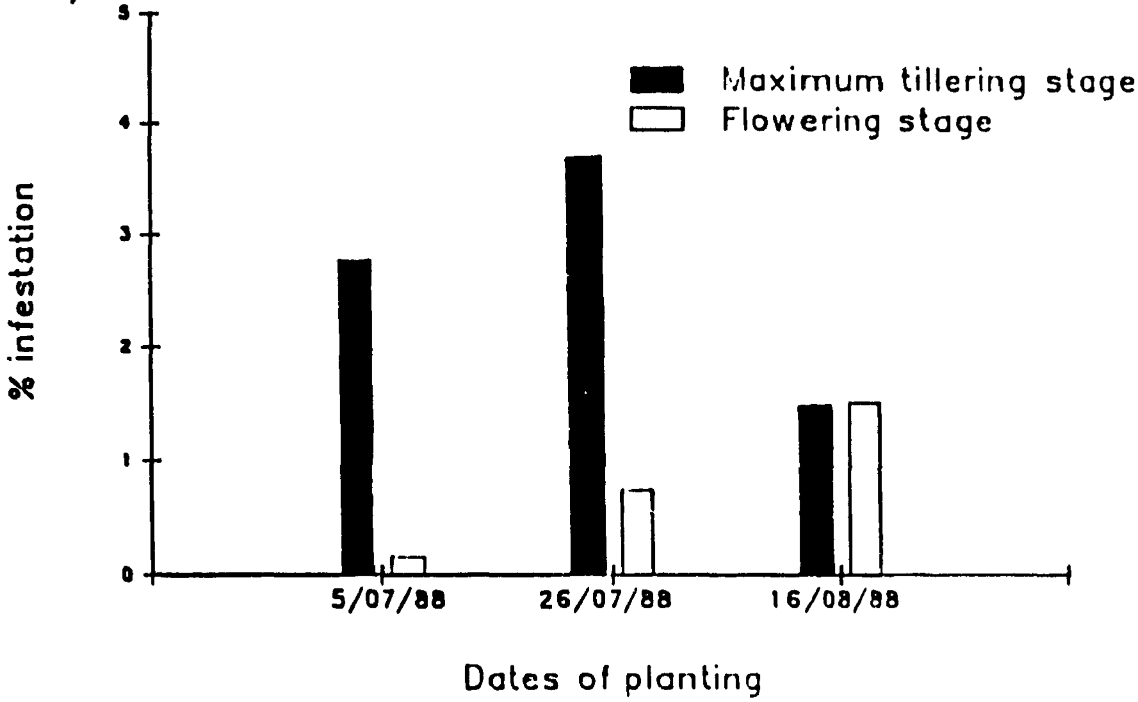
Statistical analysis of DH results indicated that the crop sown on the first date of planting was significantly more damaged than those sown on the second and third dates. Methods of planting and blocks had no significant affect on DH numbers (Table 15).

Percentage infestation observations taken at maximum tillering (MT) and at flowering (FL) showed that direct seeded rice was more damaged than transplanted rice (Figures 28a & b) as with weekly sampling results. However, percentage infestation observations show that the plots of direct seeded rice sown on the second date had more DH than the other direct seeded rice plots. With the transplanted rice, the plots planted on the third date had more DH than the others. It is important to note, however, that because the values are very low, these conclusions can only be tentative.

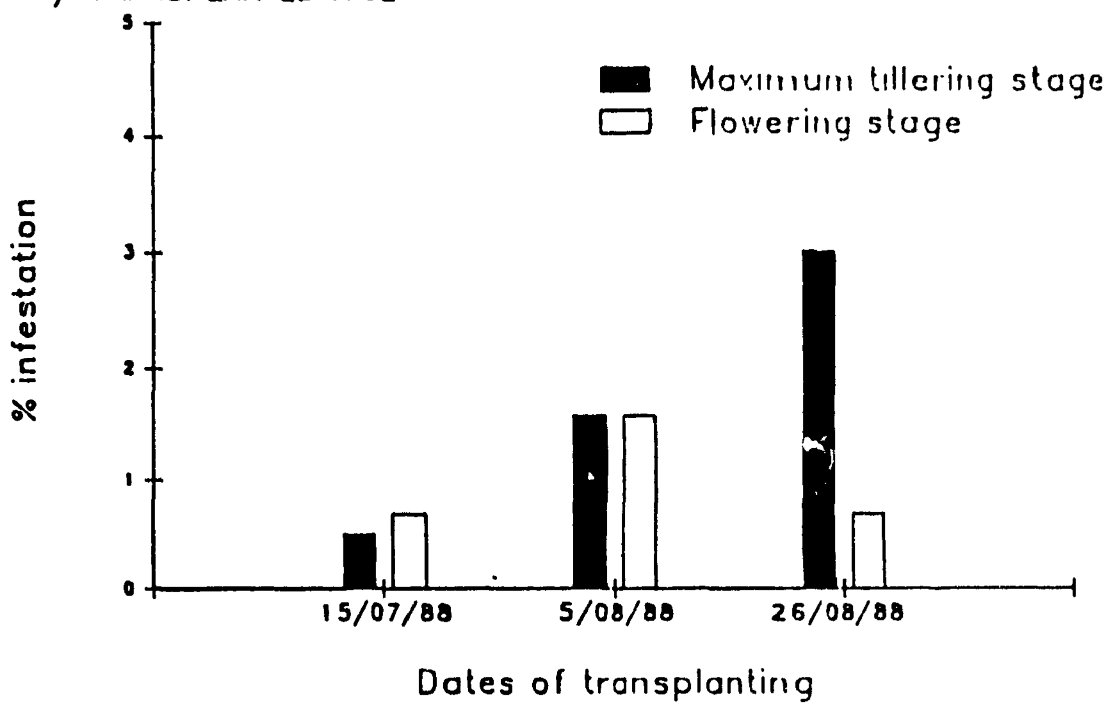
Fig. 28.

Percentage infestation of direct seeded vs transplanted rice by diopsid larvae[1] – Wet Season, 1988

a) DIRECT SEEDED RICE

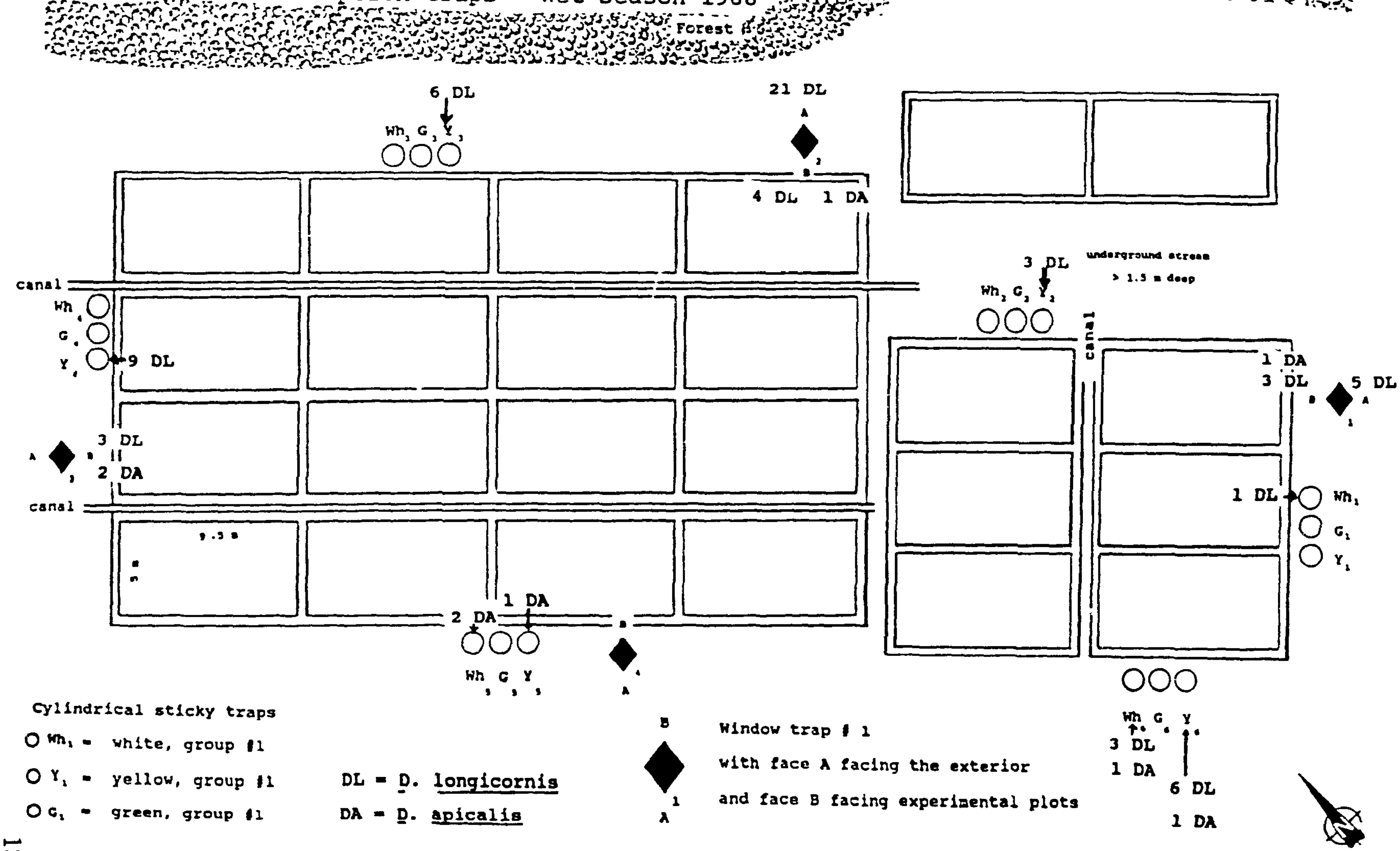


b) TRANSPLANTED RICE



[1]based on numbers of dead hearts (at MT) or of white panicles (at FL) in 100 plants/plot

Fig. 29. Total number of *Diopsis longicornis* and *D. apicalis* adults collected from weekly monitoring of interception traps - Wet Season 1988



Interceptions traps. Sticky traps. Both sticky traps and window traps were monitored from the beginning of June (one month before planting) to the end of November (two weeks after harvesting the last crop).

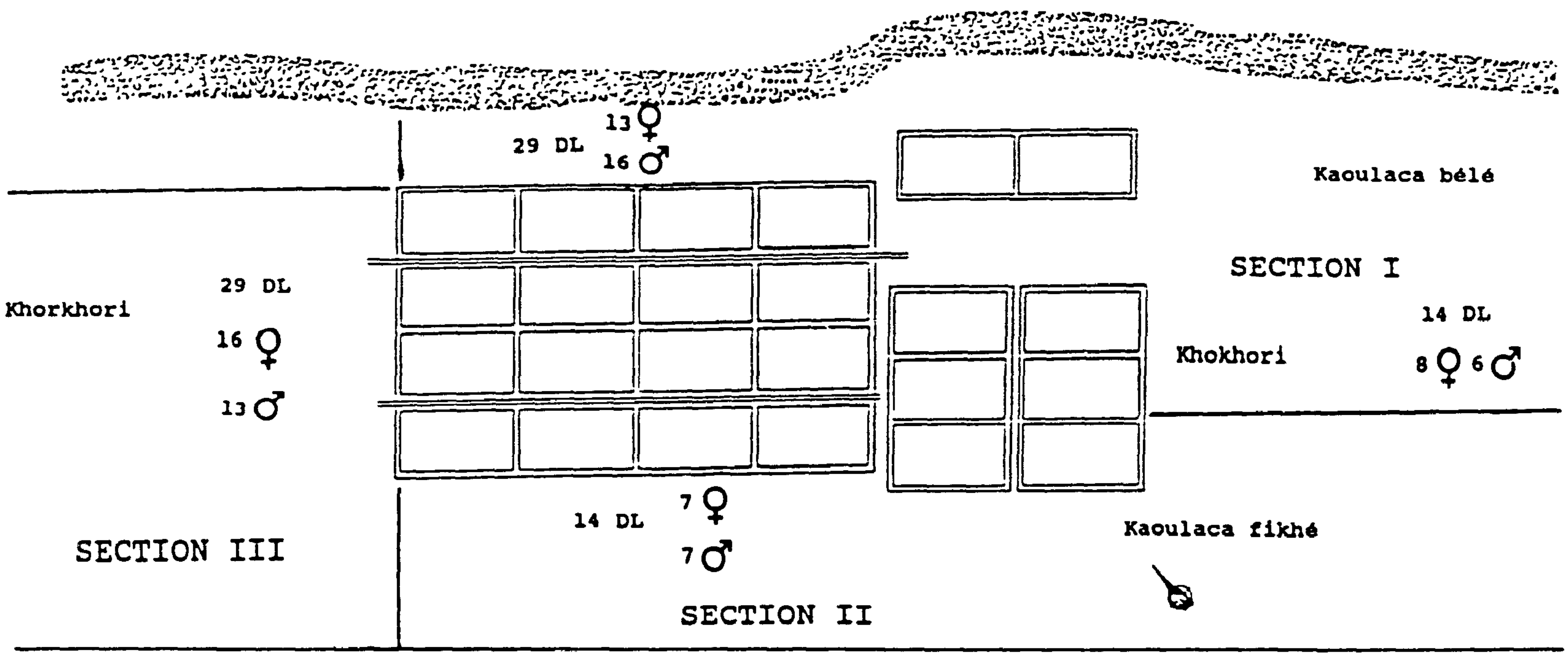
The yellow traps captured more insects (27 *D. longicornis* and 2 *D. apicalis*) than the other two coloured traps; the white trap captured 4 *D. longicornis* and 4 *D. apicalis* and the green trap captured none (Figure 29). Catches were well distributed amongst the traps throughout the experimental area, and also throughout the season, except for a period of four weeks between June 28 to July 30 during which only one insect was captured. Rain might have been a deterrent on insect activity in July, although rains were only slightly higher that month (1467mm) than in August (1439mm) when 13 diopsids were intercepted.

Interception traps. Window traps. As in the 1987 wet season, these traps caught more diopsids than did the sticky traps. Thirty-six *D. longicornis* and four *D. apicalis* were collected. Twelve *D. longicornis* were captured in one week at the beginning of June on the exterior entrance of trap no. 2, adjacent to the forest edge (Figure 29). At this time, *Diopsis* spp. were leaving their forest refugia and dispersing. During both the 1988 dry and wet seasons, more diopsids were collected from the exterior face of the traps than from the interior face. This might suggest that at these times there was immigration of diopsids from the surrounding area to the field and little emigration from the field to the outlying areas.

Sampling of farmers´ fields adjacent to the experimental plots.

As seen in the 1987 wet season, numbers collected in the farmers´ fields remained very low in 1988 (less than 4 insects per 20 sweeps: Figure 30). These values corresponded with those obtained in the experimental plots

Fig. 30. Total number of *Diopsis longicornis* adults collected from farmers' fields[1] - Wet Season 1988



[1] Based on weekly sampling of 20 sweeps per plot on 4 plots.

DL = *D. longicornis*

Khokhori = Rice variety

at the beginning of the sampling period (July to October). In late October, numbers in the experimental field rose to 8 insects per 20 sweeps; insects collected in adjacent farmers´ plots remained well below 4 insects per 20 sweeps at this time and dropped to less than 2 *D. longicornis* per 20 sweeps in November. No *D. apicalis* were collected during this sampling period.

Whereas in 1987, percentage females collected in farmers´ fields (57%) were slightly lower than percentage females captured in the experimental plots (65%), in 1988, the reverse was found (55% females in farmers´ fields and 47% females in experimental plots. However, average (for both 1987 and 1988) percentage of females found in both peasant fields and experimental field is the same (56%).

Results from this study indicate that under local farming practices, diopsid presence is low and does not pose a threat to the rice crop.

Results of Pooled Wet Season Data

As with the pooled data from the three dry seasons, data from the 1987 and 1988 wet seasons were pooled and tested with the same statistical analyses. Dates of planting were excluded from these tests because they were not the same from one season to the other.

Only data from adult *D. longicornis* numbers and from dead heart counts could be analysed statistically; data from other groups were too low. Adult *D. longicornis* were collected in significantly greater numbers on the direct seeded rice than on the transplanted rice, but this is most likely caused by the availability of the first crop of direct seeded rice early in the season when rains were not heavy. When data were pooled there was no block effect on adult numbers (Table 17).

More dead hearts were found in direct seeded rice than in transplanted rice, although the differences are not significant. There was no block effect on DH numbers (Table 17).

Table 17. Variation in mean numbers of *D. longicornis* adults and of dead hearts collected with date, method of planting and block. Pooled data. Wet Seasons 1987 1988 +

	Mean number of *D. longicornis*	Mean number of dead hearts
METHOD OF PLANTING		
Direct seeded	18.5a	7.1a
Transplanted	8.5b	3.1a
BLOCK		
1	12.7a	5.9a
2	14.3a	4.7a
3	12.0a	4.4a
3	9.4a	4.5a

Note: Any two means in one column and within one section followed by different letters differ significantly at $P < 0.05$

+data based on weekly sampling over the three seasons (adults = 10 sweeps per plot; dead hearts = 10 dissected plants per plot)

GENERAL DISCUSSION - WET SEASON EXPERIMENTS

The results obtained with the wet season tests reflect, above all, the attenuating effect of rain on insect activity. Rain had a greater influence on the pest's presence than any other factors, including method of planting and block. Differences in infestation that were detected during these studies, between direct seeded rice and transplanted rice are probably related to rainfall. Direct seeded rice from the first date of planting was significantly more damaged than all the other plantings because this rice was at the vegetative stage and thus available to diopsids at a time when rain was intermittent; when the other crops were at the vegetative stage, rain was too abundant to permit diopsid activity. Date of planting can therefore affect diopsid presence on the crop. An early planting date will coincide with the dispersal period of *D. longicornis* and *D. apicalis* individuals, whereas a later date (generally after July 20) will avoid the pests.

The proportion of females in the *D. longicornis* population, as well as percentage of gravid females, were larger in the wet season than in the dry season. Cochereau (1985a) found that as immature females emerged from the rice crop over the season, percentage of gravid females decreased. In my study, percentage of gravid females remained constant; the few adults emerging from the crop could not significantly augment the proportion of immature females.

An substantial fat body was found in females at the end of the 1988 wet season. According to Chapman (1982), fat bodies are present as energy reserves for either, a) egg development in insects that do not feed as adults, b) survival during periods of quiescence or for c) migration or dispersal requiring long-distance flight. The purpose of the fat body will be further dealt with (Chapter 4).

Sampling in local farmers' fields indicate that diopsid presence is low and impact is minimal; further studies are necessary to confirm this. Even though rain reduces diopsid activity, local farming practices may also be important in keeping pest numbers at a minimum. These practices have permitted a diverse agroecosystem; diversity both in crop species grown in an area and in varieties within a crop species. For example, during the intensive rice growing period in the wet season, several varieties of rice are interspersed. Altieri (1987) claims that different variaties within a crop species can be as important a deterrent on pest numbers as can different species.

SEASONAL EFFECTS ON INSECT ABUNDANCE AND INFESTATION OF THE RICE CROP

Whereas adult diopsids were generally more numerous during the dry season than during the wet season, larval infestation and numbers of tillers damaged were low in both seasons (Table 18). The 1987 dry season had the highest infestation figures, but they averaged only 8% (MT results).

Transplanted rice was significantly more damaged during the dry period, and this should be taken into consideration when programmes are established to intensify the cultivation of rice. Direct seeded rice was not significantly more damaged than transplanted rice during the wet season (pooled data of dead hearts, Table 17). The highest infestation on direct seeded rice was found on the first crop when rain was still intermittent. Heavy rain severely reduced insect activity on subsequent crops.

Because overall infestation was low, it seems that *D. longicornis* and *D. apicalis* are not serious pests of rice in the cropping system represented in the Dubreka area of the Republic of Guinée. The specific reasons for this are enumerated below:

a) During the dry season, even though adult numbers may be high, fecundity remains at a minimum (< 25% and 9% of total *D. longicornis* and *D. apicalis* females are gravid respectively). More *D. longicornis* males (58%) than females were collected but sex ratio is close to 1:1 for *D. apicalis*; however, it is possible that the searching behaviour of

Table 18. Overall diopsid numbers collected and damage observed during the study period. +

Season	Total adults		Total larvae		Total dead hearts	average % infestation
	D.l.	*D.a.*	*D.l.*	*D.a.*		
Dry '87	4694	2368	58	34	441	8
Dry '88	735	97	21	0	136	3
Dry '89	1138	241	40	44	162	4
Wet '87	558	55	66	3	219	3
Wet '88	162	2	8	0	47	2

+ based on weekly sweep net sampling for adults, weekly plant dissections for larvae and infestation results taken at maximum tillering females for oviposition sites at the base of the stem may prevent them from being caught by the sweep net. If planting is delayed (more than 45 days after the last rain or generally after January 10), diopsid presence and therefore damage will be further reduced. It is important to note that *D. apicalis* presence on the dry season crop was inconsistent, e.g., whereas larvae were absent in 1988, they outnumbered *D. longicornis* larval numbers in 1989.

During the wet season, percentage infestation was even lower than during the dry periods (<2% over the 1987 and 1988 wet seasons), although fecundity was higher (31% and 48% of *D. longicornis* and *D. apicalis* females were gravid during the two wet periods). However, rainfall in Dubreka greatly limits egg-laying activity.

It was apparent during these studies that diopsids were continually mobile and searching during both wet and dry seasons of the study. Intensification (double- or triple-cropping) could increase *D. longicornis* abundance by making the host crop available over a longer period, as reported with the brown planthopper in rice in the Philippines by Loevinsohn et al. (1988). Altieri (1987) reports that the traditional practice of producing only one rice crop a year during the wet season and allowing the plot to fallow during the dry season, is partly an attempt to avoid damage by rice stem borers. From conversations held with farmers in Dubreka, it appears that farmers have developed their present cultural practices to reduce problems in general. With few resources (e.g. fertilizers, insecticides, labour), farmers have chosen practices that demand a minimum of resources, and have opted for constant rather than higher yields.

This research has shown that *D. apicalis* was not limited to cultivated rice as a food source and oviposition site. This confirms the findings of Scheibelreiter (1974) and Cochereau (1985a) that *D. apicalis* is not an important pest of rice and may remain insignificant even under intensification. This insect should no longer be referred to as a major pest of West African rice in the literature.

CHAPTER 4.

FACTORS INFLUENCING *D. LONGICORNIS* ABUNDANCE DURING THE DRY PERIOD.

INTRODUCTION

As mentioned in the literature review, biotic and abiotic conditions that enable the diopsid population to persist when the climate is unfavourable, and when rice is absent, are poorly understood. The following experiments were conducted to determine the key factors that permit *D. longicornis* to survive the six-month dry period, a time in Guinée when rice is not normally grown. The results of these trials provide basic inform-tion on the ecology of this species, and indicate the effects that a more intensified rice cropping programme might have on *D. longicornis* abundance.

Danks´ (1987) definition of quiescence, the direct inhibition of development by adverse environmental conditions, was used in this study. In contrast to diapause, which is programmed far in advance of the actual period of arrested development, quiescence is an immediate response to outside conditions. *D. longicornis* undergoes reproductive quiescence, which delays maturation of the reproductive system of the young adults that emerge from the wet season rice crop. Experiments were started with the hypothesis that besides this interruption in development, environmental conditions also alter other aspects of *D. longicornis* ecology and behaviour, creating a dry season form that is different from the wet season form (based on personal communication with Michael Loevinsohn, International Development Research Center: and Denlinger 1986).

The general objectives of these studies were:

1. to determine the main environmental factors that regulate the quiescent period in *D. longicornis*.

2. to describe the effects of these regulators on *D. longicornis* ecology and behaviour.

The chapter will begin with a general description of *D. longicornis* refugia, and of the specific sites that were studied.

DESCRIPTION OF *D. LONGICORNIS* REFUGIA.

Diopsis longicornis is known to choose refugia that border bodies of water (e.g., streams, irrigation canals, meandering rivers), usually sheltered and shaded by overhanging trees (Descamps 1957a). During this study, *D. longicornis* refugia were further defined.

In Dubreka, swarms were found in shaded and humid areas where water was high in organic matter, and in which aquatic or semi-aquatic plants thrive. Plant species found in the refuge sites contained one or more of the following species: *Cyperus* sp., *Panicum trichoides* Sw., *Panicum laetum* Kunth, *Panicum* sp., *Brachiaria plantaginea* (Link.) Hitchc., *Echinochloa* sp., *Ischaemum rugosum* Salisb., *Rottboellia exaltata* L., *Commelina diffusa* Burm., *Paspalum conjugatum* Berg.. During this study period individuals of *D. longicornis* were seen resting in dense aggregations on these plants. On one occasion, between 50 and 125 insects were counted on each of 20 blades of a *Cyperus* sp. plant.

The sites chosen for the 1988 and 1989 dry season refugia studies are indicated in Figures 30a) & b). All sites, except site 5, were situated along an irrigation canal on the NW border of a 1.25 km X 50 m field where rice was cultivated during the wet season. A mixed palm and broad-leaf forest bordered both sides of the field. The experimental plots were situated in an area measuring more than 1200 m^2, close to the eastern tip of the narrow strip of cultivated land.

Although rice was grown in the experimental plots during the dry periods of the research programme, the rest of the field remained fallow during this time, except for small patches of vegetable and fruit crops.

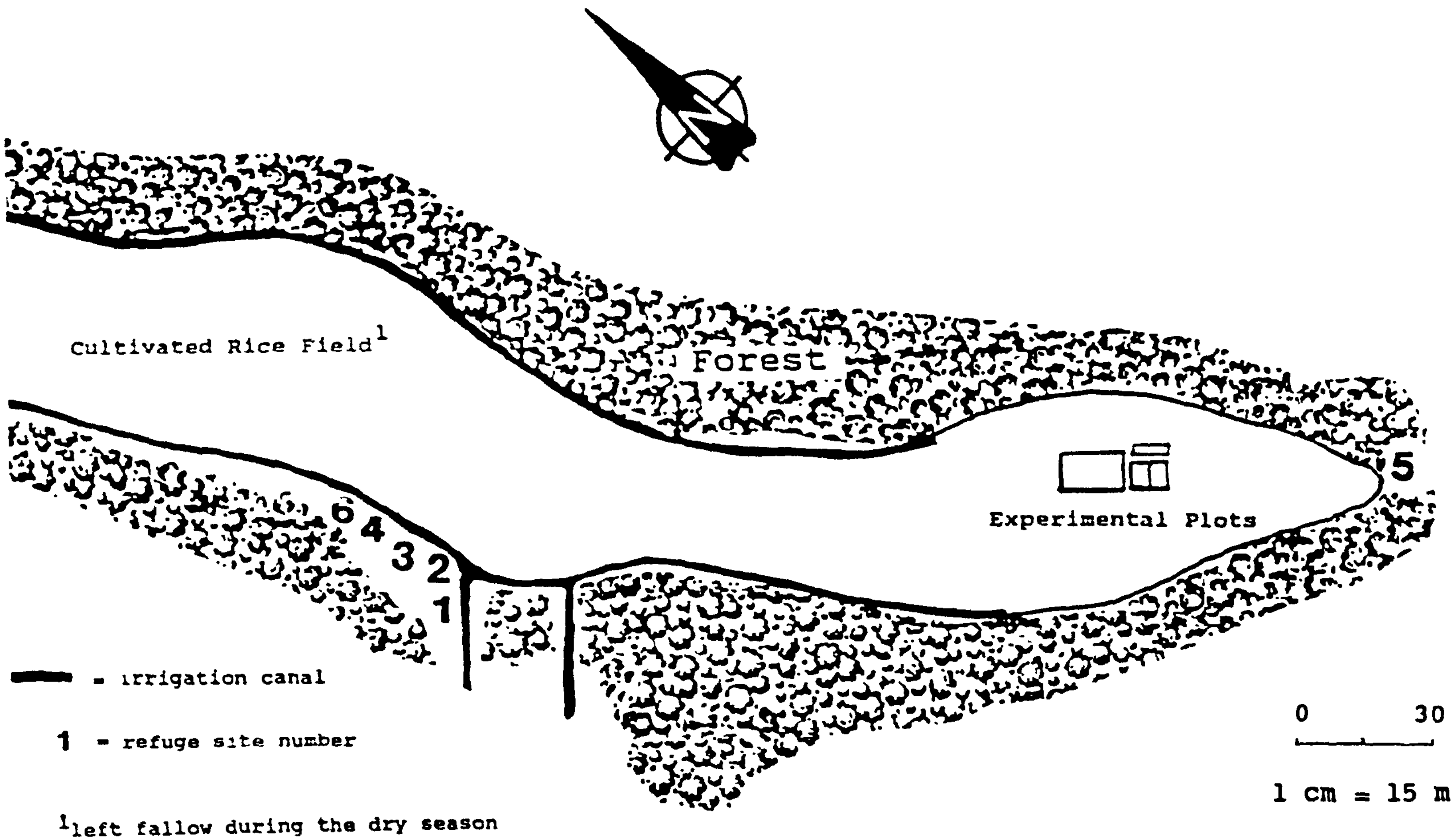


Fig. 31.a) Location of <u>Diopsis longicornis</u> refugia - Dry Season 1988

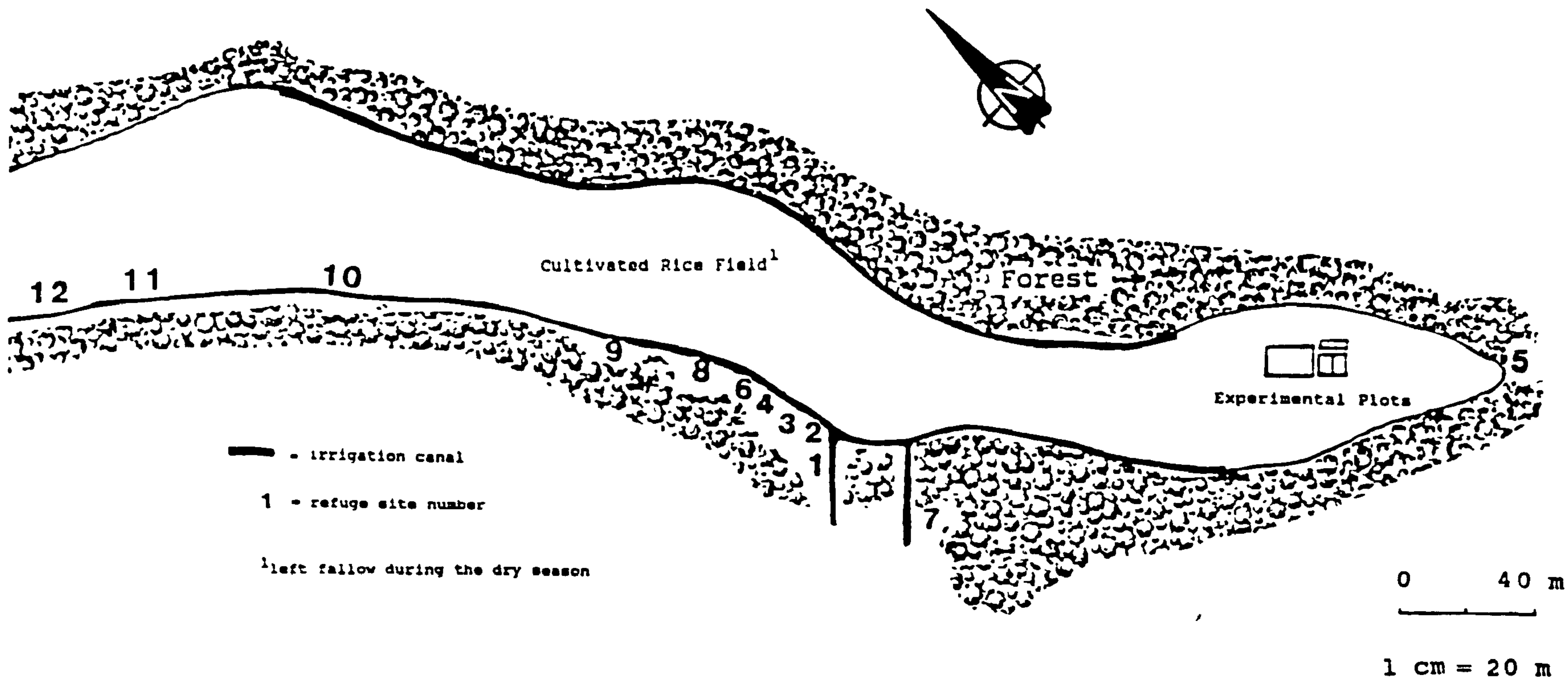


Fig. 31.b) Location of Diopsis longicornis refugia - Dry Season 1989

ENVIRONMENTAL FACTORS

Denlinger (1986) suggests that in the tropics, selective pressure on insect seasonality is likely to come from biotic rather than abiotic factors. Temperature, rainfall and photoperiod would then have their effect mainly via type and abundance of both the vegetation and the natural control agents. The first part of this chapter will describe experiments that were designed to determine the relative importance of key biotic and abiotic factors influencing *D. longicornis* presence.

BIOTIC FACTORS

I. PRESENCE OF CULTIVATED RICE.

Because cultivated rice is considered to be the main host plant of *D. longicornis*, its presence may be expected to affect the activity, abundance and behaviour of this insect. In Dubreka, as in most parts of Guinée, rice is grown almost exclusively in the rainy season (June to November). The *D. longicornis* population must maintain itself on alternative hosts and in an alternative habitat (the refugia) for the interim period of six months (from December to May).

The specific objectives of these studies were:

1. to determine if there was a direct correlation between the time of *D. longicornis* movement from the rice field to the refugia and time of rice harvest at the end of the wet season; and between the time of dispersal from the refugia and dates of rice planting at the beginning of the next wet season.
2. to determine the uniformity of the delay period in *D. longicornis* reproductive activity, by presenting the insect with rice throughout the dry period.

I.1. Relationship between availability of rice and *D. longicornis* presence in the refugia.

Materials and Methods. On December 18, 1987, two refuge sites were found, and by early January 1988 five sites were identified and selected for the study. On April 1, a sixth site (site 6) was included in the sampling programme (Figure 31a). In December 1988, at the beginning of the following dry season, six additional sites (sites 7-12) were also chosen for sampling (Figure 31b). Refugia were monitored from December 1987 (the beginning of the 1988 dry season) to February 1990 (the middle of the 1990 dry season) to determine the times when diopsids were present.

During the 1988 dry and wet periods, from January 15 to July 26, sites were monitored with a sweep net (5 sweeps per site), every 14 days. Sex ratio and presence of gravid females were also noted.

During the 1989 dry and wet periods, from the end of December 1988 to July 1989, refuge sites were monitored only for data on the times of movement to, and of dispersal from, the refugia. Throughout the dry season, monthly samples were collected to check sex ratio and presence of gravid females to confirm the previous season's results.

The same sites studied during the 1989 dry and wet periods were also monitored (5 sweeps per site every 7 days) at the end of the 1989 wet period and into the 1990 dry season (from October 18, 1989 to February 3, 1990). Time of movement to the refugia during this period was compared with times observed in 1988 and 1989.

Results and discussion. Dry Season 1988. On December 18, 1987, *D. longicornis* was first seen in the refugia at the time of rice harvesting in the adjacent fields. If we assume that the absence of suitable rice initiates movement to, and aggregation in, refugia, we can surmise that *D. longicornis* left the rice fields about 35 days earlier (November 13), when rice was at the flowering stage. Unfortunately, the location of the refugia had not been detected at this time.

Numbers of *D. longicornis* collected in 1988 are presented in Figure 32. Population densities in each site remained approximately constant until May 27 (end of dry season), unless the water level dropped to small pools, then the insects would disperse to a more favourable location. For example, on April 15, when sites 2, 3 and 4 were almost dry, few or no *D. longicornis* were found. Upon examination of the canal beyond site 4, a large number of diopsids were found 20 m away in an area where farmers had deepened the canal to permit accumulation of water for their nearby vegetable crops. This location became site 6. Sites 1 and 6 seemed to have received the diopsids leaving the drier sites.

On May 27, and again on June 10, 1988 (beginning of the wet season), the *D. longicornis* population in all sites dropped dramatically. On June 10, insects were found only in sites 1 (1 insect per 5 sweeps) and 4 (8 insects per 5 sweeps). A small population of diopsids remained in site 4 after June 10 until June 28, but all other sites were abandoned, even though the water level remained high in all.

Those diopsids, therefore, left the refugia well in advance (late May/early June) of the availability of the wet season rice crop (late July/August). Land preparation and rice seeding began in early July, but transplanting was sometimes postponed until mid-August. Farmers delayed planting in 1988 because the heavy rains were also delayed.

Sex ratio within the populations at each refugia remained constant throughout the dry period (Table 19). As many as 1720 insects were sexed from a total of 2305 individuals collected throughout the season. Of the 1720 insects, 968 (56%) were female, and only 8 of those were gravid. Six of the latter were collected on January 15;

Fig. 32. Occurence of D. longicornis in 6 refuge sites adjacent to the rice fields. Dry Season 1988

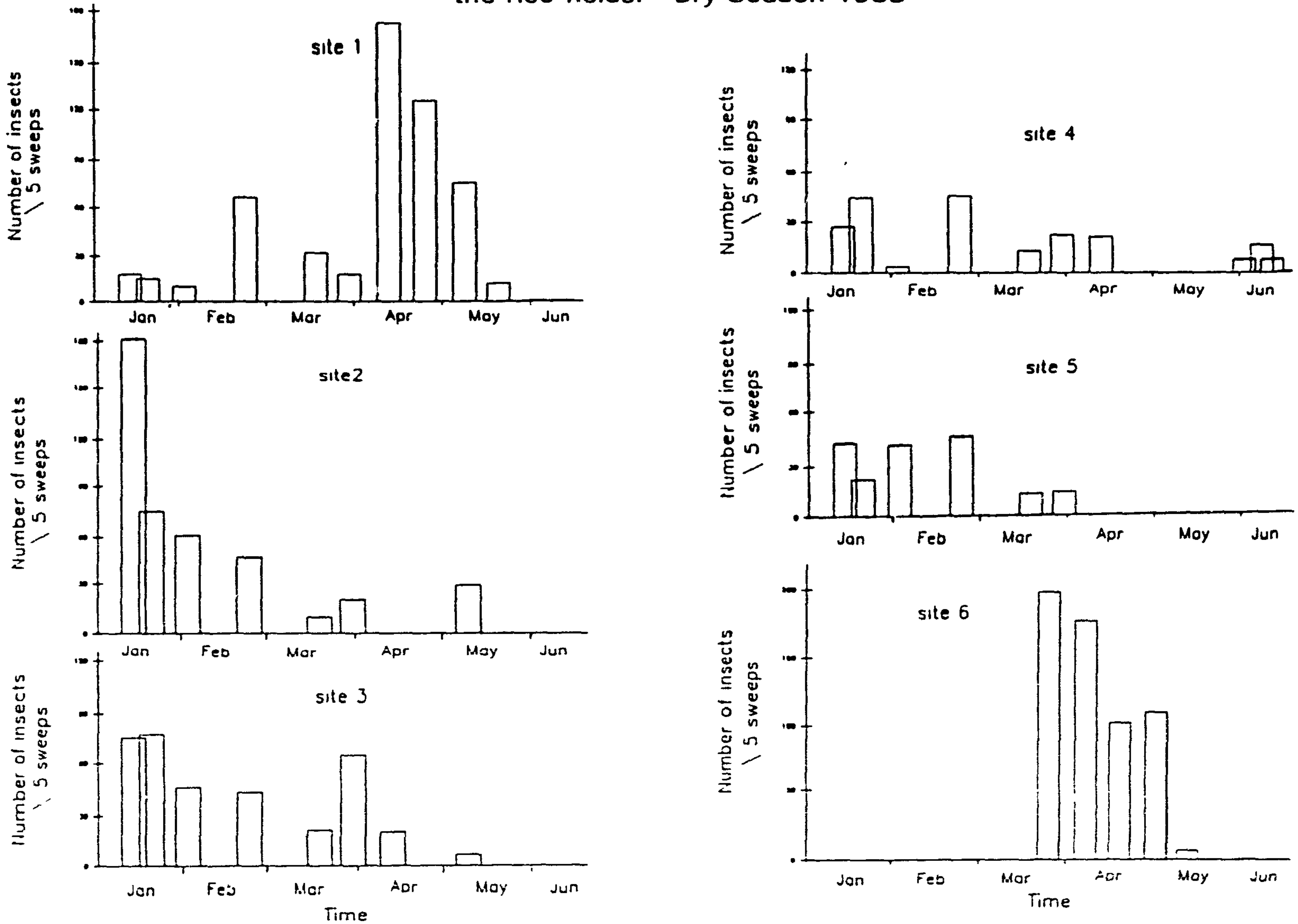


Table 19. Sex ratio of *D. longicornis* in six refuge sites adjacent to the rice fields[1]. Dry Season 1988

DATE	SITE LOCATION											
	1		2		3		4		5		6	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
15-01-88	7	11	51	130	22	54	8	19	9	34	--	
22-01-88	5	7	31	44	29	49	15	29	8	14	--	
5-02-88	5	5	21	40	20	25	0	4	17	25	--	
19-02-88	28	36	19	25	18	24	18	27	14	32	--	
18-03-88	20	12	0	10	14	8	8	5	9	4	--	
31-03-88	9	9	13	7	35	30	11	11	4	6	nc	
15-04-88	101	79	0	0	nc		nc		0	0	108	69
29-04-88	nc		0	0	0	0	0	0	0	0	nc	
14-05-88	28	47	14	15	2	5	0	0	*		nc	
27-05-88	7	5	0	0	0	0	0	0	--		3	4
10-06-88	1	0	0	0	0	0	8	0	--		0	0
17-06-88	0	0	0	0	0	0	6	10	--		0	0
21-06-88	0	1	0	0	0	0	5	3	--		1	0
28-06-88	0	0	0	0	0	0	1	0	--		0	0
TOTALS	211	206	149	271	140	195	80	108	61	115	111	73

[1] based on weekly sampling of 5 sweeps per site

-- not sampled

nc not calculated

* site 5 was destroyed by farmers on May 14.

all other females collected after this date were non-gravid until June 17, when 2 gravid females were collected from site 4. By this time, most of the insects had left the refugia. Dissection of females throughout the dry season, showed an absence of the fat body that was present at the end of the wet season. This was noted in all dissected insects collected in the subsequent season as well.

The high proportion of males is important if one considers that aggregation is likely to not only protect *D. longicornis* from predation, but also improves the chances of females finding a mate; however, this remains to be proven. J.A. Downes (personal communication), on the other hand, presumes that mating occurs with non-gravid females prior to aggregation in the refugia.

Dry Season 1989. Diopsids began aggregating between November 11 and 18 (end of wet season). No insects were found in the refugia on the first sampling date, and close to 30 were counted in each of two sites on the second date. The canals on both sides of the field were surveyed to an extent of 1 km. On November 18, insects were concentrated in site 4 and in a site 30 m east of site 1 (site 7; Figure 31b). Rice in most fields were beyond the flowering stage at this time. Before diopsids entered the refuge sites, aggregation behaviour was observed in shaded and humid areas bordering the rice field as early as the beginning of November. The humidity within these areas derived from water accumulated in puddles, ditches or the canal that bordered the rice field. By January 1, 1989, *D. longicornis* had moved from these areas, since rice had been harvested and the humidity had decreased with the beginning of the dry season. These sites of early aggregation were seen again in the following year and were then identified as ´pre-aggregation´ sites.

Time of dispersal from the refugia was similar in 1989 and 1988. On June 2, 1989, 141 *D. longicornis* were collected. By June 9 (beginning ot the wet season) numbers were down to 51, and they continued to drop until June 23 when no *D. longicornis* was found in any of the sites. Gravid females were first collected on June 16.

Dry season 1990. Aggregation of a smali group of *D. longicornis* (4 insects collected in 15 sweeps) was noted in a humid and partially shaded area bordering the rice field ('pre-aggregation' site) on October 18, 1989 (end of wet season). Although numbers increased gradually in this area, diopsids were not detected in the previously located refugia until December 7. Nevertheless, by December 17, all of these sites had an important population of diopsids, averaging 55 insects per 5 sweeps until the end of the sampling period on February 3, 1990. *D. longicornis* seem to first form groups in areas where rice is still present and where the required conditions of humidity and shade are met. Aggregation behaviour may then be initiated as early as the middle of October in these temporary sites. Movement to more permanent refugia appears to occur when the temporary sites dry up (generally in December).

General Discussion. Whereas timing of movement to refugia at the end of the wet period coincided with the time of flowering of the rice crop (late October to mid-November), time of dispersal after the quiescent period occured at least one month before the land was prepared for the rice cropping season. The seasonal movement of *D. longicornis* is illustrated in Figure 33. Although the absence of suitable rice may affect movement of *D. longicornis* to refugia, presence or absence of rice had no influence on the insect's dispersal from the refugia or on female fecundity.

Pre-aggregation sites appear to form a link between the wet season habitat (the rice field) and the dry season habitat (a shaded, humid area close to or in the forest). Whatever the cues that initiate aggregation may be (biotic and/or abiotic factors), the choice of aggregation sites may involve visual cues. Prokopy and Owens (1983) claim that insects can detect objects by their dimensions, by contrast against a background, by the optical properties of the medium and the intensity of illumination; furthermore, insects will respond to objects that match a specific, predetermined template of stimulus perception. In the case of *D. longicornis*, the flies may be attracted to a species-specific landmark once the cues for aggregation are initiated. These landmarks are probably associated with sites where conditions are favourable for diopsid survival over the dry period.

Comparison between the sites observed in these studies (regular aggregation or refuge sites and pre-aggregation sites) indicate consistency in the sites chosen by the flies. Since humidity is of great importance in the choice of a site, the reflection of a pond or pool of water may indicate to the flies that a site can provide the humid conditions that they require. Shade is also necessary during the dry season to stabilise and maintain humidity. These conditions would be provided if diopsids selected for landmarks that consisted of a reflection from a body of water that was broken into many small sec-

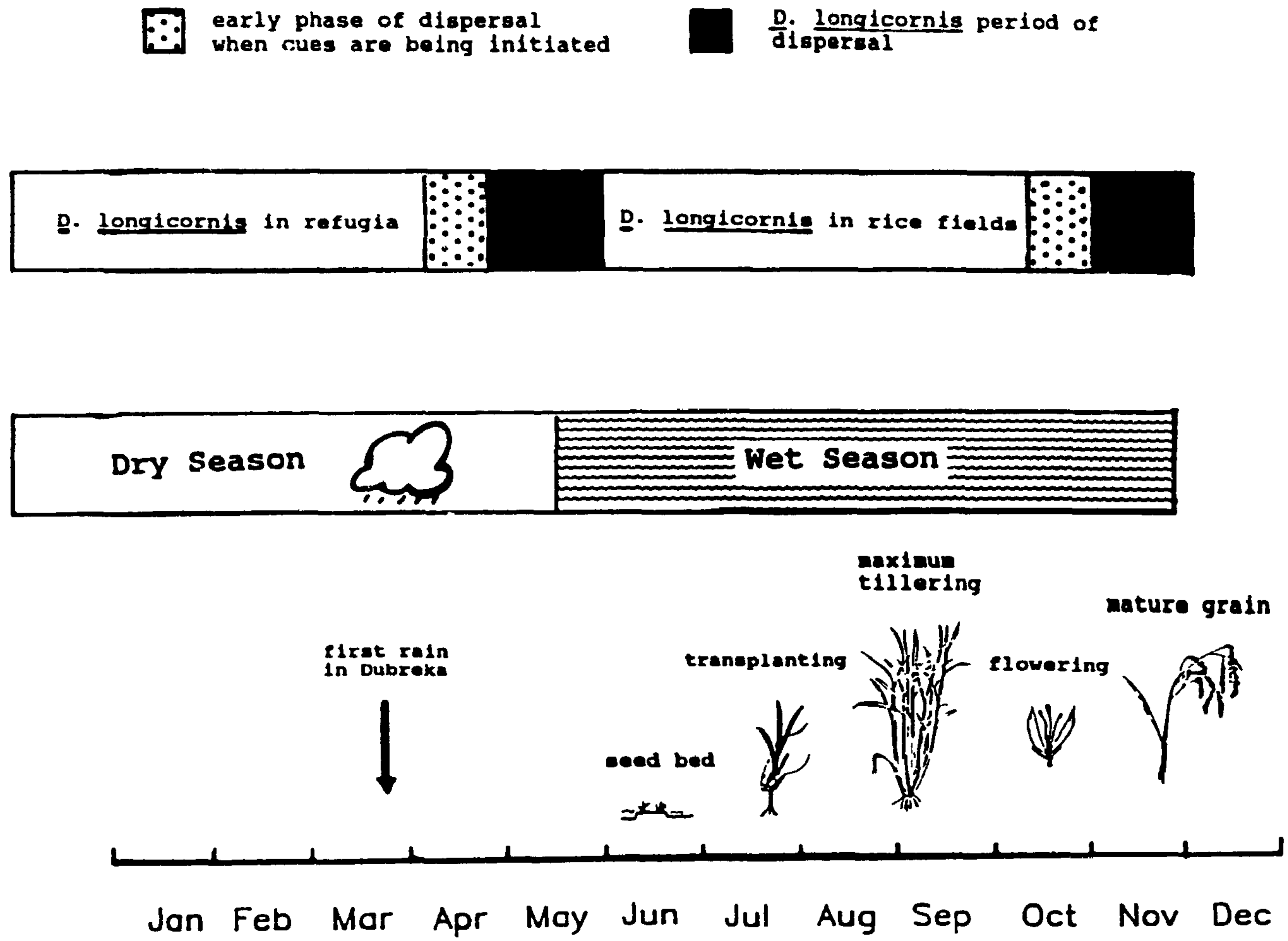


Fig. 33. Relationship between *D. longicornis* seasonal dispersal behaviour and the Dubreka rice cropping season.

tions, as created by either tall rice plants (as in pre-aggregation sites) or overhanging trees and bushes (as in the dry season refugia).

Prokopy and Owens (1983) further point out that an organism with an eye with the complexity of the insect compound eye must also possess a sophisticated visual system. *D. longicornis* with a compound eye reaching nearly 360^0 in all directions, most likely has very acute vision.

I.2. Uniformity of the delay period in *D. longicornis* reproductive activity in the presence of cultivated rice.

The previous observations showed that maturation of the rice plant at the end of the wet season coincided with *D. longicornis* departure from the field to the forest refugia. This experiment was set up to further determine the relationship between rice phenology and *D. longicornis* quiescence. Initial results (Chapter 3. Results. Dry season 1987) suggested that, in the dry season, rice in the experimental plots was damaged only by flies carried over from the wet season crop. Later in the experiments, it appeared that diopsids not only came from the wet season crop, but also from the dry season refugia, generally during the mid and late dry period. The objective of this experiment was to show whether *D. longicornis*, taken from the refuge sites and introduced to a rice crop, would maintain their arrested state of reproductive development until the end of the dry period. If *D. longicornis* readily terminated their quiescent state, it would seem that the species could invade dry season crops at all times and present a problem if a double-cropping system was to be established.

Materials and Methods. Four cages, (1.5 m X 1.0 m X 1.0 m) were placed at the periphery of the experimental plots, each over five rows of seven hills of rice seedlings. These rice seedlings were carefully inspected for *D. longicornis* eggs or larvae that might have been present in the seed bed.

From October 18, 1988 until June 23, 1989, at two-weekly periods, rice was transplanted into one cage at a time. Prior to mid-June, individuals of *D. longicornis*, introduced into the cages, were collected from the refugia; after that time, when they were no longer available there, they were collected from the rice field.

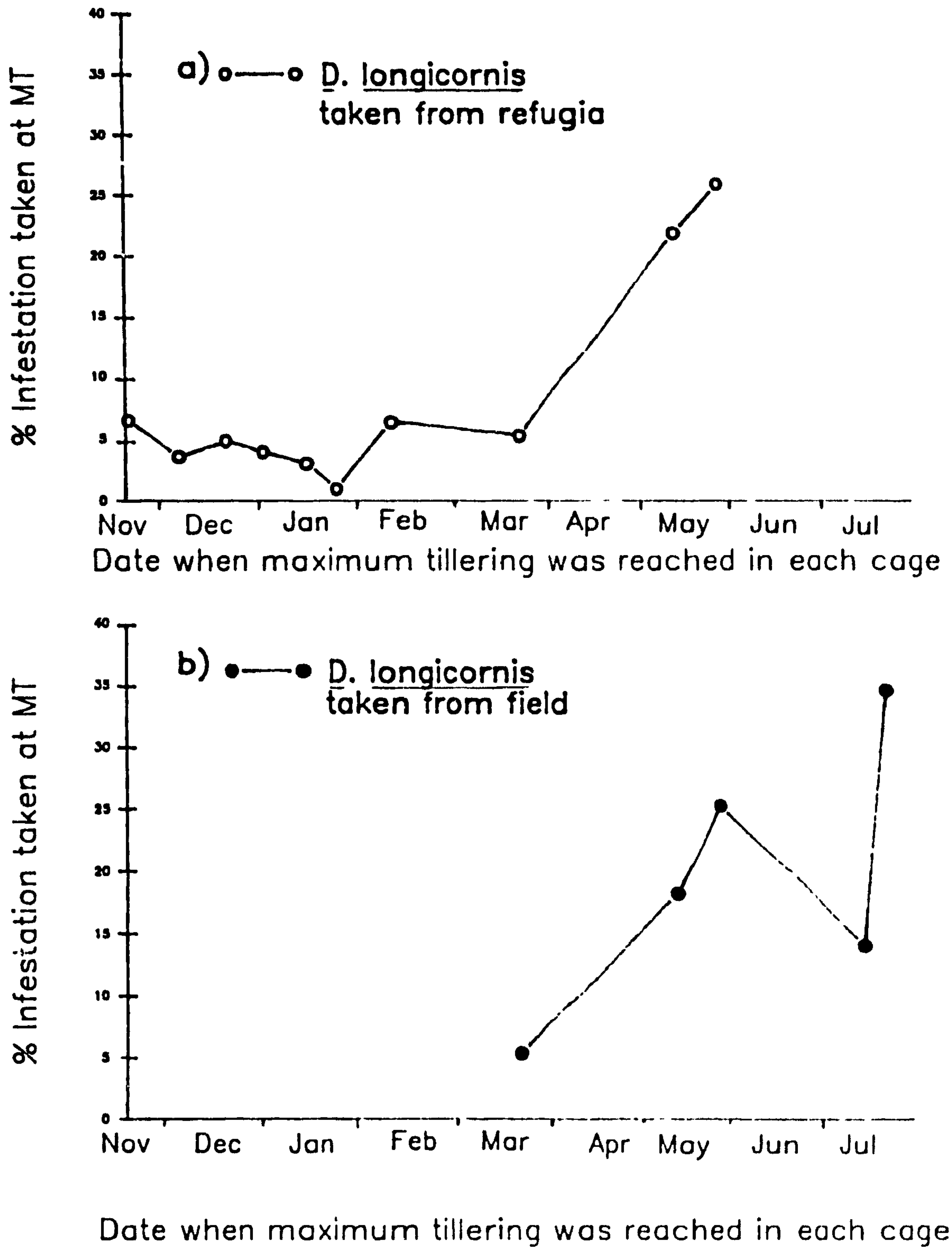
On March 13, to determine if behaviour of *D. longicornis* taken from the rice field differed from the behaviour of those from the refugia, a parallel set of cages was prepared in which *D. longicornis* taken from the field was introduced to compare results from the first set of cages. A population of about 40 insects was maintained in both sets of cages, until the rice within the cage reached the flowering stage, at which time the crop was removed and a new one planted.

On day 20, 35 (maximum tillering: MT) and 55 (flowering: FL) days after transplanting, percentage infestation was calculated by counting numbers of dead hearts and of white panicles, and by using Oñate's formula described in Chapter 3 (Materials and Methods).

Results and discussion. Percentage infestation results are shown in Figures 34a and b. Infestation at MT will be discussed here as this is the time when infestation has reached its peak.

Results from the first part of the experiment showed that *D. longicornis* females break their reproductive quiescence and begin egg-laying in the presence of rice. Infestation was nevertheless low (Figure 34a). From Cage 1 (MT on November 18) to Cage 7 (MT on February 14) infestation varied between 1% and 7%, with a mean of 4%.

Fig. 34. Percentage infestation at maximum tillering of caged rice plants by diopsid larvae - Dry Season 1989



This level of infestation was similar to infestation in the transplanted rice in the neighbouring experimental plots, which had a mean of 4% damage at MT.

In the second part of the experiment, infestation at first remained low (5%: MT on March 28), but then rose significantly to as high as 35% (MT on July 27) (Figure 33b). The rise in infestation was first seen on the plants reaching MT on May 19. This suggests that more females were gravid at this time than previously.

Infestation at MT did not differ greatly whether insects were taken from the refugia or from the field. Since there is infestation by *D. longicornis* taken from the refugia throughout the dry period, it is apparent that the insect can avoid dormancy and reproduce on available rice. There is nevertheless a restraint on reproductive activity during the dry period for both groups that is not related to presence of rice. Reproductive quiescence may be equally regulated by abiotic factors, such as rainfall, relative humidity, and temperature, as well as biotic factors. Andrewartha and Birch (1984) underline the importance of relative humidity (R.H.) in maintaining sufficient metabolic water for egg maturation. In the dry season, the flies in the rice field may contain less metabolic water than in the wet season; from 1986 to 1988 records, R.H. is on average 71% during the dry season (December to May) and 84% during the wet season (June to November). As mentioned previously, dissected flies collected in the dry period had dried viscera within their abdomen, but in the wet period, flies had regular internal organs and even a conspicuous fat body towards the end of the wet season.

It is important to note that infestation occured soon after diopsid introduction, even in cages where *D. longicornis* taken from the refugia were introduced. Only one week after introduction, dead hearts were seen on the caged plants. Such a short time may indicate that mating had occured earlier in the refugia or sooner and that *D. longicornis* females are ready for oviposition when favourable conditions occur. This flexibility and variability in choosing oviposition time would improve the species chances for survival by permitting its distribution over a longer time period.

BIOTIC FACTORS

II. SECONDARY HOSTS

Some plant species found in the *D. longicornis* refugia, have been found to be alternate hosts of *D. apicalis*, e.g., *Cyperus* sp., *Paspalum* sp., *Oryza barthii*, *Echinochloa* sp. (Deeming, 1982; Morgan and Abu, 1972). There is no record in the literature of these plant species as secondary hosts of *D. longicornis*, except for wild rice, *Oryza barthii* and *O. longistaminata*; even then records are few. Jordan (1966) did not find any infestation in these plants, even though the species was plentiful around fields of cultivated rice in Sierra Leone. No record of *D. longicornis* infestation of wild rice has been made in Guinée (L. Traoré, entomologist, Institut des Sciences Agro-Zootechniques de Foulayah, Kindia). Cochereau (personal communication) claims that *O. barthii*, *O. longistaminata*, and closely related *Leersia* sp., have been found to be hosts to *D. longicornis* in Côte d'Ivoire.

The following experiments were designed to identify whether there is a relationship between plants found in the refugia during the dry period (as a food source for the adult flies or as oviposition sites for females and hosts of ensuing larvae). As discussed in the experiment on the relationship between availability of rice and *D. longicornis* presence in the refugia, dissection of plants found in the refuge sites yielded no eggs, larvae or pupae. Thus, *D. longicornis* does not use these plants as oviposition sites. Furthermore, dissection of females showed that *D. longicornis* maintained its period of reproductive arrest while in the refugia.

The following experiment was designed to determine whether these plants would be accepted as alternate hosts under controlled conditions when female *D. longicornis* are fecund. Based on results from the 1988 dry period discussed below, *Panicum* nr. *laetum* was selected for further studies in 1989.

Even though wild rice species, *Oryza breviligulata* (=*O. barthii*) and *O. longistaminata*, and a related genus, *Leersia*, should ideally have been included in these experiments, they had not been found in the vicinity of the experimental field. The Dubreka area was searched regulary for these plants and local botanists and farmers had been consulted, but these searches proved to be unsuccessful until the end of the research programme. On November 18, 1989, *O. longistaminata* was found and specimens were placed under cages with *D. longicornis* for closer observation.

Materials and Methods. Cage experiment with plants taken from the refugia. On April 1, 1988, two cages (1.5 m X 1.0 m X 1.0 m) were placed over sites that had been previously planted with *Echinochloa* sp., *Panicum* nr. *laetum*, *Paspalum conjugatum* and *Cyperus* sp. Into these cages, 50 *D. longicornis* adults, taken from the experimental field, were introduced. Numbers were kept constant by means of regular introductions of insects. On April 8, and every week thereafter until October 15, 1988, all plant parts were observed for *D. longicornis* eggs, and every two weeks, two plants per species were dissected in search of larvae and pupae. Plants were reintroduced when needed, to maintain their variety and abundance throughout the study period.

***Panicum* nr. *laetum*.** During the following dry season (1989), concurrent with cage experiments designed to relate *D. longicornis* reproductive activity and presence of rice (cf. uniformity of the delay period in *D. longicornis* reproductive activity), an experiment was set up to verify *D. longicornis* affinity to *Panicum* nr. *laetum*. In March, 1989, two plants of *P.* nr. *laetum* were placed in each of two cages where rice and *D. longicornis* had been introduced. In one cage, the introduced diopsids had been taken from the refugia (until June 16 when refugia were empty and insects had to be taken from the field) and in the other, the flies had come from the experimental field. The *P.* nr. *laetum* plants were observed weekly from their introduction in mid-March to mid-August.

To further test the relationship between *D. longicornis* and the weed, *P.* nr. *laetum*, a refugium was selected where both the diopsid and the plant were plentiful. The hypothesis that initiated this experiment, maintained that if the weed played a role in attracting *D. longicornis* to a particular site, its removal from a site would induce departure of the insects. On March 25, 1989, all *P.* nr. *laetum* plants were pulled out of site 2. Beyond this 8 m^2 area, this species of plant was absent for a radius of more than 20 m. The site was visited 3 days later and weekly thereafter until the beginning of the wet season (mid-June) to denote possible displacement of the *D. longicornis* population.

Oryza longistaminata. On November 8, 1989, the perennial species of wild rice, *Oryza longistaminata*, was found bordering a banana plantation 1.5 km south of the experimental site. Dead hearts were apparent among the plants and, upon dissection of 10 of these damaged stems, one larva and two pupae of *D. longicornis* were found. To further observe *D. longicornis* infestation of these plants, an area within the experimental site was prepared for that purpose. On November 15, seven rows of six plants each were transplanted, and the following week a cage (1.5 m X 1.0 m X 1.0 m) was placed over these plants and 40 *D. longicornis* were introduced. This population was maintained throughout the experiment. Weekly visits to the site where

O. longistaminata was first found, and of the caged plants, commenced on November 18 and continued until February 3, 1990. *D. longicornis* activity and infestation were recorded.

Results and Discussion. Cage experiment with plants taken from the refugia. From April 8, 1988 to October 15, 1988, the four selected species of plants taken from the refugia were observed weekly for presence of eggs; these observations, as well as two-weekly dissections of plant parts, revealed that the plant species were not used as secondary hosts under the conditions of this experiment. No eggs, larvae nor pupae were found. Regular checking of *D. longicornis* individuals revealed that few gravid females were present (5% of total diopsid population). Results from mid-July to the end of August are subject to error because, at this time, *D. longicornis* was difficult to collect. Heavy rainfall had significantly reduced the number of individuals available for the experiment. These results show that *D. longicornis* females do not choose to oviposit, even during their period of fecundity, on the four species of refugia plants.

After a few weeks, on April 29, leaf damage was noted on *Panicum* nr. *laetum*. Damage was characterised by a series of minute and clear patches on the leaves of the plants, as if the contents of individual plant cells had been extracted. Since *D. longicornis* was by far the most abundant species of insect present (all other invading insects were regularly removed), it was presumed to have caused the damage. At one point, four fresh plants of *P.* nr. *laetum* were introduced into the cages and *D. longicornis* was observed constantly to check its feeding behaviour. Individuals of *D. longicornis* were seen continually passing their proboscis over the leaves, and within a few days all leaves of the newly introduced plants had the characteristic feeding marks. Upon observation of *P.* nr. *laetum* plants in the refugia, the damage was seen here as well. None of the other plants chosen for the experiment showed similar damage.

Throughout this study period, however, damage was found to be inconsistent. It was common from April 1 to June 15, but then diminished, and by the end of July no new damage was seen on the plants.

This first experiment demonstrated that *P.* nr. *laetum* is a source of food for *D. longicornis* adults. *D. longicornis* affinity for this plant appears to be seasonal, however, since damage was not observed during the wet season. During the reproductive period, diopsids may either cease feeding or use another source of food.

As discussed in the wet season experiments (Chapter 3), the fat body present in *D. longicornis* at the end of the wet period may be used as an energy reserve for either egg development in non-feeding adults, for survival during quiescence or for migration over long-distances (Chapman 1982). Since we have seen that *D. longicornis* is without a fat body from the beginning of the dry season (cf. Chapter 3. General discussion. Dry season experiments), well before usual time of egg development (end of dry and beginning of wet season), and, in this experiment, that adults feed on plant juices during their period of quiescence, the fat body is most likely used for migration or dispersal.

***Panicum* nr. *laetum* under cages.** On March 31, two weeks after *P.* near *laetum* plants had been transplanted under cages, two leaves of one plant were damaged in the cage containing individuals of *D. longicornis* coming from the field and five leaves of one plant were damaged in the cage containing *D. longicornis* collected in the refugia. Marks were few on all leaves (2 to 3 damaged areas measuring 2 cm^2 each). In April, a few additonal marks were seen on the plants in the cage where insects were taken from the refugia, but marks were not observed on plants in the other cage with field collected diopsids. From May onwards, no damage was noted on *P.* nr. *laetum* until August 21, when the experiment was terminated.

When *P.* nr. *laetum* plants were placed under cages with rice, a small amount of feeding occured soon after introducing the plants, but completely stopped after six weeks. It appeared that the presence of rice had initiated egg-laying; it may be that this activity had in turn stopped *D. longicornis* feeding on the weed. Further work could verify this assumption.

Towards the end of the research period, another plant was found as a food source for *D. longicornis*. *Commelina diffusa* Burm. grew in abundance along the bunds of the experimental fields. It showed the characteristic feeding marks, and when introduced into a cage with *D. longicornis*, the insects were seen feeding on the plant in the same manner as on *P.* nr. *laetum*.

***Panicum* nr. *laetum* in the refugia.** Three days after removing all *P.* nr. *laetum* from site 2, diopsids were still abundant. However, no other plant in the site had the characteristic feeding marks. A week after removal, *D. longicornis* was still present (35 insects per 5 sweeps) and one month later, on April 21, *D. longicornis* was collected again (46 insects per 5 sweeps). Diopsids were present until May 19 (5 insects per 5 sweeps), when numbers of flies were decreasing in other sites as well. No other plants within the area showed *D. longicornis* feeding damage throughout this study period. It is possible that *P.* nr. *laetum* had first attracted *D. longicornis* to the refugia; however, the diopsids apparently were not kept there by this plant once they had established themselves. Other cues or attractants, such as relative humidity, may have been present to keep the population there. Also, once there the diopsids may no longer have the ability to move or make other choices.

***Oryza longistaminata*.** On November 18, *D. longicornis* adults were in large numbers in the area where *O. longistaminata* had been transplanted (the cage had not yet been placed on the plants). Ten *D.*

longicornis were counted on one leaf and several leaves held from 2 to 5 flies. Three sweeps over the plants collected 40 insects. Then the cage was placed over the plants.

The following week, one dead heart was found on a caged plant and during the following weeks new dead hearts occurred at a frequency of three to five dead hearts (over all the plants) per week until February 3 when the study ended.

Infestation of *O. longistaminata* in the site where it was originally found, was observed until the end of December.

O. longistaminata, being a perennial species of wild rice, it propagates by rhizomes rather than by seeds. Like most wild species of rice, it is photoperiod sensitive and starts developing when daylength increases and returns to dormancy when daylength decreases (Oka, 1988). Increasing daylength and renewed growth of *O. longistaminata* coincide with the onset of the rainy season. At this point, *D. longicornis* enters its reproductive cycle. Wild species of rice, such as *O. longistaminata* (and possibly the annual species of wild rice, *O. breviligulata* (=*O. barthii*), and the stalk-eyed fly, *D. longicornis* are endemic to Africa. *D. longicornis* reproductive behaviour may have evolved with wild rice phenology, that, in turn, was regulated by changes in photoperiod and precipitation.

ABIOTIC FACTORS AS REGULATORS IN *D. LONGICORNIS* BEHAVIOUR AND ECOLOGY

Results from a previous experiment (cf. Uniformity of the delay period in *D. longicornis* reproductive activity in the presence of cultivated rice), suggest that even though the presence of cultivated rice can initiate egg-laying in otherwise quiescent females, infestation remained low during the dry period, to rise only with the beginning of the wet season. Furthermore, monitoring of *D. longicornis* dispersal to and from refugia showed that these insects left the refugia well before the period of rice planting.

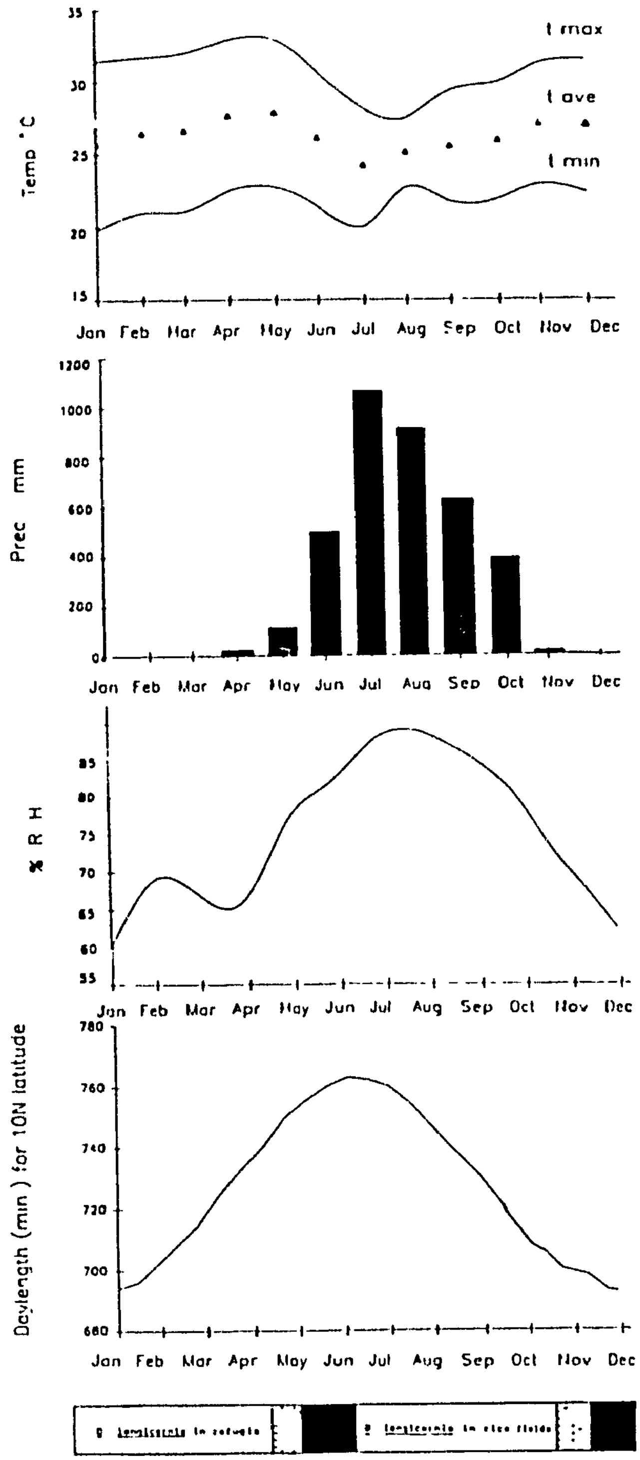
This suggests that factors other than the presence of cultivated rice control the diopsids' dispersal behaviour. The studies of *O. longistaminata* also suggest that cultivated rice may not be the only major host of *D. longicornis*. Deeming (1982) was puzzled to find a sizeable population of this insect in an area where cultivated rice was not present.

The relationship between *D. longicornis*, cultivated rice and wild rice cannot be fully understood without examining the influence of abiotic factors such as rainfall, relative humidity, temperature and photoperiod on both the insect and its hosts.

Seasonal movement of *D. longicornis* in relation to temperature, rainfall, relative humidity and photoperiod are given in Figures 35a to d. Data used for the first three factors came from the weather station (CERESCOR) near Conakry, 25 km south of Dubreka. These figures do not fully represent the situation in Dubreka since in this locality, which lies in the rainshadow of Mount Kakoulima, rainfall is known to be slightly more intense than nearer to Conakry.

D. longicornis dispersal from the refugia (at the end of the dry period) coincided with an increase in R. H., the beginning of the rains, and an increase in daylength. Dispersal from the rice crop at the end of the rainy season occurs when these parameters are decreas-

Fig. 35. a) Seasonal movement of D *longicornis* in relation to temperature[1] rainfall[1], relative humidity[1] and photoperiod[2]. 1986



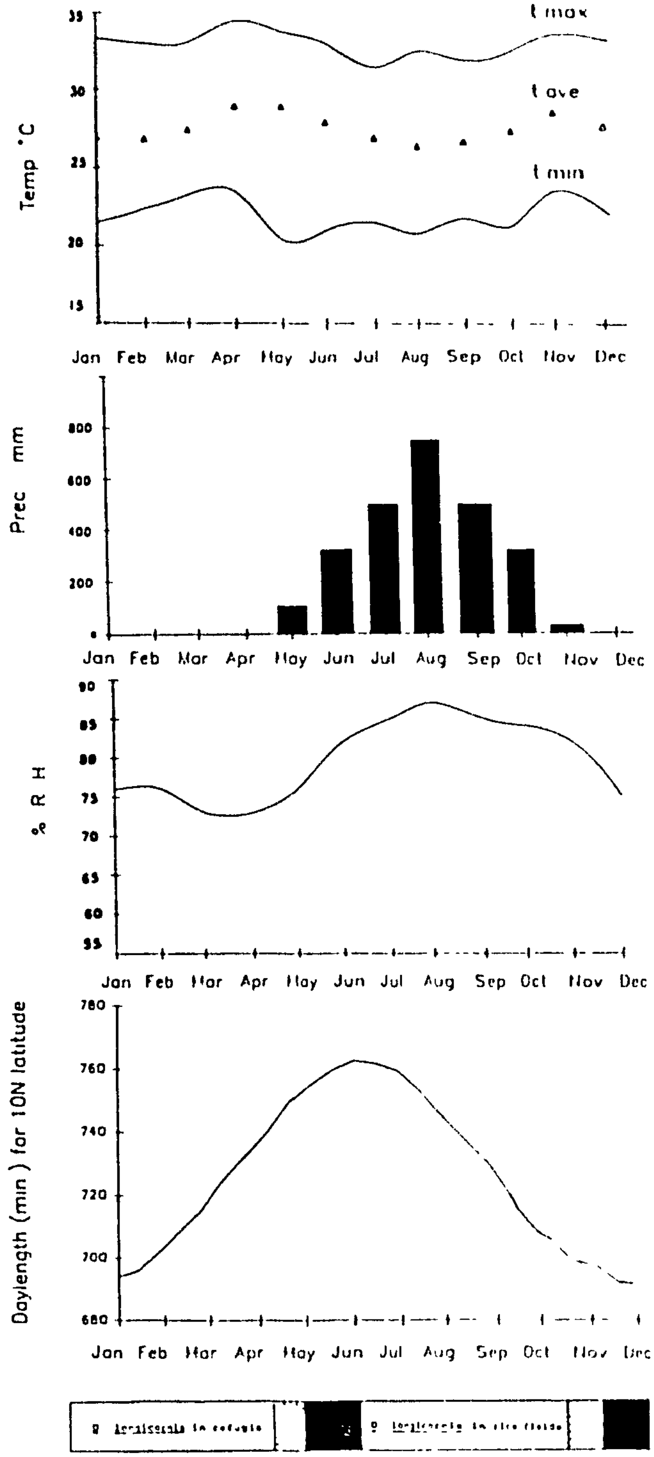
early phase of dispersal when cues are being initiated

D. longicornis period of dispersal

[1]taken from CERESCOR records

[2]taken from Beck 1981

b) Seasonal movement of D longicornis in relation to temperature[1] rainfall[1], relative humidity[1] and photoperiod[2]. 1987



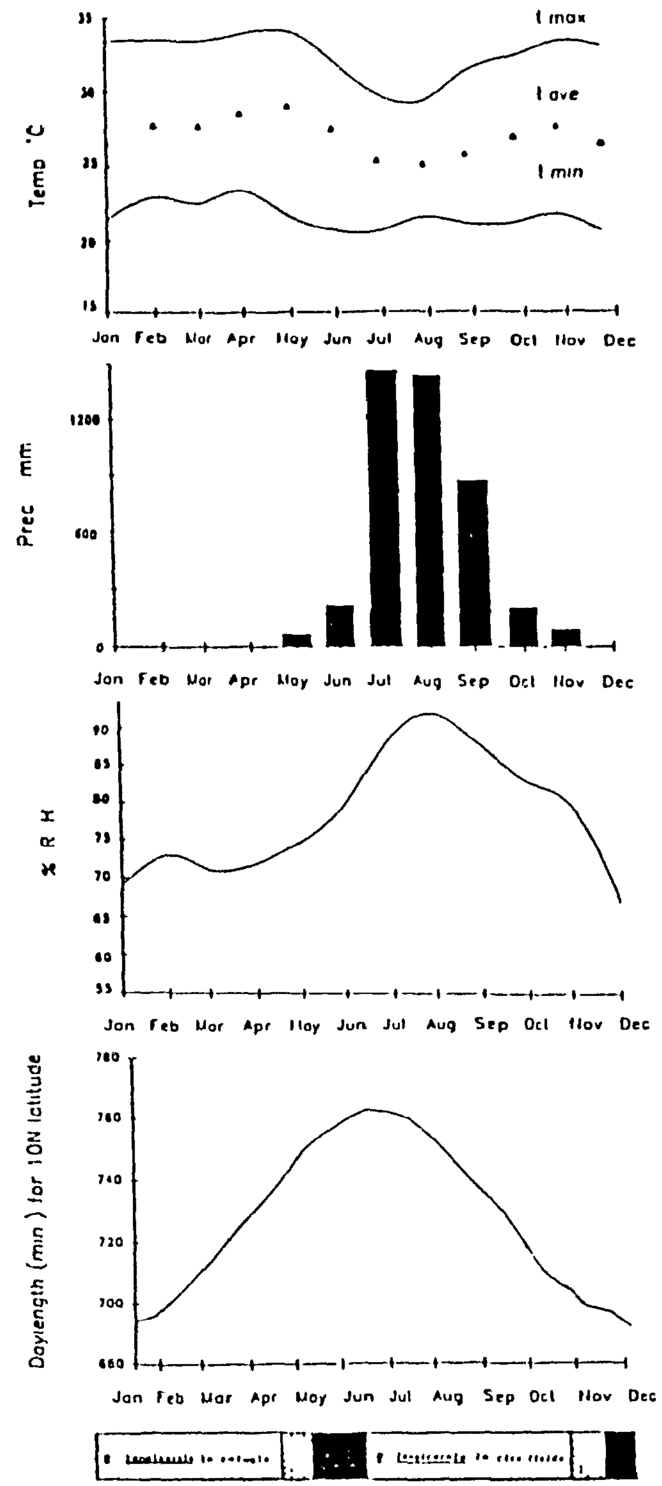
early phase of dispersal when cues are being initiated

D. longicornis period of dispersal

[1]taken from CERESCOR records

[2]taken from Beck 1981

c) Seasonal movement of D longicornis in relation to temperature[1] rainfall[1], relative humidity[1] and photoperiod[2]. 1988



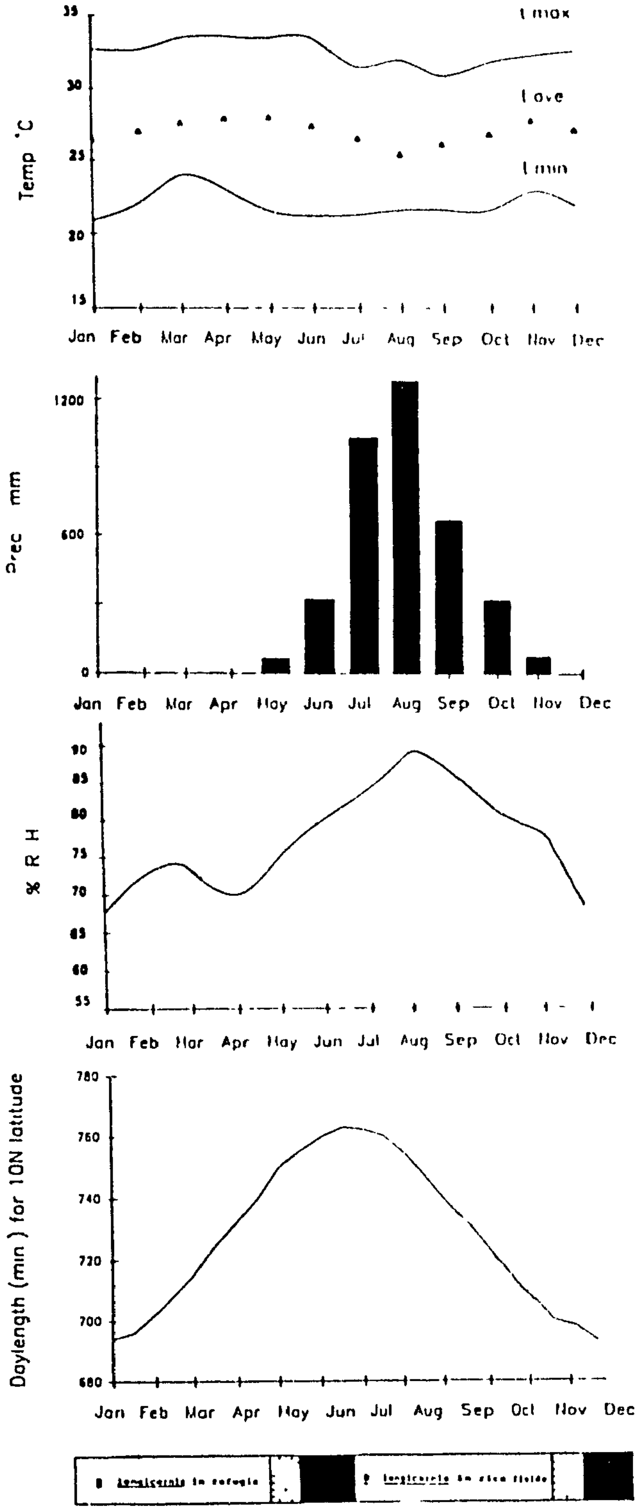
early phase of dispersal when cues are being initiated

D. longicornis period of dispersal

[1]taken from CERESCOR records

[2]taken from Beck 1981

d) Seasonal movement of D longicornis in relation to temperature[1] rainfall[1], relative humidity[1] and photoperiod[2]. 1989



early phase of dispersal when cues are being initiated

D. longicornis period of dispersal

[1]taken from CERESCOR records

[2]taken from Beck 1981

ing. Because changes in temperature are more gradual and seem to follow seasonal rhythms rather than initiate them, they do not seem to be of major importance.

Several possibilities emerge as initiators of *D. longicornis* movement from the refugia at the end of the dry period:

1. It may be that the first rainfalls trigger seasonal changes in *D. longicornis* physiology resulting in sexual development and receptivity, and the initiation of dispersal behaviour. The first rainfall may not have a direct influence on these changes (except to signal that changes are imminent) since the first rains often arrive three to four weeks before a more regular pattern of precipitation sets in. Such effects of rainfall on insect dispersal have been documented by Tanaka, Wolda and Denlinger (1987). Concurrently, rainfall and increased humidity brings on a flush in vegetation that include the wild species of rice, *O. longistaminata* and *O. breviligulata* (=*O. barthii*). As fecund females leave the refugia they may infest wild rice as early as May, since both are at favourable stages in their development. Egg-laying and infestation of wild rice can begin well in advance of the cultivated rice season.
2. It may also be that the rainfall permits growth of dormant wild rice prior to the availability of cultivated rice. If diopsids exhibit searching behaviour throughout the dry period, they will eventually encounter and subsequently infest this wild rice.
3. Photoperiod may also have a triggering effect on growth of wild rice (Oka, 1988) and on subsequent diopsid movement.

Cues responsible for induction of quiescence in *D. longicornis*, and movement to the refugia, are more difficult to interpret. As rain and R.H. are decreasing, this may reduce the moisture content of the food source (Denlinger, 1986), and this, in turn, would be a signal to *D. longicornis* females for dispersal. Furthermore, a decrease in daylength could also act as a due for diopsid dispersal.

DISPERSAL OF *D. LONGICORNIS*

Since *D. longicornis* individuals readily changed from a state of reproductive inactivity to one of egg-laying (cf. Uniformity of the delay period in *D. longicornis* reproductive activity in the presence of cultivated rice), the uniformity and permanency of the aggregation of individuals in the refugia was questioned. Is there group cohesion once an aggregation has been formed? If there is dispersal from the refugia throughout the dry season, what is the purpose of the movement at a time when conditions are unfavourable outside of these sites? Whereas the first part of the chapter examined factors that regulate *D. longicornis* abundance during the dry period, this latter part will focus on *D. longicornis* dispersal behaviour from the end of one wet season to the beginning of the next to identify peak dispersal periods and to further determine the influence of the regulators on diopsid behaviour.

If *D. longicornis* has a physiologically and behaviourally distinct dry season form, it is likely that time of dispersal, whether at the beginning or at the end of the dry period, will occur during a fixed time period. A mark, release and recapture experiment was established to test this. The following three sites were chosen for marking: a) early or pre-aggregation sites found close to and in fields of a late rice crop; b) *D. longicornis* refuge sites; and c) the experimental field. These sites, as well as surrounding areas, were monitored every 14 days to determine whether *D. longicornis* individuals disperse during the dry season, and if so, whether there are specific periods of dispersal, and whether there is a direction to the movement. The experiment also generated data on the age of individual flies during the dry period.

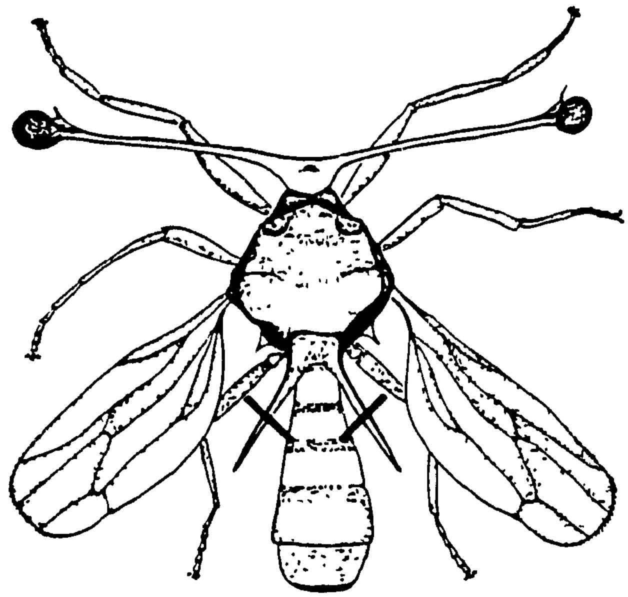
Material and Methods.

Marking Techniques. **Marking of Scutellar Spines.** A preliminary marking experiment employing only locally available materials was conducted in the 1988 dry period, to obtain quick information on diopsid dispersal behaviour. Marking consisted of cutting either the left, right or both scutellar spines of adult *D. longicornis* (Figure 36a). With only three possible combinations, flies from only three sites could be marked. Eventually, insects from only two sites were marked since only two had a large enough population to sample from at the time of the experiment.

On March 25 and April 1, 1988, 619 and 101 flies respectively were marked in site 3, by having the right thoracic spine removed. On April 8, 1988, 1033 individuals collected from site 1, had the left spine removed. During a marking session, *D. longicornis* was captured with a sweep net and placed in a plastic bag. Flies were let out one by one, held between the fingers and the insect´s spine was cut with a nail clipper. The flies were then immediately released. All manipulation occured within the collection site. Only a few dozen flies were captured at a time to avoid any risk of death from overheating.

From April 15 until June 28, 1988, refuge sites 1 to 6 were monitored weekly (10 sweeps per site) for the presence of marked flies. After June 28 (at the end of the dry season) no more flies were found in these sites, and until August 19, 1988 the surrounding fields were sampled weekly for marked individuals. Both marked and unmarked insects in the samples were counted and were immediately released. Marked and unmarked flies were very difficult to differenciate, a process that required handling and close examination.

Marking with paint. The second marking scheme used during the 1989 dry season consisted of placing a small drop of paint on the dorsum of the insect´s thorax (Figure 36b). Several types of paints were tested (Sears Finishing Touch Enamel®, Château Ferro-Plastique®, a)



b)

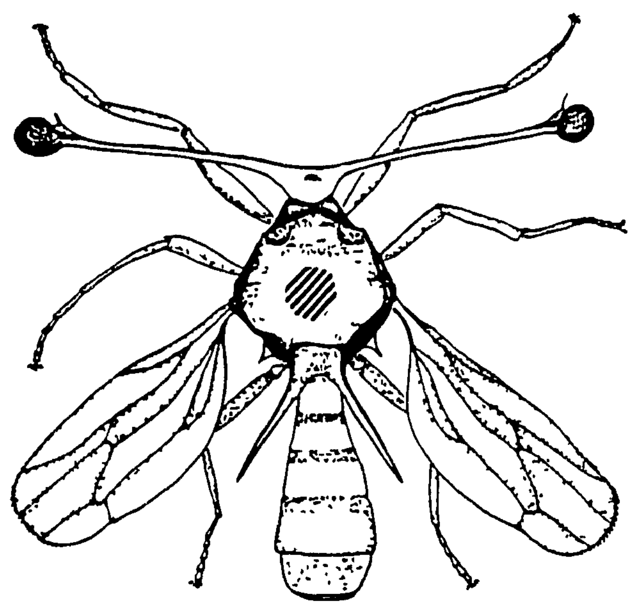


Fig. 36. Marking techniques.

a) Spine-clipping. Dry Season 1988

b) With paint. Dry Season 1989

Sears Plastique Liquide®, Motomaster Laque®) by applying a drop of paint on the thorax of two groups of five freshly collected *D. longicornis* specimens. Both groups were killed and pinned to a piece of styrofoam; one group was left in the open air, the other was inverted in a container of water so that the insects were immersed with the styrofoam on top. The adhesion of the paint was checked after one week. In the open air, all paints remained fixed, whereas in the water, all had washed off except for Château Ferro-Plastique®[1]. This latter paint after being immersed could be removed by rubbing, but it was nevertheless chosen for the study. Château Ferro-Plastique® also had a selection of colours that were bright and attractive. A small drop on the thorax, applied with the end of an entomological pin, could easily identify the insect. Marking began on November 24, 1988 with the silver paint and ended on April 25 with the silver green paint. The marking schedule is reported in Table 20. Marking and releasing was done at the capture sites, as with the spine clipping technique.

The importance of choosing a marking technique that does not interfere with the activity and well-being of the insect was emphasized by Southwood (1978). Both marking techniques were therefore tested for their effect on *D. longicornis*.

Test on the effect of marking on *D. longicornis* adults. For both marking techniques, an equal number (30) of unmarked and marked *D. longicornis* adults were placed in each of two small screened cages (40 cm X 40 cm X 50 cm). The cages contained 4 petri dishes lined with a filter paper to which one of the following was added: pond water, a 70% methyl alcohol, an agar solution and crushed pineapple. These solutions were

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1. Les Peintures Château Inc., 6833 ave. du Parc, Montréal, Qué. H3N 1W8

Table 20. Marking schedule of *D. longicornis* adults.
Dry Season 1989

COLOUR OF MARK	DATE OF MARKING	NUMBERS OF INSECTS MARKED
Silver	24/11 to 9/12/88	142
Green	29/11 to 16/12/88	307
Orange	30/11 to 22/12/88	409
White	1/12/88	125
Yellow	1/01 to 5/01/89	671
Blue	1/01 to 5/01/89	1725
Gold	15/03/89	1035
Silver-green	11/04 to 25/04/89	2345

replenished when necessary. In the test on marking with paint, an additional dish contained rice seedlings. The filter paper was kept moist until the end of the experiment. These materials normally should attract (water, rice, pineapple), repel (alcohol) or are neutral (agar) to *D. longicornis*; these substances were offered to the flies to see if marking would change their response towards these substances. The insects were kept in the cages until all had died. Longevity was noted for both groups. Insects were checked on 6, 12, 18, 24, 30, 36, 48, 60, and 72 hours after introduction and daily after this. The cages were left outdoors (in the shade) for the duration of the experiment.

Results. In both tests, neither unmarked or marked diopsids were either attracted to or repelled by the substances offered in the petri dishes except that the flies were attracted to the rice plants in the second test. Most insects clung to the top of the screen in the direction of the sun (positive phototropism). In the first test, the insects died quickly. All were dead after 72 hours, dying at a rate of 2 to 3 per 6 hours. In the second test, some insects survived 22 days; deaths occured at a rate of 1 to 2 per day in both cages. The presence of the rice plants seems to have extended the life of the flies. However, the main point to note about these tests is that deaths occured at the same rate with both unmarked and marked insects, and for both tests, indicating that marking had no detectable effect on the longevity of the insects.

Results and discussion.

Marking of Scutellar Spines. April to August, 1988. Recaptures revealed that *D. longicornis* dispersed from one refugia to another and that there was no dominant direction of movement (Figure 37). By

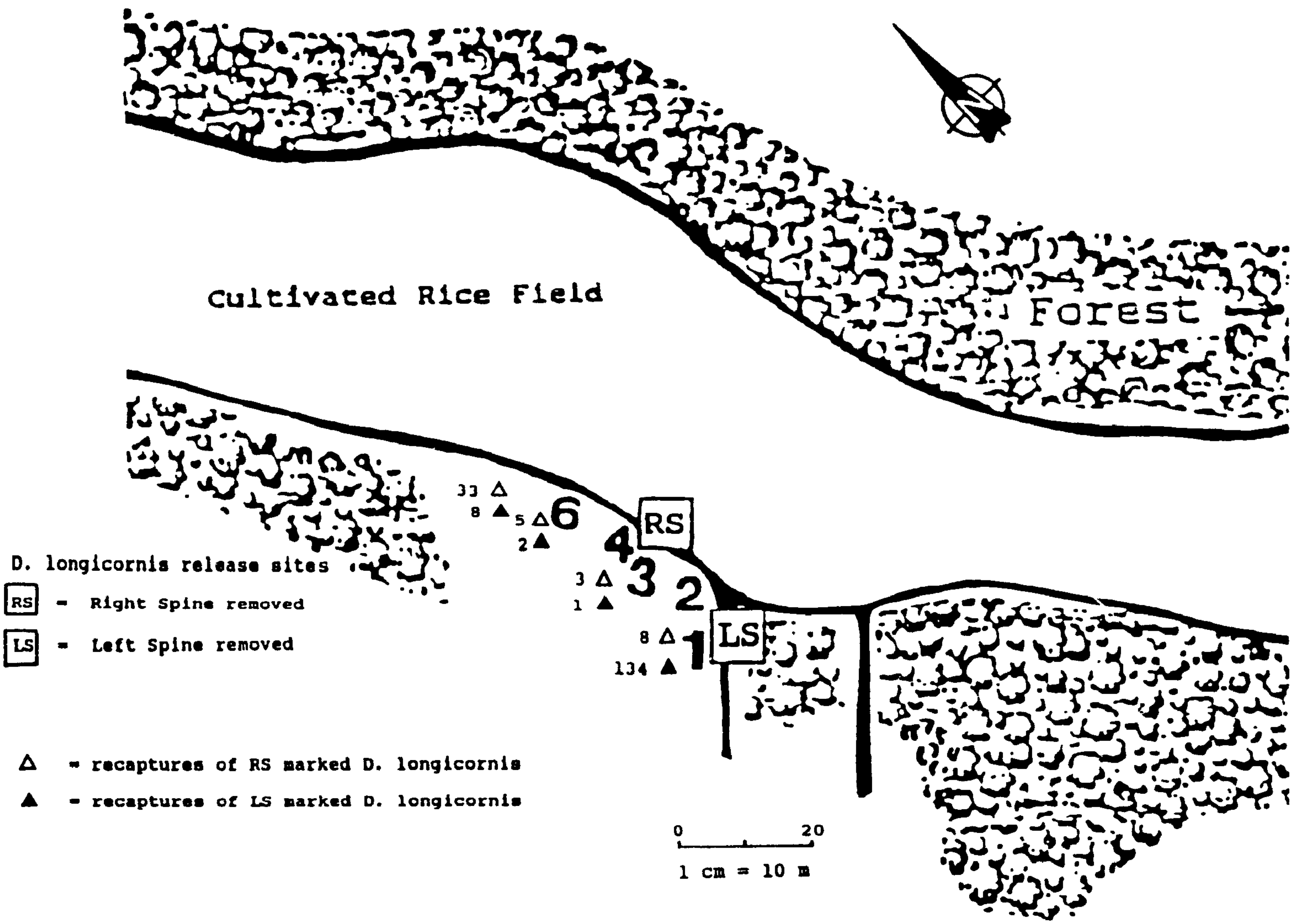

Fig. 37. Release and recapture sites of D. longicornis marked with the spine clipping technique. Dry Season 1988

June 17, when few insects could be found in the refugia, neighbouring fields that were then in preparation for the planting of the rice crop, were sampled for detection of marked *D. longicornis*. No marked individual was collected and very few unmarked diopsids were found. Two hundred sweeps caught only 5 *D. longicornis*. Thus, the diopsids were very dispersed.

Marking with Paints. November, 1988 to June, 1989 Number of recaptures for each colour code is illustrated in Figure 38a to h. Very few insects from the smaller releases were recaptured, i.e., white (one recapture), green (one recapture) and silver (no recapture). These diopsid populations came from a ´pre-aggregation site´ (from a humid and shaded area bordering a late crop of rice). The population density of the flies was small here, so marking could not be done as intensively as in the refuge sites.

The orange and yellow release sites were also ´pre-aggregation sites` but, since a larger number of insects were collected and marked (409 and 671 respectively) from these sites, the chances of recapture were higher. Insects marked in orange were collected as far as site 9, 570 m away, and were captured as long as 142 days after release (Table 21). Yellow-marked individuals were recaptured from two directions, some to the west towards and beyond the experimental field as far as site 4, and others to the east to site 5. Yellow individuals were also long lived, with 139 days between date of release and last date of recapture.

Diopsids marked in blue and in gold (both from permanent refuge sites) also travelled far; blue and gold insects were collected in site 11, 480 and 405 m away respectively. Blue-marked specimens were captured as long as 152 days after release. Although many silver-green specimens were recaptured (149 out a total of 2345 marked), only 2 were found at a site (site 1) other than the release site, the experimental field.

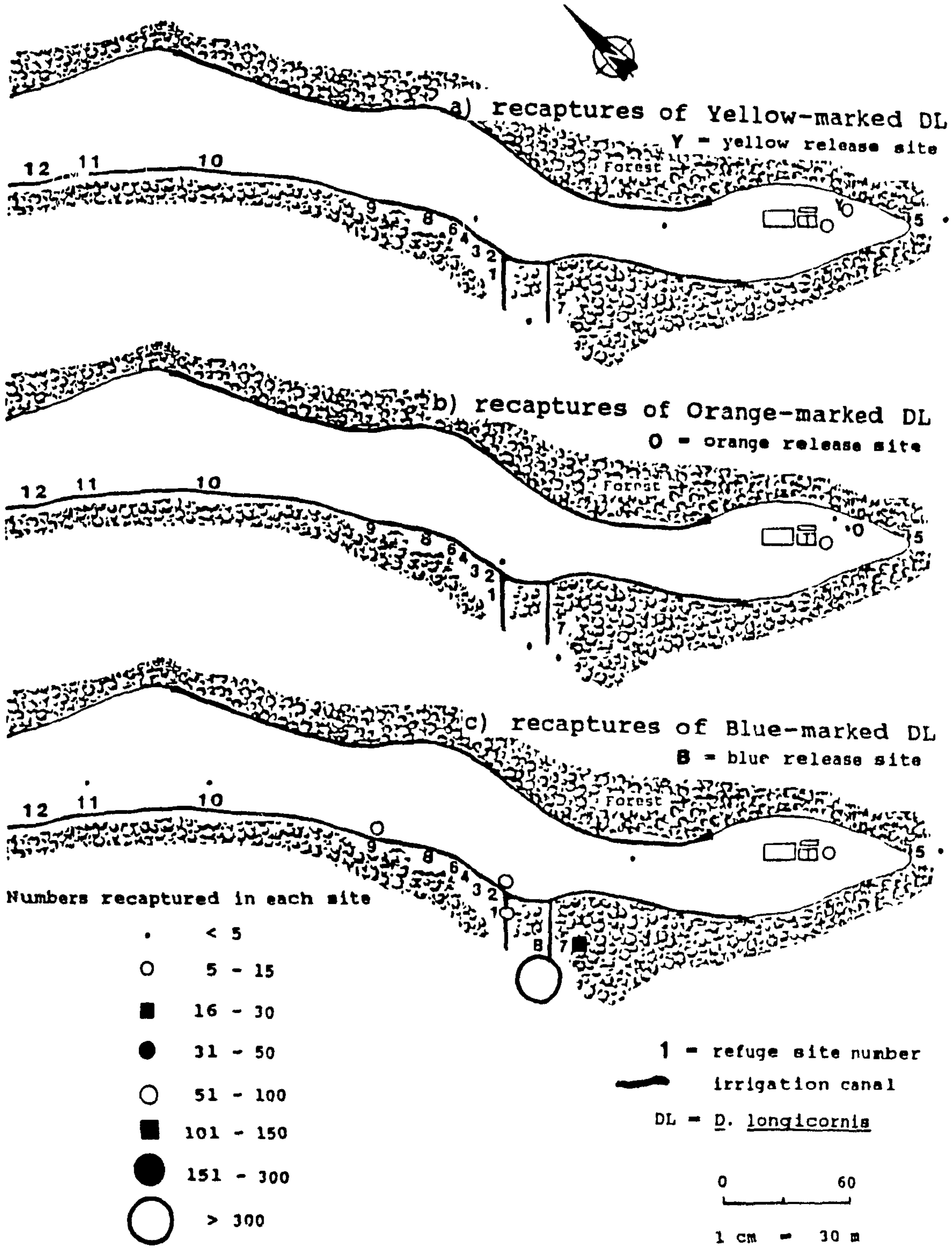

Fig. 38.Recapture of marked D. longicornis. Dry Season 1989

Each section represents one colour code of marked and recaptured individuals.

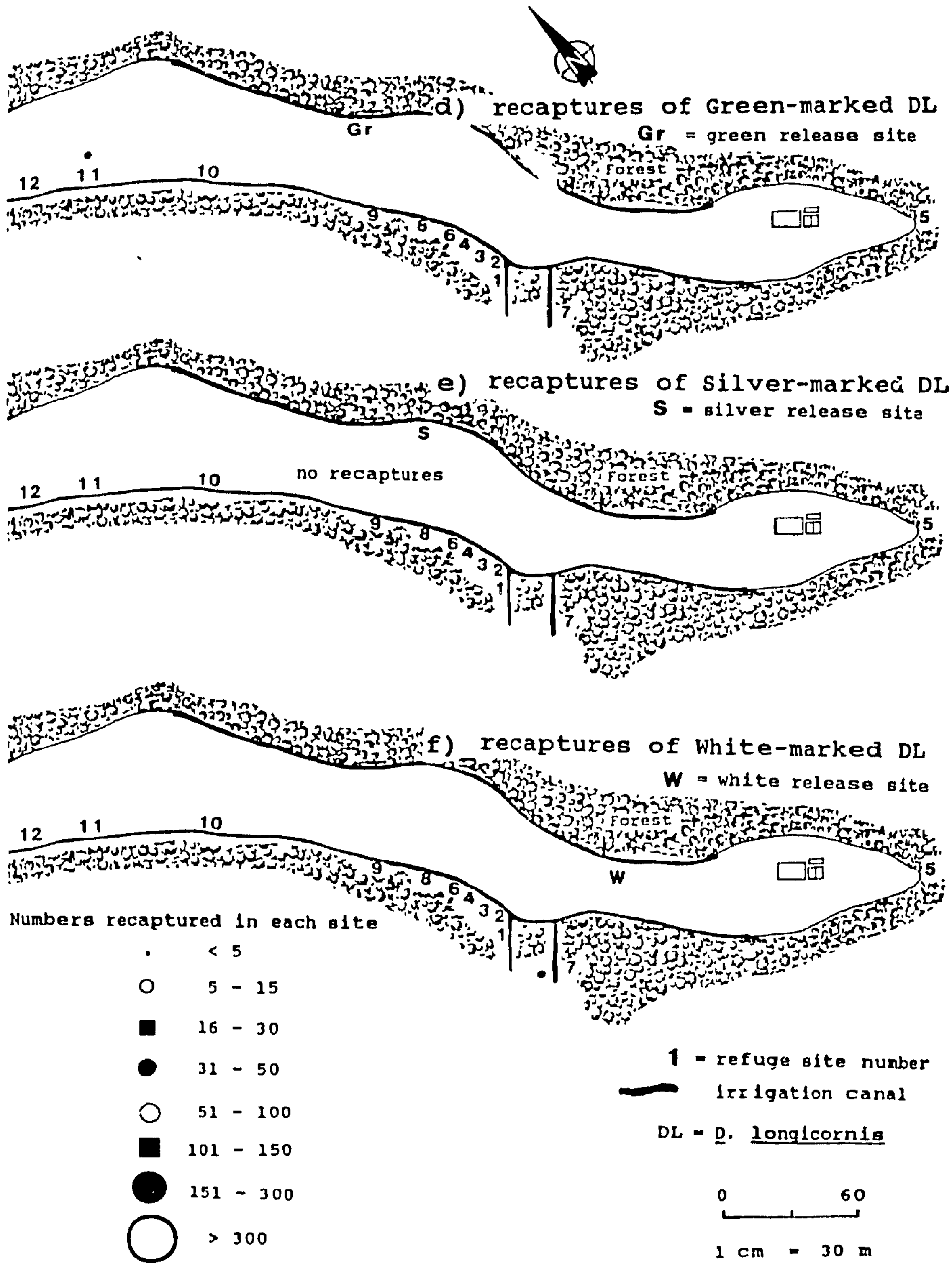

Fig. 38. Recapture of marked *D. longicornis*. Dry Season 1989

Each section represents one colour code of marked and recaptured individuals.

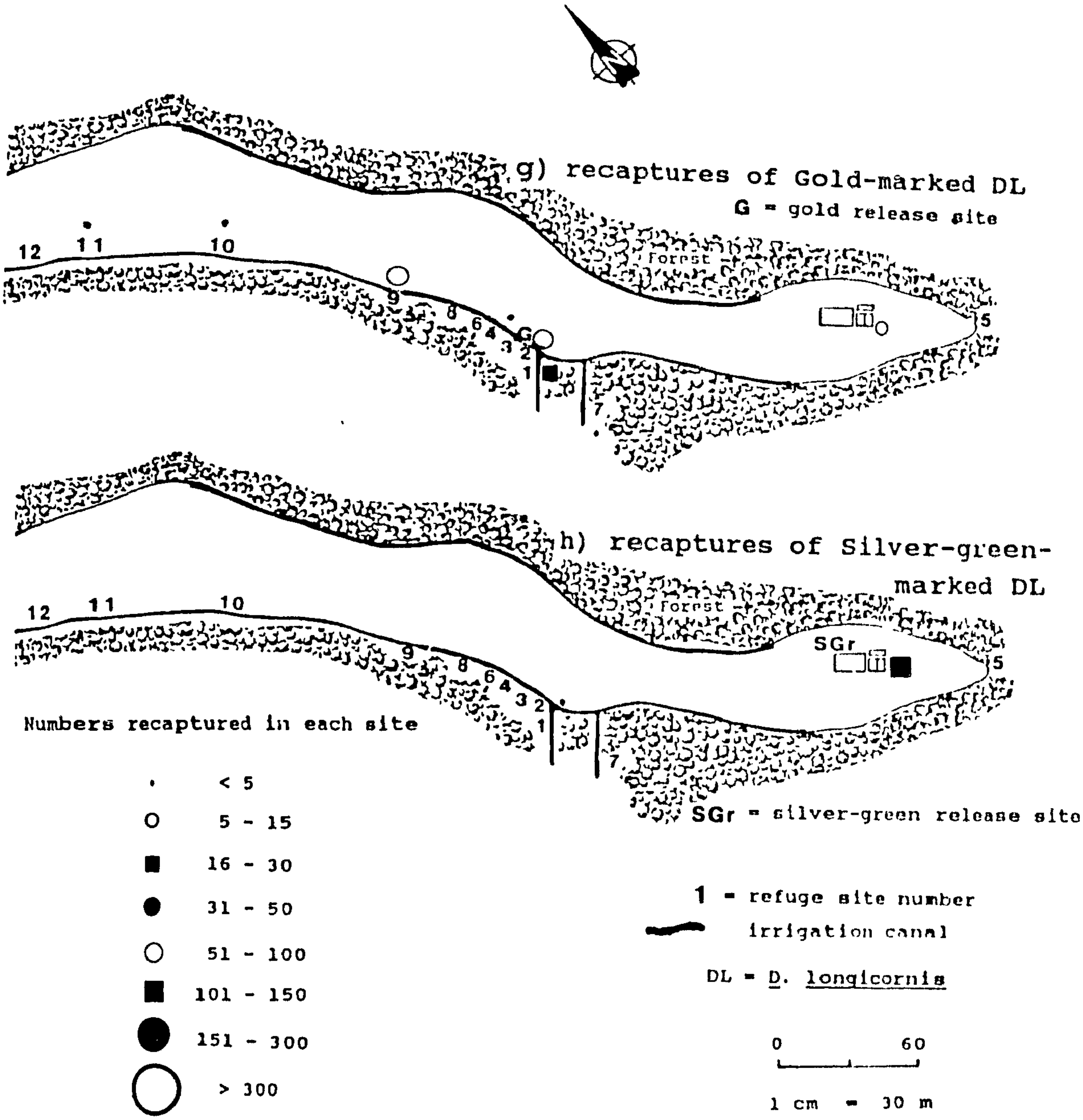

Fig. 38.Recapture of marked *D. longicornis*. Dry Season 1989

Each section represents one colour code of marked and recaptured individuals.

Table 21. Survival time of marked *D. longicornis* individuals Dry Season 1989

COLOUR OF MARK	DATE MARKED	LAST DATE RECAPTURED	SURVIVAL TIME (days)
Silver	24-11-88	nd	nd
Green	29-11-88	31-03-89	122
Orange	30-11-88	21-04-89	142
White	1-12-88	24-01-89	54
Yellow	1-01-89	19-05-89	139
Blue	1-01-89	9-06-89	159
Gold	15-03-89	16-06-89	93
Silver-Green	11-04-89	7-07-89	87

nd = no data

These results show that *D. longicornis* continually dispersed throughout the dry period. They also indicate that there was no cardinal direction of movement, but that movement seemed to be in relation to neighbouring refugia. Movement was slow from week to week.

Because of the precarious environmental conditions of the dry season, dispersing *D. longicornis* (possibly scouts) most likely are searching for other humid refugia in the event that their former sites dry up. Further study of *D. longicornis* dispersal within refugia, with sex determination of recaptured individuals, could provide valuable insights concerning this subject.

CONCLUSIONS

Pest status of *D. longicornis* and *D. apicalis* in coastal Guinée has now been defined. As with findings in other regions of West Africa, *D. apicalis* was proven to be a minor pest damaging a low percentage of rice stems during both the wet and dry seasons. *D. longicornis*, believed to be a major pest in neighbouring countries, was found to have a negligible effect on rice in Guinée, regardless of the cultural practices or the season.

During the wet season, rain appears to be the main controlling factor of diopsid activity; choosing a later date of planting (generally after July 20) when rains have become well established will avoid or greatly reduce diopsid infestation.

The dry season crops also suffered little damage (5 % average), although transplanted rice was significantly more damaged than direct seeded rice probably because during the unfavourable climatic conditions of the dry period, both *D. longicornis* and *D. apicalis* are known to enter a quiescent period, moving to forested aggregation sites, here referred to as refugia. Again, by choosing a date of planting in the dry season well after diopsid dispersal from the wet season crop and to the refugia (generally 45 days after the last rainfall), infestation will be checked. In addition, later planting will not constitute an economic penalty.

Intensification of the rice crop by double- or triple-cropping may increase damage by *D. longicornis*, since this insect can readily forego its quiescent period and invade and infest a dry season rice crop. If multiple cropping became general practice, the *D. longicornis* population that had developped on one crop would remain in the field and continue to multiply on the next crop. Under present farming practices, diopsid populations are controlled by the dry season fallow and by planting of crops other than rice during the dry period. This break in rice planting limits the diopsids' chances of survival during unfavourable periods. If intensification is necessary, increasing rice acreage may be a better solution than increasing number of crops in the same fields This has been previously recommended by Loevinsohn et al. (1988) to avoid brown plant hopper damage to rice in the Philippines.

Cues that determine *D. longicornis* quiescence are various and interdependent.

Presence of cultivated rice proved to be significant. *D. longicornis* immature females taken from forested refugia and placed under caged rice plants readily broke their reproductive inactivity and started laying eggs. Therefore gravid females found on the dry season crop may have come from the refugia as well as from the previous wet season rice crop.

Although absence of rice at the vegetative stage seemed to trigger diopsid dispersal from the wet season rice crop (at the end of the wet period), movement from the forested refugia (at the end of the dry period) had no relationship with availability of rice since this latter time of dispersal occured several months before the next wet season rice crop was planted. Therefore regulators, other than presence of cultivated rice, must influence *D. longicornis* quiescence. For example, even though gravid *D. longicornis* females were present on the dry season rice, their proportion was low. Reasons for this low level of fecundity are still unclear, but it is possible that abiotic factors such as low relative humidity indicate to *D. longicornis* that conditions are unfavourabe for egg maturation.

Other biotic factors such as presence of secondary hosts were found to play major roles in *D. longicornis* ecology and behaviour. Wild species of rice, such as *Oryza longistaminata* and *O. breviligulata = O.. barthii*, may serve as alternative hosts at the beginning and end of the wet season (before and after the cultivated rice crop is available). This would extend *D. longicornis*' period of reproductive activity and therefore increase the species' chances of survival. *Panicum* nr. *laetum* and *Commelina diffusa* were identified as the main food source of quiescent *D. longicornis* adults. Importance of these weeds as a food source, and of wild rice as alternative oviposition sites, could explain why *D. longicornis* populations have been found in areas where cultivated rice is absent (Deeming 1982).

Abiotic factors such as photoperiod, relative humidity and rainfall have an important impact on *D. longicornis* behaviour by acting as signals and initiators of seasonal changes in physiology and behaviour.

Observations therefore indicate that *D. longicornis* exhibits characteristic seasonal behaviour probably paralleled by differences in physiology.

During the dry season *D. longicornis* are known to be:

- generally reproductively inactive;
- feed on plant juices of common weeds such as *Panicum* nr. *laetum* and *Commelina diffusa*;
- long-lived (up to 6 months and apparently longer);
- found in aggregations in shaded and humid forested refugia;
- have no fat body.

During the wet season, *D. longicornis* have the following characteristics:

- reproductively active;
- adults may not be feeding on plant juices;
- individuals are well dispersed over a large open territory;
- develop an important fat body later in the wet season.

These characteristics are, however, very flexible and factors or cues that determine the beginning and end of quiescence seem to depend on a selection of choices rather than a fixed sequence or combination of determining events.

FUTURE RESEARCH

The study of traditional agricultural systems, like the one found in Dubreka, can generate very valuable information on the ecological principles that maintain minimum pest presence in a diversified cropping system. We need to understand the ecological requirements of the pests and of their natural enemies, including factors, such as the social and agronomic context of local rice farming practices, that all contribute to the patterns of distribution and abundance of rice pests.

Priority areas to investigate:

1. identification of regulators of female fecundity to determine whether fecundity would increase with continuous, intensive dry season planting.
2. studies on the impact of natural enemies as important regulators of diopsid populations, especially of immatures. Identification of these beneficials, including predators, parasites and pathogens. Studies of their impact on the diopsid pests and of their ecology have only been slightly addressed so far.
3. further work on *D. longicornis* quiescence and dispersal to refugia would provide fundamental knowledge on tropical insect dormancy.
4. studies on *D. longicornis* and *D. apicalis* mating habits, of which nothing is presently known, e.g., time and place of mating.
5. studies on real diopsid damage and impact on Guinean farmers' rice crops.

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APPENDIXES

Appendix 1.A. Incidence of parasitism of D. longicornis during the study period. Dry season data.

DRY SEASON 1987

Stage of the insect	Total in sample	Numbers para.	% para.	Type of parasitism
Adult	4694	157 *	3	fungus, Conidiobolus near giganteus +
Larva	58	13	22	pathogen: larvae are dull grey to black or swollen, fluid-filled

* the 157 mentioned here were collected out of a total of 206 during a one month period. The fungus was not found during the rest of the study.
\+ identified by Dr. Tadeus Poprawski, European Parasite Laboratory, 13-17 rue de la Masse,Orgerus-Behoust 78910, France

DRY SEASON 1988

Adult	735	34	4	-4 by fungus:Laboulbeniales! -30 by pathogen: decomposed internal organs
Larva	21	3	14	-2 by pathogen -1 by two diptera larvae

! all Laboulbeniales found in this study were identified by Dr. Hans Feijen

DRY SEASON 1989

Adult	1138	19	2	-4 by fungius:Laboulbeniales -15 by pathogens: 14 with decomposed internal organs; 1 with abdominal scar tissue
Larva	30	4	13	pathogen: larvae are sticky
Pupa	20	2	10	-1 filled with several cylindrical eggs -1 parasitized by Aprostoccius sp.:Eulophidae@

@ identified by Dr. J. Huber, Biosystematics Research Centre, Ottawa,Canada

Appendix 1.B. Incidence of parasitism of _D. longicornis_ during the study period. Wet Season data.

WET SEASON 1987

Stage of the insect	Total insects sampled	Numbers para.	% para.	Type of parasitism
Adult	558	3	0.5	fungus: Laboulbeniales
Larva	66	10	15	- 6 by pathogen: larvae dull grey to black - 4 by microhymenoptera
Pupa	11	1	9	covered by pupae of microhymenoptera

WET SEASON 1988

Stage of the insect	Total insects sampled	Numbers para.	% para.	Type of parasitism
Adult	162	6	4	pathogen: decomposed internal organs or eggs
Larva	8	3	38	pathogen: larvae dull grey to black

Appendix 1.C. Incidence of parasitism of *D. apicali*- during the study period

DRY SEASON 1987

Stage of the insect	Total in sample	Numbers para.	% para.	Type of parasitism
Adult	2368	86 *	4	fungus: *Conidiobolus* near *giganteus*
Larva	34	3	9	pathogen: larvae are dull grey to black or swollen, fluid-filled

* out of 156 collected at same time (one month period)

DRY SEASON 1988

Adult	97	2	2	-1 by fungus:Laboulbeniales -1 by pathogen: decomposed internal organs

DRY SEASON 1989

Adult	241	1	0.4	pathogen: decomposed internal organs
Larva	44	7	16	6 with pathogen:larvae are sticky; 1 parasitized with Dipteran larva

Appendix 2.A. Weekly sampling data for *D. longicornis* adults.!
Dry Season 1987

SAMPLING DATE	*D. longicornis*		♂♂	♀♀	% ♀♀
	Total coll.	No. per 40 sweeps			
31-12-86	0	-	--	--	--
7-01-87	0	-	--	--	--
14-01-87	4	4	--	--	--
21-01-87	4	1	--	--	--
24-01-87	11	4	--	--	--
28-01-87	29	7	--	--	--
3-02-87	185	37	--	--	--
10-02-87	641	107	--	--	--
17-02-87	512	73	276	236	46
24-02-87	788	113	--	--	--
3-03-87	277	35	165	112	40
10-03-87	404	51	291	113	28
17-03-87	455	57	343	107	24
24-03-87	243	41	144	93	38
31-03-87	393	98	222	137	35
7-04-87	309	77	105	67	--
14-04-87	309	103	193	116	38
21-04-87	89	45	38	51	57
28-04-87	41	41	23	18	44
TOTALS	4694		1800	1050	37

! based on weekly sweep net sampling (10 sweeps per plot on 32 plots)

-- missing data, before February 17, insects were not sexed

Appendix 2.B. Weekly sweep net sampling of
D. apicalis adults.!
Dry Season 1987

SAMPLING DATE	*D. apicalis*				
	Total coll.	No. per 40 sweeps	♂♂	♀♀	% ♀♀
31-12-86	0	-			
7-01-87	0	-			
14-01-87	8	4	--	--	--
21-01-87	14	5	--	--	--
24-01-87	34	11	--	--	--
28-01-87	120	30	--	--	--
3-02-87	253	51	--	--	--
10-02-87	500	83	--	--	--
17-02-87	388	55	206	182	47
24-02-87	305	44	--	--	--
3-03-87	141	18	82	55	39
10-03-87	157	20	109	48	31
17-03-87	172	22	120	52	30
24-03-87	52	9	26	26	50
31-03-87	58	15	26	32	55
7-04-87	99	25	56	43	43
14-04-87	37	12	17	20	54
21-04-87	26	13	10	16	62
28-04-87	4	4	1	3	75
TOTALS	2368		653	477	42

! based on weekly sweep net sampling (10 sweeps per plot on 32 plots)

-- missing data, before February 17, insects were not sexed

Appendix 2.C. Weekly sampling data for *D. longicornis* and *D. apicalis* larvae and dead hearts.! Dry Season 1987

SAMPLING DATE	*D. longicornis* larvae		*D. apicalis* larvae		Dead hearts	
	Total coll.	No. per 40 plants	Total coll.	No. per 40 plants	Total coll.	No. per 40 plants
14-01-87	1	0.3	0	--	0	--
28-01-87	0	--	0	--	4	0.8
10-02-87	9	1.5	13	2.2	73	12.2
24-02-87	9	1.5	6	1.0	101	16.8
10-03-87	26	5.2	7	1.4	113	22.6
24-03-87	7	1.8	3	0.8	83	20.8
7-04-87	5	2.5	5	2.5	57	28.5
21-04-87	1	1.0	0	--	10	10.0
TOTALS	58		34		441	

! data based on weekly plant dissections (10 plants per plot on 32 plots)

Appendix 2.D. Weekly sampling data for *D. longicornis* adults.!
Dry Season 1988

SAMPLING DATE	Total coll.	No. per 40 sweeps	♂♂	♀♀	% ♀	Gravid ♀	% Grav. ♀ of total ♀
25-01-88	0	-	0	0	-	-	-
2-02-88	5	2.5	2	3	60	0	0
9-02-88	31	15.5	12	19	61	1	5
16-02-88	32	10.7	23	9	28	6	67
23-02-88	52	17.3	29'	16'	31	0	0
1-03-88	47	8.5	25	22	47	2	9
8-03-88	84	21.0	41'	42'	50	17	41
15-03-88	57	11.4	23	34	60	14	41
22-03-88	59	11.8	35'	21'	36	6	27
29-03-88	104	26.0	45	59	57	38	64
6-04-88	106	25.0	56'	46'	43	28	61
12-04-88	74	18.5	46'	26'	35	13	50
20-04-88	40	20.0	20	20	50	4	20
26-04-88	15	7.5	7	8	53	7	88
3-05-88	29	14.5	10	19	66	9	47
TOTALS	735		374	344	47	145	42

! based on weekly sweep net sampling (10 sweeps per plot on 24 plots)
' missing data due to damaged insects

Appendix 2.E. Weekly sampling of *D. apicalis* adults.!
Dry Season 1988

SAMPLING DATE	Total Coll.	No.per 40 sweeps	♂♂	♀♀	%♀	Gravid ♀	% Grav. ♀ of total ♀
25-01-88	0	-	0	0	-	0	-
2-02-88	5	2.5	2	3	60	0	0
9-02-88	12	6.0	4	8	67	0	0
16-02-88	7	1.8	3	4	57	0	0
23-02-88	9	2.3	6	3	33	0	0
1-03-88	7	1.8	6	1	17	0	0
8-03-88	18	3.0	8	10	56	1	10
15-03-88	12	2.0	6	6	50	3	50
22-03-88	4	0.7	1	3	75	1	33
29-03-88	6	1.5	3	3	50	1	33
6-04-88	14	3.5	4	10	75	2	20
12-04-88	3	0.8	1	2	67	0	-
20-04-88	0	-	0	0	-	0	-
26-04-88	0	-	0	0	-	0	-
3-05-88	0	-	0	0	-	0	-
TOTALS	97		44	53	55	8	15

! based on weekly sweep net sampling (10 sweeps per plot on 24 plots)

Appendix 2.F. Weekly sampling data for *D. longicornis* larvae and for dead hearts.! Dry Season 1988

SAMPLING DATE	*D. longicornis* larvae		Dead hearts	
	Total coll.	No. per 40 plants	Total coll.	No. per 40 plants
25-01-88	0	-	0	-
2-02-88	0	-	1	0.5
9-02-88	1	0.5	3	1.5
16-02-88	2	0.5	10	2.5
23-02-88	0	-	17	4.3
1-03-88	4	1.0	9	2.3
8-03-88	2	0.3	15	2.5
15-03-88	1	0.2	17	2.8
22-03-88	3	0.5	27	4.5
29-03-88	0	-	11	2.8
6-04-88	4	1.0	10	2.5
12-04-88	2	0.5	9	2.3
20-04-88	2	0.5	3	0.8
27-04-88	0	-	0	-
3-05-88	0	-	4	2.0
TOTALS	21	-	136	-

! based on weekly plant dissections (10 plants per plot on 24 plots)

Appendix 2.G. Weekly sampling data for *D. longicornis* adults.!
Dry Season 1989

SAMPLING DATE	Total coll.	No. per 40 sweeps	♂♂	♀♀	%♀	Gravid ♀	% Grav. ♀ of Total ♀
27-12-88	0	-	0	0	-	0	-
3-01-89	0	-	0	0	-	0	-
10-01-89	0	-	0	0	-	0	-
17-01-89	29	14.5	18	11	38	5	46
24-01-89	45	11.0	29	16	36	2	13
31-01-89	59	14.8	41	17	29	5	29
7-02-89	79	19.8	38	41	52	10	24
14-02-89	83	13.8	43	40	48	5	13
21-02-89	122	20.3	68	52	43	8	15
28-02-89	110	27.5	62	48	44	19	40
7-03-89	37	9.3	18	19	51	6	32
14-03-89	56	14.0	31	25	45	13	52
21-03-89	174	43.5	106	68	39	14	21
28-03-89	162	81.0	88	74	46	12	16
4-04-89	128	64.0	70	56	44	14	25
11-04-89	54	27.0	31	23	43	8	35
TOTALS	1138		643	490	43	121	25

! based on weekly sweep net sampling (10 sweeps per plot on 24 plots)

Appendix 2.H. Weekly sampling data for *D. apicalis* adults.!
Dry Season 1989

SAMPLING DATE	Total coll.	No. per 40 sweeps	♂♂	♀♀	% ♀	Gravid ♀	% Grav. ♀ of Total ♀
27-12-88	0	-	0	0	-	0	-
3-01-89	0	-	0	0	-	0	-
10-01-89	0	-	0	0	-	0	-
17-01-89	15	7.5	6	9	60	1	11
24-01-89	19	4.8	11	8	42	2	25
31-01-89	44	11.0	24	20	46	2	10
7-02-89	24	6.0	8	16	67	0	0
14-02-89	23	3.8	9	14	61	0	0
21-02-89	22	3.7	12	10	46	1	10
28-02-89	13	3.3	5	8	62	2	25
7-03-89	4	1.0	3	1	25	0	0
14-03-89	2	0.5	1	1	50	0	0
21-03-89	15	3.8	5	7	47	2	29
28-03-89	17	8.5	9	8	47	0	0
4-04-89	40	10.0	21	19	48	1	5
11-04-89	3	1.5	1	2	67	0	0
TOTALS	241		115	123	51	11	9

! based on weekly sweep net sampling (10 sweeps per plot on 24 plots)

Appendix 2.I. Weekly sampling data for _D. longicornis_ and _D. apicalis_ larvae and for dead hearts.! Dry Season 1989

SAMPLING DATE	_D. longicornis_ larvae		_D. apicalis_ larvae		Dead hearts	
	Total coll.	No. per 40 plants	Total coll.	No. per 40 plants	Total coll.	No. per 40 plants
27-12-88	0	-	0	-	0	-
3-01-98	0	-	0	-	0	-
10-01-89	0	-	0	-	0	-
17-01-89	2	0.7	1	0.3	4	1.3
24-01-89	2	0.5	2	0.5	4	1.0
31-01-89	1	0.3	2	0.5	8	2.0
7-02-89	0	-	0	-	8	1.6
14-02-89	0	-	0	-	7	1.2
21-02-89	1	0.2	5	0.8	10	1.7
28-02-89	0	-	3	0.8	6	1.5
7-03-89	5	1.3	10	2.5	17	4.3
14-03-89	10	2.5	0	-	11	2.8
21-03-89	6	1.5	3	0.8	19	4.8
28-03-89	5	2.5	11	5.5	28	14.0
4-04-89	4	2.0	3	1.5	13	6.5
11-04-89	4	2.0	4	2.0	27	13.5
TOTALS	40	-	44	-	162	-

! based on weekly plant dissections (10 plants per plot on 24 plots)

Appendix 2.J. Weekly sampling data for D. longicornis adults.!
Wet Season 1987

SAMPLING DATE	Total coll.	No. per 40 sweeps	♂♂	♀♀	% ♀	Gravid ♀	% Grav. ♀ of Total ♀
7-07-87	0	-	0	0	-	0	-
14-07-87	17	17.0	4	13	77	3	23
21-07-87	67	33.5	25	42	63	10	24
28-07-87	45	15.0	12	33	73	8	24
4-08-87	46	11.5	14	32	70	16	50
11-08-87	36	7.2	10	26	72	14	54
18-08-87	50	8.3	18	32	64	12	38
25-08-87	26	3.3	9	17	65	7	41
1-09-87	57	7.4	18	39	66	10*	*
9-09-87	41	5.9	8*	25*	61	*	*
16-09-87	17	3.4	6	11	65	1*	*
23-09-87	no sampling due to excessive rain						
29-09-87	12	2.5	4	8	80	2*	*
6-10-87	27	6.8	8	21	78	12	57
13-10-87	62	15.5	27	35	57	*	*
20-10-87	55	27.5	28	27	49	10	37
TOTALS	558		191	361	65	105*	29*

! Based on weekly sweep net sampling (10 sweeps per plot on 32 plots)
* missing data due to damaged insects

Appendix 2.K. Weekly sampling data for *D. apicalis* adults.!
Wet Season 1987

SAMPLING DATE	Total coll.	No. per 40 sweeps	♂♂	♀♀	% ♀	Gravid ♀	% Grav. ♀ of Total ♀
7-07-87	0	-	0	0	-	0	-
14-07-87	0	-	0	0	-	0	-
21-07-87	0	-	0	0	-	0	-
28-07-87	4	1.3	2	2	50	0	-
4-08-87	4	1.0	3	1	25	1	100
11-08-87	11	2.2	5*	5*	46	3	60
18-08-87	26	4.3	11	15	58	7	47
25-08-87	1	0.1	1	0	0	0	0
1-09-87	2	0.3	1	1	50	1	100
9-09-87	2	0.3	1	1	50	0	0
16-09-87	4	0.7	2	2	50	1	50
23-09-87	no sampling due to excessive rain						
29-09-87	0	-	0	0	-	0	0
6-10-87	0	-	0	0	-	0	0
13-10-87	0	-	0	0	-	0	0
20-10-87	1	0.5	1	0	0	0	0
TOTALS	55		27	27	49	13	48

! based on weekly sweep net sampling (10 sweeps per plot on 32 plots)
* missing data due to damaged insects

Appendix 2.L. Weekly sampling data for D. longicornis and D. apicalis immatures and for dead hearts.! Wet Season 1987

SAMPLING DATE	D. longicornis			D. apicalis		Dead hearts	
	Larvae		Pupae	Larvae			
	Total coll.	No. per 40 plants	Total coll.	Total coll.	No. per 40 plants	Total coll.	No. per 10 plants
7-07-87	0	-	0	0	-	0	-
14-07-87	0	-	0	0	-	0	-
21-07-87	0	-	0	0	-	0	-
28-07-87	6	1.5	0	2	0.5	21	5.3
4-08-87	3	0.8	1	0	-	23	5.8
11-08-87	12	2.0	0	0	-	46	7.7
18-08-87	19	3.2	4	1	0.2	42	7.0
25-08-87	9	1.1	2	0	-	34	4.3
1-09-87	9	1.1	1	0	-	33	4.1
9-09-87	5	0.6	0	0	-	13	1.6
15-09-87	1	0.1	2	0	-	4	0.7
23-09-87	no sampling due to excessive rain						
29-09-87	1	0.2	0	0	-	1	0.2
6-10-87	1	0.2	0	0	-	2	0.3
13-10-87	0	-	1	0	-	0	-
20-10-87	0	-	0	0	-	0	-
27-10-87	0	-	0	0	-	0	-
TOTALS	66	-	11	3	-	219	-

! based on weekly plant dissections (10 plants per plot on 32 plots)

Appendix 2.M. Weekly sampling data for D. longicornis adults.!
Wet Season 1988

SAMPLING DATE	Total coll.	No. per 40 sweeps	♂♂	♀♀	% ♀	Gravid ♀	% Grav. ♀ of Total ♀
12-07-88	0	-	0	0	-	0	-
19-07-88	0	-	0	0	-	0	-
26-07-88	2	1.0	1	1	50	0	0
2-08-88	5	2.5	2	3	60	2	67
9-08-88	8	4.0	3	5	63	5	100
16-08-88	4	1.0	1	3	75	3	100
23-08-88	no sampling due to excessive rain						
30-08-88	23	3.8	12	11	48	2	18
6-09-88	5	0.8	3	2	40	1	50
12-09-88	25	4.2	14	11	44	6	55
20-09-88	20	3.3	11	9	45	3	33
27-09-88	20	5.0	14	6	30	2	33
3-10-88	7	3.5	4	3	43	1	33
11-10-88	15	7.5	7	8	53	0	0
18-10-88	28	14.0	13*	14*	50	0	0
TOTALS	162		85	76	47	25	33

! based on weekly sweep net sampling (10 sweeps per plot on 24 plots)
* missing data due to damaged insects

Appendix 2.N. Weekly sampling data for *D. longicornis* larvae and for dead hearts.! Wet Season 1988

SAMPLING DATE	*D. longicornis* larvae		Dead hearts	
	Total coll.	No. per 40 plants	Total coll.	No. per 40 plants
19-07-88	0	-	0	-
26-07-88	1	0.5	4	2.0
2-08-88	1	0.5	4	2.0
9-08-88	3	0.8	6	1.5
16-08-88	1	0.3	6	1.5
23-08-88	0	-	5	1.3
30-08-88	0	-	4	0.7
6-09-88	0	-	1	0.2
12-09-88	0	-	4	0.7
20-09-88	1	0.3	1	0.3
27-09-88	0	-	3	0.8
3-10-88	1	0.5	2	1.0
11-10-88	0	-	0	-
18-10-88	0	-	7	3.5
TOTALS	8	-	47	-

! based on weekly plant dissections (10 plants per plot on 24 plots)

Appendix 2.0. Egg counts from visual observation of 50 plants samples/plot

DRY SEASON 1988

DATE OF OBSERV.	TOTAL EGGS ON DATE OF OBSERVATION	TREATMENTS IN WHICH EGGS WERE FOUND'						
		Seed bed	1A	1B	2A	2B	3A	3B
28-01-88	0	0	--	--	--	--	--	--
5-02-88	1	0	1	--	--	--	--	--
16-02-88	5	0	1	1	3	0	--	--
23-02-88	2	0	0	2	0	0	--	--
1-03-88	1	0	0	0	0	1	0	--
8-03-88	8	--	0	0	2	6	0	0
15-03-88	1	--	0	0	1	0	0	0
22-03-88	2	--	--	--	1	0	0	1
29-03-88	5	--	--	--	0	1	0	4
6-04-88	1	--	--	--	0	0	0	1
12-04-88	0	--	--	--	--	--	0	0
29-04-88	0	--	--	--	--	--	0	0
TOTALS	26	0	2	3	7	8	0	6

WET SEASON 1988

DATE OF OBSERV.	TOTAL EGGS ON DATE OF OBSERVATION	TREATMENTS IN WHICH EGGS WERE FOUND'						
		Seed bed	1A	1B	2A	2B	3A	3B
5-07-88	0	0	--	--	--	--	--	--
12-07-88	0	0	--	--	--	--	--	--
19-07-88	0	0	0	0	--	--	--	--
26-07-88	0	0	0	0	--	--	--	--
2-08-88	0	0	0	0	--	--	--	--
9-08-88	2	0	1	1	0	0	--	--
16-08-88	3	1	2	0	0	0	--	--
23-08-88	0	0	0	0	0	0	--	--
30-08-88	0	--	0	0	0	0	0	0
6-09-88	1	--	0	0	0	1	0	0
10-09-88	0	--	--	--	0	0	0	0
17-09-88	no	sampling	due to	excessive rain				
24-09-88	1	--	--	--	0	0	0	1
3-10-88	0	--	--	--	--	--	0	0
11-10-88	0	--	--	--	--	--	0	0
17-10-88	0	--	--	--	--	--	0	0
TOTALS	7	1	3	1	0	1	0	1

' 1 treatment (e.g. 1A) = 4 plots

-- plots were not sampled, being either not yet planted or beyond the flowering stage

Appendix 3. Weekly sampling data for D. *longicornis* adults in neighbouring farmers' fields.!

Wet Season 1987

SAMPLING DATE	NUMBER OF PLOTS SAMPLED	TOTAL COLLECTED	NUMBER PER 20 SWEEPS	♂♂	♀♀	% ♀ OF TOTAL ♀
9-09-87	4	12	3.0	4	8	67
15-09-87	4	15	3.8	9	3	25
22-09-87	6	19	3.2	8	11	58
6-10-87	6	6	1.0	3	3	50
13-10-87	9	26	1.8	4	12	75
20-10-87	8	9	1.2	4	4	50
27-10-87	6	10	1.6	3	7	70
3-11-87	8	2	0.2	2	0	0
10-11-87	2	--	--	--	--	--
TOTALS		99		37	48	57

Wet Season 1988

SAMPLING DATE	NUMBER OF PLOTS SAMPLED	TOTAL COLLECTED	NUMBER PER 20 SWEEPS	♂♂	♀♀	% ♀ OF TOTAL ♀
30-07-88	4	0	-	0	0	-
19-08-88	4	5	1.2	3	2	40
16-09-88	4	4	1.0	1	3	75
27-09-88	4	2	0.6	1	1	50
7-10-88	4	1	0.2	1	0	0
14-10-88	4	10	2.6	3	7	70
18-10-88	4	9	3.0	3	6	67
21-10-88	4	12	3.0	6	6	50
28-10-88	4	13	3.2	7	6	46
4-11-88	4	10	2.4	5	5	50
11-11-88	4	5	1.2	2	3	60
18-11-88	4	2	0.6	1	1	50
TOTALS		73		33	40	55

! based on weekly sweep net sampling (20 sweeps per plot)

Appendix 4. Number of *D. longicornis* recaptured marked with paint. Dry Season 1989

COLOUR	TOTAL MARKED	TOTAL RECAPTURED	% RECAPTURE
Silver	142	0	0
Green	307	1	0.3
Orange	409	20	4.9
White	125	1	0.8
Yellow	671	25	3.7
Blue	1725	585	33.9
Gold	1035	144	13.9
Silver-Green	2345	149	6.9