RESURGENCE POTENTIAL OF THE RICE LEAF FOLDER, *Cnaphalocrocis medinalis* Guen. AS INFLUENCED BY THE SOIL APPLICATION OF CARBOFURAN GRANULES

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THESIS

Submitted in partial fulfilment of the
requirement for the degree

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

Department of Agricultural Entomology
COLLEGE OF HORTICULTURE
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1991

DEDICATED TO

MY

PARENTS, WIFE AND

KIDS

DECLARATION

I hereby declare that this thesis entitled "Resurgence potential of the rice leaf folder, Cnaphalocrocis medinalis Guen. as influenced by the soil application of carbofuran granules" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title, of any other University or Society.

BABY P SKARIA

Vellanikkara,
5th ...ch, 1991.

CERTIFICATE

Certified that this thesis entitled "Resurgence potential of the rice leaf folder, Cnaphalocrocis medinalis Guen. as influenced by the soil application of carbofuran granules" is a record of research work done independently by Sri. BABY P. SKARIA, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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We, the undersigned, members of the Advisory Committee of Sri. BABY P SKARIA, a candidate for the degree of Doctor of Philosophy in Agriculture, agree that the thesis entitled "Resurgence potential of the rice leaf folder, Cnaphalocrocis medinalis Guen. as influenced by the soil application of carbofuran granules" may be submitted by Sri. BABY P SKARIA in partial fulfilment of the requirement for the degree.

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Introduction

INTRODUCTION

The biotic stress from a multitude of pests and diseases is the major constraint to the realisation of high yielding potential of superior rice varieties. To break the yield barriers in rice and to increase rice production and productivity by quantum leaps, it is necessary to reduce crop losses due to pests and diseases substantially.

Consequent on the introduction of high yielding varieties, the rice leaf folder, Cnaphalocrocis medinalis Guen. rated as a minor pest until the recent past has now attained the status of a major pest of national importance. The yield losses caused by the leaf folder range from 30 to 80 per cent (Kushwaha, 1988). Damage to the flag leaf at varying intensities alone can cause substantial reduction in grain yield from 47 to 70 per cent (Sellammal and Chelliah, 1983).

In India, the two major crops that account for heavy pesticide consumption are cotton (64 per cent) and rice (22 per cent). The annual All-India consumption of pesticides on the rice crop is estimated to be worth Rs 89 to 98 crores at 1983-84 prices. In crops which receive heavy insecticidal applications, resistance to insecticides and insecticide-induced resurgence of non-target species of pests have become major hazards. The unprecedental outbreaks of the gram caterpillar, Heliothis armigera Hubner and of the white fly, Bemisia tabaci (Gennadius) in the cotton crop during 1987-89 in several parts of the Andhra Pradesh due to widespread indiscriminate pesticide mismanagement are formidable examples of insecticide-induced resurgence of pest species.

In Kerala State, the rice leaf folder, Cnaphalocrocis medinalis Guen. used to be controlled effectively by spray applications of quinalphos/carbaryl/monocrotophos/fenitrothion/fenthion/phosalone/phenthoate. The application of carbofuran against the major pests of rice has become very popular among the farmers of Kerala, particularly in the Kuttanad (Alleppey) and the Kole lands (Thrissur), where intensive monocropping of high yielding varieties has become an established practice.

Application of carbofuran granules used to be one of the control recommendations against C. medinalis in Kerala (Kerala Agricultural University, 1986). At the Regional Agricultural Research Station, Pattambi, carbofuran applications were found to be ineffective to curb leaf folder outbreaks and in fact, the crop which received the insecticide, at a later stage showed a tendency to become heavily infested by the pest (Anon., 1983 and 1984). On the basis of the above reports, the recommendations of carbofuran for the control of leaf folder has been withdrawn (Kerala Agricultural University, 1989).

In sucking insects, there are numerous reports of insecticide-induced resurgence (Bartlett and Ewart, 1951; Pradhan et al., 1960; Shanks, 1966; IRRI, 1969; Kiritani, 1972; Mani and Jayaraj, 1976; Alam and Karim,1977; Chand 1979; Raman, 1981; Chelliah and

Heinrichs, 1984; Reddi *et al.*, 1987; Velusamy, 1987; Mathew, 1989; Sheila, 1989). Reports on insecticide-induced resurgence of lepidopteran leaf feeders are however, very few (El-Lakwah and Abdel Salam, 1974; Bandong and Litsinger, 1986; Panda and Shi, 1989).

The present studies were undertaken to generate basic information on the impact of soil application of carbofuran granules at graded doses at specific timings on the possible resurgence of the rice leaf folder, *C. medinalis* and to understand the biochemical and biophysical bases for insecticide-induced resurgence.

In the present studies, changes in the biological attributes of *C. medinalis* such as reproductive rate, progeny production, larval and pupal mortality and feeding behaviour as a result of soil application of carbofuran granules at 0.50, 0.75 and 1.00 kg ai/ha at 20, 50 days after transplanting (DAT) as well as at both the stages were assessed in the insectary and laboratory experiments to bring out any trend of resurgence induction through insecticide-induced factors. In the field experiments, the likely intensification of leaf folder incidence under influence of the same set of treatments as well as the various factors involved have been studied. The biochemical and biophysical changes in plants due to insecticidal treatments and their impact on resurgence of *C. medinalis* have also been assessed in the present studies.

Review of Literature

2. REVIEW OF LITERATURE

The resurgence of target pests or secondary pests following application of insecticides has become a widespread problem in pest control. Resurgence is characterised by an abnormally rapid increase in the pest population often far exceeding the economic threshold, following insecticidal treatment.

Insecticides causing resurgence include some synthetic pyrethroids, organophosphates and carbamates and no single class of insecticide has been identified free from resurgence inducement (Chelliah, 1979; Reissig *et al*., 1982 b). The resurgence of arthropod pests following insecticide applications has been recorded from several crops including rice (IRRI, 1969; Chelliah and Heinrichs, 1978; Mochida and Heinrichs, 1980; Mathew, 1989); citrus (Bartlett and Ewart, 1951), corn (Ball and Su, 1979); bhendi (Regupathy and Jayaraj, 1973 a and b); mustard (Pradhan *et al*., 1960) and straw berry (Shanks, 1966). Pest outbreaks induced by insecticides have also been reported in walnut (Bartlett and Ewart, 1951), hemlock (McClure, 1977), soybeans (Shepard *et al*., 1977) and cotton (Bottrell and Rummel, 1978). Reynolds (1971) and Eveleens *et al*. (1973) gave general views of the insect population upsets and resurgence of insect pests caused by pesticidal chemicals. Resurgence of different arthropod pests has also been recorded by Huffacker and Spitzer (1950) and Bartlett (1968). Specific reports of resurgence of rice leaf folder, *Cnaphalocrocis medinalis*

Guen. are very few (Jayaraj et al., 1976; Subramanian et al., 1985; Nadarajan and Skaria, 1988; Panda and Shi, 1989).

A review of available literature on the cause, mechanisms and factors influencing manifestation of insecticide-induced resurgence of arthropod pests is made in this chapter.

2.1. Phenomenon of insecticide-induced resurgence

The problem of insecticide induced pest resurgence was reported for the first time by Ripper (1956) who described this phenomenon as a tremendous increase in pest population, brought about by an insecticide, despite good control in the beginning. Besides target arthropods, several non-target species were also reported to resurge as a result of application of insecticides against the target organisms. Ripper (1956) reported the resurgence of 50 species of arthropods.

Coppel and Mertins (1977) defined pest resurgence/ flare back as the rapid increase of a target insect pest population subjected to an insecticidal treatment which also destroys its associated and possibly regulative natural enemies. Heinrichs et al. (1981 and 1982 a) defined resurgence as significantly more damage or more number of insect in an insecticide-treated crop after application than in an untreated crop. According to Jayaraj and Regupathy (1987) a mere statistically significant increase in the pest population in the treated plots over untreated plots at any particular period after insecticide application cannot be recognised as resurgence, but the overall rate of increase should be manifested over sufficiently longer period of time in the crops receiving the particular insecticidal treatment.

Mochida and Heinrichs (1980) conjectured the possible basic mechanisms of resurgence on the basis of selective elimination of natural enemies; selective removal of competitive species; change in the physiology of the plant which enhances its nutritional value; increase in the growth of the plant which has an effect on the ecology of the insect; the control of insect pathogens with insecticide and the direct effect of the insecticide on the insect which increases the feeding and reproductive rate.

Jayaraj and Regupathy (1987) have suggested the following method for quantifying the degree of resurgence of insects:

$$\text{Percentage Resurgence} = \left(\frac{T_S}{C_S} \times \frac{C_F}{T_F} - 1\right) \times 100$$

where,

T_F = infestation in the treated plot during first count,

T_S = infestation in the treated plot during subsequent count,

C_F = infestation in the untreated plot during first count, and

C_S = infestation in the untreated plot during subsequent count.

Boudreaux (1963) ascribed the increase in phytophagous mite populations following application of DDT as due to killing of predators, change in the nutrition of the plants, stimulation of reproduction of mites and increase in the oviposition potential.

2.2. Resurgence in insect and mite pests of crops following insecticidal applications

Among insect pests, reports on the insecticide induced resurgence are widespread in members belonging to the order hemiptera while in lepidoptera, coleoptera and diptera, such cases are very rare. In mite pests of crops, resurgence reports are legion.

2.2.1. Order: Hemiptera

Following application of insecticides in rice, resurgence of *Nilaparvata lugens* (Stal.) was reported from several countries including Philippines (IRRI, 1969); Bangladesh (Alam and Karim, 1977); India (Varadharajan *et al*., 1977; AICRIP, 1978; Chandy, 1979); Indonesia (Oka, 1978; Soekarna, 1979) and the Solomon Islands (Stapley *et. al*., 1979). Detailed studies on the resurgence of *N. lugens* have been conducted at IRRI (1969-77) on the causes and factors of induction of resurgence of the pest. A good number of insecticides have been reported to induce outbreaks of *N. lugens*. Chelliah and Heinrichs (1978) reported the resurgence of *N. lugens* due to foliar application of methyl parathion and the synthetic pyrethroids. Aquino and Heinrichs (1979) reported that cypermethrin applied at 20 g ai/ha induced populations of *N. lugens* on resistant rice varieties and they warned that the resurgence-causing insecticides could accelerate biotype selection on resistant rice varieties.

Heinrichs *et al*. (1980) field-tested thirty five insecticides for their resurgence potential and found that sixteen of these as causing the resurgence of the brown plant hopper, *N. lugens*. These insecticides included diazinon 5 G, isazophos 3 G, carbofuran 3 G, tetrachlorvinphos 75 WP, methyl parathion 50 EC, monocrotophos 16.8 EC, pyridaphenthion 75 WP, cyanofenphos 40 EC, triazophos 40 EC, decamethrin 31 EC, penncap-M 25 EC and fenvalerate 38 EC. In later studies conducted at IRRI (1980), the biochemical changes in rice plants that led to feeding stimulation in *N. lugens* were brought to light. Cornelio *et al*. (1983) reported the resurgence of *N. lugens* on resistant IR-36 variety in Philippines. Chelliah and Heinrichs (1984) gave a review of the different factors favouring the insecticide-induced resurgence of BPH. They have stated that some insecticides contribute to a favourable environment in the rice ecosystem for *N. lugens* to alight, feed and survive. Such environments were favourable to realise the reproductory potential of the insect which caused progressive build up of the population and severe damage. Mochida and Heinrichs (1980) also gave a similar explanation for the resurgence of the brown plant hopper induced by the application of methyl parathion and diazinon. According to Mathew (1989), foliar sprays of malathion, methyl parathion, methyl demeton, FMC-35001, fenvalerate, permethrin and cypermethrin and granular applications of diazinon, phorate, cartap and carbofuran induced resurgence of *N. lugens* in Kerala State.

Induction of resurgence of the brown plant hopper has been attributed to various reasons such as the suppression of natural enemies (Kobayashi, 1961; Miyashita,1963);

Kiritani *et al.*, 1971; Kiritani, 1972 and 1975); insecticide induced plant growth (Heinrichs *et al.*, 1979); Chelliah, 1979; Raman, 1981); increase in feeding rate (Chelliah and Heinrichs, 1980; Raman, 1981); favourable influence on the biology of *N. lugens* (Chelliah, 1979; Raman, 1981; Heinrichs *et al.*, 1982 a); effect of sub-lethal doses (Chelliah, 1979); chemical nature of the insecticide (Chelliah, 1979; Reissig *et al.*, 1982 b); insecticide application rate (IRRI, 1977; Heinrichs *et al.*, 1980); timing and number of application (Heinrichs *et al.*, 1982 b); method of insecticide application (Heinrichs *et al.*, 1982 b); influence of insecticide on nymphal and adult stages (Chelliah, 1979; Heinrichs and Mochida, 1984) and the genetic resistance of rice varieties in such a way that the amount of pest resurgence decreased as the varietal resistance increase (Reissig *et al.*, 1982 a). However, Chelliah and Heinrichs (1978) found no reason for attributing resurgence to changes of major and minor nutrients in plants.

Kobayashi (1961); Miyashita (1963) and Sasaba and Kiritani (1972) reported that in Japan, *Nephotettix cincticeps* Uhler. populations showed resurgence as a result of frequent insecticide applications against the rice stem borer. Application of phorate granules at 2 kg ai/ha induced *N. virescens* (Dist.) populations in rice fields and the resultant population was twice as that in the control plots (Velusamy, 1987). Salim and Heinrichs (1987) observed that the white backed plant hopper, *Sogatella furcifera* H. resurged in susceptible and resistant varieties of rice as a result of foliar applications of deltamethrin. Systemic insecticide-induced resurgence of the blue leaf hopper, Zygina maculifrons (Motch) in rice was reported by Mani and Jayaraj (1976).

Application of fenvalerate led to about 4.7 fold increase of the cotton mealy bug, Ferrisia virgata (Cockrell) (Uthamasamy et al., 1987. In the case of permethrin, cypermethrin and deltamethrin the increase was two to four fold in this species (Patel et al., 1987). In citrus, Bartlett and Ewart (1951) recorded serious increase of populations of the soft (brown) scale, Coccus hesperidium L. due to application of parathion.

Satpute and Subramaniam (1983) gave an account of the resurgence of the white fly, Bemisia tabaci G. in cotton, due to the application of phosalone. Resurgence of B. tabaci in plots treated with cypermethrin and deltamethrin was 35 and 27 per cent respectively higher than in the untreated control in the cotton variety MCU-5 (David et al., 1987). Natarajan et al. (1987 a) obtained better control of the white flies by alternate sprays of synthetic pyrethroids and monocrotophos.

In studies conducted in Kerala, Ravindranath and Pillai (1987) reported increase in the population of Aphis malvae K. by 80 per cent above the levels in the untreated control in bitter gourd, following two sprayings with deltamethrin. In Myzus persicae Sulzer. there was increase in populations to the extent of 314.5 and 129.5 per cent over control in the brinjal crop due to five rounds of application of cypermethrin and deltamethrin (Reddi et al., 1987). DDT induced resurgence of the walnut aphid, Chromaphis juglandicola Kltb. (Bartlett and Ortega, 1952). Mueke et al. (1978) observed an increase of aphid, Acyrthosiphon pisum (Harris) by spray treatment of the alfalfa plants with leptophos at sub-lethal levels. Soil application of disulfoton, phorate, dimethoate and lindane (Sithananantham et al., 1973) as well as foliar application of synthetic pyrethroids (Sellammal et al., 1979) have been reported to induce resurgence of Aphis gossypii Glover in cotton. Similar instances of resurgence of sucking insects following insecticide applications have been observed on mustard in the case of the aphid, Lipaphis erysimi (Kalt.) (Pradhan et al., 1960); on bhendi of the leaf hopper, Amrasca devastans (D.) (Jotwani et al., 1966) and also on strawberry of the aphid, Chaetosiphon fragaefolii (Cock.) (Shanks, 1966).

According to Natarajan et al. (1987 b), application of deltamethrin, cypermethrin and fenvalerate brought about four to six fold increase in the population of A. gossypii in cotton over control plot, while Rengarajan et al. (1987) reported a corresponding increase to the extent of 10-15 fold over control. Two to three fold increase of A. gossypii were reported due to the application of the synthetic pyrethroids fenpropathrin, flucythrinate and fenvalerate (Rengarajan et al., 1987) and S-524 (Surulivelu and Sundaramurthy, 1987). Alternate use of synthetic pyrethroids and monocrotophos reduced the population of A. gossypii (Natarajan et al., 1987 a). Thimmiah and Kadapa (1987) observed increase of the aphid following dusting with carbaryl, the increase being 37 to 71 per cent over control.

2.2.2. Order: Lepidoptera

The reports of resurgence of lepidopteran pests on crops are very few. Resurgence of the rice leaf folder, Cnaphalocrocis medinalis Guen. following application of phorate was reported from Pattambi (Anon., 1977) and Aduthurai (Anon., 1982) centres. A tendency of resurgence of C. medinalis was reported by Valencia and Heinrichs (1979) consequent on foliar sprays of perthane at 0.04 per cent on N-1 variety. A cursory mention of leaf folder resurgence due to carbofuran application has been made by Chelliah and Heinrichs (1984). Velusamy (1985) applied phorate granules for causing artificial population flare-up of C. medinalis in order to enable screening of rice varieties for their relative resistance to the leaf folder and the results were quite promising. The population increase was particularly marked in the CO-36 variety.

The trials conducted at RARS, Pattambi from 1982 showed severe resurgence of the leaf folder, C. medinalis due to the application of carbofuran at 1.0 kg ai/ha at 20, 40 and 60 days after planting of the rice crop (Anon., 1983; 1984; 1985; 1987a, 1988). Bandong and Litsinger (1986) observed increased damage by leaf folder subsequent to application of sprays of insecticides like monocrotophos, methyl parathion, cypermethrin, methomyl and endosulfan which are commonly used by Philippine farmers, applied two to four times beginning three to five weeks after transplanting. They suspected that the destruction of natural enemies as an important factor causing resurgence. Excessive application of nitrogenous fertilizers coupled with indiscriminate application of granular and other formulations of pesticides have been attributed for resurgence of C. medinalis in Haryana, India (Qadeer *et al*., 1988). Carbofuran-induced rice leaf folder resurgence has been reported by Nadarajan and Skaria (1988) and Panda and Shi (1989).

The resurgence of *Spodoptera littoralis* Boisd. has been reported after application of sub-lethal doses of organophosphates (El-Lakwah and Abdel Salam, 1974). Deecher *et al*. (1990) reported stimulation of larvae of the gypsy moth, *Lymantria dispar* L. with 10, 5 and 1 ppm treatments of avermectin and milbemycin as evidenced by the increased frass output and weight gain compared to untreated control.

2.2.3. Order: Coleoptera

In coleoptera, cases of resurgence due to application of insecticides are very scanty. Tenhet (1947) recorded increase in the reproductive rate of *Lasioderma serricorne* F. following treatment with pyrethrum at sub-lethal doses and *Tribolium castaneum* Duval due to sodium fluoride (Johansson Tage, 1950). Kuenen (1958) reported higher reproductive rates of *Sitophilus granarius* L. weevils exposed to sub-lethal doses of DDT. In *Coleomegilla maculata* De Geer, treatment with DDT caused increase in reproductive potential (Attallah and Newsom, 1966). Ball and Su (1979) reported that carbaryl and carbofuran applied at sub-lethal dosages stimulated the egg production in the western corn root worm, *Diabrotica virgifera* Le Conte. Resurgence of *Callosobruchus chinensis* L. was induced by different insecticides through shortening the life cycle of F_1 generation from parent exposed to sub-lethal doses (Dutt, 1988).

2.2.4. Order: Diptera

Increase in adult life-span and the resultant increase in fecundity by 7.6 per cent were observed in *Drosophila melanogaster* Meigen following the application of sub-lethal doses of dieldrin (Knutson, 1955). The increase in larval, pupal and adult populations were of the order of 5.6, 5.7 and 5.8 per cent, respectively. Oatman and Kennedy (1976) observed the resurgence of the agromyzid fly, *Liriomyza sativae* Blanchard in market samples of tomatoes which were treated with methomyl.

2.2.5. Order: Acarina

There are several reports of resurgence of mite pests induced by insecticides and acaricides. Hoyt *et al*. (1978) observed increase in mite populations as a result of treatment with synthetic pyrethroids. In apple and pear orchards, Zwick and Fields (1978) reported flare-up of the mite populations following spray applications of fenvalerate. Patel *et al*. (1982) recorded resurgence of the two spotted spider mites, *Tetranychus telarius* L. in brinjal as a result of spray applications of carbaryl and endosulfan. Population increase of *T. cinnabarinus* Boisd. was recorded in cotton, subsequent to the application of permethrin, cypermethrin, deltamethrin, fenvalerate and cyfloxylate (Patel *et al*., 1987).

Variations in the extent of resurgence of *T. cinnabarinus* was noticed when different types of spray equipments were used for spraying cypermethrin in cotton

(Pasupathy and Venugopal, 1987). The spider mite resurgence was also detected after application of endosulfan, fluvalinate and deltamethrin (Verma and Bose, 1987). Mansour (1988) reported an upsurge of T. urticae (Koch.) and T. cinnabarinus at four weeks after a single application of 0.006 per cent cypermethrin, 0.001 per cent decamethrin, 0.016 per cent fenvalerate and 0.012 per cent permethrin.

Reduction in the population of the predators of T. urticae was found to be the major reason for increase of the mite populations in bhendi (Rao et al., 1987). In their studies, the T. urticae mites resurged two weeks after the third round of spraying with ethion and the increase was about four fold higher than control plots. Permethrin, phosmet and phosalone showed favourable influence in increasing the populations of T. urticae on the tart cherry Prunus cerasus L. (Jones, 1990). Resurgence of T. neocaledonicus Andre. was found to be due to the continuous use of synthetic pyrethroids in cotton (Reddy et al., 1987). The increase in population of the two spotted spider mites, T. bimaculatus Harvey and the european red mite, Paratetranychus pilosus (C. and F.) was associated with DDT sprays which killed their natural enemies (Bartlett and Ortega, 1952).

Studies conducted in Taiwan on the resurgence of Panonychus citri McG. showed significant increase following application of carbaryl, methyl parathion, ethyl parathion, fenitrothion, dimethoate or methomyl at recommended concentrations, depending on the number of applications (Ho, 1984). Buschman and De Pew (1990) reported resurgence of the grass mite, Oligonychus pratensis Banks due to the spray application of chlorpyriphos at 0.28 kg ai/ha to control the green bug, _Schizaphis graminum_ Rondani in sorghum.

2.3. Effects of insecticides on plants in relation to resurgence

2.3.1. Effects on growth and yield

Increase in tillering, height and root weight was recorded in rice plants that received carbofuran and dacamox granules at 1.0 kg ai/ha (Chelliah and Heinrichs, 1978). Increase in plant height as a result of treatment with miral, ethoprop and acephate was reported by Heinrichs (1979). Venugopal and Litsinger (1980 & 1984) reported increased rice root growth, plant height, total and productive tillers, grain yield and rapid maturity by carbofuran application. Venkataraman and Lakshminarayanan (1980) also observed phytotonic effect of carbofuran on rice plants. In trials conducted at IRRI (Heinrichs _et al_., 1980) most of the granular insecticides increased seedling shoot weight, plant height post-seedling shoot weight and tiller number. In some other experiments in pot cultures, carbofuran and its major metabolites, 3-OH carbofuran and 3-CO carbofuran recorded stimulation of root development and tillering leading to higher yield and reduced plant maturation-time.

Balasubramaniyan and Morachan (1981) observed positive effects of carbofuran application in rice on its growth components like productive tillers/hill, number of filled grains and 1000 grain weight in the variety IET-1444. In the case of methyl parathion treatment also, increase in tiller number and leaf number was observed in rice plants which rendered the plants more attractive to the adults of N. lugens. Diazinon treatments did not increase the growth of rice plants. On this basis, Heinrichs and Mochida (1984) suggested that growth increase of plants is not an essential pre-requisite for resurgence-induction in the case of N. lugens populations on rice. However, Chelliah and Heinrichs (1984) suggested that the phytotonic effect of insecticides might contribute to resurgence since green, healthy plants attracted more macropterous immigrants of N. lugens. In a previous work reported in 1980, they reported that the resurgence of the brown plant hopper induced by methyl parathion and decamethrin appeared to be due to attraction of insects to treated plants due to enhanced plant growth. They have postulated that alighting followed by increased feeding, higher reproduction and longevity would have an added effect on BPH resurgence. The results obtained by Raman (1984) was also in conformity with the reports of Chelliah and Heinrichs (1980). In this study, methyl parathion and deltamethrin increased tiller production, mean number of leaves and plant height of rice plants which promoted lush plant growth following insecticide application, rendering them more attractive to the immigrating hopper populations. But Aquino et al. (1979) found that the odour from the residues of resurgence causing insecticides had no influence on orientational response of N. lugens alighting on rice plants under different treatments. They reported that the improved plant growth caused by insecticides did influence the orientational response of the hoppers.

Pillai *et al*. (1985) applied carbofuran at 0.75 kg ai/ha along with N fertilizers and recorded increased plant height, effective tillers and grain yield in rice irrespective of N levels and the N management practices followed. The grain yield increase by carbofuran was 0.4 to 0.5 t/ha and they suggested that biological activity in soil might have been enhanced by carbofuran due to transformation of soil nutrients into more available forms. Increase in grain yield due to application of graded doses of carbofuran has been reported by Balasubramanian and Thangamuthu (1988) and Bhattacharya *et al*. (1988). That the incorporation of carbofuran or phorate granules at 1.0 kg ai/ha before transplanting increased the number of panicles/sq m, 1000 grain weight, N uptake and grain yields has been reported by Thakur *et al*. (1988). The yields obtained with carbofuran or phorate in combination with 80 kg N/ha was on par with that obtained from 120 kg N/ha alone.

Abdul Salam (1989) also reported increased growth of rice plants by application of carbofuran granules and the growth increase was expressed on tiller production, leaf area index, root production and grain yield. Mathew (1989) in his studies found some morphological changes in the stand of rice crop by resurgence-inducing insecticides, but the magnitude of such changes were not adequate to positively influence the attraction of *N. lugens* or the build-up of the pest population. Jaiswal *et al*. (1973) investigated the insecticide induced shoot emergence, shoot growth and development of tillers and roots by soil application of gamma BHC and telodrin in sugarcane. The effect of carbofuran, phorate, mephospholan and disulfoton on cowpea plants and the pea aphid, *Aphis craccivora* Koch. in different soil types was studied in Kerala (Das *et al*., 1975). They found that persistent toxicity is not directly correlated with yield, but the growth and yield was influenced by soil factors favouring plant growth. Increased growth of chilli (*Capsicum annuum* L.) plants was reported by Sinha and Roy (1977) when 30 day old seedlings were dipped for six hours in 500 ppm carbofuran. But higher concentrations of carbofuran reduced plant growth. Mueke *et al*. (1978) were of the view that the phytotonic effect of carbofuran and other insecticides in alfalfa were indirectly due to the better control of aphids.

Increase in the growth of bhendi plants due to soil application of aldicarb and disulfoton granules was reported by Sarma (1979). Increase in shoot length, number of leaves/plant and higher dry and fresh weights of plants was caused due to treatments with synthetic pyrethroids in groundnut (Devi *et al*., 1988). According to Singh and Kavadia (1988), soil application of disulfoton and aldicarb granules at 1.5 kg ai/ha, substantially improved growth of brinjal plants. Singh and Mathur (1989) found out that the phorate granules stimulated growth of root and shoot, number of nodules/ plant and activity of enzymes in black gram. Similar effects of phorate granules applied at 1.0 and 3.0 kg ai/ha was reported by Bagle and Varma (1989). In green gram, higher number of root nodules were formed as a result of soil application of disulfoton, phorate and aldicarb at 1.5 kg ai/ha (Sinhan *et al*., 1988). In the case of aldicarb, higher soil populations of bacteria and actinomycetes were recorded by them. Contrary to the general growth promoting influence of methyl parathion, Youngman *et al*. (1990) recorded that in cotton this insecticide reduced mesophyll conductance, boll retention, number of immature and open bolls/plant, number of first position bolls/plant, weight of lint cotton at harvest and dry weight accumulation of fruiting forms.

2.3.2. Residue dynamics and resurgence

Instances of increased pest infestations after the toxicants loose their toxic stimulus have been reported by several workers (Pradhan *et al*., 1960; Jotwani *et al*., 1966; Shanks, 1966; Sithananthan, 1968). Aquino and Pathak (1976) reported increased persistence of residues of carbofuran in plant tissues, when incorporated into top soil than when applied to paddy water and ascribed this phenomenon to the reduction in the volatilization loss from paddy water. Pathak and Dyck (1973) as well as Siddaramappa (1978) suggested that root zone application of carbofuran reduced volatilization losses. The increased uptake of carbofuran was ascribed to the easy accessibility of roots to the toxicant. The plant uptake was highest in the first week and most of the carbofuran thus absorbed was detected in leaf blades and roots. Carbofuran and its metabolites are transported acripetally to the leaf tips by transpiring water and is also lost by vaporisation. Within 20 day period, most of the absorbed carbofuran is thus lost to atmosphere, the loss being directly related to the amount of water lost through traspiration (Siddaramappa, 1978). Siddaramappa *et al*. (1979) also recorded similar results. They reported the influence of soil pH in the degradation of carbofuran. In the Luisiana soil with a pH of five, degradation was found only after 40 days. Rapid degradation of carbofuran occurred in neutral to alkaline soils. Re-treatment of the soil resulted in an acceleration of carbofuran degradation. Siddaramappa and Watanabe (1979) reported for the first time, the loss of carbofuran in the vapour phase through plant surfaces following uptake and systemic translocation of the toxicant.

Mohamed Ali (1978) recorded considerable variations in the absorption and persistence of carbofuran in rice plants at different growth stages. A positive correlation between the carbofuran content on the one hand and the per cent mortality of nymphs of brown plant hopper, N. lugens in rice was established in his studies. Carbofuran in the plant was found partly metabolised to carbofuran-phenol, 3-OH carbofuran, 3-CO carbofuran and their phenols (IRRI, 1977). Kanaak (1970) reported some other metabolites of carbofuran such as 2, 3-dihydro-7-hydroxy-2,2-dimethyl benzofuran and 2,3-dihydro-3,7-dihydroxy-2,2-dimethyl benzofuran and these are usually stored as glucosides in plants.

Seiber et al. (1978) conducted detailed investigations on the behaviour of carbofuran residues in rice plants treated by broadcast, soil incorporation and root zone application and by seedling root soak and root coat techniques. Placement of gelatin capsules in root zone gave good persistence (about 60 days) and leaf residue (as much as 45 ppm at 10 days after treatment). Carbofuran applied to wet land rice crop is primarily absorbed through the rice roots and translocated to the leaves. Consistently higher carbofuran residues were observed in the leaf. The residue of carbofuran and metabolites in whole grain was well below the tolerance limit allowed, for upto four applications each at the rate of 1.0 kg ai/ha. When applied to paddy water, carbofuran dissolves in water uniformly within 24 hours. The insecticide can also move physically to the plant surfaces by capillary action. Much of the chemical applied to paddy water is lost by decomposition and run off and is also lost through volatilization. From leaf surfaces also, there is loss of chemical through volatilization. Mochida and Heinrichs (1980) stated that insecticides which may control BPH at the recommended doses could induce resurgence of populations after disappearance of their residual action. Rao and Rao (1980) observed very low residue levels of carbofuran following its application at 1.0 kg ai/ha at 15, 40 and 70 days after planting. The residues in such cases were below tolerance limits in rice grain and straw. Pillai and Nair (1983) assayed the residues of carbofuran applied at 1.0 kg ai/ha, of phorate at 2.0 kg ai/ha and of mephospholan applied at 1.0 kg ai/ha in rice straw and grain and found that residues of all the insecticides applied at 21 days after transplanting were the least, but relatively higher under single application given at 45 days after transplanting and the highest residues being found when these were applied both at 21 and 45 days after transplanting. Residues of carbofuran ranged from 0.038 to 0.107 ppm, phorate 0.048 to 0.161 ppm and mephospholan 0.033 to 0.108 ppm in straw and grain.

Nandakumar and Visalakshy (1983) conducted a field experiment to assess the effect of different methods of placement of carbofuran in soil on the uptake, translocation and persistence of granules of phorate, carbofuran and disulfoton. The maximum residue of 1.41 ppm was observed in the case of disulfoton followed by phorate

(0.79 ppm) and carbofuran (0.13 ppm) in cowpea plants. Carbofuran applied at 0.5 kg ai/ha at sowing was detected in cowpea plants even after 35 days of application and Faleiro et al. (1985) suggested a safety interval of 54.44 days. Similarly, Rajukkannu et al. (1988) observed that carbofuran applied at 0.5 and 1.0 kg ai/ha to betelvine dissipated to non-detectable levels in 41 days.

2.3.3. Resurgence due to insecticide induced biochemical changes in plants

Biochemical changes in plants consequent on the application of resurgence inducing insecticides have been reported by Jayaraj and Regupathy (1987) in cotton, rice and brinjal on aphids, leaf hoppers and mites, respectively. Mani and Jayaraj (1976), while studying the resurgence of the blue leaf hopper, *Z. maculifrons* in rice, found that low concentrations of calcium and high levels of nitrogen and phosphorus were favourable for the pest resurgence. They also recorded a lower content of carbohydrate and a narrow C/N ratio in treated plants. The levels of major and minor nutrients in rice plants such as N, P, K, Ca, Mg, Zn and Cu content in plants treated with Decis, FMC - 35001, methyl parathion, diazinon and perthane in relation to *N. lugens* resurgence did not reveal any marked changes (Chelliah and Heinrichs, 1978; Chelliah, 1987). However, the level of Mn was uniformly high in plants receiving diazinon, isazophos, metalkamate, dacamox and carbofuran granular treatments.

Studies conducted at IRRI (1980) established that the resurgence causing insecticides influenced the biochemical constituents in rice plants. Among methyl parathion (0.04

per cent), decamethrin (0.002 per cent) and perthane (0.04 per cent) applied 10, 20 and 30 days after planting, decamethrin showed the highest level of free amino nitrogen in leaf sheath, while perthane caused the least. The carbohydrate-nitrogen ratio of the soluble constituents was also lowest in decamethrin treated plants followed by methyl parathion. The change in carbohydrate-nitrogen ratio might have increased the feeding rate of N. lugens. Changes in levels of starch, sugars and total nitrogen in leaf and leaf sheath in treated plants were negligible. Buenaflor et al. (1981) also reported similar results with decamethrin treatment of rice plants. In the BPH resistant variety, IR-36 such differences were not detected between treated and untreated plants.

Sujatha et al. (1987) observed the relationship between chemical composition and resistance of 11 rice varieties to N. lugens in field. They suggested that the phenol, silica, phosphorus, potassium, calcium, sulphur and iron contents were positively correlated with resistance while protein, nitrogen, zinc and manganese contents were negatively correlated. Mishra and Nayar (1987) studied the influence of carbofuran granule incorporation in rice soils, on the changes in the secondary elements of the plant and found that incorporation of carbofuran into Fe-rich alluvial soil increased the dry matter production, grain yield and Mn content, but had no effect on Zn and Cu contents. The iron content in plants was reduced significantly by carbofuran. Mathew (1989) found that the application of resurgence causing insecticides produced significant variations in the nutrient content and biochemical constituents of treated rice plants causing consistent changes in the total nitrogen, free sugars and free amino acid contents.

Van Der Laan (1961) explored the reason for the depression in population of cotton white fly, B. tabaci during two to three days after treatment with DDT and thereafter an increase in population by about two to three weeks. He found that the eggs of aleurodids are in physical contact with the host plant and the physiological changes in the plant brought about by DDT would be favourable to the egg stage and so the indirect effect of DDT influences the population build up. This effect was described as exclusive for DDT or its formulations by the author. Sithanantham et al. (1973) conducted an experiment to study the changes in biochemical status of cotton plants due to systemic insecticidal protection, in relation to resurgence of the aphid, A. gossypii. They observed lower carbohydrate content, narrower C/N ratio and greater quantities of amino acids especially cystine, asparagine and tryptophan.

Regupathy and Jayaraj (1973 b) observed low total nitrogen and calcium and high ammoniacal nitrogen and potassium in leaves of bhendi plants treated with phorate granules. Alteration in the physiology of plants was expected to be enhanced by supply of phosphorus from the insecticide. A reduction in carbohydrates and calcium contents would be favourable for aphids and jassids. Singaram and Manickam (1978) observed an increase in the uptake of nitrogen in carbofuran applied plots in ragi (Eleucine coracana) variety CO-10. In sorghum Buschman and De Pew (1990) found physiological changes caused by the application of Chlorpyriphos which induced resurgence of banks grass mite, O. pratensis.

Investigations of the biochemical changes in egg plant, Solanum melongena due to insecticidal sprays in relation to mite incidence indicated that application of carbaryl + molasses, dicrotophos, monocrotophos, phosalone, endosulfan, chlorfenvinphos and acephate altered the biochemical constituents of brinjal plants. Of the various changes brought about by these insecticides, Uthamasamy et al. (1976) found that the population of the red spider mite, T. cinnabarinus was highly influenced by changes in phenolics, sugars and minerals. The studies with monocrotophos seed treatment in cluster bean showed that increasing the concentration or exposure period caused a gradual decrease in germination, seedling growth, plant height, chlorophyll biosynthesis and stomatal index. Plant height and chlorophyll biosynthesis were stimulated by short exposure to a low concentration of 300 ppm of monocrotophos (Ramulu and Rao, 1987). Thirumaran and Anne (1987) enunciated a reduction in growth rate and an initial enhancement followed by a sharp decrease of protein in seedlings of black gram when methyl parathion was applied as a seed coat at 0.01 and 0.02 per cent concentrations. A pronounced decrease in soluble amino acid and an accumulation of total phenol was also noticed. Jones (1990) attributed the resurgence of T. urticae on tart cherry induced by permethrin, phosmet and phosalone to the changes in host plant nutritional value which stimulate mite physiology directly or indirectly.

2.4. Effects of insecticides on insects in relation to resurgence induction

The major influence of insecticides on insects in relation to resurgence are the effects on reproductive potential, feeding behaviour and growth and development and survival of insects.

2.4.1. Effects on reproductive potential

Alteration of insect biotic potential by sub-lethal doses of insecticides has been observed as early as 1950 by Huffacker and Spitzer (1950). Several other workers have later studied such effects on various insect pests of crops and other insects of economic importance (Kuenen, 1958; Attallah and Newsom, 1966; Madhavan *et al*., 1970; Hart and Ingle, 1971; Essac *et al*., 1972). There are several reports that the insecticidal residues in host plants or insecticides applied at sub-lethal doses stimulated the reproduction and survival of phytophagous insects and mites, leading to pest resurgence (Vrie *et al*., 1972; Dittrich *et al*., 1974; El-Lakwah and Abdel Salam, 1974). Roan and Hopkins (1961) suggested that sub-lethal doses might positively stimulate neural activity to bring about a favourable neurohormonal influence on insect reproduction, in studies conducted with some coleoptera, diptera and orthoptera. Sub-lethal doses of insecticides could influence the populations by affecting the reproductive potential of the individuals and by altering the genetic make up of the future generations (Moriarty, 1969).

Variations in the fecundity of *N. lugens* were recorded when they were confined on plants treated with different insecticidal granules at 0.5 and 1.0 kg ai/ha, after the insecticides lost their lethality (Chelliah and Heinrichs, 1978). In all the granular insecticides tested except cartap, fecundity of hoppers was higher in plants receiving 0.5 kg ai/ha than 1.0 kg ai/ha. Diazinon and cartap were recorded to increase the fecundity even at 1.0 kg ai/ha. Raman (1981) observed that the reproductive rate of *N. lugens* was increased when the hoppers fed on rice plants treated with deltamethrin, methyl parathion, quinalphos; cypermethrin, permethrin and fenvalerate as sprays and this was attributed to the action of insecticide residues or their metabolites, chemical changes in the host plants or a combination of these factors. Chelliah (1979) and Heinrichs *et al*. (1982 b) also observed such population increases of the BPH induced by insecticides.

Stimulation of reproduction either by contact action of insecticides or by plant growth increase as a cause of resurgence of BPH by methyl parathion and decamethrin were observed by Chelliah and Heinrichs (1980) and Chelliah *et al*. (1980). Highest reproductive stimulation occurred at the LD_{25} dosage for methyl parathion and at LD_{50} for decamethrin. Perthane did not cause reproductive stimulation at any of the four topically applied dosages tested. In another trial Heinrichs and Mochida (1984) reported 42 per cent increase in the reproductive rate of the 95 per cent surviving hoppers of treatment with LD_5 dosage of decamethrin. Such increase in reduction of mortality and increased reproduction will lead to very heavy resurgence than LD_{50} with 76 per cent increase in reproductive rate. Fenvalerate at sub-lethal doses and deltamethrin at lower and higher doses were found to increase progeny production of *N. lugens* (Balaji *et al*., 1987). However in the opinion of Krishnaiah and Kalode

(1987), resurgence of BPH cound not be attributed to stimulation in reproduction of the pest by insecticide but to reduction in natural enemy and low persistent toxicity of insecticides. But Mathew (1989) also found that methyl parathion, deltamethrin and carbaryl had direct stimulating effect on the progeny production of N. lugens at sub-lethal doses and carbaryl and methyl parathion were stimulatory only at lower levels but deltamethrin stimulated reproduction at both lower and higher levels.

Mature females of Aphis rumicis L. treated with low concentrations of rotenone were found to produce more young ones than controls which were dusted with talc (Sun, Yun-pei, 1945). Shanks (1966) in his studies on soil application of phorate and disulfoton against the aphid, C. fragaefolii has reported enhancement of reproduction of aphids due to application of these insecticides. Increase in size of the insect was noticed by Sithanantham (1968) in aphids of cotton. The insecticide treated plants were more vigorous and nutritionally favourable for insects and hence increased population was attributed due to enhanced reproduction of A. gossypii of bigger size. Bartlett (1968) observed increased reproduction by fifty nine pesticides on the aphid, A. gossypii and the mite T. urticae on cotton plants. Sithanantham et al. (1973) established the role of sub-lethal amounts of toxicants in the plant sap in inducing higher reproduction of the aphid, A. gossypii on cotton plants.

Huffacker and Spitzer (1950) reported a physiological stimulus to reproduction under DDT influence on the european red mite, Panonychus ulmi (Koch.). In a study on the effects of DDT and sub-lethal doses of dicofol on reproduction of the two spotted spider mite, T. urticae, Saini and Cutkomp (1966) found contradictory results by topical application and the treatment of plant parts on which mites grew and reproduced. Direct application of DDT at sub-lethal levels did not affect fecundity. When treated on plants, mite population and reproduction was greatest and nitrogen content of leaves was moderate indicating the influence of nutrition in reproduction. Jones and Parella (1984) revealed the importance of hormoligosis than inhibition of predator or host plant effects with sub-lethal doses of selected insecticides in the mite, P. citri.

Tenhet (1947) while studying the effect of pyrethrum on the cigarette beetle, L. serricorne observed that the sub-lethal dosages of pyrethrum caused rapid knock down action but many consequently recovered. The surviving females deposited about half as many eggs as the normal ones. Kuenen (1958) reported higher reproductive rate of S. granarius weevils exposed to the sub-lethal doses of DDT.

Reproduction of D. melanogaster treated with sub-lethal doses of dieldrin continued over a long period by an increased life span of the flies (Knutson, 1955). An initial reduction in progency production and subsequent increase was noted in dieldrin treated houseflies, Musca domestica L. at sub-lethal dosages and the F_1 generation of treated flies showed an increase of 69.2 per cent progeny production (Affifi and Knutson, 1956).

Lucky (1968), based on his studies on the effect of insecticides on the house crickets, Acheta domesticus (L.) propounded the hormoligosis hypothesis, which predicts that sub-harmful quantities of any stressing agent will be stimulatory to the organism by providing it increased sensitivity to respond to changes in its environment and increased efficiency to develop new or better systems to fit sub-optimal environment. El-Lakwah and Abdel Salam (1974) provided evidence to the influence of insecticide residues in host plants or of insecticides applied at sub-lethal doses on the stimulation of the reproduction and survival of Spodoptera littoralis (Boisd.) thereby causing resurgence.

2.4.2. Effects on feeding behaviour

Increased feeding of N. lugens on plants treated with resurgence-inducing insecticides such as quinalphos, cypermethrin, fenthion, permethrin and fenvalerate was reported by Raman (1981). Similar effects were also reported by Chelliah and Heinrichs (1980 and 1984). They observed that in rice plants sprayed with deltamethrin, methyl parathion and diazinon, the feeding rate of N. lugens was higher than in the check by 61, 43 and 33 per cent, respectively. They also found that improved plant growth did not compensate for the increased feeding. Liu and Wilkins (1987) studied the antifeeding effect of sub-lethal levels of carbofuran against the white backed plant hopper, S. furcifera. Anti-feeding response was maximum when the insects were topically applied with carbofuran at the sub-lethal levels. The efficiency index was 4.8 for leaf treatment, 128.9 for topical application and 9.8 for root zone application. Mathew (1989) recorded increased feeding of *N. lugens* on rice plants treated with resurgence-inducing insecticides.

2.4.3. Effects on growth, development and survival

Chelliah and Heinrichs (1978) have reported that some of the resurgence inducing insecticides at their sub-lethal doses increased feeding activity of *N. lugens*, reduced the length of their nymphal stages and increased adult longevity and stimulated reproduction. Reduction in length of nymphal stage resulting in a shortened life cycle and increased longevity resulting in a longer oviposition period were found to be induced by insecticides (Chelliah, 1979). Difference in the rates of resurgence of *N. lugens* was found to be influenced by the stage of the insect at which the chemicals are sprayed (Chelliah, 1979). The reproductive rate of *N. lugens* was higher when plants were sprayed with resurgence inducing insecticides at fourth and fifth instar nymphal stages and at adult stage and a subsequent reduction in length of nymphal stage and increased adult longevity (Chelliah and Heinrichs, 1980). In methyl parathion, decamethrin and untreated control, the nymphal duration was 14.1, 13.6 and 14.7 days, respectively and the adult longevity was 11.1, 12.7 and 10.2 days, respectively (Heinrichs and Mochida, 1984). An increased feeding rate indicated by radioactivity counts was 61, 43 and 33 per cent over control in the case of decamethrin, methyl parathion and diazinon, respectively.

Ball and Su (1979) studied the effects of topically applied sub-lethal doses of carbofuran and carbaryl on oviposition and longevity of Diabrotica virgifera Leconte females. At low dosages, females treated with both the insecticides oviposited significantly more and lived longer than control females. Carbofuran enhanced these phenomena more than that by carbaryl. The mean number of eggs oviposited/female/day for insects treated with 0.0025 µg was 4.21 as compared to 3.19 for females treated with 0.000025 µg/insect and 3.02 for untreated insects. Similarly, longevity of females treated with 0.0025 and 0.000025 µg was 38.2 days for both treatments and 35.5 days for untreated control. Bio-ecological behaviour of F_1 immature forms obtained from crosses of parents of Callosobruchus chinensis (L.) exposed to different sub-lethal concentrations of diazinon, fenitrothion, fenthion, dimethoate and methyl demeton was studied by Dutt (1988). Reduction in incubation period of egg, larval and pupal periods were observed and the period of reduction varied with insecticides.

Ramdev and Rao (1980) studied the effect of sub-lethal doses of insecticides on consumption and utilization of dry matter and dietary constituents of castor (Ricinus communis L.) by the castor semi-looper, Achaea janata L. The insecticidal treatment significantly lowered the rate of food intake, but increased significantly the weight gain and digestibility of the larvae. The efficiency of conversion of ingested food to body matter was relatively more in treatments with DDT and the pupal lipid was greater indicating the lower maintenance requirement of treated insects. Sub-lethal levels of DDVP topical applications on Pericallia ricini F. larvae were shown to result in abnormal metamorphosis like abnormal moulting, ecdysial failure, development of abnormal adult offspring with crumpled and short wings and aggregation of body hairs in bundles due to acceleration of secretion and release of juvenile hormone and interference with the levels of the moulting hormone by sub-lethal levels (Singh and Shaheen, 1987).

Rosenheim and Hoy (1988) did not find any changes in the various traits such as longevity, daily rate of progeny production per female, size and sex ratio of offsprings of the parasitoid Aphitis melinus as a result of treatment with sub-lethal doses of carbaryl but more of males were produced by the chlorpyriphos treatments.

Salim and Heinrichs (1987) found that the foliar application of deltamethrin attracted more adults, increased nymphal survival, growth index and population development of S. furcifera on T(N)-1 rice variety which led to resurgence of the pest.

2.5. Resurgence due to selective elimination of the natural enemies

Dyck and Orlido (1977) reported that reduction in the population of the mirid bug predator Cyrtorhinus lividipennis after regular spraying with methyl parathion caused N. lugens resurgence. However, extensive field studies conducted did not show adequate evidence that reduction in the C. lividipennis population caused resurgence (IRRI, 1978; Chelliah, 1979). In some of the studies conducted at

IRRI, destruction of predators by the resurgence inducing insecticides did not appear to be a major factor for resurgence of BPH. Although decamethrin adversely affected spider and mirid bug populations, quinalphos, another resurgence inducing insecticide did not adversely affect predator species. Similarly chlorpyriphos + BPMC did not cause resurgence but these significantly reduced spider and C. lividipennis populations (Heinrichs et al., 1980). Suppression of natural enemies appeared only as a minor factor in BPH resurgence (Heinrichs et al., 1982 a and b). Chelliah and Heinrichs (1984) reported suppression of natural enemies of BPH due to the broad spectrum activity of the commonly used insecticides. High toxicity of deltamethrin to predators like C. lividipennis and wolf spider, Lycosa pseudoannulata and subsequent resurgence of N. lugens was reported by Jayaraj and Rengarajan (1987). Krishnaiah and Kalode (1987) attributed reduction in natural enemy and low persistent toxicity of insecticides as the cause for resurgence of N. lugens following application of monocrotophos, phosalone and phosphamidon at sub-lethal doses.

Bartlett and Ewart (1951) observed serious increase of populations of soft (brown) scale, C. hesperidium by the application of parathion to citrus trees. They found parathion as highly lethal to Metaphycus luteolus (Timb.) the most effective parasite of the scale. In Southern California, increases in populations of the walnut aphid, C. juglandicola and the two spotted spider mites, T. bimaculatus and the european red mite, P. pilosus were associated with decrease in populations of the coccinellid, lacewing and coniopterygid predators following DDT spray applications. Bartlett (1968) opined that reproductive stimulation alone is not the cause of resurgence of aphids and mites, but the natural enemy destruction is also an important factor to be considered.

Meuke _et al_. (1978) observed an increase of the aphid, _A. pisum_ following treatment of alfalfa with leptophos at sub-lethal levels due to destruction of natural enemies. Rock (1979) in the case of _T. urticae_ and Buschman and De Pew (1990) in the case of the banks grass mite in sorghum have also reported their resurgence consequent on the elimination of their natural enemies following insecticide applications.

Chatterjee and Rao (1974) reported resurgence of the rice leaf folder, _C. medinalis_ as due to mortality of their natural enemies caused by pesticides. Oatman and Kennedy (1976) observed methomyl-induced resurgence of _L. sativae_ on tomato due to destruction of their parasites by the insecticide.

2.6. Biophysical factors in plants and insecticide-induced resurgence of pests

Though the influence of biophysical traits of crop varieties on the level of resistance to pest species is very well documented, insecticide induced resurgence mediated by such changes has not been reported so far. Among the biophysical characters influencing the relative susceptibility of crop varieties, length, density and disposition of glandular/non-glandular trichomes (Jadhav _et al_., 1986; El-Rahman and Saleh, 1987; Jackai and

Oghiakhe, 1989; Luczynski *et al*., 1990), pubescence (Sosa, Jr. 1988; Jackai, 1990) and leaf colour and glossiness (Jadhav *et al*., 1986) have been reported to be important.

2.7. Insect resistance to insecticides in relation to resurgence

The degree of resistance in insects to insecticides was found to be related to resurgence of *N. lugens* in rice (Heinrichs *et al*., 1980; Chelliah *et al*., 1980; Heinrichs *et al*., 1982b). In laboratory studies *N. lugens* showed resistance to carbofuran and this field collected population was seven times more resistant than the laboratory strain (Heinrichs and Valencia, 1978). Resurgence of *N. lugens* due to continued application of methyl parathion was recorded by Mochida and Heinrichs (1980) when the insecticide was applied at 0.75 kg ai/ha on IR-22 variety of rice.

Harrington *et al*. (1989) found that the resurgence of the aphid, *M. persicae* in potato treated repeatedly with cypermethrin and mineral oil mixtures was mainly due to the increased survival of insecticide-resistant strain of the aphid.

2.8. Insecticide dosage, method and timing of application in relation to resurgence

In field studies at IRRI (1977) to determine the effect on resurgence of various methods of carbofuran application it was found that populations of *N. lugens* were higher when the insecticide was applied thrice as foliar sprays than when applied as broadcast or by broadcast and soil incorporation. Out of different BPH resurgence-inducing insecticides, a few at sub-lethal doses were found to induce BPH resurgence by the methods and timings of application, because of the differences in the amount of insecticides which reached the insects which are found at the base of the plant close to the water level (Chelliah and Heinrichs, 1978). The highest population of brown plant hopper, *N. lugens* was seen in FMC-35001 applied at the low rate of 0.2 kg ai/ha. Sub-lethal doses of insecticides were found to induce the reproductive rate and reduced nymphal duration of *N. lugens* (Chelliah, 1979). Aquino *et al*. (1979) in their studies have found that critical timing of insecticide application is to be determined so as to avoid resurgence of *N. lugens*.

Mochida and Heinrichs (1980) and Heinrichs and Mochida (1984) in field tests conducted at IRRI have found that foliar sprays of carbofuran caused the highest resurgence rate in BPH followed by paddy water broadcast-application. When the insecticide was applied by soil incorporation, there was no resurgence. Increased levels of resurgence were noticed by lower rates of isazophos, while in the case of methomyl the resurgence rates were equal (Heinrichs *et al*., 1980). They also found that deltamethrin at 30 g ai/ha induced significantly higher *N. lugens* population as compared to the lower doses of 20 and 10 g ai/ha. In the case of methyl parathion, resurgence was higher at 750 g ai/ha compared to the levels in the lower doses, namely, 500 and 250 g ai/ha, thereby bringing out the influence of rate of application on resurgence. In deltamethrin, Chelliah et al. (1980) reported that in N. lugens receiving treatment with LD_{50} of deltamethrin, more number of nymphs (287.5) hatched as compared to the nymphal emergence at LD_{10}. The nymphal emergence in treatments receiving LD_5, LD_{10}, LD_{25} and LD_{50} of methyl parathion was 147.3, 147.5, 247.3 and 180.8 respectively, showing that the LD_{25} received population could register rapid increase than LD_5 or LD_{10}.

Foliar sprays of methyl parathion and decamethrin applied at 50 and 65 days after transplanting resulted in a high N. lugens egg number and subsequent nymphal population, reaching a peak at 80 days (Heinrichs et al., 1982a) showing the influence of timing, number of applications and stage of the crop on resurgence of the pest. They have also found that foliar sprays recorded 20-fold increase of N. lugens while root zone application showed only four fold increase in population evidencing the effect of method of carbofuran application on resurgence of BPH. Raman and Uthamasamy (1983) found a positive correlation between the reproductive rate of N. lugens and the number of applications of resurgence-inducing insecticide sprays. The influence of dosage/rates, timing and number of applications and method of application on resurgence of the brown plant hopper was also been reported by Heinrichs and Mochida (1984).

Bartlett (1968) explained the delayed effects of applications of pesticides as the chemical or metabolites has to be absorbed and translocated through the plant to induce pests. Variations in severity of upsets depending on dosage has been well demonstrated from his experiments with spider mites, *T. urticae* and cotton aphid, *A. gossypii*. Ho (1984) found a positive correlation between the number of applications of different insecticides and the resurgence of the citrus red mite, *P. citri*. Increase in the number of applications of synthetic pyrethroids in the cotton ecosystem was found to be a positive factor for the resurgence of *B. tabaci* (Jayaraj *et al.*, 1987; David *et al.*, 1987). Regupathy and Jayaraj (1973 a) observed resurgence of *A. gossypii* and *A. devastans* in the case of soil treatment with granular disulfoton and phorate than with foliar applications with methyl demeton and dimethoate. The resurgence was more when the dosage was increased in soil treated plots.

Materials and Methods

MATERIALS AND METHODS

Laboratory and field experiments were carried out to study different biological, biophysical and biochemical changes in rice plants following the soil application of different rates of carbofuran granules. The effect of such treatments on the biological traits of the rice leaf folder, C. medinalis feeding on treated plants was also studied in these experiments.

3.1. Biological studies

3.1.1. Maintenance of stock culture of the test insects

The mass rearing of the leaf folder, C. medinalis was done by the method developed by Waldbauer and Marciano (1979) with slight modifications. Larvae in the third instar were field collected and brought to the insectary for establishing the stock culture required for various experiments. These larvae were reared on 60 day old potted rice plants (variety: Jaya). The plants were grown in earthernware pots (30 cm x 30 cm). In each pot, there were about 150 tillers in all. The pots were kept in a GI tray and the water column in the tray was maintained at 10 cm. The pots were then covered over with a cylindrical metallic frame (100 cm tall and 35 cm diameter). Nylon net cloth was used as a wrap-around for the metallic frame. The top of the cage (Plate I) was covered over with circular piece of nylon net cloth. A side sleeve (50 cm long) of kora cloth having a diameter of 20 cm was provided in the middle of the cage. The side sleeve was tied over when not in use. Additional plants

PLATE I. Cage used for rearing of *C. medinalis* larvae

PLATE I

were provided in small (15 cm tall x 13 cm diameter) earthernware pots whenever found necessary. To avoid inbreeding depression, field collected larvae were introduced frequently into the culture.

The adults were allowed to emerge inside the cages. Every day morning, freshly emerging adults were carefully collected using a glass vial. Any adult of Marasmia patnalis Bradley emerging in the cages were discarded. The cues provided by the wing markings (Mathew and Menon, 1986) were used for quick identification of M. patnalis. In C. medinalis, the post-median line of the forewing extends direct across the wing from costa to dorsum. In M. patnalis, the post-median line on forewing is much displaced with three prominent median line (Plate II a and b).

The C. medinalis moths were sexed on the basis of the shape of abdominal terminalia, blunt in the female and pointed in the male. The tuft of setae on the basal tarsomere of the male's front leg is much denser and darker than the females and this character was also depended upon for sexing. Thirty sexed moths were released to oviposition cages in equal proportions.

The oviposition cages were made out of a metallic frame work (66 cm tall) having circular metallic rings (27 cm diameter) on both extremities around which polythene sheet (1200 guage) was wrapped (Plate III). The overlapping edges were glued with fevicol SR-998. The top of the cage was covered over with polythene sheet of same thickness. In order to provide air circulation, a

PLATE II A. *Marasmia patnalis* Bradley - Adult moth in resting position

B. *Cnaphalocrocis medinalis* Guen. - Adult moth in resting position

PLATE II

A

B

circular nylon mesh covered hole 5 cm in diameter was provided at the centre of the top cover of the cage. The nylon mesh was fixed to the polythene film by means of fevicol SR-998 and held in that position by means of a cellotape. Access into the cage was through a side sleeve of polythene sheet (750 guage) attached at a point 10 cm above the bottom. A sleeve 25-30 cm long and 15 cm diameter was fixed by glueing with fevicol SR-998 and also by stitching along the seams. The sleeve was provided with circular perforations, each of 0.5 cm diameter. These holes were provided in five linear series on the upper half of the sleeve at equidistant intervals covering a distance of up to 15 cm from the seams on the cage. A thermohygrograph was run in the insectary. Whenever the relative humidity was found reduced below 90 per cent, the top ventilator was partly closed with a bit of mylar film. The cage assembly was placed in a plastic basin (33 cm diameter and 10 cm height) containing fine moist river sand.

Sustained nutrition of adult moths confined in the ovipositional cages was ensured by providing honey after extending with distilled water to get a terminal concentration of 25 per cent by volume. Honey thus diluted was offered in cotton swabs placed on a small plastic cup of 1.5 cm depth and 2.5 cm diameter kept in a pedestal made out of the same size of tubing. The pedestal along with the feeder was inserted into soil contained in the pot in such a way that the cup remained at 5 cm above the soil surface.

Rice plants of the variety Jaya (60 days old) planted in earthern pots of size 10 cm tall and 12 cm diameter were used. To start with, a pot containing 5 to 8 tillers was inserted into the ovipositional cage. Since the moths preferred drooping leaves for oviposition, care was taken to select taller plants, the leaves of which tended to droop after insertion into the cage or the pot with plants were placed on an inverted pot so that the leaves touched the top of the cage and then drooped. These small pots could easily pass through the sleeve of the cage.

Eggs laid on first seven days only were collected from the ovipositional cage commencing from the second day onwards along with the plants which were then kept in trays in a slanting position with the roots dipped in a little quantity of water for two days. Fresh plants were provided for egg laying in the ovipositional cage as and when plants with eggs were taken out. The plants kept in trays were then taken out and each tiller was cut and examined carefully. The eggs on leaves could be seen easily but those on culms were visible only with a 10 X hand lens. The eggs along with the plant part carrying them were removed by cutting the plant part concerned and the bits were then transferred to a moist filter paper contained in paired petridishes (9 cm diameter) at 300 eggs/dish. The petri dishes containing eggs were placed in an incubator at 23 ± 1°C. Most of the eggs hatched on the fourth day of egg laying and the rest on the next day. The freshly emerging first instar larvae were used for the experiments and for further culturing of larvae. Sufficient number of cages for larval rearing and oviposition were used.

3.1.2. Raising of plants for insecticidal treatments

Germinated seeds of variety Jaya was sown in wooden seedling boxes (60 cm length, 40 cm width and 10 cm height) filled with soil collected from wet lands which did not receive any carbofuran treatments for the past four years. The boxes were then placed in cement basins filled with water, in the insectary. Water was controlled to required levels in the seedling box for facilitating proper germination and stand of seedlings. Chemicals or fertilizers were not applied to the seedlings.

The seedlings were transplanted on the 24th day in small plastic buckets (15 cm height and 18 cm diameter on top) almost filled with untreated soil. The soil was thoroughly mixed before filling. Healthy seedlings were planted at the rate of two per bucket. All the cultural operations except plant protection measures suggested in the Package of Practices Recommendations (Kerala Agricultural University, 1986) were followed. The plants were maintained in the insectary under pest free condition.

For all the insectary experiments, three replications were provided and the treatments were arranged in a Randomised Block Design. Additional plants were also grown to cater to the demands whenever required in the case of all the treatments. Carbofuran at 0.50, 0.75 and 1.00 kg ai/ha was applied to the plants based on the surface area of the soil contained in the buckets at the following times and method of application.

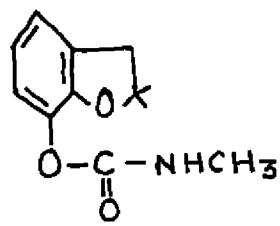
3.1.3. Treatments

Tr. No.	Treatment	Rate (kg ai/ha/ application)	Time and method of application
1.	Carbofuran 3G	0.50	broadcasting at 20 days after transplanting (DAT)
2.	Carbofuran 3G	0.75	,,
3.	Carbofuran 3G	1.00	,,
4.	Carbofuran 3G	0.50	broadcasting at 50 DAT
5.	Carbofuran 3G	0.75	,,
6.	Carbofuran 3G	1.00	,,
7.	Carbofuran 3G	0.50	broadcasting at 20 and 50 DAT
8.	Carbofuran 3G	0.75	,,
9.	Carbofuran 3G	1.00	,,
10.	Untreated control		

3.1.4. Test insecticide

The details of the test insecticide carbofuran are given in Table 1 (Anon., 1987b).

Table 1. Details of insecticide used in the experiment

Property	Test insecticide details
Generic name	Carbofuran
Trade names	Furadan, FMC 10242, Curaterr; Yaltox; Bay 70143; Pillarfuran; Kenofuran
Chemical family	Carbamate
Formulation in common use	Three per cent granules
Chemical name	2,3-dihydro-2,2-dimethyl-7-benzofuranyl N-methyl carbamate
Structural formula	
Molecular formula	$C_{12}H_{15}NO_3$
Molecular weight	221.25
Physical form	Colourless crystals
Melting point	153-154°C (pure); 150-152°C (technical)
Vapour pressure	2.7 mPa at 33°C
Specific gravity	1.18 at 20°C
Stability	Unstable in alkaline media. Stable in acidic and neutral media
Solubility	Fairly soluble in water. Soluble in most organic solvents. Barely soluble in xylene and petroleum ether.
Acute oral LD_{50} (rats)	8.2-14.1 mg/kg
Acute dermal LD_{50} (rats)	120 mg/kg
Maximum Residue Limit	0.20 ppm in rice wholegrain 1.00 ppm in straw

The chemical was supplied by M/s Rallis India Ltd., Bangalore.

3.1.5. Insectary studies on the effect of carbofuran on feeding rate, mortality, duration and sex-ratio in *C. medinalis* larvae/pupae/adults

For these studies, cages made of 175 micron thick mylar films (supplied by M/s Garware Plastics and Polyester Ltd., Bombay) were used. The sheets were cut to appropriate size and rolled over two heavy aluminium wire rings (25 cm diameter) kept on the upper and lower sides of the cage (Plate IV). The aluminium wire rings were held in position by glueing with fevicol SR-998 and by stitching them to the cage, using thread. The height of the cage was 70 cm and the top was covered by nylon net cloth which was held in position by fevicol SR-998. A side sleeve was provided as that of ovipositional cage (Section 3.1.1). To reduce mortality of larvae that fall into water film in the bucket, a 175 micron thick circular (25 cm diameter) mylar film disc was placed above the bucket surface around the plant base.

The buckets containing treated plants were arranged in Randomized Block Design on a cement platform, the sides of which were slightly raised to hold water. Three sets of such plants served as replications. A duplicate set of treated plants were also maintained in the experiment to draw out larvae of the required instars in order to make compensatory releases to provide for those larvae which succumbed to the treatments and natural mortality.

PLATE III. Oviposition cage for *C. medinalis* adults (with sleeve)

PLATE IV. Cage used for studies on feeding rate, mortality, duration and sex-ratio of *C. medinalis*

PLATE III

PLATE IV

Thirty freshly emerged first instar larvae from the culture reared in the insectary were released on the foliage of treated and untreated plants in the buckets. After a few minutes of release, the plants were carefully covered with mylar film cage. An wooden stake was provided inside the bucket to prevent dislodging of the cages. Before release of first instar larvae the weight of 20 larvae were recorded on a high precision Sartorius 2462 model balance.

The first instar larvae mainly concentrated on the base of the tender leaves and the feeding was in narrow streaks (Plate V). These larvae were observed carefully every day. On the third day morning, a good number of larvae moulted to the second instar. The moulting of first instar larvae to second instar was easily identified by the colour difference of the head capsule. In first instar, the head capsule is black while in the second instar the colour changed to light brownish. Weight of 20 freshly emerged second instar larvae were recorded before transfering the larvae to fresh treated plants. The time of emergence of each instar was noted for computing the duration of each larval instar. On emergence, the second instar larvae were transferred to a new set of plants. The larvae which moulted on the third day were also transferred to the new set of plants. From the number of second instar larvae thus transferred, the mortality/ survival of first instar larvae was recorded. After recording the mortality in first instar, so much number of freshly emerged second instar larvae were released on to the new plants from the reserve plants which received similar treatments. The plants which were provided for first instar larval development were then examined for the

PLATE V. Feeding injury caused by the first instar larvae of *C. medinalis*

PLATE V

length of leaf fed using a scale marked in millimeters under a stereomicroscope at 14 X magnification. Each linear scraping was measured separately and the total length of leaf thus fed by 30 larvae was measured. The mean leaf length fed by a single larva was worked out from this data.

After transferring the second instar larvae to fresh plants, the larvae were observed for moulting to the third instar, on the second, third and fourth days of release of the second instars. Twenty numbers of freshly emerged third instar larvae were weighed, emergence time noted and were then transferred to fresh plants. The area of leaf damaged by second instar larvae were also recorded. Compensatory releases were made for the third instar also. From the number of larvae of third instar shifted to fresh plants the mortality/survival of larvae in the second instar could be obtained.

The process of recording of weight of freshly emerged larvae, transferring of larvae, compensatory releases and measurement of leaf area damage was done for all the instars up to the sixth instar larvae. The mortality/ survival of each instar and the duration of each instar were also recorded and the mean values worked out for all the above parameters. The observations on the above parameters relating to the third instar larvae were taken on the third and fourth days after transferring of the third instar larvae. Similarly, for the fourth instar, observations were taken on the third and fourth days after shifting of the fourth instar stages. Observations on the fifth instar larvae were recorded on third, fourth and fifth days of transferring of the fifth instar and of the sixth instar larvae on the fourth and fifth days of transferring sixth instar to fresh plants.

The different instars of the larvae (Plate VI a to f) were identified primarily by the moulted head capsule within the leaf folds by carefully opening the leaf folds using a fine pointed bamboo pick and examining the leaf using a 10 X hand lens. The light colour of the head capsule of the freshly moulted larvae also helped in the identification of different larval instars. As the sixth instar larvae attained a prepupal stage of about 24 hours before pupation, the observations on duration, mortality/ survival and feeding were recorded before this stage. In the prepupal stage there was no feeding by the larvae and they excreted more faecal matter and the size of larvae were reduced. On the fourth day of pupation all the pupae were collected and weight of 20 pupae recorded. The pupae were then kept in petridishes (9 cm diameter) placed in cages for emergence. The time of emergence of adults were recorded and from that the pupal period worked out. The emerged adult moths were sexed and the sex ratio was determined. From the total number of moths emerged from each treatment, the per cent mortality of pupae were also determined.

3.1.6. <u>Recording of leaf area damage</u>

For recording leaf area damage a new simple technique was developed and adopted. For this, an open wooden box of size 30 x 30 x 30 cm with a glass plate provided on the upper open area was used (Plate VII). The box was provided with a side opening through which a 40 watt clear electric bulb and holder were inserted and kept mounted in

PLATE VI. Larval stages of _C. medinalis:_

A. First instar

B. Second instar

C. Third instar

D. Fourth instar

E. Fifth instar

F. Sixth instar

PLATE VI

A

B

C

D

E

F

such a manner that the bulb faced the glass plate and was 10 cm below the glass plate. The bulb was energised through a table lamp kept near the box. For measuring the leaf area damaged by the leaf folder, the infested leaves were unrolled and kept flat on the glass plate. If the length of damaged leaf was more than the size of the glass plate, it was cut into bits and measurements taken separately. The unrolled leaves were held in flat position by keeping another thin glass plate over the leaves. A graph sheet (25 x 25 cm) was photocopied on a 125 micron thick mylar film sheet and this transparent printed sheet was superposed over the two glass plates and the sandwitched damaged leaf. The area damaged was measured by counting the number of squares of the graph sheet over the damaged portion of the leaf in mm^2

3.1.7. Study on the F_1 progeny production

For this study, adult moths emerging from pupae collected from the previous study (Section 3.1.5) were utilised. Five pairs of moths each from different treatments were released on untreated 60 day old plants in the ovipositional cages, for egg laying. The treatments were arranged in RBD. Three replications were maintained here also. The collection of eggs was made as already explained in section 3.1.1. The collected eggs were counted on each successive day for a total of eight days in all ie., till all the adult moths died in the oviposition cage. From this, the total number of eggs laid by five females were obtained and the mean number of eggs laid by single female was thus worked out.

After counting the eggs, the plant tissue along with eggs were placed in petridishes (9 cm diameter) containing moistened filter paper disc. The petridishes were placed in an incubator kept at 23±1°C for egg-hatching. On the third and fourth days, the number of first instar larvae which emerged from each treatment were counted and the total emergence of the first instar larvae in each treatment worked out. From these values the per cent hatching and per cent mortality of eggs in F_1 generation were determined.

3.1.8. Study of ovipositional potential of moths on treated plants

Five pairs of freshly emerged moths reared out in section 3.1.1 were released on treated plants kept in ovipositional cages for egg laying. The treatments were arranged in RBD. The oviposition cages have been described in section 3.1.1. Fresh treated plants were provided every two days and old plants were removed for collecting eggs. The plants were taken out and kept inside the cages after removing the moths carefully from the cage and were then released into the same cage. By thinning, the number of tillers was kept at five to six per treatment. The plants kept for egg laying were prepared as detailed in section 3.1.2. Four sets of treated plants were kept for periodical replacement. The first release of moths was on plants at 60 DAT. The eggs laid on every two days were counted on successive days for a total of eight days. From the total number of eggs laid in each treatment mean fecundity per female on treated plants was calculated.

3.1.9. Study of ovipositional preference on treated plants

The adult moths required for this experiment were obtained from the stock culture maintained (section 3.1.1) and the treated plants were maintained as in section 3.1.2. The treated plants were tinned to five to six tillers/treatment before using in the experiment. Four such sets of plants were used for changing plants on every two days.

The study was conducted in a cage made out of a wooden frame-work (Plate VIII) of 125 cm length, 50 cm width and 60 cm height. The entire frame-work was fully covered with a polythene cover (1200 guage) of the correct size so that the cover snugly covered the frame-work when put over. Nylon mesh ventilators of 10 cm diameter were provided on all sides of the cage. For getting access into the cage, a vertical cut was given on one side of the polythene hood. For inserting plants, the flap thus provided on the hood was lifted. The flap was kept closed by means of threads stitched on the cut ends of the flaps. There were three such cages each of which served as one replication. Ten buckets holding the plants belonging to each treatment were arranged in RBD inside each of the cage.

Freshly emerged moths from the stock culture were carefully released at the rate of 10 pairs/treatment into the cage. Feeders as described in section 3.1.1 were placed in each treatment. The plants and the cages were placed in moistened river sand spread on a cement platform inside the insectary. The leaves of the plants drooped from the top of the cage. The first set of plants were

PLATE VII Contrivance used for recording the leaf area damage by *C. medinalis* larvae

PLATE VIII Chamber used for assessing the ovipositional preference of *C. medinalis* in the multiple-choice test

PLATE VII

PLATE VIII

removed after two days of release of the moths and a fresh set of plants were provided. The removal and replacement of plants were done every two days for a total of eight days. The eggs laid on leaf as well as leaf sheath and culm were counted and the total number of eggs laid on each treatment was worked out at the end of eight days.

3.2. Biophysical Studies

3.2.1. Length of leaf

These observations were recorded from plants grown as described in section 3.1.2 in the insectary. The length of leaf was recorded at 60 DAT in healthy plants. The plants which were used for measuring length of leaf were also used for determining other biophysical and biochemical aspects. The leaf length was measured from the base of the leaf blade to the tip of the leaf using a meter scale. In each treatment, first, second and third leaves of 10 primary tillers were measured separately. The mean leaf length in each treatment was worked out from this for the three replications of the treatments.

3.2.2. Width of leaf

The leaf width was measured using a 30 cm transparent acrylic scale at the point of maximum width of selected leaves.

3.2.3. Height of plants

The maximum height of plants in each treatment (replication-wise) was recorded at 60 DAT using a wooden meter scale. Three sets of such observations were recorded. The height measurement was taken from soil level to the tip of the tallest leaf. From the three sets of observations recorded for each replication, the mean values were worked out.

3.2.4. Thickness of leaves

The thickness of 30, first, second and third leaves were measured using a vernier micrometer for each treatment and the mean thickness worked out in micrometer (μ).

3.2.5. Study of cross-section of leaf

Transverse sections of leaves of plants drawn from various treatments were taken for measuring the thickness of upper epidermis, lower epidermis, vascular bundle including bundle sheath, mesophyll, bulliform cells and the fibrous patch below upper epidermis as well as the total thickness. For this, 10 number of second leaf from the primary tillers of plants in each treatment were excised from plants at 60 DAT. These leaves were tied together loosely and kept immersed in water in a tray. The treated and untreated plants from which the leaves were taken for the study were raised as detailed in section 3.1.2. For taking sections, bits of leaf blade from the centre of the leaf excluding the midrib was taken. The leaf bits for the study were taken from the same leaf margin of all the leaves to avoid the thicker veins on one side of the leaf blade. Leaf sections were taken after keeping the leaf bits within vertically cut slits in unripe papaya fruit bits. The sections were then put in distilled water taken in petridishes. Thin sections were selected from water and transferred to diluted safranin red stain contained in small glass pollen dishes for staining. After about two minutes of staining, the sections were again transferred to distilled water in a glass pollen dish, using a fine pointed camel hair brush and a fine pointed bamboo pick to remove excess stain on the section.

A clear microscopic glass slide was taken and a small drop of 25 per cent glycerol was placed at the centre of the slide. Using a fine pointed bamboo pick, the leaf section was placed in the glycerol drop on glass slide and mounted with a cover glass. Excess glycerol if any was removed with blotting paper.

The thickness of each tissue layer in cross section and the total thickness were measured using an ocular micrometer kept in the eye piece of the microscope. The measurement was taken from the portion where there was maximum thickness for the vascular bundle and from either side of it on the section using a 10 X eye piece and 45 X objective. The thickness measured in ocular units were then converted to micrometer (μ) by multiplying the ocular reading with the conversion factor found out by coinciding the ocular and stage micrometers at the same magnification in the microscope. In the experiment, one division on ocular micrometer was found to be 2.0 μ on stage micrometer. Thus all the leaves were measured and the mean data from 10 leaves in each treatment was worked out for statistical analysis.

3.2.6. Counting of leaf hairs/unit area

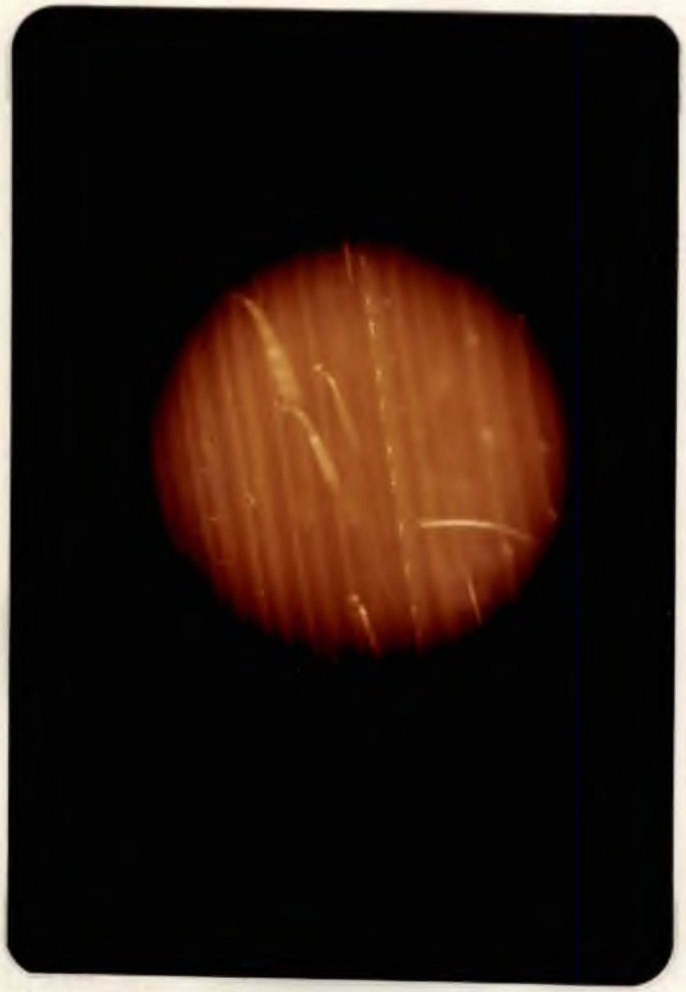
The samples of first, second and third leaf from the treatments and replications were excised from the primary tillers of the plants grown as detailed in section 3.1.2. Ten leaves each of first, second and third leaves were collected from each treatment and loosely tied together after labelling. The leaf bundles were kept immersed in water in a metal tray. Leaf bits of about 4 cm length were then taken from the middle portion of the leaf and only from that side of the lamina where the thickness of parallel veins were relatively lesser.

The leaf bits were put in a long test tube (15 cm long and 2.5 cm diameter) and 10 to 12 ml of lactophenol was added and it was then boiled for about one minute to remove the wax layer on leaf lamina and to reduce the dark green colour of leaf lamina so that the leaf hairs would become prominent on the leaf surface. After boiling, the contents were cooled and the lactophenol was removed by repeated washing in distilled water. The leaf bits were then transferred to petridishes containing distilled water.

Two drops of 25 per cent glycerol was placed on a clear glass slide and the leaf bit was then placed on it with the upper side exposed and gently pressed to remain flat on the glass surface. The leaf hairs (Plate IX) were then counted using a GSZ-77 model Getner make zoom stereo microscope using a 2 X supplementary objective and a 20 X eye piece at the 2 X zooming position to give 80 X magnification of the leaf bit/leaf hairs clearly. The hairs visible in one field of the microscope were then counted and recorded.

PLATE IX Disposition and density of laminar leaf hairs (80 X)

PLATE IX



At the above magnification, the field diameter of sight through the microscope was 2.82 mm. From this value the area of actual field was worked out and the number of leaf hairs per cm^2 was worked out as follows:

$$\text{No. of leaf hairs/cm}^2 = \frac{\text{No. of hairs counted in microscopic field}}{\text{Area of microscopic field in mm}^2} \times 100$$

The number of leaf hairs/unit area was thus worked out for all the leaves and the mean of 10 leaves were taken for statistical analysis.

3.2.7. Measurement of length of leaf hairs

The preparation of leaf samples for measuring length of leaf hairs was done as detailed in section 3.2.6. The leaf bit was then folded horizontally and placed on glass slide and gently pressed with fingers to the glass slide to prevent unfolding of the leaf. The leaf was observed along the fold at a magnification of 40 X using a GSZ-77 model Getner make zoom stereo microscope and the length of hairs was measured from the base in the fold to the tip. A total of 50 hairs each from the first, second and third leaves of plants in each treatment were measured as already explained in the previous section.

3.3. Biochemical analysis of leaf samples

The leaf samples drawn at 60 DAT from plants grown as in section 3.1.2 were assayed for the following biochemicals adopting the standard methods mentioned.

Organic carbon (ISI, 1964)
total nitrogen by Microkjeldahl method (AOAC; 1960),
chlorophyll 'a', chlorophyll 'b' and chlorophyll a+b (Sertak, 1966),
total carbohydrates as starch and total sugars (Jose,1979) and
silica (Nayar *et al*., 1975).

Chlorophyll was determined on fresh weight basis and the other constituents on dry weight basis. The crude protein content of the leaf samples were determined from the total nitrogen estimated.

3.4. Estimation of carbofuran residues and metabolites in leaf samples

The residues and metabolites of carbofuran in leaf samples at 60 DAT were estimated by modifying the methods described by Gupta and Dewan (1971) and Siddaramappa and Watanabe (1979).

3.4.1. Preparation of leaf extract

Twenty five grams of fresh leaf sample was chopped to small bits and were transferred to a 250 ml boiling flask to which was added 150 ml of 0.25 N HCl. The contents were boiled for about one hour while refluxing, after which it was cooled to room temperature. It was then filtered through glass wool. Additional quantity of 0.25 N HCl was used to rinse the walls of the condenser and the filter cake. To the filtrate, 5 g of NaCl was added to check the formation of emulsion and transferred it to a 500 ml separating funnel. Aqueous sodium lauryl sulphate solution was added to break emulsions present, if any. Added 40 ml of methylene chloride and shaken for two minutes. Then the lower layer of methylene chloride was collected by passing through a funnel containing anhydrous sodium sulphate and activated charcoal over cotton to remove moisture and coloured substances present. The extraction was repeated with 40 ml each of methylene chloride twice and it was dried in 125 ml bottles containing sufficient quantity of anhydrous sodium sulphate and stored at 4°C in a deep freeze.

3.4.2. Preparation of chromatogram

Thirty grams of silica gel G. was shaken with 60 ml of distilled water for two minutes. The slurry was spread on glass plates of 20 x 20 cm size by the applicator to provide a 300 μ thick silica gel layer. Plates were allowed to set for three hours at room temperature and then activated by keeping them in an air oven maintained at 100°C for one hour.

3.4.3. Developing of the chromatogram

The organic extract stored at 4°C was taken out and brought to room temperature and then filtered through whatman No.1 filter paper containing anhydrous sodium sulphate and the filtrate collected. The extract was then evaporated to about 10 ml in a 250 ml flask. The contents were then transferred to 50 ml graduated test tubes and again dried by repeated washing down of the contents to the base of the tube. Before complete drying of methylene chloride, a small quantity of methanol was added to the extract.

The residues in the extract was spotted on the silica gel plates after concentration, 3 cm apart alongside authentic compounds of carbofuran and metabolites carefully. The residue in the extract was thus quantitatively spotted on silica gel plates. The residues were then separated to a distance of 15 cm by employing ether-hexane (3:1 v/v) as a solvent system. The authentic compounds were then detected by spraying 2 N NaOH in absolute methyl alcohol and then with a solution of p-nitrobenzene diazonium tetrafluoroborate (5 mg dissolved in 25 ml of absolute methanol + 25 ml of diethyl ether).

Silica gel areas opposite to authentic compounds were scrapped off into centrifuge tubes carefully. Carbofuran compounds in the silica gel was allowed to react with 1.25 ml of 0.3 per cent sodium nitrite solution, 1.25 ml of 0.2 per cent sulfanilic acid in one normal HCl and 2.5 ml of 4 N NaOH in a boiling water bath for 20 minutes. After cooling, silica gel was removed by centrifugation at 5000 rpm and the supernatent was made up to 10/20 ml depending on colour intensity prior to colorimetric analysis at 490 nm in a Spectronic 20 spectrophotometer. From the absorbance values obtained, the concentration of the residues and the metabolites were calculated based on the standard curve prepared using standard compounds and represented in µg/g of leaf.

3.4.4. Preparation of standard curve

Standard solutions of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl N-methyl carbamate), 3-hydroxy carbofuran (2,3-dihydro-2,2-dimethyl-3-hydroxy-7-benzofuranyl N-methyl carbamate), 3-keto carbofuran (2,3-dihydro-2,2-dimethyl-3-keto-7-benzofuranyl N-methyl carbamate), 7-phenol (2,3-dihydro-2,2-dimethyl-7-benzofuranol), 3-hydroxy-7-phenol (2,3-dihydro-2,2-dimethyl-3, 7-benzofurandiol) and 3-keto-7-phenol (2,3-dihydro-2,2-dimethyl-3-oxo-7-benzofuranol) in methanol containing 40 µg/ml and 100 µg/ml were prepared from stock solutions containing 1000 µg/ml (the standards were supplied by M/s Rallis India Ltd., Bangalore). Zero, 0.25, 0.50, 1.00, 1.5, 2.0 and 2.5 ml of stock solution containing 40 µg/ml and 1.6 ml of the stock solution containing 100 µg/ml of each of the standards were transferred into separate test tubes using a microburette to give 0, 10, 20, 40, 60, 80, 100 and 160 µg/ml of the standards. The preparation and developing of the chromatogram using the standards were done as described in section 3.4.2 and 3.4.3. The standard curves were prepared for each standard material by plotting the concentration on X-axis and absorbancy on Y-axis. The detectable levels of carbofuran, 3-OH carbofuran, 3-CO carbofuran, 7-phenol, 3-OH-7-phenol and 3-CO-7-phenol were 0.09, 0.07, 0.18, 0.07, 0.03 and 0.10 µg/ml, respectively.

3.5. Estimation of carbofuran residues and metabolites in straw

The residues and metabolites of carbofuran in straw were estimated after drying of the straw in the sun for two days after harvest of the field crop during the kharif and rabi seasons. The procedure followed for leaf samples was followed for straw also (sections 3.4.1, 3.4.2 and 3.4.3).

3.6. Estimation of carbofuran residues and metabolites in whole grain

The harvested grains from different treatments for the kharif and rabi experiments were dried to 14±1 per cent moisture. The grain samples were smashed in a mixer. Fifty grams of smashed grains from each treatment were hydrolysed with 0.25 N HCl and extracted in methylene chloride as described in section 3.4.1. Acetonitrile-hydrocarbon partition technique described by Jones and Riddick (1952) was used for removing the fatty materials from grain sample extracts. The method is detailed below.

The methylene chloride extract was concentrated and to that 50 ml acetonitrile was added and concentration operation continued to remove the methylene chloride. The solution was then transferred into 250 ml separating funnel. It was then extracted twice with 30 ml each of hexane saturated with acetonitrile. The hexane layer was discarded and acetonitrile portion concentrated to less than 5 ml. Again, it was transferred to 250 ml separating funnel. 100 ml of 0.25 N HCl was added and extracted thrice with 50, 25 and 25 ml each of methylene chloride and stored in 125 ml bottles containing anhydrous sodium sulphate. Further processing and colour determination were carried out as described in sections 3.4.2 and 3.4.3.

3.7. Recovery experiment

Twenty five grams each of leaf, straw and grain samples from untreated rice plants were fortified at the rate of 2, 4, 6, 8 and 10 μg/g of carbofuran and its metabolites except 3-OH-7-phenol which was fortified at 1, 2, 3, 4 and 5 μg/g of leaf, straw and grain samples and kept overnight. The samples were then extracted and determined using thin layer chromatographic and colorimetric techniques described earlier. The recovery percentages for each chemical in leaf, straw and whole grain samples were worked out and presented (Appendix-I).

3.8. Field experiments to study the effect of different rates and timings of application of carbofuran on *C. medinalis* resurgence

Two field experiments were conducted; one in the late kharif and the other in the rabi seasons of 1989 at the 'palliyal' (single crop) and wet lands (double crop) of Regional Agricultural Research Station, Pattambi, respectively. The plots that were not applied with carbofuran for the past four years were selected for the experiments. The 'palliyal' soil was lateritic-loamy and the wet lands were alluvial. The soil pH was around 5.5 in both fields. For both the experiments, the details of operations such as treatments, variety, fertilizer, cultural operations and observations were the same.

3.8.1. Lay out of the experiment

Jaya seedlings (24 days old) were transplanted at two seedlings/hill with a spacing of 15 x 15 cm. The gross plot size was 4.5 x 4.35m^2 with inter-plot alley-ways of 1.0 m width all around each plot. The plots were protected by raised bunds to control water and to prevent loss of the chemical applied through surface run off. Randomized Block Design with three replications was adopted for the experiment. The fertilizer dosage was 100:45:45 kg/ha of N P K applied in split doses. A higher dose of N was applied to induce the *C. medinalis* damage in the plots. Various operations as recommended in the Package of Practices Recommendations (Kerala Agricultural University, 1986) were adopted.

A border strip crop of 3 m wide of Jaya variety was grown around the experimental field, 15 days ahead of the experimental crop and was given heavy nitrogen doses. The strip crop was treated with phorate 10 per cent granules at 1.0 kg ai/ha at 10 and 30 DAT for resurgence induction. The strip crop was grown to accelerate C. medinalis populations to ensure that the experimental crop gets heavy infestation.

3.8.2. Treatments

The treatments in the field experiments were as in section 3.1.3.

3.8.3. Observations

In the field experiments the following observations were recorded: damage by leaf folder, stem borer, gall midge and whorl maggot at different days from 20 hills based on the leaf damage in the case of leaf folder and whorl maggot to total leaves and based on tiller damage in the case of stem borer and gall midge to total tillers using a random sampling method and were converted to per cent damage.

Plant growth attributes such as plant height at flowering, number of tillers at flowering, number of tillers at harvest and productive tillers at harvest from 20 hills selected randomly within each plot, the length and width of first three leaves separately from 20 primary tillers from each plot and from the mean values the mean leaf area of first three leaves separately, the mean of first three leaves together and the total leaf area of the first three leaves within the net plot were worked out before statistical analysis, the leaf area damaged by C. medinalis larvae from 20, first, second and third leaves as detailed in section 3.1.6 and the mean damage for the first three leaves worked out and the yield attributes such as mean length of earhead, weight of 10 panicles of main tiller, total grains per earhead, grain yield, straw yield, number of filled grains per earhead, half filled grains per earhead and chaff per earhead along with 1000 grain-weight of filled grains, half-filled grains and chaff were recorded. The percentage of filled grains, half-filled grains and chaff to total grains was also worked out.

3.9. Statistical analysis

The different observations recorded were given appropriate transformations whenever necessary and the data collected from the experiments were subjected to analysis of variance and the treatment means were compared by DMRT following Gomez and Gomez (1984). The observations which showed more number of zero values for the treatments were not analysed statistically. The factors which showed influences on the different growth, development, survival or reproduction were then subjected to correlation and regression analysis and such of the data which showed significant correlation with the tested parameters alone were selected for conducting path coefficient analysis. The effects of rates and timings of carbofuran application on the different parameters were assessed in terms of per cent increase over control and graphically depicted.

Results

4. RESULTS

4.1. INSECTARY STUDIES

4.1.1. Studies on the effect of carbofuran on feeding rate, growth rate, mortality, duration and sex-ratio of *C. medinalis* eggs/larvae/pupae/adults

4.1.1.1. Effect on rate of feeding by different larval stages

The data on the rate of feeding by the different larval stages of the rice leaf folder, *C. medinalis* and the results of statistical analysis are presented in Table 2.

The linear area fed by the first instar larvae and the mean leaf area consumed by the second, third, fourth, fifth and sixth instar larvae did not show any significant variations between treatments and untreated control. The maximum feeding of the larvae was noticed in the case of the fourth instar larvae, followed by third, second, fifth and sixth instars. The mean leaf area fed by the fourth, third, second, fifth and sixth instar larvae were 371.40, 316.23, 58.31, 32.12 and 4.99 mm^2, respectively, the mean length of the lamina scraped by the first instar larvae being 21.94 mm.

4.1.1.2. Effect on weight of different stages of larvae and pupae

The data relating to the influence of carbofuran treatments on the weight of larvae and pupae and the results of statistical analysis are presented in Table 3.

Table 2. Effect of different rates and timings of carbofuran application on length/area of leaf fed by different larval stages

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Mean length fed by I instar (mm)	Mean leaf area fed (mm^2)				
				II instar	III instar	IV instar	V instar	VI instar
Carbofuran 3G	0.50	20	21.45a	52.78a	304.85a	311.64a	32.11a	3.16a
,,	0.75	,,	25.03a	70.24a	296.34a	362.90a	30.73a	2.15a
,,	1.00	,,	23.24a	51.72a	285.44a	350.40a	24.70a	7.00a
,,	0.50	50	21.01a	62.82a	334.83a	364.22a	41.96a	6.35a
,,	0.75	,,	19.67a	58.66a	339.87a	435.56a	33.23a	3.69a
,,	1.00	,,	22.21a	59.18a	335.44a	353.94a	35.11a	6.52a
,,	0.50	20&50	25.14a	67.36a	324.23a	336.14a	32.84a	4.74a
,,	0.75	,,	20.84a	55.41a	311.12a	420.00a	24.32a	8.23a
,,	1.00	,,	19.97a	46.65a	333.02a	369.20a	25.90a	4.65a
Untreated control			20.80a	58.30a	297.16a	410.04a	40.28a	3.43a
Mean			21.94	58.31	316.23	371.40	32.12	4.99

Means followed by a common letter in a column are not significantly different at 5 per cent level (DMRT)

There was no statistical difference among treatments in the weight of first and second instar larvae. In the third instar, the highest larval weight was recorded in the carbofuran treatment @ 0.50 kg ai/ha applied at 20 and 50 DAT (167.37 mg), followed by treatments receiving carbofuran at 0.75 (164.47 mg) and 1.00 (163.70 mg) kg ai/ha applied at 20 as well as at 50 DAT, respectively. These treatments however did not differ significantly. In all the above treatments, larval weights were significantly higher than that in the untreated control as well as the weights recorded in other treatments given. The applications of different doses of carbofuran at 20 DAT and 50 DAT were not significantly different and were on par with untreated control. It is thus found that application of carbofuran at 20 and 50 days after planting at all the levels tested led to increase in the weight of third instar larvae feeding on treated plants. Single application of carbofuran had no effect on the weight of third instar larvae.

In the case of the fourth instar larvae also, the effect of carbofuran treatments was quite similar. The larval weight of insects fed on plants which received 1.00, 0.75 and 0.50 kg ai/ha of carbofuran at both 20 and 50 days were 226.87, 216.70 and 210.07 mg, respectively, while the larval weight in untreated control was 185.13 mg. In respect of larval weight at fourth instar all the other treatments were on par with untreated control.

In respect of the fifth instar larvae, their weight in treatments of 0.75 and 1.00 kg ai/ha applied at both 20 and 50 days,only were higher than untreated control, their

Table 3. Effect of different rates and timings of carbofuran application on the weight of larvae of different stages and pupae

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Weight of 20 larvae (mg)						Weight of 20 pupae (mg)
			I instar	II instar	III instar	IV instar	V instar	VI instar	
Carbofuran 3G	0.50	20	19.90a	49.80a	136.50b	183.73c	443.93c	505.57d	514.60b
,,	0.75	,,	19.87a	48.57a	135.43b	182.97c	453.00bc	515.78cd	540.20a
,,	1.00	,,	20.50a	49.77a	139.23b	181.87c	447.67c	489.23d	455.11c
,,	0.50	50	20.43a	50.90a	143.73b	187.93c	463.07abc	510.03cd	453.10cd
,,	0.75	,,	20.10a	50.03a	146.90b	195.03bc	456.50bc	528.60bcd	443.23de
,,	1.00	,,	20.37a	51.73a	143.37b	199.00bc	461.17abc	525.20bcd	436.20e
,,	0.50	20&50	20.67a	51.53a	167.37a	210.07ab	479.30abc	546.80abc	453.61cd
,,	0.75	,,	21.20a	52.90a	164.47a	216.70a	502.03a	562.67ab	453.44cd
,,	1.00	,,	20.93a	52.63a	163.70a	226.87a	493.83ab	575.67a	453.20cd
Untreated control			20.40a	48.57a	139.17b	185.13c	447.87c	515.40cd	419.30f

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

mean weights being 502.03 and 493.83 mg, respectively, as compared to untreated control in which the mean weight was 447.87 mg. However, these two treatments were on par with application of 0.50 kg ai/ha both at 20 and 50 days and 0.50 and 1.00 kg ai/ha applied once at 50 days after planting (Table 3). All the doses applied once either at 20 DAT or at 50 DAT and treatment of 0.50 kg ai/ha both at 20 and 50 DAT were on par with untreated control.

In the case of sixth instar larval weight, even though all the treatments applied both at 20 and 50 DAT were on par, the carbofuran treatments at 0.75 and 1.00 kg ai/ha only led to increase in larval weight as compared to untreated control. The larval weight (n=20) in carbofuran treatments at 1.00, 0.75 and 0.50 kg ai/ha applied at both 20 and 50 DAT were 575.67, 562.67 and 546.80 mg, respectively, as compared to 515.40 mg recorded in untreated control.

The weight of pupae in all the carbofuran applied treatments were significantly higher than in untreated control, the maximum weight being in the treatment at 0.75 kg ai/ha applied at 20 DAT (540.20 mg) and the lowest in untreated control (419.30 mg). In the treatments of 0.50, 0.75 and 1.00 kg ai/ha applied at 20 DAT, the pupal weights were higher being 514.60, 540.20 and 455.11 mg, respectively. In the treatments which received carbofuran at 0.50, 0.75 and 1.00 kg ai/ha twice and 0.50 kg ai/ha at 50 DAT, the pupal weights were 453.61, 453.44, 453.20 and 453.10 mg, respectively and these were on par with each other.

The maximum increase of weight of pupae over control was in the treatments at 0.75 and 0.50 kg ai/ha, the increase being 14.2 and 13.0 per cent respectively (Fig.1). In the third instar larvae, the increase in weight due to rate of application was of a lower order. Highest increase in weight in the fourth instar larvae was in the treatment receiving carbofuran at 1.00 kg ai/ha (9.3 per cent), followed by the lower doses of 0.75 and 0.50 kg ai/ha in that order. In the fifth and sixth instar larvae, maximum increase in weight over control was at the dose of 0.75 kg ai/ha and the increase rates were 5.1 and 3.9 per cent in fifth and sixth instar larvae, respectively.

In the third, fourth, fifth and sixth instar larvae, the influence of timing of application of carbofuran on increase in weight over control was positive for 50 DAT and 20 as well as 50 DAT applications. For the 20 DAT application, the influence was either negative or almost equal to that in control. In all the larval instars, maximum positive influence on weight was recorded in the carbofuran treatment given twice at 20 and 50 DAT. In the fifth and sixth instars the increase in larval weight was relatively of a lower order as compared to other instars. The increase in weight of third, fourth, fifth and sixth instar larvae over control was 18.7, 17.7, 9.8 and 9.0 per cent respectively. But in pupae, the maximum incremental effect on weight was found under single application given at 20 DAT (20.0 per cent over control), while 50 DAT and 20 as well as 50 DAT applications showed only 5.9 and 8.1 per cent increase in weight over control, respectively.

Fig. 1. Effect of rates of application of carbofuran on weight of larvae and pupae

Fig. 2. Effect of timings of application of carbofuran on weight of larvae and pupae

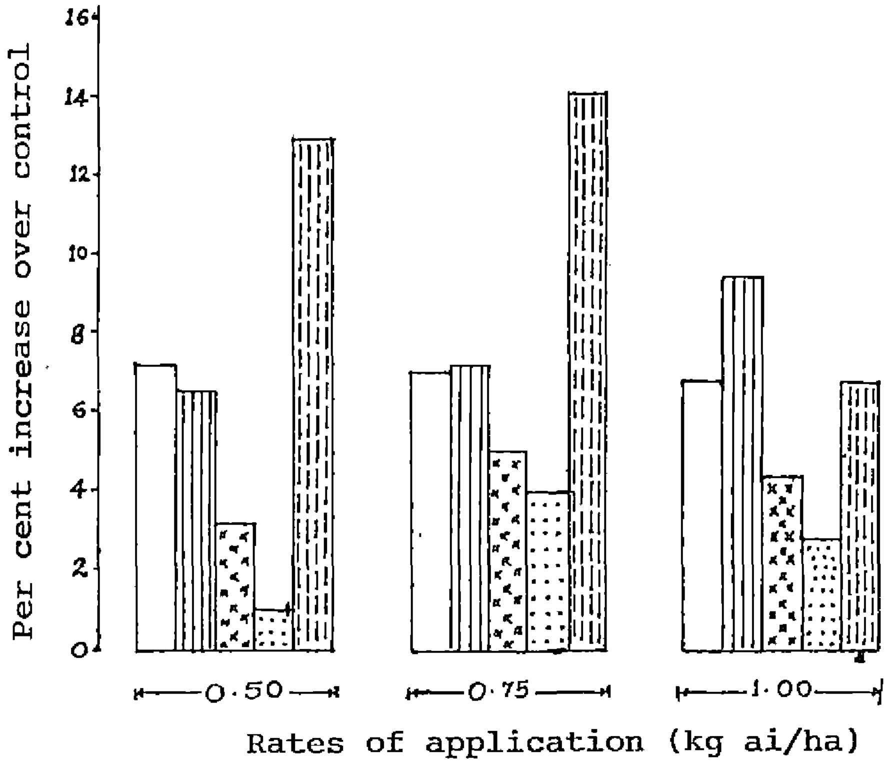


FIG-1

III instar larvae
IV ,, ,,
V ,, ,,
VI instar larvae
Pupae

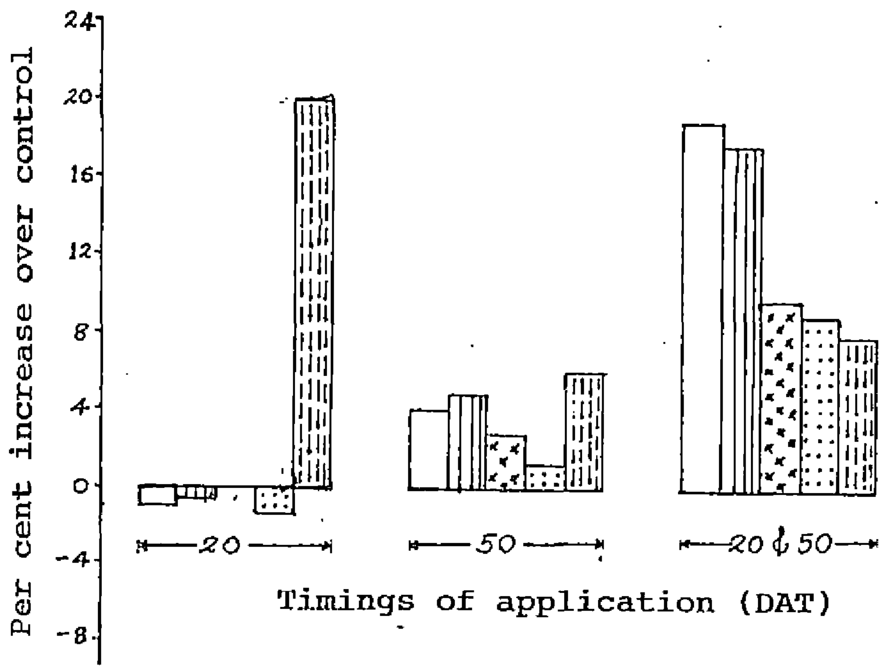


FIG-2

4.1.1.3. Effects on larval and pupal mortality

The data relating to the effect of carbofuran application on the larval and pupal mortality and the results of statistical analysis are presented in Table 4. The mortality in the fifth instar larvae was too low and hence the data could not be analysed statistically.

Among the different larval instars, variation in mortality due to treatments was noticed only in the case of first instar larvae. In the first instar larvae, none of the carbofuran treatments significantly changed the mortality rates as compared to that of untreated control. However, a significant reduction in mortality was noticed in the case of all treatments of carbofuran applied twice at 20 and 50 DAT as compared to that of application given at 1.00 kg ai/ha at 20 DAT (37.67 per cent) and the per cent mortality in the above three treatments were 26.51, 26.69 and 26.09 for 0.50, 0.75 and 1.00 kg ai/ha applied twice, respectively.

The mean larval mortality was significantly less in the dose of 1.00 (36.19 per cent) and 0.75 (39.23 per cent) kg ai/ha applied twice at 20 and 50 DAT than in untreated control (50.36 per cent). But the treatment at 0.75 kg ai/ha applied twice was on par with treatment at 0.50 kg ai/ha given twice, treatments at 0.50, 0.75 and 1.00 kg ai/ha at 50 DAT and treatment at 0.50 kg ai/ha applied at 20 DAT.

There was no significant increase/decrease in the pupal mortality in the carbofuran treatments, as compared

Table 4. Effect of different rates and timings of carbofuran application on the larval and pupal mortality

Treatment	Rate (kg ai/ha)	Time of appli-cation (DAT)	Mean mortality of different instars of larva (%)						Mean larval morta-lity (%)	Mean pupal morta-lity (%)
			I instar	II instar	III instar	IV instar	V instar (Data not analysed statistically)	VI instar		
Carbofuran 3G	0.50	20	35.50ab	14.40a	1.87a	0.76a	0.00	1.87a	47.88ab	7.71ab
,,	0.75	,,	36.60ab	12.95a	5.44a	0.00a	2.22	2.67a	50.70a	9.81ab
,,	1.00	,,	37.67a	15.40a	2.67a	1.54a	0.00	2.67a	50.19a	7.22ab
,,	0.50	50	29.20ab	15.06a	4.33a	0.76a	0.00	0.76a	44.43abc	8.64ab
,,	0.75	,,	28.76ab	15.52a	0.76a	0.76a	3.33	2.67a	46.06abc	11.60a
,,	1.00	,,	31.09ab	13.33a	4.33a	0.76a	0.00	1.36a	44.21abc	7.22ab
,,	0.50	20&50	26.51b	12.17a	0.76a	1.54a	0.00	4.33a	40.44abc	4.32b
,,	0.75	,,	26.69b	9.81a	0.76a	1.87a	0.00	1.87a	39.23bc	6.37ab
,,	1.00	,,	26.09b	11.06a	0.76a	0.00a	1.11	0.00a	36.19c	4.32b
Untreated control			32.63ab	15.26a	4.33a	0.00a	3.33	4.34a	50.36a	10.86ab

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

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to the mortality level in untreated control. The maximum mortality was recorded in the carbofuran treatment at 0.75 kg ai/ha given at 50 DAT (11.60 per cent) and the lowest mortality of 4.32 per cent was in 0.50 and 1.00 kg ai/ha applied twice.

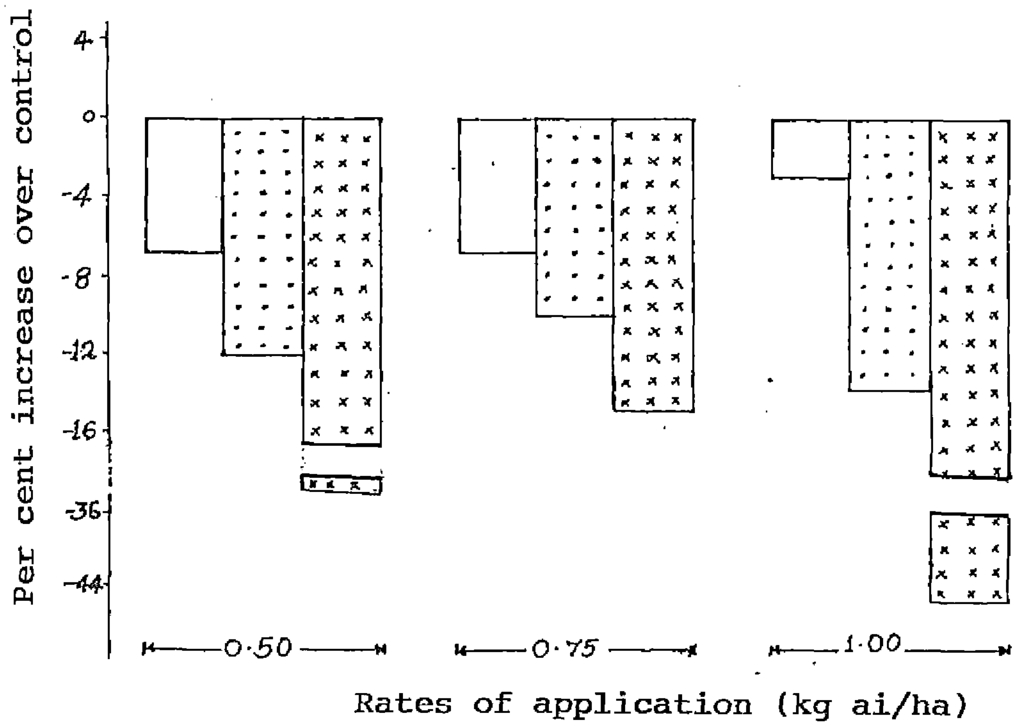
The comparison of the three rates (0.50, 0.75 and 1.00 kg ai/ha) of application of carbofuran with untreated control in terms of the per cent increase/decrease in mortality in the first instar larvae, mean larval mortality and pupal mortality showed a reduction under different levels of carbofuran treatments (Fig. 3). In the first instar larvae maximum reduction of mortality by 6.8 per cent over control was detected in 0.50 kg ai/ha followed by 0.75 and 1.00 kg ai/ha. However, in respect of the mean larval mortality, the reduction over control was highest for 1.00 kg ai/ha followed by 0.50 and 0.75 kg ai/ha in that order, their per cent decrease over control being 13.6, 12.1 and 10.0, respectively. The same trend of reduction in mortality was observed for pupae also. However, the reduction in mortality of pupae over untreated control was highly pronounced in the case of 1.00 and 0.50 kg ai/ha.

The different timings (20, 50 and 20 and 50 DAT) of application of carbofuran also negatively influenced the mortality of first instar larvae, mean larval mortality and pupal mortality except in the case of 20 DAT application on first instar larvae, which increased the mortality by 12.1 per cent over control (Fig. 4). In the case of the larvae and the pupae, the 20 as well as 50 DAT

Fig. 3. Effect of rates of application of carbofuran on larval and pupal mortality

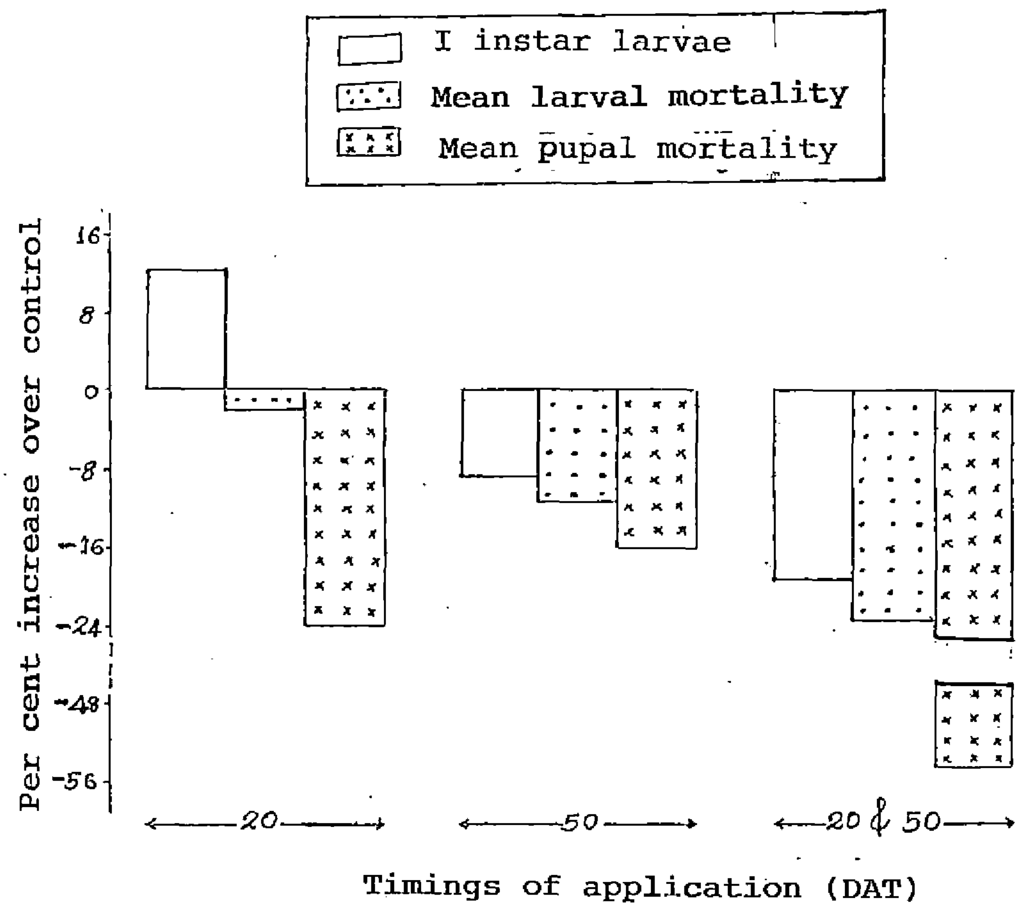
Fig. 4. Effect of timings of application of carbofuran on larval and pupal mortality

FIG-3



Per cent increase over control
4
0
-4
-8
-12
-16
-36
-44
0·50
0·75
1·00
Rates of application (kg ai/ha)

FIG-4



I instar larvae
Mean larval mortality
Mean pupal mortality
Per cent increase over control
16
8
0
-8
-16
-24
-48
-56
20
50
20 & 50
Timings of application (DAT)

application of carbofuran highly reduced the mortality, the maximum reduction (53.9 per cent) being in the pupal mortality. By the 50 DAT treatments, the reduction in mortality of pupae were comparatively less than that by 20 DAT and 20 and 50 DAT applications.

4.1.1.4. Effect on larval and pupal duration

The data on the influence of different rates of carbofuran applied at different timings of crop growth along with the data of untreated control, in the duration of different larval instars and pupal duration and the results of statistical analysis are presented in Table 5.

In respect of the duration of the larvae of different instars there was no significant difference between carbofuran treatments and untreated control of all the larval stages. In the second instar there was slight, but significant variation between treatments. The shortest larval duration of 2.12 days was recorded under carbofuran 0.75 kg ai/ha treatment at 20 DAT and the longest was in the treatment receiving 0.50 kg ai/ha of the toxicant, given both at 20 and 50 DAT, these two treatments being significantly different. The rest of the treatments were on par.

In the case of pupal duration also, all the carbofuran treatments were on par with untreated control which had 5.36 days duration. For pupal stage the shortest duration of 5.21 days was recorded in the carbofuran treatments at 0.50 kg ai/ha on 20 DAT, this

Table 5. Effect of different rates and timings of carbofuran application on larval and pupal duration

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Larval duration (days)						Pupal duration (days)
			I instar	II instar	III instar	IV instar	V instar	VI instar	
Carbofuran 3G	0.50	20	2.02a	2.25ab	3.05a	3.06a	3.38a	4.13a	5.21b
,,	0.75	,,	2.07a	2.13b	3.05a	3.07a	3.43a	4.11a	5.33ab
,,	1.00	,,	2.08a	2.21ab	3.02a	3.07a	3.53a	4.24a	5.35ab
,,	0.50	50	2.09a	2.23ab	2.98a	3.15a	3.36a	4.27a	5.34ab
,,	0.75	,,	2.08a	2.22ab	3.06a	3.08a	3.45a	4.17a	5.32ab
,,	1.00	,,	2.10a	2.21ab	2.97a	3.03a	3.51a	4.21a	5.30ab
,,	0.50	20&50	2.15a	2.30a	3.02a	3.12a	3.46a	4.15a	5.34ab
,,	0.75	,,	2.16a	2.25ab	3.03a	3.18a	3.44a	4.23a	5.32ab
,,	1.00	,,	2.13a	2.25ab	3.05a	3.09a	3.50a	4.21a	5.52a
Untreated control			2.11a	2.23ab	2.97a	3.06a	3.44a	4.17a	5.36ab

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

being on par with all other treatments except the treatment receiving carbofuran at 1.00 kg ai/ha applied twice at 20 and 50 DAT in which case the pupal duration was 5.52 days.

4.1.1.5. Effect on male and female adult emergence and sex-ratio

The data on the male and female adult emergence in *C. medinalis* and the results of statistical analysis are presented in Table 6 and illustrated in Fig. 5 and 6.

The maximum male emergence was recorded in untreated control (57.88 per cent) and this treatment was on par with the rest of the treatments except application of carbofuran at 1.00 kg ai/ha given twice at 20 and 50 DAT which showed the lowest male emergence of 44.17 per cent. With regard to female adult emergence the trend was quite opposite and there was maximum adult female emergence in the treatment receiving 1.00 kg ai/ha twice (55.83 per cent), the emergence being the least in control (42.12 per cent). These two treatments were significantly different from each other but in comparison with the rest of the treatments, were on par. In respect of the female/male ratios, the treatments were all alike.

An analysis of the results for differential rates of application of carbofuran showed that there was a decrease in male emergence upto 16.4 per cent over untreated control at increasing dosage rates (Fig. 5) while in respect of the female emergence there was a spectacular increase in per cent of emergence upto 22.5 per cent over

Table 6. Effect of different rates and timings of carbofuran application on male and female adult emergence and sex-ratio

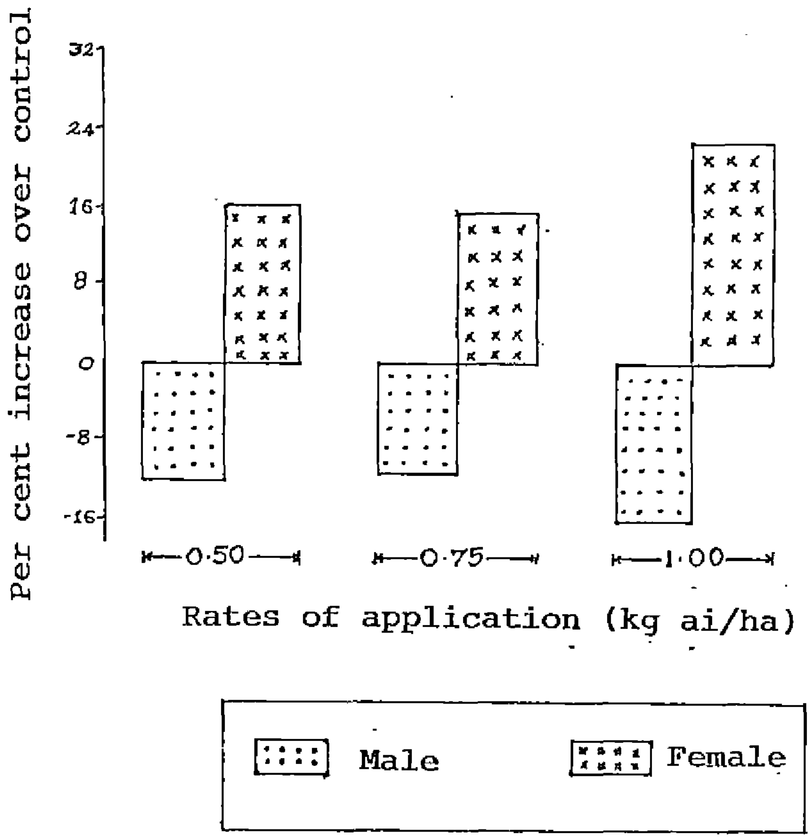
Treatment	Rate (kg ai/ha)	Time of application (DAT)	Adult emergence (%)		Female/Male ratio (% on male)
			Male	Female	
Carbofuran 3G	0.50	20	53.09ab	46.91ab	89.26a
,,	0.75	,,	54.19ab	45.80ab	86.44a
,,	1.00	,,	54.20ab	45.80ab	84.53a
,,	0.50	50	51.28ab	48.72ab	95.45a
,,	0.75	,,	51.50ab	48.50ab	96.25a
,,	1.00	,,	46.86ab	53.14ab	113.98a
,,	0.50	20&50	48.89ab	51.11ab	105.09a
,,	0.75	,,	48.85ab	51.15ab	105.28a
,,	1.00	,,	44.17b	55.83a	126.94a
Untreated control			57.88a	42.12b	75.80a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

Fig. 5. Effect of rates of application of carbofuran on male and female emergence

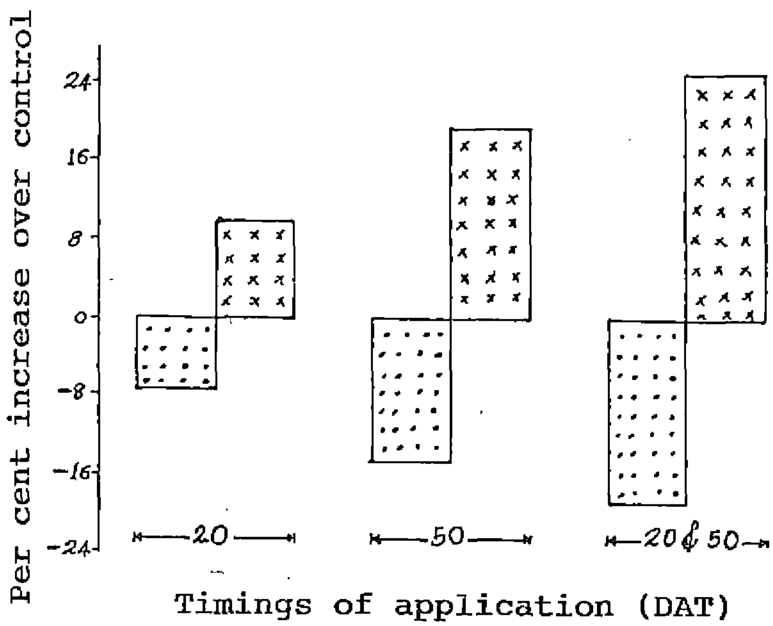
Fig. 6. Effect of timings of application of carbofuran on male and female emergence

FIG-5



Per cent increase over control
32
24
16
8
0
-8
-16
0·50
0·75
1·00
Rates of application (kg ai/ha)
Male
Female

FIG-6



Per cent increase over control
24
16
8
0
-8
-16
-24
20
50
20 & 50
Timings of application (DAT)

control in the insecticidal treatments. The effect of timing of application ie. 20, 50 and 20 and 50 DAT showed an increasing level of reduction in the male emergence (Fig.6) the increase being in that order. In respect of female emergence, a uniform rate of increase over control was indicated in these treatments in the same order.

4.1.2. Studies on the F_1 progeny production of *C. medinalis* moths reared on different treatments

The data related to the studies on the F_1 progeny production and the results of analysis are presented in Table 7.

In respect of fecundity and the number of first instar larvae, the treatment differences were not significant. The percentage of emergence of first instar larvae from eggs, however, showed treatment variations, the highest values being in the carbofuran treatments given at 1.00 kg ai/ha and 0.50 kg ai/ha applied twice at 20 and 50 DAT. As compared to these treatments, the percentage emergence in the treatment receiving 0.75 kg ai/ha at 50 DAT alone was significantly lower. The rest of the treatments were on par.

4.1.3. Studies on the fecundity and ovipositional preference of *C. medinalis* females (untreated) on treated and untreated plants

The data and the results of statistical analysis of the above studies are presented in Table 8 and illustrated in Fig. 7.

Table 7. Effect of different rates and timings of carbofuran application on the F_1 progeny production

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean no. of eggs laid/female	Mean no. of I instar larvae/female	Emergence of I instar larvae (%)
Carbofuran 3G	0.50	20	75.81a	64.47a	84.93ab
,,	0.75	,,	71.61a	61.23a	85.62ab
,,	1.00	,,	88.49a	75.74a	85.97ab
,,	0.50	50	79.40a	67.38a	84.88ab
,,	0.75	,,	74.28a	60.89a	81.87b
,,	1.00	,,	90.90a	76.90a	84.48ab
,,	0.50	20&50	82.67a	73.22a	88.64a
,,	0.75	,,	81.83a	72.53a	88.60ab
,,	1.00	,,	86.11a	76.87a	89.28a
Untreated control			76.94a	64.23a	83.50ab

Means followed by a common letter in a column are not significantly different at5% level (DMRT)

Table 8. Effect of different rates and timings of carbofuran application on the mean fecundity and preference of *C. medinalis* moths

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean fecundity per female (No.)	Total no. of eggs laid on each treatment (n = 10 females)
Carbofuran 3G	0.50	20	76.82a	472.85e
,,	0.75	,,	78.04a	542.52de
,,	1.00	,,	86.89a	499.17de
,,	0.50	50	82.31a	599.64de
,,	0.75	,,	64.69a	684.95de
,,	1.00	,,	72.33a	842.96cd
,,	0.50	20&50	80.60a	1196.03bc
,,	0.75	,,	76.95a	1286.21b
,,	1.00	,,	78.64a	1848.56a
Untreated control			85.46a	527.69de

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

When the untreated freshly emerged females were confined on treated plants to study their ovipositional potential, there was no difference in the fecundity in between the treatments, the fecundity range being 64.69 and 86.89 per female. In a multiple-choice test significant variations in the total number of eggs laid on each treatment were recorded when the females were released at the rate of 10 per treatment. Significantly higher number of eggs (1848.56) were laid on plants receiving carbofuran treatment given at 1.00 kg ai/ha applied twice at 20 and 50 DAT and this was higher than the rest of the treatments. The egg laying in the treatment with carbofuran given at 0.75 kg ai/ha applied twice was lower (1286.21 eggs) followed by that in the treatment receiving 0.50 kg ai/ha twice (1196.03 eggs), the above two treatments being on par. The application at 0.50 kg ai/ha twice was also on par with application at 1.00 kg ai/ha on 50 DAT which had 842.96 eggs which was also on par with untreated control having 527.69 eggs and other treatments. The lowest egg laying was in the application at 0.50 kg ai/ha given at 20 DAT.

When the effects of doses and timings of insecticide application on the ovipositional preference was considered, both increased the ovipositional preference on treated plants except in the application at 50 DAT (Fig.7). In the different doses of application maximum ovipositional preference was shown by the highest rate of application of 1.00 kg ai/ha (101.6 per cent over control) followed by the lower doses in order. Similarly an increase of 173.6 per cent over control was recorded in the carbofuran treatment given at 20 as well as 50 DAT, but the single applications did not increase the ovipositional preference to that extent.

4.1.4. Effects on the biophysical characters of rice plants

4.1.4.1. Effects on the length and width of leaves

The data relating to the influence of carbofuran treatments at different rates and timings of application along with the results of statistical analysis are presented in Table 9.

In the length of first leaf significant differences were obtained between treatments. Maximum length of 58.53 cm was recorded in the highest rate of application (1.00 kg ai/ha twice at 20 and 50 DAT). This treatment resulted in an increase in the length of leaves as compared to that in the control. The lower rates of 0.75 and 0.50 kg ai/ha applied twice were on par with each other and also with untreated control which recorded 48.07 cm leaf length.

In the case of second leaf also, highest leaf length (67.13 cm) was recorded in the insecticidal applications given at 1.00 kg ai/ha twice at 20 and 50 DAT. This treatment was on par with application at 1.00 kg ai/ha on 20 DAT (65.93 cm), the latter being on par with the treatment receiving carbofuran at 0.50 and 0.75 kg ai/ha at 20 DAT. But in the third leaf, highest leaf length of 63.60 cm was recorded in the treatment at 0.75 kg ai/ha at 20 DAT but this was on par with untreated control. It is

Table 9. Effect of different rates and timings of carbofuran application on length and width of leaves at 60 DAT

Treatment	Rate (kg ai/ ha)	Time of appli- cation (DAT)	Length (cm)				Width (cm)			
			I leaf	II leaf	III leaf	First three leaves	I leaf	II leaf	III leaf	First three leaves
Carbofuran 3G	0.50	20	51.67b	63.47bc	58.87ab	58.00abcd	1.79bcde	1.53ab	1.32abc	1.55a
,,	0.75	,,	51.80b	63.60bc	63.60a	59.67ab	1.91abc	1.57a	1.21abcd	1.57a
,,	1.00	,,	52.93b	65.93ab	60.13ab	59.67ab	1.65e	1.43ab	1.28abc	1.45ab
,,	0.50	50	48.80bc	58.40de	56.47b	54.55e	1.73de	1.36b	1.00e	1.37b
,,	0.75	,,	45.93c	61.47cd	57.20b	54.87de	1.74cde	1.51ab	1.19 bcd	1.48a
,,	1.00	,,	47.60bc	61.87cd	59.33ab	55.64cde	2.02a	1.61a	1.18cd	1.60a
,,	0.50	20&50	52.33b	63.33bc	59.67ab	58.44abc	1.81bcde	1.55ab	1.34ab	1.57a
,,	0.75	,,	53.07b	61.00cde	59.53ab	57.87bcd	1.93ab	1.49ab	1.35a	1.59a
,,	1.00	,,	58.53a	67.13a	57.67b	61.11a	1.78bcde	1.50ab	1.34ab	1.54a
Untreated control			48.07bc	57.53e	61.00ab	55.53cde	1.83bcd	1.45ab	1.12de	1.46ab

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

generally found that none of the treatments significantly increased the length of the third leaf. In respect of the mean length of the first three leaves, the maximum length was found in the treatment receiving 1.00 kg ai/ha at 20 as well as 50 DAT, this being significantly higher than in untreated control.

The width of first leaf was 2.02 cm for the carbofuran treatment given at 1.00 kg ai/ha at 50 DAT and was significantly higher than in untreated control (1.83 cm). At 0.75 kg ai/ha given at 20 DAT and the same dose given twice at 20 and 50 DAT, the width of leaves was the same as that in the treatment receiving 1.00 kg ai/ha at 50 DAT. In the width of second leaf, all the insecticidal treatments were on par with untreated control. The leaf width recorded at 1.00 kg ai/ha on 50 DAT and that at 0.75 kg ai/ha on 20 DAT were on par and significantly higher than application of 0.50 kg ai/ha at 50 DAT. In the third leaf (Table 9) the width was highest (1.35 cm) in the treatment receiving 0.75 kg ai/ha of carbofuran at 20 and 50 DAT followed by the treatments involving 0.50 and 1.00 kg ai/ha given twice, all these being on par with each other. There was no significant difference in the effects of insecticidal treatments on the mean width of the first three leaves and that of untreated control. However, among the treatments, application of carbofuran at 0.50 kg ai/ha on 50 DAT led to reduction in width when compared with other insecticide treatments.

4.1.4.2. Effect on height of plants and leaf thickness

The data and the results of statistical analysis of height of plants and leaf thickness are presented in Table 10.

The maximum height of 114.17 cm of the treated plants was observed under application of carbofuran granules at 1.00 kg ai/ha applied twice and was significantly higher than in untreated control (106.00 cm) and also as compared to the application at the two rates of 0.50 and 0.75 kg ai/ha once at 50 DAT.

In the thickness of first, second and third leaves there was no significant differences between treatments. The mean thickness of the first three leaves also did not show any significant variation between treatments.

4.1.4.3. Effect of carbofuran treatments on the thickness of different transverse layers of the second leaf

The data on the thickness of different layers of cross section of second leaf under different doses of carbofuran treatments are given in Table 11.

In respect of thickness of upper epidermis, it was found that the highest thickness of 9.5 μ was in plants receiving carbofuran treatment at 0.75 kg ai/ha on 20 DAT followed by 0.50 kg ai/ha applied at 50 DAT as well as for the two applications at 20 and 50 DAT, their thickness being 9.4 μ for both the doses. These three treatments

Table 10. Effect of different rates and timings of carbofuran application on plant height and leaf thickness at 60 DAT

Treatment	Rate (kg ai/ ha)	Time of applica- cation (DAT)	Mean height of plants (cm)	Mean leaf thickness* (μ)			
				I leaf	II leaf	III leaf	First three leaves
Carbofuran 3G	0.50	20	109.50ab	257a	237a	234a	244a
,,	0.75	,,	111.33ab	267a	252a	220a	247a
,,	1.00	,,	108.00ab	239a	223a	199a	221a
,,	0.50	50	106.33b	275a	239a	212a	242a
,,	0.75	,,	106.33b	283a	242a	206a	244a
,,	1.00	,,	108.33ab	269a	246a	200a	239a
,,	0.50	20&50	109.17ab	261a	234a	229a	241a
,,	0.75	,,	109.67ab	258a	235a	231a	241a
,,	1.00	,,	114.17a	256a	227a	197a	237a
Untreated control			106.00b	285a	228a	187a	234a

* Leaf thickness measured using a Vernier micrometer.

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

Table 11. Effect of different rates and timings of carbofuran application on the thickness of different layers of second leaves in cross section at 60 DAT

Treatment	Rate (kg ai/ ha)	Time of appli- cation (DAT)	Tickness of leaf layers (μ)						
			Upper epider- mis	Lower epider- mis	Vascular bundle	Mesophyll	Bulli- form cells	Fibrous patch on the upper surface	Total thick- ness
Carbofuran 3G	0.50	20	8.7abc	10.0a	30.0a	28.0a	34.0a	12.0a	85.2a
,,	0.75	,,	9.5a	10.0a	31.0a	27.0a	35.0a	15.0a	86.4a
,,	1.00	,,	9.2abc	10.0a	30.0a	27.0a	34.0a	12.0a	86.7a
,,	0.50	50	9.4ab	10.0a	31.0a	28.0a	34.0a	14.0a	87.5a
,,	0.75	,,	8.5bc	9.0a	31.0a	26.0a	35.0a	14.0a	84.6a
,,	1.00	,,	9.0abc	10.0a	31.0a	28.0a	32.0a	15.0a	87.2a
,,	0.50	20&50	9.4ab	9.0a	29.0a	27.0a	33.0a	14.0a	83.9a
,,	0.75	,,	9.1abc	10.0a	31.0a	27.0a	31.0a	14.0a	86.4a
,,	1.00	,,	8.9abc	9.0a	30.0a	26.0a	31.0a	13.0a	85.2a
Untreated control			8.3c	10.0a	30.0a	26.0a	33.0a	13.0a	83.4a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

led to significant increase in the upper epidermal thickness as compared to untreated control in which the thickness was only 8.3 μ . All the other treatments were on par with the untreated control. The thickness of other layers of leaf such as lower epidermis, vascular bundle, mesophyll, bulliform cell layer and fibrous patches on the upper surface and the total thickness of the cross section did not show any significant variations among the treatments.

4.1.4.4. Effect on leaf hair density and length

The data on the effect of different treatments on the density and length of leaf hairs are presented in Table 12 and illustrated in Fig. 8.

The leaf hair number in the first leaf per cm^2 was found to be the highest (218.85) in the carbofuran treatment at 1.00 kg ai/ha applied twice at 20 and 50 DAT, but this was on par with untreated control which showed a density of 203.82 leaf hairs/cm^2. The leaf hair density under carbofuran treatment at 1.00 kg ai/ha was distinctly higher than in treatments receiving 0.50 and 1.00 kg ai/ha of carbofuran at 20 DAT and 50 DAT, the latter two being themselves on par. The results of analysis of the leaf hair number/unit area in second leaf, third leaf and the mean of first three leaves also gave somewhat similar trends with a reduction in the leaf hair number/cm^2 under carbofuran treatments, the significant reduction being in the treatment receiving carbofuran at 1.00 kg ai/ha at 50 DAT and 0.50 kg ai/ha at 20 DAT as compared to the application at 1.00 kg ai/ha at both 20 and 50 DAT in

Table 12. Effect of different rates and timings of carbofuran application on leaf hairs at 60 DAT

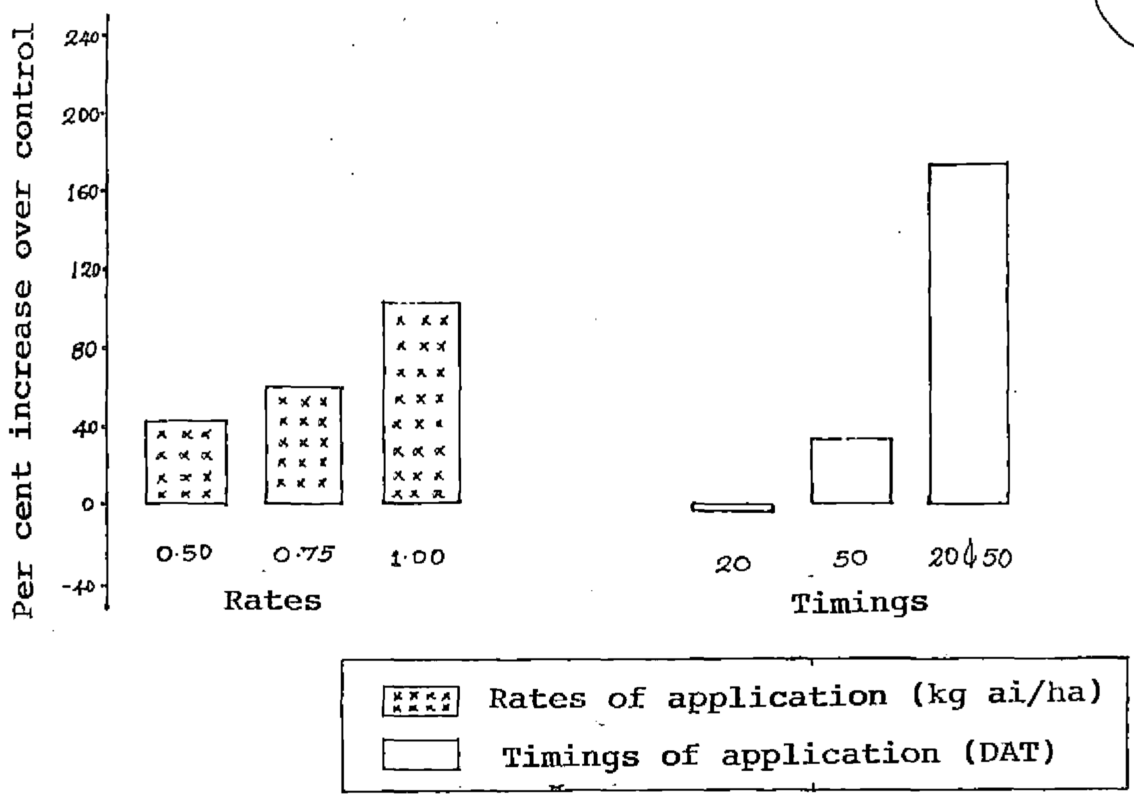
Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Leaf hair no. per cm^2				Leaf hair length (μ)			
			I leaf	II leaf	III leaf	Mean of first three leaves	I leaf	II leaf	III leaf	First three leaves
Carbofuran 3G	0.50	20	169.87b	151.23c	152.94c	158.23d	508a	600a	566a	558a
,,	0.75	,,	191.15ab	177.11abc	198.45ab	189.13bc	522a	653a	565a	580a
,,	1.00	,,	189.27ab	199.58ab	185.43abc	191.81abc	584a	634a	627a	615a
,,	0.50	50	188.80ab	169.44bc	174.52abc	177.63bcd	578a	626a	567a	590a
,,	0.75	,,	190.19ab	176.09abc	168.97bc	178.89bcd	592a	653a	615a	620a
,,	1.00	,,	169.68b	156.43c	174.40abc	167.04cd	534a	617a	595a	582a
,,	0.50	20&50	178.44ab	194.21ab	164.37bc	179.28bcd	596a	663a	613a	624a
,,	0.75	,,	173.82ab	195.20ab	183.97abc	184.64bc	564a	647a	602a	604a
,,	1.00	,,	218.85a	212.12a	217.15a	216.19a	596a	654a	620a	624a
Untreated control			203.82ab	200.95ab	192.77abc	201.66ab	609a	639a	602a	617a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

Fig. 7. Effect of rates and timings of application of carbofuran on ovipositional preference on treated plants

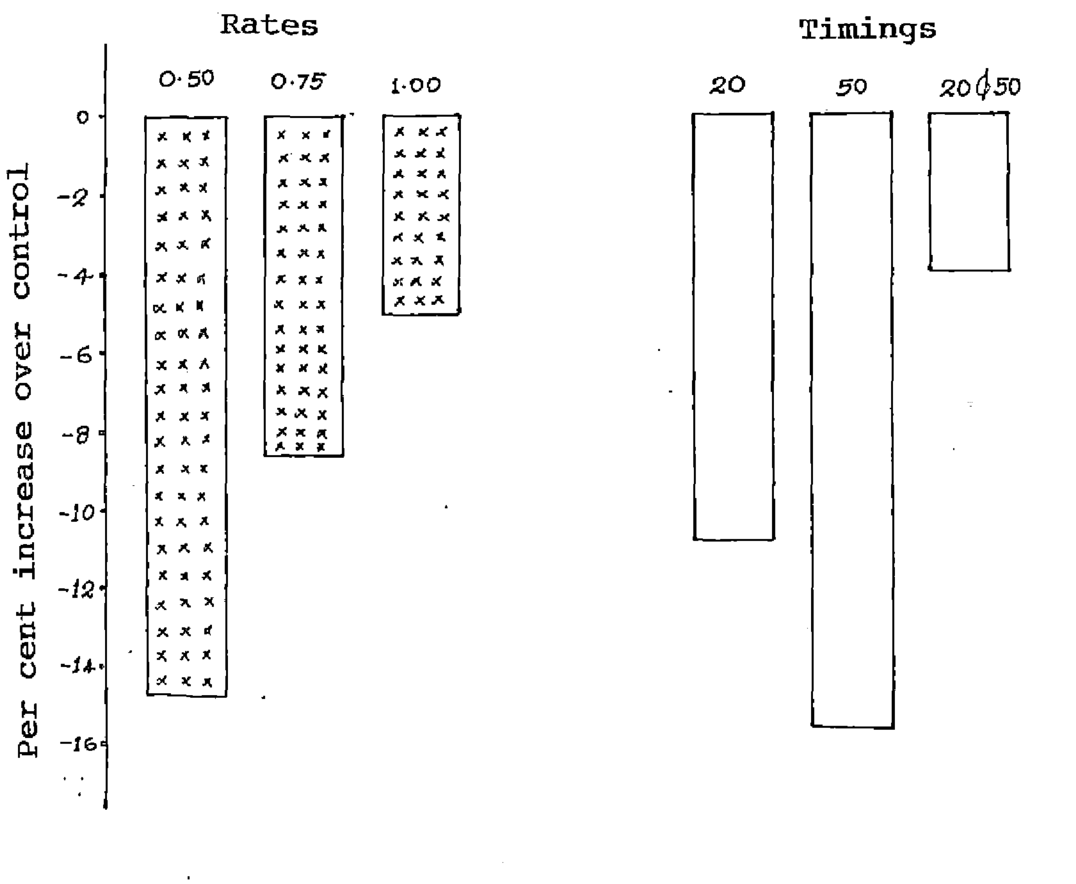
Fig. 8. Effect of rates and timings of application of carbofuran on mean leaf hair density of first three leaves

FIG-7



Per cent increase over control
240
200
160
120
80
40
0
-40
0.50
0.75
1.00
Rates
20
50
20 & 50
Timings
Rates of application (kg ai/ha)
Timings of application (DAT)

FIG-8



Rates
Timings
0.50
0.75
1.00
20
50
20 & 50
Per cent increase over control
0
-2
-4
-6
-8
-10
-12
-14
-16

second leaf. In the third leaf, the reduction in the leaf hair density was highly significant in the treatment receiving carbofuran at 0.50 kg ai/ha (152.94/cm^2) as compared to the dose of 1.00 kg ai/ha applied at both 20 and 50 DAT. In the mean leaf hair density of first three leaves, significant reduction was recorded in application of carbofuran at 0.50 kg ai/ha at 20 DAT and 1.00 kg ai/ha at 50 DAT as compared to that of untreated control.

The leaf hair length recorded for the first, second and third leaf and the mean of first three leaves did not show any variation between treatments (Table 12).

The effect of rates and timings of application of carbofuran on the mean number of leaf hairs of first three leaves showed a reduction when compared to untreated control (Fig. 8). Among the rates of application 0.50 kg ai/ha showed maximum reduction of leaf hairs (14.9 per cent over untreated control) followed by the other doses in order. In respect of timings of application of carbofuran, 50 DAT application showed maximum reduction in leaf hairs (13.5 per cent over control).

4.1.5. Effect on different biochemicals in leaf

The data on the effect of different treatments on the biochemical constituents of leaf samples at 60 DAT are presented in Table 13 and graphically depicted in Fig.9 and 10.

The organic carbon content in the different treatments did not show any significant difference and the organic carbon content in the untreated control was 36.65 per cent.

Table 13. Effect of graded doses and timings of carbofuran application on the content of different biochemicals in leaf at 60 DAT

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Per cent of					
			Organic carbon	Nitrogen	Crude protein	Total carbohydrates as starch on moisture free basis	Total sugars	Silica (SiO_2)
Carbofuran 3G	0.50	20	37.37a	1.95c	12.21c	13.50a	13.22ab	23.48a
,,	0.75	,,	35.26a	1.97bc	12.32bc	12.40ab	13.43a	18.98a
,,	1.00	,,	35.14a	1.97bc	12.31bc	12.51ab	12.73ab	15.74a
,,	0.50	50	36.43a	2.22ab	13.90ab	12.78ab	12.16ab	29.42a
,,	0.75	,,	36.28a	2.14abc	13.38abc	13.05ab	11.47b	25.18a
,,	1.00	,,	38.56a	2.10abc	13.10abc	13.49a	12.84ab	17.67a
,,	0.50	20&50	38.71a	1.99bc	12.42bc	11.99b	13.78a	17.66a
,,	0.75	,,	37.12a	2.00bc	12.50bc	12.11ab	12.58ab	16.85a
,,	1.00	,,	38.48a	2.33a	14.56a	12.25ab	13.33a	17.09a
Untreated control			36.65a	2.08abc	12.98abc	11.95b	12.87ab	29.10a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

The nitrogen and crude protein contents showed similar treatment differences, but none of the insecticide treatments were significantly different in the contents from untreated control which had 2.08 per cent nitrogen and 12.98 per cent crude protein. Within the different carbofuran treatments, there existed significant variations in nitrogen and crude protein.

The highest quantity of nitrogen and crude protein was recorded in the carbofuran treatment of 1.00 kg ai/ha applied twice at 20 and 50 DAT, the N and crude protein contents being 2.33 and 14.56 per cent, respectively. This treatment was on par with all the rates applied at 50 DAT and untreated control. A significantly higher carbohydrate content than in untreated control was recorded in the carbofuran treatments of 0.50 kg ai/ha applied at 20 DAT (13.50 per cent) and 1.00 kg ai/ha applied at 50 DAT (13.49 per cent), the carbohydrate content in untreated control being 11.95 per cent. These two treatments were significantly superior to application of 0.50 kg ai/ha twice at 20 and 50 DAT also. The total sugar contents in all the insecticide treatments were on par with 12.87 per cent in untreated control, although there was significant variation within the insecticide treatments. The highest quantity of 13.78 per cent total sugars was present in the application of 0.50 kg ai/ha applied twice at 20 and 50 DAT and this was on par with all the other treatments except application of 0.75 kg ai/ha at 50 DAT which recorded 11.47 per cent total sugars. The silica (SiO_2) content in the leaf samples at 60 DAT did not show any significant difference between treatments.

The different rates of carbofuran application showed differential effects in the contents of biochemicals in leaf samples (Fig. 9). In the case of nitrogen and crude protein, the lower doses of 0.50 and 0.75 kg ai/ha of carbofuran resulted in reduction while 1.00 kg ai/ha increased the contents. In respect of carbohydrates the different rates increased the contents over that in untreated control and the contents of total sugars was less than that in untreated control by the application of carbofuran at 0.75 kg ai/ha.

The effect of timings of application on the different plant biochemicals also showed varying trends (Fig. 10). While the 20 DAT applications resulted in a decrease in the nitrogen and crude protein contents as compared to untreated control, the 50 DAT and 20 and 50 DAT applications increased the same. With regard to carbohydrates, the increase in its content by 20 DAT and 50 DAT single applications were of a higher order as compared to that at 20 as well as 50 DAT applications. In the case of total sugars, the application at 50 DAT only reduced its contents over untreated control.

4.1.6. Effect on the chlorophyll content in leaf

The data on the chlorophyll content of leaf samples estimated at 60 DAT along with the results of statistical analysis are presented in Table 14 and depicted in Fig. 11 and 12.

The highest quantity of chlorophyll$_a$ was detected in the carbofuran treatment given at 0.50 kg ai/ha at 50 DAT, the quantity being 1.05 mg/g on fresh weight basis. This treatment alone was significantly higher than untreated

Fig. 9. Effect of rates of application of carbofuran on the biochemical contents in leaf at 60 DAT

Fig. 10. Effect of timings of application of carbofuran on the biochemical contents in leaf at 60 DAT

FIG 9

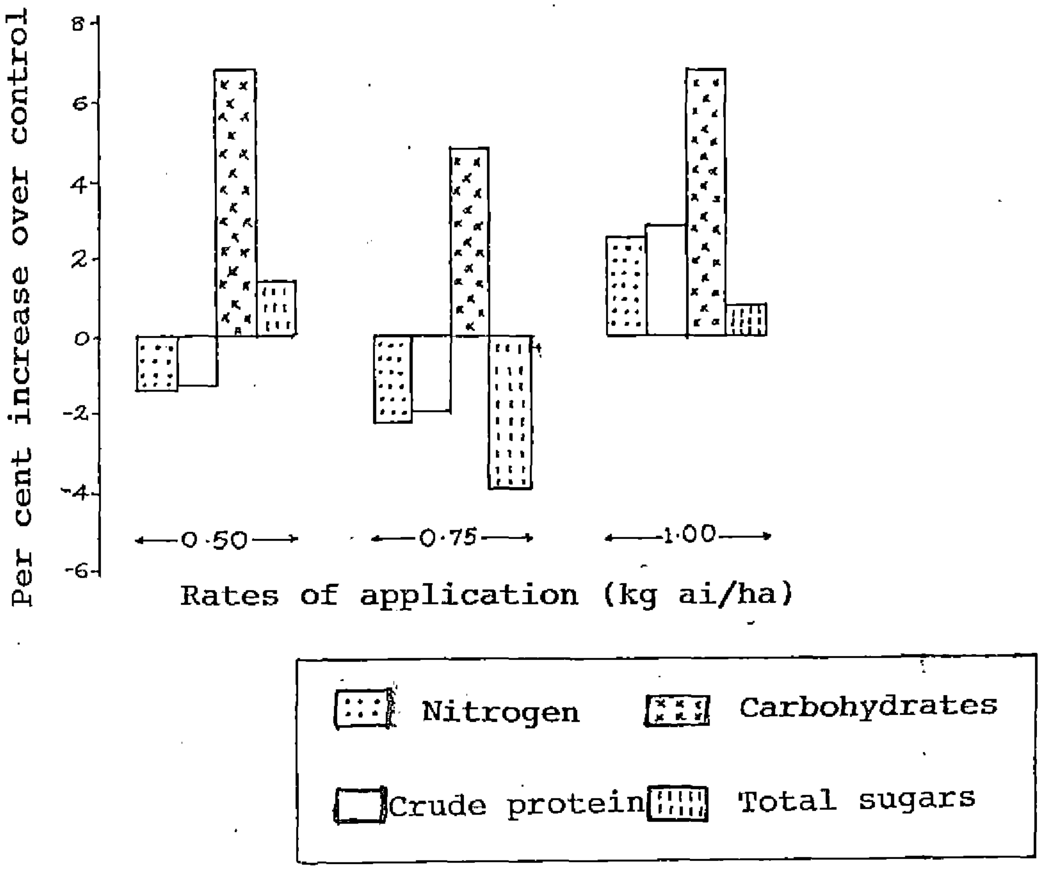

Per cent increase over control
8
6
4
2
0
-2
-4
-6
0·50
0·75
1·00
Rates of application (kg ai/ha)
Nitrogen
Carbohydrates
Crude protein
Total sugars

FIG 10

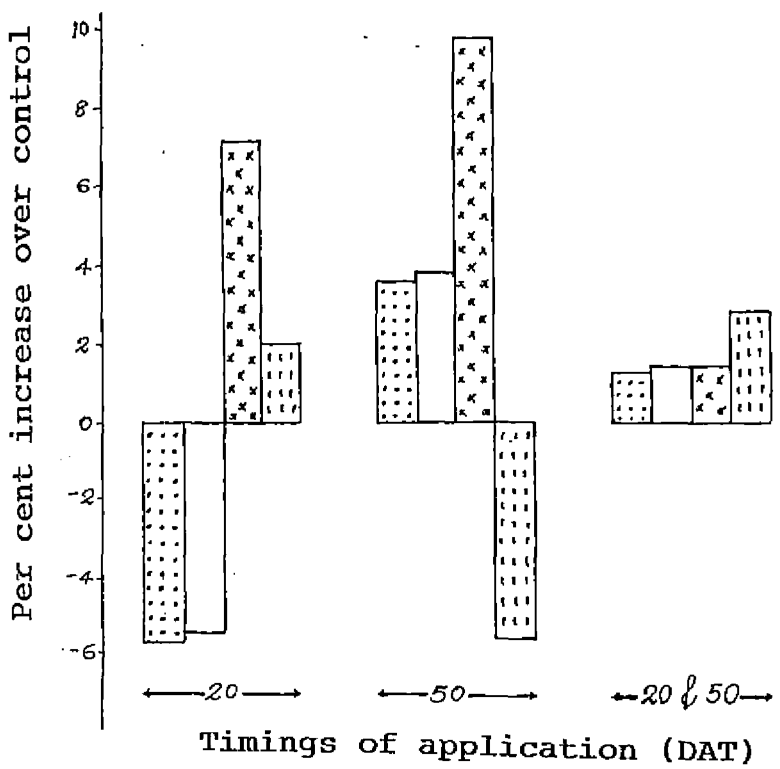

Per cent increase over control
10
8
6
4
2
0
-2
-4
-6
20
50
20 & 50
Timings of application (DAT)

Table 14. Effect of graded doses and timings of carbofuran application on the chlorophyll content of rice leaf at 60 DAT

Treatment	Rate (kg ai/ha)	Time of application (DAT)	mg/g on fresh weight basis		
			Chlorophyll$_a$	Chlorophyll$_b$	Chlorophyll$_{a+b}$
Carbofuran 3G	0.50	20	0.87c	1.22b	2.10b
,,	0.75	,,	0.93abc	1.31ab	2.24b
,,	1.00	,,	0.94abc	1.33ab	2.27ab
,,	0.50	50	1.05a	1.47a	2.52a
,,	0.75	,,	0.98ab	1.36ab	2.34ab
,,	1.00	,,	0.90bc	1.24b	2.14b
,,	0.50	20&50	0.94abc	1.31ab	2.25ab
,,	0.75	,,	0.90bc	1.26b	2.16b
,,	1.00	,,	0.92bc	1.28b	2.20b
Untreated control			0.90bc	1.23b	2.12b

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

Fig. 11. Effect of rates of application of carbofuran on the chlorophyll contents in leaf at 60 DAT

Fig. 12. Effect of timings of application of carbofuran on the chlorophyll contents in leaf at 60 DAT

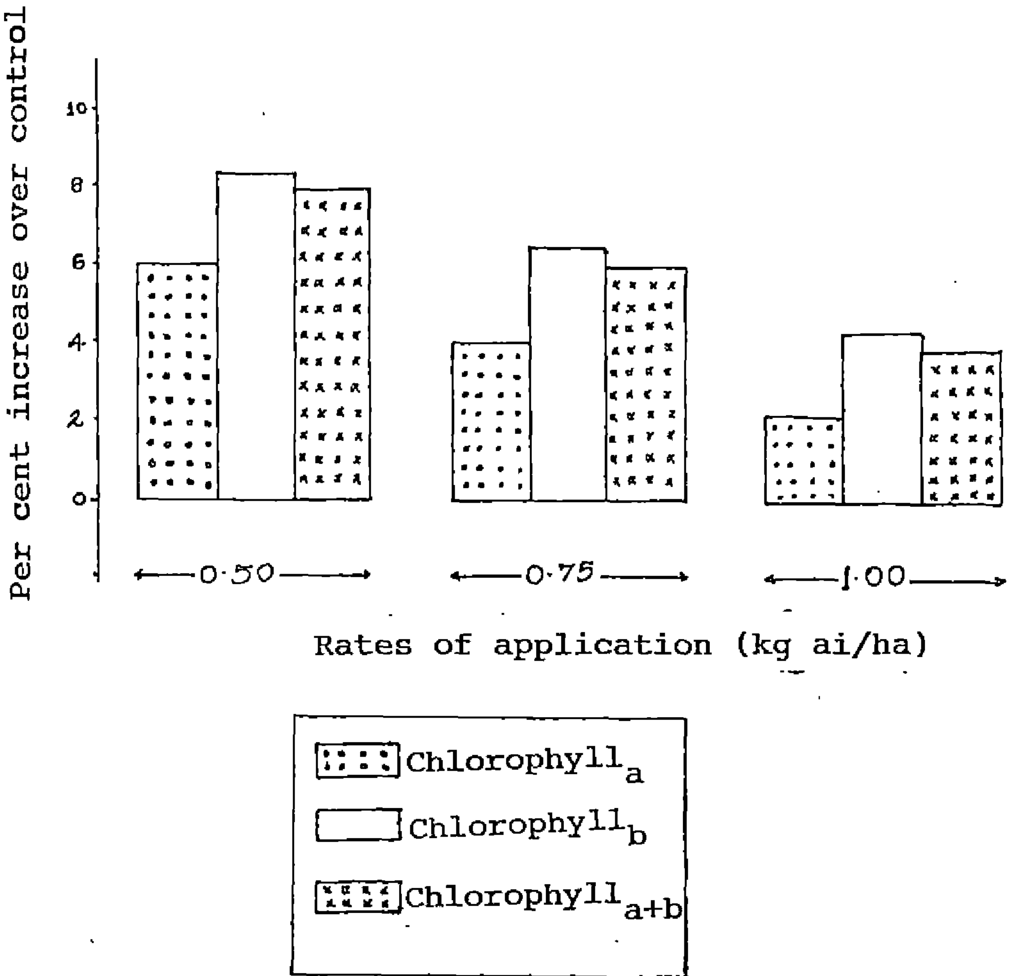

Per cent increase over control
0
2
4
6
8
10
0·50
0·75
1·00
Rates of application (kg ai/ha)
Chlorophyll a
Chlorophyll b
Chlorophyll a+b

FIG-11

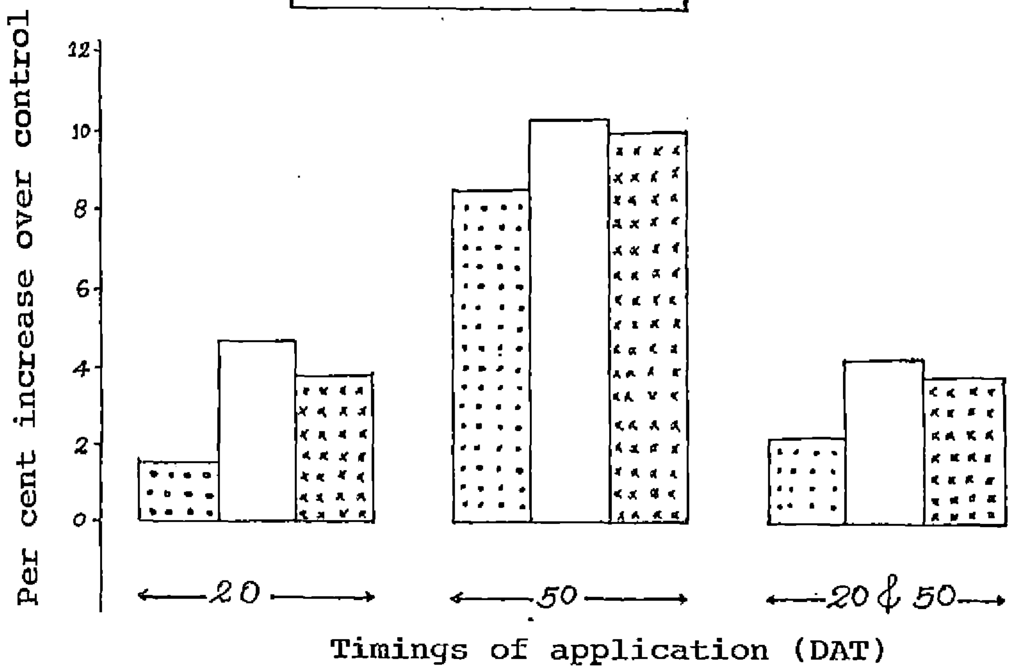

Per cent increase over control
0
2
4
6
8
10
12
20
50
20 & 50
Timings of application (DAT)

FIG-12

control. In the case of $chlorophyll_b$ also the highest quantity of 1.47 mg/g was recorded in the treatment of 0.50 kg ai/ha applied at 50 DAT and was the only treatment in which it exceeded the level in control. In respect of total chlorophyll content also, the result was quite similar.

In the case of $chlorophyll_a$, $chlorophyll_b$ and $chlorophyll_{a+b}$, the effect of rates of application was similar and the rate of increase over control by 0.50 kg ai/ha of carbofuran was highest in all, the increase being 5.9, 8.4 and 8.0 per cent, respectively (Fig. 11). This increasing trend decreased with increasing doses of carbofuran application. The different timings of application also showed an increase in the $chlorophyll_a$, $chlorophyll_b$ and $chlorophyll_{a+b}$ contents as compared to untreated control (Fig. 12). The increase in the chlorophyll contents was most pronounced in the application at 50 DAT, the increase being 8.5, 10.3 and 10.1 per cent over control for $chlorophyll_a$, $chlorophyll_b$ and $chlorophyll_{a+b}$, respectively.

4.1.7. Effect on the residue and metabolites of carbofuran in leaf

The data and results of statistical analysis of the residue and metabolites of carbofuran are presented in Table 15.

High levels of carbofuran residue was detected in all the insecticidal treatments given twice at 20 and 50 DAT and in 0.75 and 1.00 kg ai/ha applied at 50 DAT. These treatments gave higher values of residues than in the rest

Table 15. Effect of graded doses and timings of carbofuran application on the residue and metabolites of carbofuran in leaf at 60 DAT

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Carbofuran residue (µg/g)	Metabolites of carbofuran (µg/g)					Total residue of carbofuran and metabolites (µg/g)
				3-OH-carbofuran	3-CO-carbofuran	3-OH-7-phenol	3-CO-7 phenol	7-phenol	
Carbofuran 3G	0.50	20	1.01b	1.66de	0.66cd	0.37d	0.50cd	0.43f	4.63d
,,	0.75	,,	0.92bc	2.88d	1.02cd	0.31de	0.50cd	0.61ef	6.23cd
,,	1.00	,,	0.45bc	5.60c	0.77cd	0.61cd	0.39cd	0.69def	8.51cd
,,	0.50	50	0.92bc	5.58c	0.83cd	0.86c	0.57cd	0.46f	9.22c
,,	0.75	,,	2.04a	7.16bc	1.35bc	0.92bc	0.84bc	1.19bc	13.49b
,,	1.00	,,	1.95a	7.74bc	1.72bc	1.19ab	1.05abc	0.80de	14.44b
,,	0.50	20&50	1.91a	8.53b	2.23b	1.28a	1.57a	0.92cd	14.45b
,,	0.75	,,	2.01a	10.98a	3.96a	1.27a	1.32ab	1.32b	20.86a
,,	1.00	,,	2.23a	12.35a	4.79a	1.46a	0.67bcd	1.79a	23.29a
Untreated control			0.00c	0.00e	0.00d	0.00e	0.00d	0.00g	0.00e

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

of the treatments. The residues in the above treatments were 2.23, 2.01, 1.91, 1.95 and 2.04 µg/g in 1.00, 0.75 and 0.50 kg ai/ha applied twice and 1.00 and 0.75 kg ai/ha applied at 50 DAT, respectively.

Among the metabolites of carbofuran, the 3-OH carbofuran was the dominant component in the leaf samples assayed at 60 DAT. The treatments of 1.00 and 0.75 kg ai/ha applied twice recorded the highest residues of 12.35 and 10.98 µg/g of the 3-OH carbofuran and was statistically different from all other treatments. These two treatments were followed by application of 0.50 kg ai/ha at 20 and 50 DAT (twice) and 1.00 and 0.75 kg ai/ha on 50 DAT and these were on par with each other, with mean residues of 8.53, 7.74 and 7.16 µg/g, respectively. However, the latter two treatments were on par with application of 0.50 kg ai/ha at 50 DAT and 1.00 kg ai/ha at 20 DAT, their mean values being 5.58 and 5.60 µg/g, respectively. The lower rates of 0.75 and 0.50 kg ai/ha showed low levels of residues and were statistically different from all the other insecticide treatments.

The 3-CO-carbofuran residues also showed similar trend. The maximum residues of 4.79 and 3.96 µg/g were in the treatments receiving carbofuran at 1.00 and 0.75 kg ai/ha applied twice. Their residue levels were higher than in most of the other treatments. However, the residue of 1.72 and 1.35 µg/g detected in 0.75 and 1.00 kg ai/ha applied at 50 DAT were on par with the treatments of 0.50 kg ai/ha at 50 DAT and all the treatments at 20 DAT.

In the case of 3-OH-7-phenol, highest residue of 1.46 µg/g was in 1.00 kg ai/ha applied twice followed by 0.50 and 0.75 kg ai/ha applied twice and the treatment of 1.00 kg ai/ha applied at 50 DAT and these treatments were on par with each other. In the other two treatments at 50 DAT, the residue levels were 0.92 and 0.86 µg/g in application at 0.75 and 0.50 kg ai/ha, respectively. The treatments at 20 DAT showed lower residue levels ranging from 0.31 to 0.61 µg/g.

With regard to the 3-CO-7-phenol contents, the maximum residue of 1.57 µg/g was detected in the treatment of 0.50 kg ai/ha applied twice at 20 and 50 DAT and was followed by the application of 0.75 kg ai/ha applied twice which recorded 1.32 µg/g residue. The treatment at 1.00 kg ai/ha had only a low residue content of 0.67 µg/g. The residue content of 3-CO-7-phenol in all the treatments at 20 and 50 DAT were on par with residue levels ranging from 0.39 to 1.05 µg/g.

The 7-phenol residue in all the treatments were significantly higher than that in the untreated control. Among the treatments the lowest residue of 0.43 µg/g was in the application of 0.50 kg ai/ha applied at 20 DAT and the highest was in treatment of 1.00 kg ai/ha given twice at 20 and 50 DAT (1.79 µg/g). The lower dose of 0.50 kg ai/ha given at 20 DAT and at 50 DAT and the other doses at 20 DAT had lower residues of 7-phenol ranging from 0.43 to 0.69 µg/g of leaf.

In the case of all the metabolites of carbofuran, there were higher levels of residue when carbofuran was applied two times at 20 and 50 DAT than the applications given at 20 or 50 DAT.

The total residues of carbofuran and metabolites was highest in application of 1.00 kg ai/ha given twice at 20 and 50 DAT (23.29 μg/g) which was followed by the application of 0.75 kg ai/ha given twice with 20.86 μg/g and these two treatments were on par and were statistically significant from other treatments. The application of 0.50 kg ai/ha twice at 20 and 50 DAT was on par with the higher rates of 0.75 and 1.00 kg ai/ha applied at 50 DAT and were high in total residues. The lower rate of 0.50 kg ai/ha at 50 DAT was found to be on par with the higher doses of 0.75 and 1.00 kg ai/ha at 20 DAT. The lowest residue was recorded in the treatment of 0.50 kg ai/ha given at 20 DAT.

4.2. FIELD EXPERIMENTS

4.2.1. Effects of carbofuran treatments on pest resurgence

4.2.1.1. Kharif 1989

The damage by rice leaf folder, *C. medinalis* in the different treatments and the results of statistical analysis are presented in Table 16 and illustrated in Fig. 13 and 14. None of the carbofuran treated plots had significantly higher damage than the untreated control at 30 DAT, the damage in the untreated control being 4.13 per cent.

At 50 DAT, the damage in all the treatments increased heavily ranging from 48.87 to 92.64 per cent in the different treatments. In the 50 DAT observations the effect of carbofuran application given at 20 DAT alone

Table 16. Effect of different rates and timings of carbofuran application on *C. medinalis* damage (kharif, 1989)

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Per cent damage at			
			30 DAT	50 DAT	60 DAT	70 DAT
Carbofuran 3G	0.50	20	3.48ab	76.47bc	61.17c	75.67de
,,	0.75	,,	4.01ab	92.64a	98.54a	99.43a
,,	1.00	,,	3.46ab	76.11bc	82.37abc	95.39ab
,,	0.50	50	4.82ab	59.12de	81.28abc	83.22cde
,,	0.75	,,	4.72ab	68.02cd	80.03abc	87.38bc
,,	1.00	,,	5.63a	48.87e	79.93abc	86.25bc
,,	0.50	20&50	3.42ab	83.02ab	97.75a	99.03a
,,	0.75	,,	2.75ab	86.16ab	97.93a	99.97a
,,	1.00	,,	2.34b	82.89ab	89.06ab	99.98a
Untreated control			4.13ab	59.63de	73.86bc	74.74e

DAT - Days after transplanting

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

could be expected to manifest. All the treatments in which the application at 20 DAT was given, showed significant increase in leaf folder damage as compared to untreated control which had 59.63 per cent damage. The treatments which showed resurgence were the rates of 0.50, 0.75 and 1.00 kg ai/ha given at 20 DAT as well as the above rates applied twice at 20 and 50 DAT.

The observation taken at 60 DAT showed that the 0.75 kg ai/ha application at 20 DAT (Plate X a) had the highest resurgence of leaf folder followed by that of treatments of 0.75 and 0.50 kg ai/ha applied twice at 20 and 50 DAT (Plate X b and c). The damage in the above treatments were 98.54, 97.93 and 97.75 per cent and that in untreated control (Plate X d) was 73.86 per cent. All the other treatments were on par with untreated control.

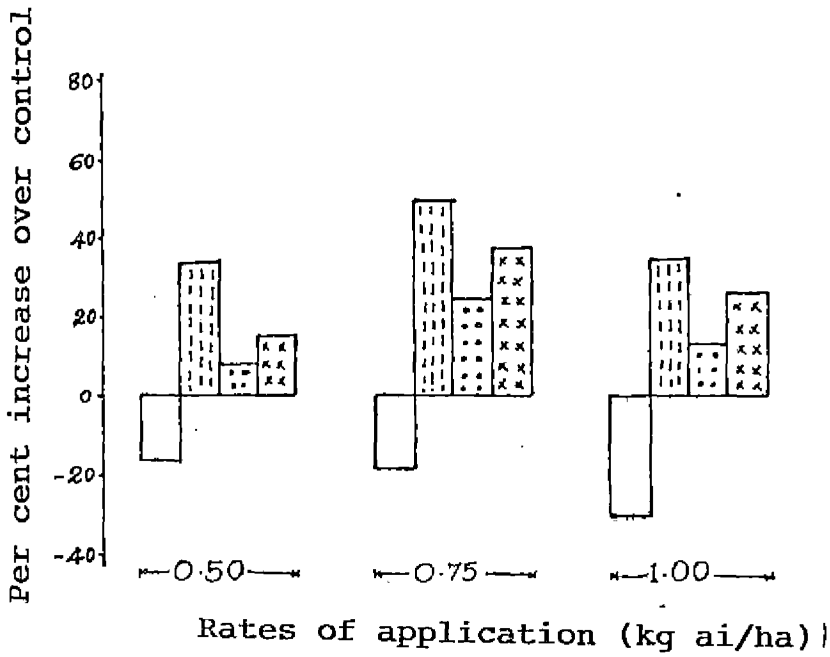
The damage levels at 70 DAT varied significantly between different treatments, the damage ranging from 74.74 per cent in untreated control to 99.98 per cent in the application at 1.00 kg ai/ha at 20 and 50 DAT (twice). All the treatments except the dose of 0.50 kg ai/ha applied at 20 or 50 DAT induced resurgence of the pest as compared to untreated control. However, the highest insect damage was found in all the dose rates applied twice at 20 and 50 DAT and 0.75 kg ai/ha applied at 20 DAT and these four treatments were significantly influencing resurgence.

When the effect of different rates of carbofuran application was assessed based on the per cent increase/decrease in leaf damage over control at different observations (Fig. 13), it was seen that all the doses of

Fig. 13. Effect of rates of application of carbofuran on leaf folder damage at different days (Kharif 1989)

Fig. 14. Effect of timings of application of carbofuran on leaf folder damage at different days (Kharif 1989)

FIG-13



at 30 DAT

at 50 DAT

at 60 DAT

at 70 DAT

FIG-14

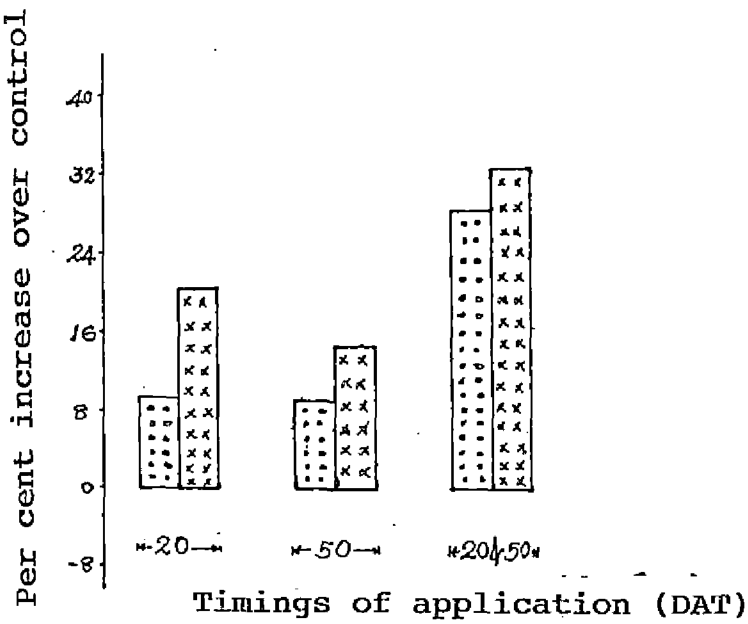


PLATE X Variations in the intensity of field infestation by *C. medinalis*, following carbofuran application (kharif, 1989)

A. Carbofuran applied at 0.75 kg ai/ha at 20 DAT

B. Carbofuran applied at 0.75 kg ai/ha twice at 20 and 50 DAT

PLATE X

A

B

C. Carbofuran applied at 0.50 kg ai/ha twice at 20 and 50 DAT

D. Untreated control

PLATE X

C

D

carbofuran decreased damage at 30 DAT. At 50, 60 and 70 DAT, there was increase in leaf damage over control by all the rates of 0.50, 0.75 and 1.00 kg ai/ha the highest increase in all the observations being inflicted by 0.75 kg ai/ha. The effect of timing of application illustrated in Fig. 14, on the leaf damage at 60 and 70 DAT showed that there was resurgence induced by 20, 50 and 20 and 50 DAT applications, the highest inducement caused by the two applications at 20 as well as 50 DAT. The resurgence induction at 60 DAT was 18.5 and 33.3 per cent at 70 DAT by the treatment at 20 as well as 50 DAT.

4.2.1.2. Rabi 1989

The data on the observations at different days and the results of statistical analysis are presented in Table 17 and illustrated in Fig. 15 and 16. The observations recorded at 30 DAT showed that all the treatments were on par.

The 50 DAT observation showed significant variations between treatments in respect of the damage by the leaf folder. As compared to the 20.78 per cent damage in untreated control, inducement of resurgence was observed in 0.50, 0.75 and 1.00 kg ai/ha doses applied twice at 20 and 50 DAT and also in treatment given once at 20 DAT. The damage in these treatments were 40.07, 49.69, 58.49, 27.33, 31.65 and 34.34 per cent, respectively. Among these treatments, higher rates of application led to more damage than the lower rates.

Table 17. Effect of different rates and timings of carbofuran application on *C. medinalis* damage (rabi, 1989)

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Damage intensity (% of leaves damaged)			
			30 DAT	50 DAT	60 DAT	70 DAT
Carbofuran 3G	0.50	20	11.17ab	27.33e	42.90c	42.01d
,,	0.75	,,	10.09ab	31.65d	44.06c	46.09cd
,,	1.00	,,	9.17ab	34.34d	55.21b	56.92b
,,	0.50	50	13.15ab	19.90f	38.97c	45.46cd
,,	0.75	,,	16.52a	21.93ef	43.56c	49.89c
,,	1.00	,,	13.10ab	21.68ef	44.55c	50.57c
,,	0.50	20&50	8.61ab	40.07c	55.00b	60.05b
,,	0.75	,,	7.94b	49.69b	59.35b	69.03a
,,	1.00	,,	9.78ab	58.49a	77.73a	77.19a
Untreated control			12.05ab	20.78f	30.92d	26.45e

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

By 60 DAT, all the insecticide treated plots had higher levels of damage than untreated control. The highest damage was in the highest rate of 1.00 kg ai/ha (Plate XI a) applied twice (77.73 per cent) and this was significantly higher than untreated control (Plate XI b) and also the other treatments. The treatments of 0.75 and 0.50 kg ai/ha given twice at 20 and 50 DAT and 1.00 kg ai/ha at 20 DAT had 59.35, 55.00 and 55.21 per cent damage, respectively and these treatments were on par. The applications at 50 DAT also induced resurgence within a short span of 10 days after application. The lower doses of 0.50 and 0.75 kg ai/ha given at 20 DAT and all the rates applied at 50DAT showed comparatively low resurgence induction and these treatments were on par with each other, the damage in these treatments ranging from 38.97 to 44.55 per cent.

At 70 DAT also, all the carbofuran treatments were found to induce leaf folder resurgence when compared to 26.45 per cent damage in untreated control. The highest damage of 77.19 per cent was recorded in the 1.00 kg ai/ha treatment given twice and this was on par with 69.03 per cent damage inflicted in 0.75 kg ai/ha given twice. The lower dose of 0.50 kg ai/ha applied twice was on par with the highest dose of 1.00 kg ai/ha given at 20 DAT. The damage in all the doses applied at 50 DAT was on par with the damage induced by 0.75 kg ai/ha given at 20 DAT which had 46.09 per cent damaged leaves.

The effect of rates of application of carbofuran on resurgence of leaf folder are illustrated in Fig. 15. There was no inducement of resurgence at 30 DAT by any of the rates(0.50, 0.75 and 1.00 kg ai/ha) applied. In the

PLATE XI Variations in the intensity of field infestation by *C. medinalis*, following carbofuran application (rabi, 1989)

A. Carbofuran applied at 1.00 kg ai/ha twice at 20 and 50 DAT

B. Untreated control

PLATE XI

A

B

Fig. 15. Effect of rates of application of carbofuran on leaf folder damage at different days (Rabi 1989).

Fig. 16. Effect of timings of application of carbofuran on leaf folder damage at different days (Rabi 1989)

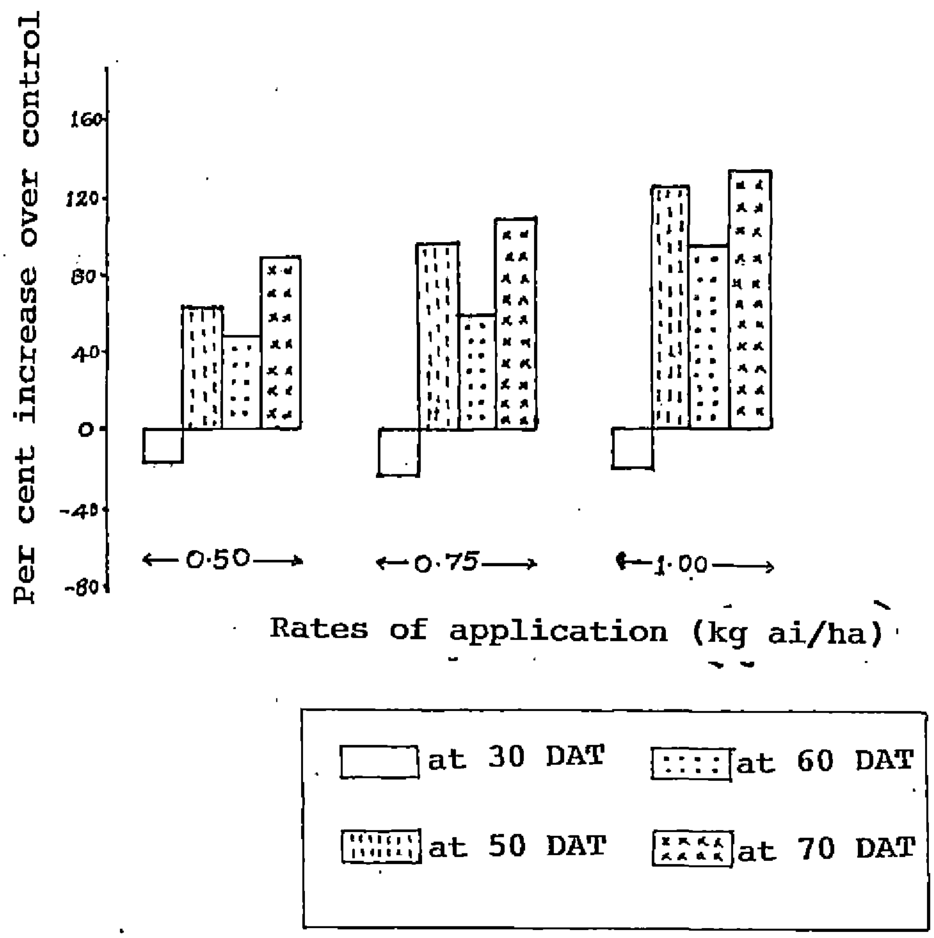

Per cent increase over control
160
120
80
40
0
-40
-80
←0·50→
←0·75→
←1·00→
Rates of application (kg ai/ha)
at 30 DAT
at 60 DAT
at 50 DAT
at 70 DAT

FIG-15

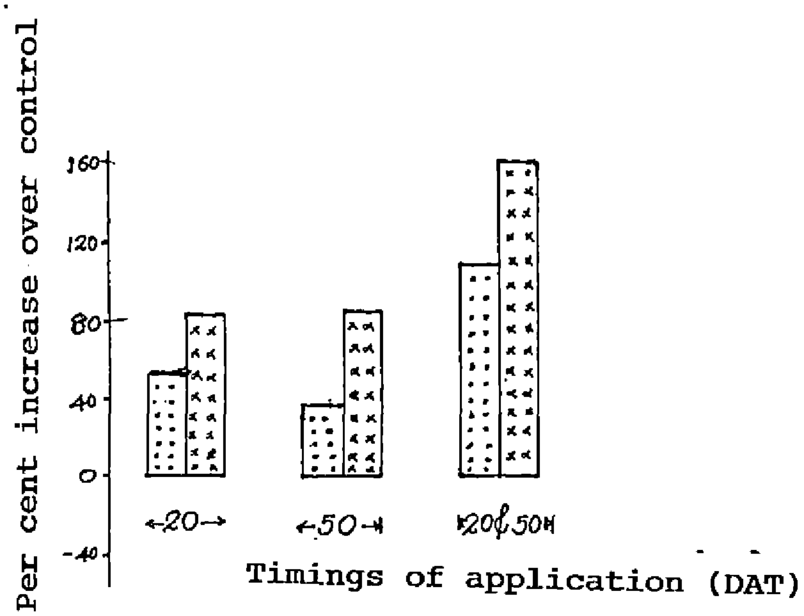

Per cent increase over control
160
120
80
40
0
-40
←20→
←50→
20 & 50
Timings of application (DAT)

FIG-16

observations at 50, 60 and 70 DAT, there was resurgence inducement by all the rates, their intensity depending on the rate of application in order. The influence of timing of applications represented in Fig. 16 showed that the applications given at 20 and 50 DAT induce higher resurgence than the treatments at 20 or 50 DAT.

4.2.2. Effect on yellow stem borer, *Scirpophaga incertulas* (walker) damage

The data on the damage by yellow stem borer in treatments at different observations during kharif and rabi seasons and the results of statistical analysis are presented in Table 18. During kharif, the stem borer damage at 30 DAT did not show any significant difference between treatments. At harvest the damage was very low and the data could not be statistically analysed. At 50 DAT also, the damage was very low ranging from 3.36 per cent to 6.64 per cent. The damage was highest (6.64 per cent) in untreated control.

In the rabi season, most of the treatments were on par with damage in untreated control in 30 and 50 DAT observations. At harvest a reduction in damage by stem borer than in control was observed by the treatment given at 1.00 kg ai/ha at 50 DAT and the damage in this treatment was 4.47 per cent.

4.2.3. Effect on rice gall midge, *Orseolia oryzae* (Wood-Mason) damage

The data on the damage in kharif and rabi seasons by gall midge in the different treatments and the results of

Table 18. Effect of different rates and timings of carbofuran application on *Scirpophaga incertulas* damage (kharif & rabi, 1989)

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Kharif: Per cent damage at 30 DAT	Kharif: Per cent damage at 50 DAT	Kharif: Per cent damage at Harvest	Rabi: Per cent damage at 30 DAT	Rabi: Per cent damage at 50 DAT	Rabi: Per cent damage at Harvest
Carbofuran 3G	0.50	20	5.75a	5.07ab		5.44b	2.41c	12.76a
,,	0.75	,,	3.74a	4.20ab		5.03b	3.75abc	7.28ab
,,	1.00	,,	4.56a	5.04ab		4.07b	3.20bc	9.20ab
,,	0.50	50	5.50a	5.75ab		9.09a	6.79a	10.95a
,,	0.75	,,	3.70a	5.89ab		5.39b	3.80abc	7.79ab
,,	1.00	,,	4.04a	5.53ab		5.78ab	6.00ab	4.47b
,,	0.50	20&50	3.78a	3.36b		5.09b	4.16abc	10.65a
,,	0.75	,,	4.52a	3.88b	<1.00	5.13b	4.40abc	8.29ab
,,	1.00	,,	2.00a	5.83ab		4.58b	2.75c	8.09ab
Untreated control			4.74a	6.64a		5.18b	3.07bc	10.97a

Means followed a common letter in a column are not significantly different at 5% level (DMRT)

Table 19. Effect of different rates and timings of carbofuran application on *Orseolia oryzae* damage (kharif & rabi, 1989)

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Kharif: Per cent damage at 30 DAT	Kharif: Per cent damage at 50 DAT	Kharif: Per cent damage at 70 DAT	Rabi: Per cent damage at 30 DAT	Rabi: Per cent damage at 50 DAT	Rabi: Per cent damage at 70 DAT
Carbofuran 3G	0.50	20	0.16b			0.58c	1.84cd	
,,	0.75	,,	0.83ab			2.06abc	1.93cd	
,,	1.00	,,	0.42ab			1.52abc	2.22bcd	
,,	0.50	50	0.73ab			2.00abc	5.36a	
,,	0.75	,,	0.42ab		< 1.00	1.87abc	3.95ab	< 1.00
,,	1.00	,,	0.64ab	<1.00		1.06bc	2.70bcd	
,,	0.50	20&50	1.43ab			1.78abc	1.63d	
,,	0.75	,,	1.27ab			2.46ab	1.75d	
,,	1.00	,,	1.60a			2.78a	1.16d	
Untreated control			0.60ab			2.09abc	3.70abc	

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

statistical analysis are presented in Table 19. In kharif the damage by gall midge at 30 DAT was low and none of the treatments increased or reduced the damage significantly on comparison with control. The damage at 50 and 70 DAT in kharif was very low and hence the data could not be statistically analysed.

During rabi also, the damage caused by gall midge was low and at 70 DAT the damage was below one per cent in all the treatments and hence the data were not analysed statistically. At 30 DAT, all the carbofuran treated plots showed more or less similar damage levels as compared to untreated control. In the observation at 50 DAT, all the treatments applied twice at 20 and 50 DAT showed a significant reduction in damage as compared to that of untreated control, these treatments being on par with each other.

4.2.4. Effect on rice whorl maggot, *Hydrellia sasakii* (Y.I) damage

The data on damage by the rice whorl maggot in different treatments during the kharif and rabi seasons are presented in Table 20. During kharif, all the carbofuran treatments were on par with untreated control in the 30 DAT observations but at 50 DAT, even though the damage in all the plots were low, the applications at 20 DAT and treatments at 0.50 and 0.75 kg ai/ha twice were found to reduce the damage as compared to untreated control. At 70 DAT, the damage was very low in all the treatments including control.

Table 20. Effect of different rates and timings of carbofuran application on *Hydrellia sasakii* damage (kharif & rabi, 1989)

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Kharif			Rabi		
			Per cent damage at			Per cent damage at		
			30 DAT	50 DAT	70 DAT	30 DAT	50 DAT	70 DAT
Carbofuran 3G	0.50	20	1.83ab	0.92cde		4.59abc		
,,	0.75	,,	2.32ab	0.22e		4.77abc		
,,	1.00	,,	2.85ab	0.89cde		4.13bc		
,,	0.50	50	3.84a	3.70a		5.50abc		
,,	0.75	,,	2.30ab	1.60bcd		7.17ab		
,,	1.00	,,	2.45ab	2.39abc	< 1.00	7.03ab	< 1.00	< 1.00
,,	0.50	20&50	1.52b	0.78de		5.27abc		
,,	0.75	,,	2.04ab	0.60de		4.17bc		
,,	1.00	,,	1.77ab	1.69bcd		3.65c		
Untreated control			3.30ab	2.53ab		7.83a		

Means followed by a common letter in a column are not significantly different a 5% level (DMRT)

During rabi, the damage by whorl maggot at 50 and 70 DAT in all the treatments were very low. At 30 DAT, the treatments at 1.00 kg ai/ha applied at 20 DAT and 0.75 and 1.00 kg ai/ha given at 20 as well as 50 DAT showed significant reduction in damage by whorl maggot as compared to untreated control in which the damage was 7.83 per cent.

4.2.5. Effect on plant growth attributes

4.2.5.1. Kharif 1989

The data on different plant growth attributes recorded during kharif are presented in Table 21. The mean number of tillers/hill recorded at flowering and at harvest and the mean number of productive tillers/hill did not show any significant treatment differences.

The mean height of plants at flowering varied significantly between treatments and the height in different treatments ranged between 69.60 and 81.67 cm. The treatment with carbofuran at 1.00 kg ai/ha given at 50 DAT recorded the maximum height of 81.67 cm followed by 80.03, 79.92 and 78.53 cm in untreated control, 0.75 and 0.50 kg ai/ha applied at 50 DAT, respectively, these treatments being on par. The different treatments at 20 DAT were on par with the treatments given twice at 20 and 50 DAT and these treatments were found to reduce the height of plants on comparison with untreated control except the lowest dose of 0.50 kg ai/ha applied at 20 DAT.

4.2.5.2. Rabi 1989

The data on the different growth attributes recorded during rabi and the results of statistical analysis are

Table 21. Effect of different rates and timings of carbofuran application on plant growth characters (kharif, 1989)

Treatment	Rate (kg ai/ ha)	Time of appli- cation (DAT)	Mean height of plants at flower- ing (cm)	Mean tillers/ hill at flow- ering (No.)	Mean til- lers/hill at har- vest(No.)	Mean produ- ctive til- lers/hill at harvest (No.)
Carbofuran 3G	0.50	20	76.03bc	7.22a	9.10a	8.00a
,,	0.75	,,	70.27d	7.88a	8.35a	7.85a
,,	1.00	,,	69.60d	7.22a	8.72a	7.73a
,,	0.50	50	78.53ab	7.95a	7.78a	7.02a
,,	0.75	,,	79.92ab	7.93a	8.28a	7.77a
,,	1.00	,,	81.67a	7.58a	7.90a	7.07a
,,	0.50	20&50	71.33cd	8.27a	8.23a	7.78a
,,	0.75	,,	72.30cd	8.67a	8.78a	7.93a
,,	1.00	,,	71.63cd	8.57a	7.85a	7.33a
Untreated control			80.03ab	7.35a	8.67a	7.98a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

Table 22. Effect of different rates and timings of carbofuran application on plant growth characters (rabi, 1989).

Treatment	Rate (kg/ai ha)	Time of application (DAT)	Mean height of plants at flowering (cm)	Mean tillers/ hill at flowering (No.)	Mean tillers/ hill at harvest (No.)	Mean productive tillers/hill at harvest (No.)
Carbofuran 3G	0.50	20	73.57ab	8.38ab	8.87a	6.80a
,,	0.75	,,	73.13ab	8.97ab	8.73a	6.78a
,,	1.00	,,	74.38a	9.20ab	8.73a	7.17a
,,	0.50	50	68.57b	8.70ab	8.75a	6.72a
,,	0.75	,,	72.88ab	9.03ab	8.70a	7.12a
,,	1.00	,,	73.40ab	9.25ab	8.63a	7.10a
,,	0.50	20&50	74.42a	9.65a	8.82a	6.97a
,,	0.75	,,	75.60a	9.43ab	8.78a	7.02a
,,	1.00	,,	74.47a	9.47ab	8.43a	6.47a
Untreated control			69.95ab	8.25b	8.98a	6.95a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

presented in Table 22. The mean number of tillers/hill at harvest and the mean number of productive tillers did not show any significant variation between treatments. Variations between treatments were detected in the mean height of plants at flowering and the mean number of tillers/hill at flowering.

Even though there was differences in the mean height of plants at flowering between treatments, all the carbofuran treatments had mean height on par with untreated control. In the case of mean number of tillers at flowering/hill, only one treatment namely application of 0.50 kg ai/ha twice at 20 and 50 DAT exerted a significant influence on the number of tillers than that in untreated control. This particular treatment was on par with all other levels of application of carbofuran granules.

4.2.6. Effect on the number, length and width of leaves at 60 DAT

4.2.6.1. Kharif 1989

The data on the number, length and width of leaves in different treatments and the results of statistical analysis are presented in Table 23. The number of leaves/hill, mean length of first, second and third leaves and mean width of first and third leaves in different treatments did not show significant variations. Even though there was significant difference between treatments in respect of the width of second leaf, only one treatment namely, 0.75 kg ai/ha applied twice at 20 and 50 DAT showed significantly higher (1.37 cm) leaf width as compared to 1.19 cm of untreated control.

Table 23. Effect of different rates and timings of carbofuran application on number, length and width of leaves (kharif, 1989) at 60 DAT

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Mean No. of leaves/ hill	Mean length of I leaf (cm)	Mean length of II leaf (cm)	Mean length of III leaf (cm)	Mean width of I leaf (cm)	Mean width of II leaf (cm)	Mean width of III leaf (cm)
Carbofuran 3G	0.50	20	30.73a	32.25a	40.20a	36.61a	1.41a	1.17c	1.03a
,,	0.75	,,	30.88a	32.31a	38.83a	37.25a	1.39a	1.18c	0.96a
,,	1.00	,,	30.90a	29.09a	39.34a	37.90a	1.48a	1.14c	1.02a
,,	0.50	50	33.23a	33.34a	36.63a	36.39a	1.36a	1.20bc	0.96a
,,	0.75	,,	34.45a	28.91a	37.28a	35.81a	1.40a	1.25abc	1.04a
,,	1.00	,,	32.28a	30.57a	40.30a	38.90a	1.44a	1.26abc	1.00a
,,	0.50	20&50	32.62a	29.88a	37.52a	37.23a	1.40a	1.27abc	0.98a
,,	0.75	,,	35.35a	33.95a	36.29a	38.24a	1.45a	1.37a	1.05a
,,	1.00	,,	31.67a	33.50a	40.80a	39.45a	1.46a	1.34ab	1.01a
Untreated control			30.98a	33.29a	40.05a	36.75a	1.33a	1.19bc	0.99a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

4.2.6.2. Rabi 1989

The data on the number, length and width of leaves in different treatments in the rabi field trial and the results of statistical analysis are presented in Table 24.

There were no significant difference between the treatments in the case of mean length of third leaf and mean width of first, second and third leaves. The application of 0.75 kg ai/ha of carbofuran at 50 DAT and 0.50 and 0.75 kg ai/ha twice at 20 and 50 DAT had a significantly higher number of leaves/hill than the untreated control with 33.07 leaves/hill, the number of leaves/hill in the above treatments were 40.62, 39.75 and 39.60, respectively.

In respect of the mean length of first leaf, only one treatment was found superior to untreated control. The application of carbofuran at 0.50 kg ai/ha twice at 20 and 50 DAT had 34.88 cm leaf length as compared to 30.95 cm in untreated control and was also significantly higher than the treatment at 0.50 kg ai/ha applied at 20 DAT which showed a leaf length of 29.87 cm. Similarly, in the case of second leaf also, application at 0.50 kg ai/ha twice at 20 and 50 DAT had the highest length of 42.10 cm which differed significantly from the leaf length of 34.91 cm in treatment at 0.50 kg ai/ha given at 50 DAT.

Table 24. Effect of different rates and timings of carbofuran application on number, length and width of leaves (rabi, 1989) at 60 DAT

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean No. of leaves/hill	Mean length of I leaf (cm)	Mean length of II leaf (cm)	Mean length of III leaf (cm)	Mean width of I leaf (cm)	Mean width of II leaf (cm)	Mean width of III leaf (cm)
Carbofuran 3G	0.50	20	35.80ab	29.87c	39.53ab	35.39a	1.81a	1.51a	1.10a
,,	0.75	,,	36.90ab	32.76abc	37.05ab	34.73a	1.92a	1.38a	1.00a
,,	1.00	,,	37.42ab	32.76abc	40.65ab	33.98a	1.95a	1.43a	1.19a
,,	0.50	50	35.90ab	31.48abc	34.91b	31.79a	1.74a	1.49a	1.14a
,,	0.75	,,	40.62a	31.64abc	37.34ab	33.61a	1.67a	1.51a	1.17a
,,	1.00	,,	38.30ab	32.15abc	36.30ab	33.43a	1.87a	1.44a	1.22a
,,	0.50	20&50	39.75a	34.88a	42.10a	34.68a	1.90a	1.39a	1.05a
,,	0.75	,,	39.60a	33.81ab	37.58ab	34.53a	1.68a	1.36a	1.26a
,,	1.00	,,	38.02ab	31.70abc	39.66ab	36.08a	1.83a	1.41a	1.04a
Untreated control			33.07b	30.95bc	40.90ab	34.77a	1.83a	1.46a	1.14a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

4.2.7. Effect on leaf area of different leaves at 60 DAT

4.2.7.1. Kharif 1989

The data on the area of different leaves and the total area of first three leaves in the net plot along with the results of statistical analysis of the same are presented in Table 25 and illustrated in Fig. 17 and 18. The leaf area of first and third leaves in different treatments did not show any statistical variations. The leaf area in the second leaf recorded significant variations between treatments, but the leaf area in all the carbofuran treated plots showed no significant variation as compared to untreated control. However, the highest leaf area of 41.08 cm^2 was recorded in the application of carbofuran at 1.00 kg ai/ha twice at 20 and 50 DAT which was significantly different from 32.77 cm^2 recorded in 0.50 kg ai/ha applied at 50 DAT.

There was significant difference between treatments in the case of mean area of first three leaves but all the treatments were on par with untreated control. The highest rate of 1.00 kg ai/ha applied twice at 20 and 50 DAT was found significantly higher than other treatments such as application at 0.50 kg ai/ha twice, 0.75 and 1.00 kg ai/ha at 20 DAT and 0.50 and 0.75 kg ai/ha at 50 DAT, the mean values in these treatments being 36.07, 31.67, 31.49, 31.55, 31.03 and 31.05 cm^2, respectively.

When the total area of the first three leaves in the net plot was worked out, the 0.75 and 1.00 kg ai/ha applications twice at 20 and 50 DAT were significantly

Table 25. Effect of different rates and timings of carbofuran application on area of leaves (kharif, 1989) at 60 DAT

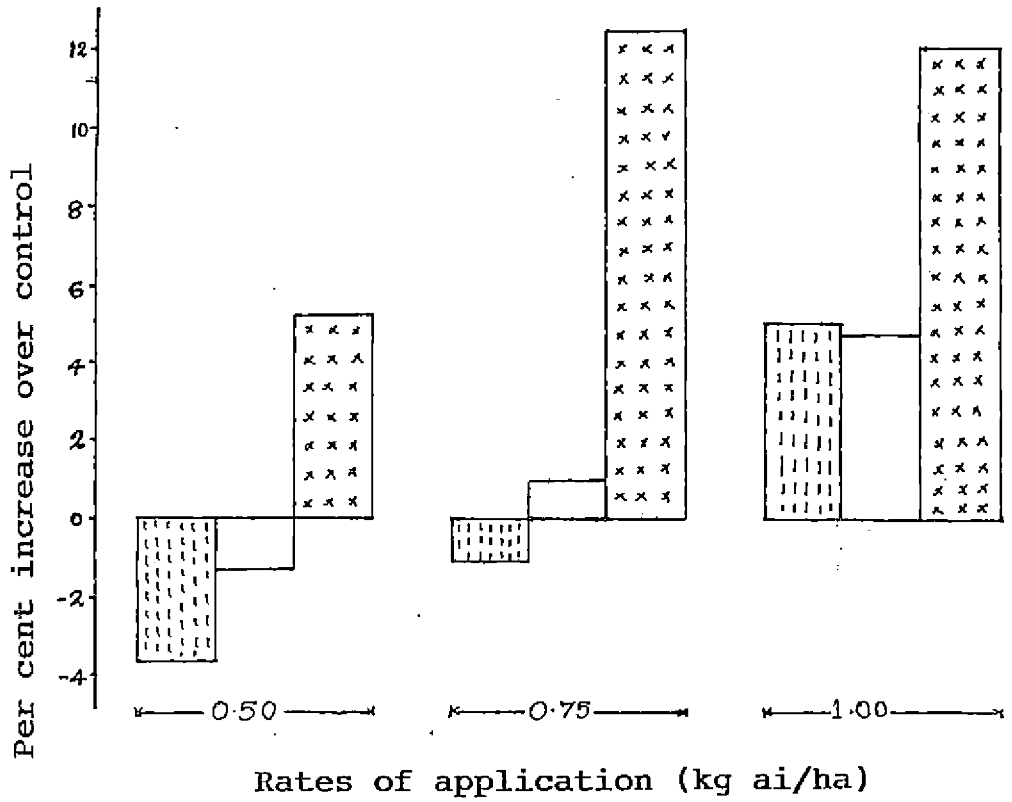
Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Mean leaf area (cm^2)				Total area of first three leaves in the net plot (m^2)
			I leaf	II leaf	III leaf	First three leaves	
Carbofuran 3G	0.50	20	33.91a	35.18ab	28.31a	32.47ab	45.86b
,,	0.75	,,	33.33a	34.22ab	26.91a	31.49b	48.35ab
,,	1.00	,,	32.06a	33.77ab	28.83a	31.55b	44.55b
,,	0.50	50	34.17a	32.77b	26.16a	31.03b	48.24ab
,,	0.75	,,	30.38a	34.75ab	28.01a	31.05b	48.16ab
,,	1.00	,,	32.88a	38.00ab	29.28a	33.39ab	49.47ab
,,	0.50	20&50	31.71a	35.66ab	27.65a	31.67b	50.97ab
,,	0.75	,,	36.91a	37.32ab	30.11a	34.78ab	58.44a
,,	1.00	,,	36.73a	41.08a	30.40a	36.07a	60.37a
Untreated control			33.22a	35.84ab	27.39a	32.15ab	45.97b

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

Fig. 17. Effect of rates of application of carbofuran on leaf area at 60 DAT (Kharif 1989)

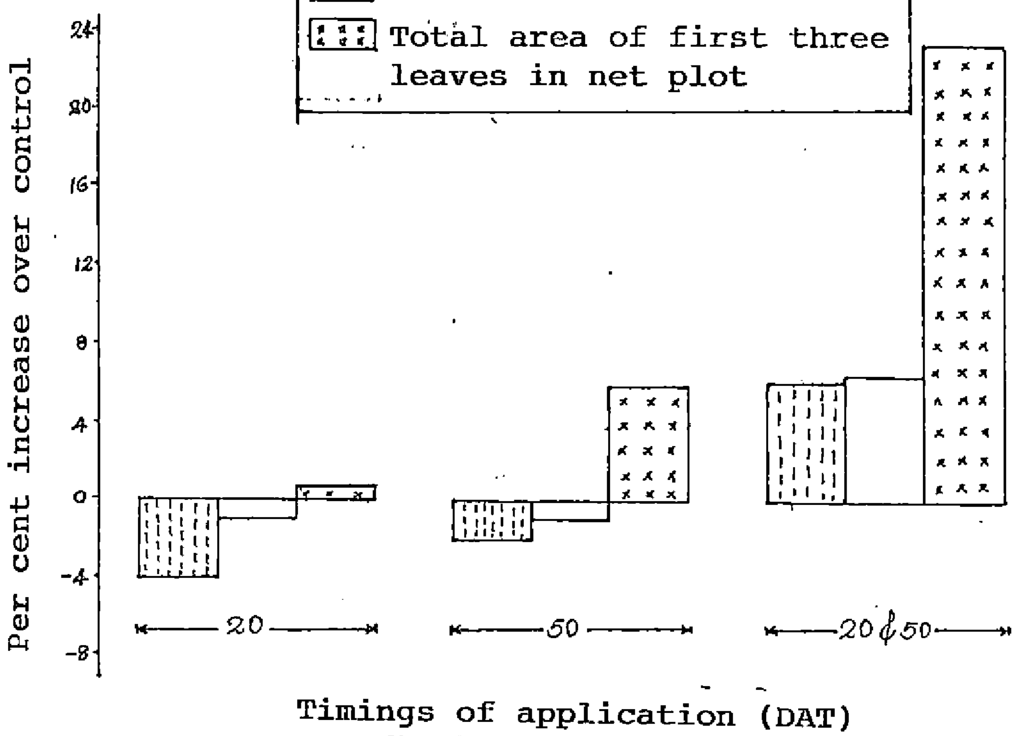
Fig. 18. Effect of timings of application of carbofuran on leaf area at 60 DAT (Kharif 1989)

FIG-17



II leaf
Mean of first three leaves
Total area of first three leaves in net plot

FIG-18



higher than untreated control having a total leaf area of 45.97 m^2. The total leaf area in the net plot for the above treatments were 58.44 and 60.37 m^2, respectively.

Effect of different rates of carbofuran application on the area of second leaf, mean of first three leaves and total area of first three leaves in net plot illustrated in Fig. 17 showed that the 0.75 and 1.00 kg ai/ha applications increased the total area of first three leaves in the net plot, substantially over untreated control.

The effect of timing of applications on the area of second leaf, mean of first three leaves and the total area of first three leaves in the net plot are presented in Fig. 18. The applications at 20 as well as 50 DAT showed increase in the leaf area in second leaf, mean of first three leaves and the total area of first three leaves in the net plot, substantial increase (23.1 per cent over control) being in the total area of first three leaves in the net plot.

4.2.7.2. Rabi 1989

The data on the area of first, second and third leaves recorded at 60 DAT, the mean of first three leaves and the total area of first three leaves in the net plot are presented in Table 26. In respect of the above parameters, statistical variation between treatments was found only in the case of the leaf area of first leaf during the season. Even though there was difference

Table 26. Effect of different rates and timings of carbofuran application on area of leaves (rabi, 1989) at 60 DAT

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean leaf area (cm^2) I leaf	II leaf	III leaf	First three leaves	Total area of first three leaves in the net plot (m^2)
Carbofuran 3G	0.50	20	40.70ab	44.75a	29.33a	38.26a	62.55a
,,	0.75	,,	47.16ab	38.41a	26.14a	37.23a	65.16a
,,	1.00	,,	48.01ab	43.68a	30.31a	40.66a	73.07a
,,	0.50	50	41.14ab	39.21a	27.38a	35.90a	60.62a
,,	0.75	,,	39.64b	42.38a	29.70a	37.24a	65.74a
,,	1.00	,,	44.95ab	39.02a	30.68a	38.22a	68.76a
,,	0.50	20&50	49.72a	44.31a	27.43a	40.48a	77.05a
,,	0.75	,,	42.52ab	38.25a	32.65a	37.80a	69.51a
,,	1.00	,,	43.56ab	41.93a	28.13a	37.87a	70.16a
Untreated control			42.46ab	44.61a	29.72a	38.93a	62.75a

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

between treatments in the area of first leaf, none of the carbofuran treatments were significantly higher than untreated control in which the leaf area was 42.46 cm^2.

4.2.8. Effect on leaf area damage in different leaves at 60 DAT

4.2.8.1. Kharif 1989

The data relating to the leaf area damage on the first, second, third and mean of first three leaves are presented in Table 27 and illustrated in Fig.19 and 20.

Significant differences between treatments were observed in all the above parameters studied. The leaf area damage in the first leaf was the highest in treatment receiving carbofuran at 0.75 kg ai/ha applied twice at 20 and 50 DAT (20.06 cm^2) followed by the treatment with 1.00 kg ai/ha twice (19.26 cm^2), treatment with 0.50 kg ai/ha twice (17.11 cm^2) and treatment with 1.00 kg ai/ha at 20 DAT (16.38 cm^2), these being on par. Carbofuran application at all the levels applied at 50 DAT and 0.50 kg ai/ha at 20 DAT were on par with untreated control, the leaf area in these treatments ranging from 7.42 to 10.41 cm^2. In the second leaf also the same trend of feeding was observed in different treatments. All the levels of carbofuran applied at 20 as well as on 50 DAT and 0.75 and 1.00 kg ai/ha applied at 20 DAT showed more damage than in untreated control. The feeding in these treatments were 19.72 cm^2 for 0.50 kg ai/ha applied twice, 20.86 cm^2 for 0.75 kg ai/ha twice, 21.72 cm^2 for 1.00 kg ai/ha twice, 15.28 cm^2 for 1.00 kg ai/ha at 20 DAT and 14.46 cm^2 for 0.75 kg ai/ha at 20 DAT. The other treatments were on par with untreated control.

Table 27. Effect of different rates and timings of carbofuran application on leaf area damage by *C. medinalis* (kharif, 1989) at 60 DAT

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean leaf area damage (cm^2)			
			I leaf	II leaf	III leaf	First three leaves
Carbofuran 3G	0.50	20	10.41cd	13.39cd	9.31c	11.03bcd
,,	0.75	,,	13.79bc	14.46c	8.17c	12.14bc
,,	1.00	,,	16.38ab	15.28bc	11.47c	14.38b
,,	0.50	50	7.42d	7.79e	10.13c	8.54cd
,,	0.75	,,	7.68d	10.85cde	11.83c	10.12cd
,,	1.00	,,	8.48d	11.39cde	13.70bc	11.19bcd
,,	0.50	20&50	17.11ab	19.72ab	20.13a	18.99a
,,	0.75	,,	20.06a	20.86a	18.24ab	19.72a
,,	1.00	,,	19.26a	21.72a	21.76a	20.91a
Untreated control			7.94d	9.09de	7.84c	8.29d

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

On the third leaf the trend was quite different. From the table it could be seen that the different levels of carbofuran applied at 20 as well as 50 DAT showed significantly more damage than untreated control. The other treatments applied once either at 20 or at 50 DAT were on par with untreated control. The leaf area damage in 0.50, 0.75 and 1.00 kg ai/ha applied plots (twice) were 20.13, 18.24 and 21.76 cm^2, respectively.

When the mean leaf area damage in the first three leaves was taken into consideration, significantly higher damage than all other treatments was recorded in 0.50, 0.75 and 1.00 kg ai/ha applied twice at 20 and 50 DAT and the damage in these treatments were 18.99, 19.72 and 20.91 cm^2, respectively and were on par. The other treatments which were significantly different from untreated control were 0.75 and 1.00 kg ai/ha applied at 20 DAT which had 12.14 and 14.38 cm^2, respectively. The lowest damage of 8.29 cm^2 was recorded in untreated control.

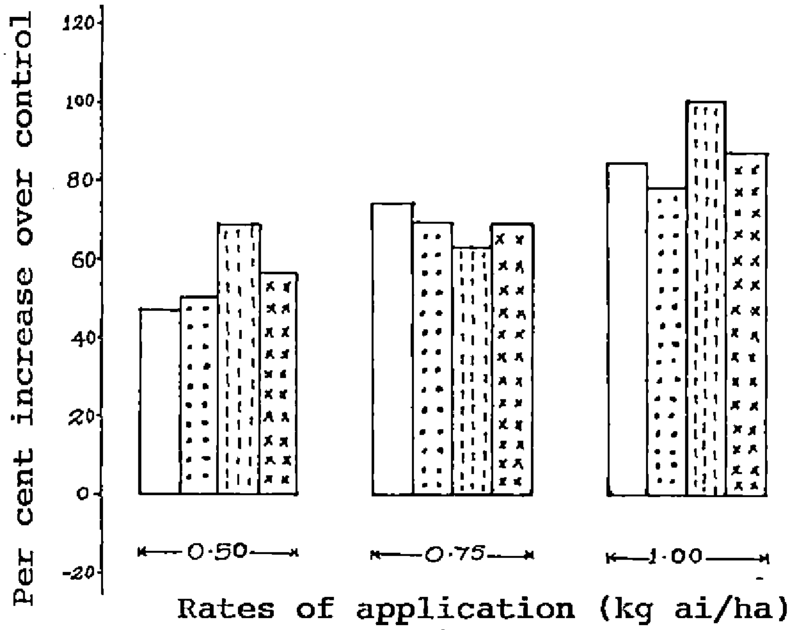
The effect of different rates of carbofuran application depicted in Fig. 19 showed that higher damage by leaf folder was induced by higher rates of application in first, second, third and mean of first three leaves. The damage induced by 1.00 kg ai/ha in these leaves were 85.2, 77.5, 99.5 and 86.9 per cent over control, respectively. However all the rates of application of carbofuran increased leaf area damage as compared to control.

The effects of timing of application of carbofuran on leaf area damage in different leaves are illustrated in

Fig. 19. Effect of rates of application of carbofuran on leaf area damage by _C. medinalis_ at 60 DAT (Kharif 1989)

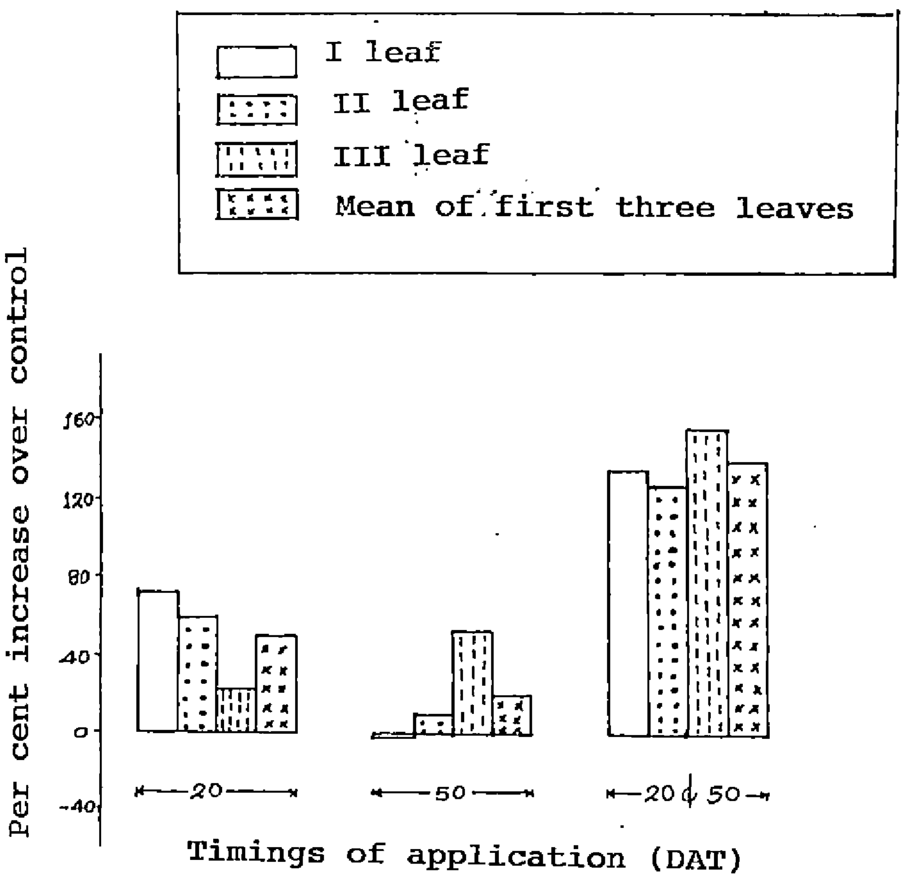
Fig. 20. Effect of timings of application of carbofuran on leaf area damage by _C. medinalis_ at 60 DAT (Kharif 1989)

FIG-19



Per cent increase over control
120
100
80
60
40
20
0
-20
0·50
0·75
1·00
Rates of application (kg ai/ha)

FIG-20



I leaf
II leaf
III leaf
Mean of first three leaves
Per cent increase over control
160
120
80
40
0
-40
20
50
20 & 50
Timings of application (DAT)

Fig. 20. The applications at 50 DAT did not influence the leaf area damage substantially but the 20 DAT and 20 as well as 50 DAT applications showed pronounced effects, the highest influence being shown by the 20 as well as 50 DAT applications. The highest influence by 20 and 50 DAT applications was on the third leaf (156 per cent increase over control). In first leaf 70 per cent increase over control was recorded in leaf area damage by the 20 DAT aplication.

4.2.8.2. Rabi 1989

The data relating to the leaf area damage in different leaves and the results of statistical analysis are presented in Table 28 and the influence of rates and timings of application of carbofuran on leaf area damage during the season are graphically represented in Fig. 21 and 22.

The damage during rabi was comparatively lower than that during kharif. The leaf area damage in different treatments recorded in the first leaf showed significant variations between treatments. All the carbofuran applied treatments showed higher damage than in untreated control. Among the carbofuran treatments application at 0.75 kg ai/ha applied twice at 20 and 50 DAT had the highest leaf area damage (711.50 mm^2) followed by 1.00 kg ai/ha twice (678.56 mm^2) and 1.00 kg ai/ha at 20 DAT (624.60 mm^2) and these were on par. The plots receiving 1.00 kg ai/ha application twice was also on par with 0.50 kg ai/ha applied twice. The latter treatment was also on par with 0.75 kg ai/ha at 20 DAT. The other treatments even though significantly different from untreated control had only lower damage.

Table 28. Effect of different rates and timings of carbofuran application on leaf area damage by C. medinalis (rabi, 1989) at 60 DAT

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean leaf area damage (mm^2)			
			I leaf	II leaf	III leaf	First three leaves
Carbofuran 3G	0.50	20	280.28e	399.89c	331.48c	338.63e
,,	0.75	,,	474.84d	450.02c	413.32bc	447.54d
,,	1.00	,,	624.60abc	664.15ab	447.54b	578.95bc
,,	0.50	50	124.08g	163.43de	202.89d	163.86gh
,,	0.75	,,	218.79ef	169.67de	219.87d	203.52fg
,,	1.00	,,	142.50fg	242.30d	239.37d	208.40f
,,	0.50	20&50	541.72bcd	691.93ab	394.62bc	543.34c
,,	0.75	,,	711.50a	812.91a	597.24a	708.45a
,,	1.00	,,	678.56ab	620.56b	651.85a	653.37ab
Untreated control			61.50h	149.28e	191.46d	134.90h

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

A similar trend of leaf area damage was observed in the second leaf also. Carbofuran at 0.75 kg ai/ha applied twice recorded highest leaf area damage (812.91 mm^2) followed by 691.93 mm^2 in two applications at 0.50 kg ai/ha and 664.15 mm^2 in 1.00 kg ai/ha at 20 DAT. This last treatment was also on par with the treatment at 1.00 kg ai/ha applied twice. The treatments of 0.50 and 0.75 kg ai/ha at 20 DAT showed 399.89 and 450.02 mm^2 leaf area damage, respectively and were significantly higher than control. The lower doses of 0.50 and 0.75 kg ai/ha at 50 DAT was on par with the damage in untreated control.

The leaf area damage in the third leaf also showed that more leaf area damage was caused by the applications of carbofuran at 20 and 50 DAT (twice) and also by applications received at 20 DAT. In the third leaf, the leaf area damage at 50 DAT treatments were on par with untreated control which had 191.46 mm^2 leaf damage.

The mean leaf area damage of the first three leaves also showed the same trend of results that the damage by different rates applied twice at 20 and 50 DAT and the applications at 20 DAT showed higher leaf area damage than the applications at 50 DAT or untreated control.

The effects of different rates of application on leaf area damage are represented in Fig. 21. Even though all the rates increased the leaf area damage the increase was highest in the first leaf which accounted to 413 and 684 per cent over control by 0.50 and 1.00 kg ai/ha doses.

Fig. 21. Effect of rates of application of carbofuran on leaf area damage by C. medinalis at 60 DAT (Rabi 1989)

Fig. 22. Effect of timings of application of carbofuran on leaf area damage by C. medinalis at 60 DAT (Rabi 1989)

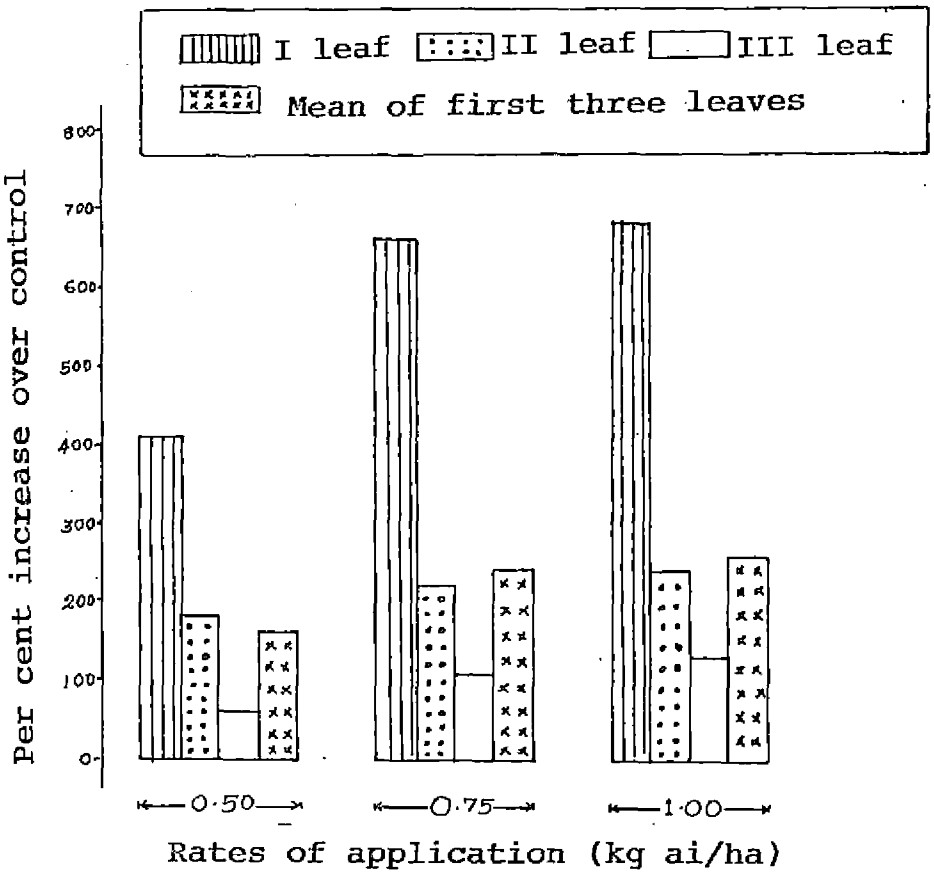

I leaf
II leaf
III leaf
Mean of first three leaves
Per cent increase over control
0
100
200
300
400
500
600
700
800
0·50
0·75
1·00
Rates of application (kg ai/ha)

FIG-21

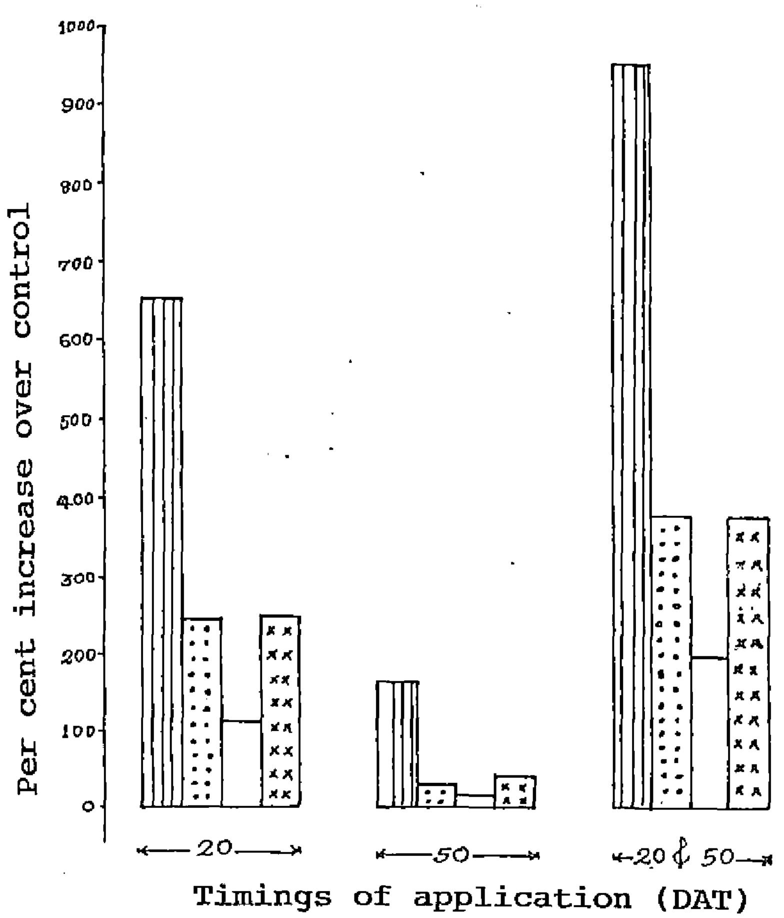

Per cent increase over control
0
100
200
300
400
500
600
700
800
900
1000
20
50
20 & 50
Timings of application (DAT)

FIG-22

The effect of number of applications on leaf area damage, illustrated in Fig. 22 also showed highest effects on the first leaf. In the first, second and third leaves and the mean of first three leaves, the 20 and 50 DAT (twice) applications showed increased leaf area damage than the 20 or 50 DAT applications. The influence of 50 DAT application on leaf area damage was very low.

4.2.8.3. Results of paired 't' test for comparison of the order of preference of leaves for feeding by *C. medinalis* larvae

The result of the paired 't' test conducted for assessing the order of preference of leaves for feeding by leaf folder larvae during the kharif and rabi seasons are presented in Table 29.

During kharif, there was significant difference in feeding by larvae between the first and second leaves only. Between first and second leaf more damage was on second leaf which indicated more preference to second leaf at 60 DAT as the 't' value obtained was -3.55. The paired 't' test conducted for rabi showed that between first leaf and second leaf, significantly different feeding preference of leaf folder larvae was for second leaf as the 't' value was -2.27. Between first and third leaf there was no difference in preference for feeding. Between the second leaf and third leaf, significantly more preference for feeding was on second leaf as evidenced by the 't' value of 2.92.

Table 29. Paired 't' test for comparison of feeding preference to first, second and third leaves by *C. medinalis* larvae

Leaf order compared	't' values obtained	
	Kharif '89	Rabi '89
First and second	-3.55**	-2.27*
First and third	-0.42 NS	0.78 NS
Second and third	1.45 NS	2.92 **

** Significant at 1.0 per cent level

* Significant at 5.0 per cent level

NS Not significant

4.2.9. Effect on yield attributes and yield

4.2.9.1. Kharif 1989

The data on different yield attributes and the grain and straw yield and the results of statistical analysis of the data are presented in Table 30 and the effects of rates and timings on different aspects illustrated in Fig. 23 and 24.

The mean length of earhead was the highest in untreated control (23.09 cm) and was on par with all the treatments at 50 DAT, 1.00 kg ai/ha applied twice at 20 and 50 DAT and 0.50 and 1.00 kg ai/ha applied at 20 DAT. The treatments which were significantly inferior to untreated control were 0.50 and 0.75 kg ai/ha applied at 20 as well as 50 DAT and 0.75 kg ai/ha applied at 20 DAT. The length of earhead in these treatments were 20.82, 21.06 and 21.09 cm, respectively.

The weight of 10 panicles of main tiller also showed highest weight (21.02 g) in untreated control and was on par with 1.00 kg ai/ha of carbofuran applied at 50 DAT (18.88 g). The latter treatment was on par with 17.29 g in 0.75 kg ai/ha applied at 50 DAT. The treatments receiving 0.50 kg ai/ha of carbofuran at 50 DAT, 0.50 and 0.75 kg ai/ha at 20 DAT and 1.00 kg ai/ha at 20 and 50 DAT applications showed very low panicle weights when compared with untreated control.

Table 30. Effect of different rates and timings of carbofuran application on yield attributes and yield of rice (kharif, 1989)

Treatment	Rates (kg ai/ ha)	Time of application (DAT)	Mean length of earhead (cm)	Weight of 10 panicles of main tiller (g)	Total grains/ earhead (No.)	Grain yield (kg/ha)	Dry straw yield (kg/ha)
Carbofuran 3G	0.50	20	22.18ab	11.85cd	105.37bc	1283cd	3096ab
,,	0.75	,,	21.09b	10.41cd	84.73d	1025ef	2481b
,,	1.00	,,	21.42ab	9.72d	100.67bc	1150de	2823ab
,,	0.50	50	22.39ab	13.43c	115.77ab	1499b	3281ab
,,	0.75	,,	22.26ab	17.29b	111.23abc	1914a	2939ab
,,	1.00	,,	22.51ab	18.88ab	116.53ab	1996a	3486a
,,	0.50	20&50	20.82b	9.03d	101.17bc	1000ef	2919ab
,,	0.75	,,	21.06b	9.80d	97.63cd	897f	2782ab
,,	1.00	,,	21.68ab	17.77c	105.80bc	1472bc	2871ab
Untreated control			23.09a	21.02a	123.23a	2035a	3008ab

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

The number of total grains/earhead was higher in treatments which received applications of carbofuran at 50 DAT and in untreated control. The untreated control had 123.23 total number of grains while 0.50, 0.75 and 1.00 kg ai/ha at 50 DAT had 115.77, 111.23 and 116.53 total grains. In the case of total grains/earhead, the applications at 20 DAT and applications at 20 as well as 50 DAT did not show much variations, the number of total grains in these treatments ranging from 84.73 to 105.80.

The results of statistical analysis of the grain yield showed that the highest yield of 2035 kg/ha was obtained from the untreated control followed by plots which received carbofuran at 1.00 kg ai/ha at 50 DAT (1996 kg/ha) and 0.75 kg ai/ha at 50 DAT (1914 kg/ha). The 0.50 kg ai/ha given at 50 DAT and 1.00 kg ai/ha given twice at 20 and 50 DAT were on par and gave grain yield of 1499 and 1472 kg/ha, respectively. The other treatments applied twice and the treatments at 20 DAT recorded lower grain yields which ranged from 897 to 1283 kg/ha.

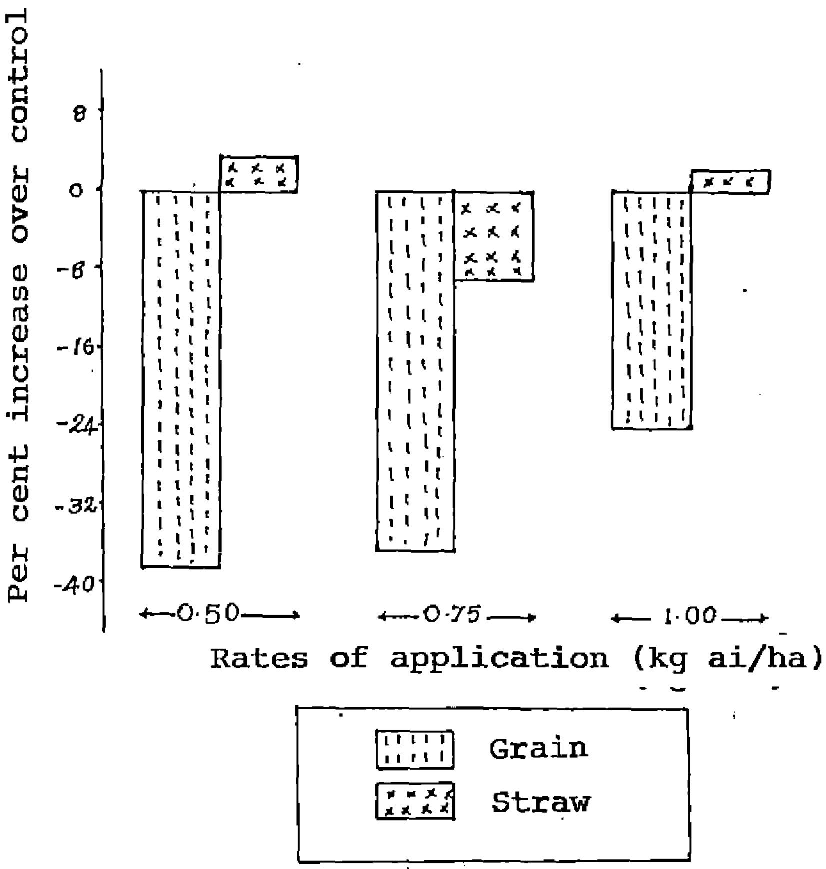
With regard to straw yield, the treatments, which differed significantly were application of carbofuran at 1.00 kg ai/ha at 50 DAT and 0.75 kg ai/ha applied at 20 DAT, the straw yield in these treatments being 3486 and 2481 kg/ha, respectively.

The effect of 0.50, 0.75 and 1.00 kg ai/ha of carbofuran on the grain yield represented in Fig. 23 showed

Fig. 23. Effect of rates of application of carbofuran on grain and straw yield (Kharif 1989)

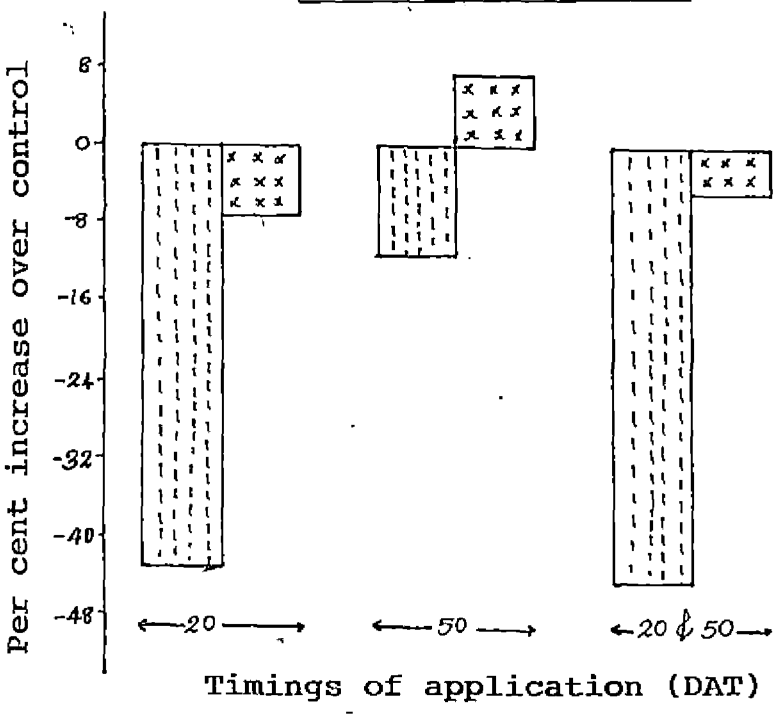
Fig. 24. Effect of timings of application of carbofuran on grain and straw yield (Kharif 1989)

FIG-23



Per cent increase over control
8
0
-8
-16
-24
-32
-40
0.50
0.75
1.00
Rates of application (kg ai/ha)
Grain
Straw

FIG-24



Per cent increase over control
8
0
-8
-16
-24
-32
-40
-48
20
50
20 & 50
Timings of application (DAT)

that all the rates of application reduced the grain yield substantially but the effect on straw yield was low on comparison with untreated control.

The effect of timing of application of carbofuran on grain and straw yield illustrated in Fig. 24 showed that the applications at 20 DAT and 20 and 50 DAT reduced the grain yield substantially over control, the reductions being 43.4 and 44.8 per cent. However, the 50 DAT application did not affect the grain yield profoundly. The effect of timings of application of carbofuran on the straw yield was only of a lower extent.

4.2.9.2. Rabi 1989

The data on different yield attributes and grain yield along with the results of statistical analysis are presented in Table 31. The effects of rates and timings of application are depicted in Fig. 25 and 26. The mean length of earhead and the total number of grains/earhead did not show any statistical difference between the treatments, these parameters in untreated control being 22.78 cm and 134.93, respectively.

In respect of the weight of 10 panicles of main tiller, significant variations were detected between treatments, the maximum weight of 40.01 g being recorded in untreated control. All the carbofuran treatments differed significantly from untreated control in the weight of panicles. The lowest weight of 14.89 g was

Table 31. Effect of different rates and timings of carbofuran application on yield attributes and yield of rice (rabi, 1989)

Treatment	Rate (kg ai/ha)	Time of application (DAT)	Mean length of earhead (cm)	Weight of 10 panicles of main tiller (g)	Total grains/earhead (No.)	Grain yield (kg/ha)	Dry straw yield (kg/ha)
Carbofuran 3G	0.50	20	22.32a	21.32def	134.73a	2353cd	3623bc
,,	0.75	,,	21.60a	22.37de	143.57a	2194d	3917abc
,,	1.00	,,	21.77a	18.35efg	132.30a	2014de	4170abc
,,	0.50	50	21.62a	30.84b	128.93a	3372b	3712abc
,,	0.75	,,	21.68a	28.52bc	126.67a	3151b	4443a
,,	1.00	,,	21.85a	25.77cd	129.63a	2712c	4217ab
,,	0.50	20&50	21.98a	16.27g	140.23a	1793ef	3759abc
,,	0.75	,,	22.30a	17.13fg	129.93a	1572f	4081abc
,,	1.00	,,	21.72a	14.89g	129.13a	1474f	3691bc
Untreated control			22.78a	40.01a	134.93a	4065a	3466c

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

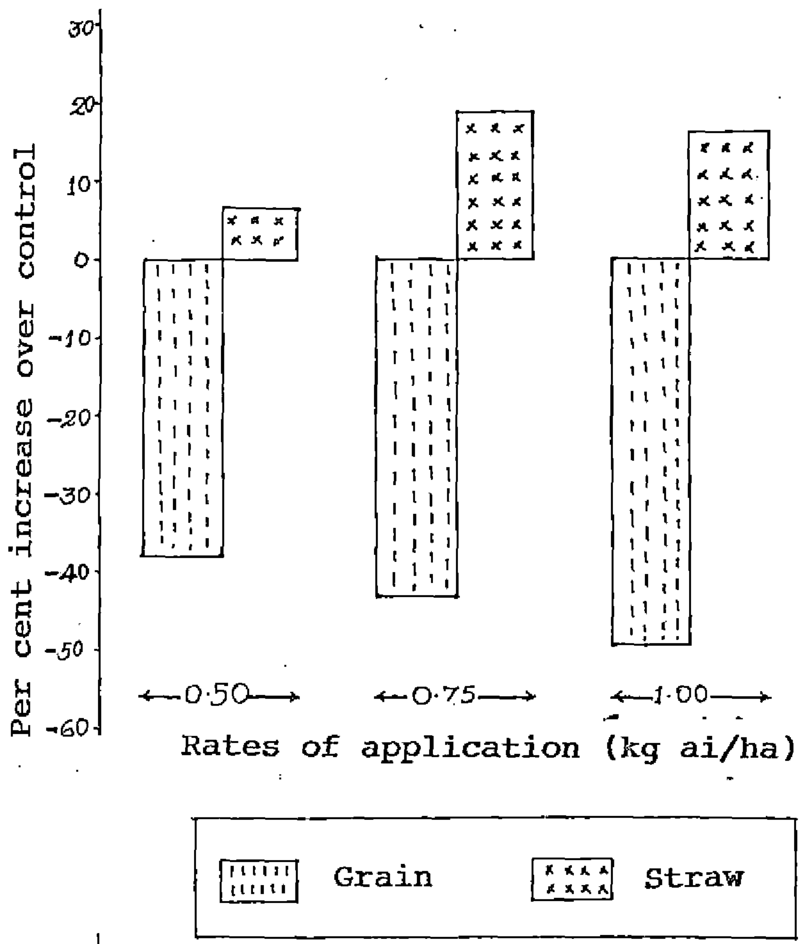
recorded in carbofuran applied at 1.00 kg ai/ha twice at 20 amd 50 DAT followed by 16.27 g in 0.50 kg ai/ha twice, 17.13 g in 0.75 kg ai/ha twice and 18.35 g in 1.00 kg ai/ha at 20 DAT and these treatments were on par. Among the carbofuran treatments, comparatively higher weight of panicles was recorded in the treatments at 50 DAT. The 20 DAT and 20 and 50 DAT treatments recorded only very low panicle weights. The highest panicle weight of 40.01 g was in the untreated control.

Grain yield recorded during the season was highest for untreated control (4065 kg/ha). Among the carbofuran treatments better grain yields were obtained from 0.50 kg ai/ha (3372 kg/ha) and 0.75 kg ai/ha (3151 kg/ha) applied at 50 DAT and these treatments were on par. From 1.00 kg ai/ha of carbofuran applied at 50 DAT, a grain yield of 2712 kg/ha was obtained and was on par with 2353 kg/ha from 0.50 kg ai/ha treated plots given at 20 DAT. This latter treatment was on par with the other treatments at 20 DAT. Lower grain yields were recorded in plots which received the applications at both 20 and 50 DAT.

During rabi, the highest yield of straw was from carbofuran applied plots @ 0.75 kg ai/ha at 50 DAT (4443 kg/ha) followed by 4217 kg/ha in 1.00 kg ai/ha applied at 50 DAT. Among the carbofuran treated plots the lowest straw yield was in 0.50 kg ai/ha applied at 20 DAT (3623 kg/ha) followed by 3691 kg/ha in carbofuran applied @ 1.00 kg ai/ha twice at 20 and 50 DAT and were on par with untreated control.

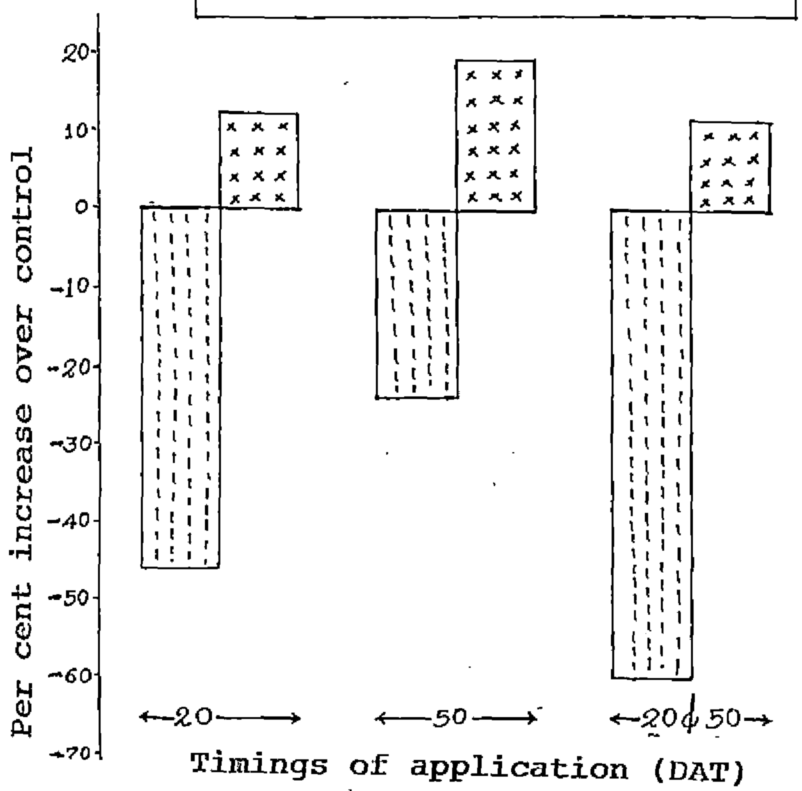
Fig. 25. Effect of rates of application of carbofuran on grain and straw yield (Rabi 1989)

Fig. 26. Effect of timings of application of carbofuran on grain and straw yield (Rabi 1989)



Per cent increase over control
30
20
10
0
-10
-20
-30
-40
-50
-60
0·50
0·75
1·00
Rates of application (kg ai/ha)
Grain
Straw

FIG-25



Per cent increase over control
20
10
0
-10
-20
-30
-40
-50
-60
-70
20
50
20 & 50
Timings of application (DAT)

FIG-26

The effect of different rates of application of carbofuran on the grain and straw yield are graphically represented in Fig. 25. The different rates, 0.50, 0.75 and 1.00 kg ai/ha showed a reduction in grain yield over untreated control, the rates of reduction being in that order. However, the different rates of carbofuran application manifested an increasing trend of straw weight over untreated control.

The effect of timings of application of carbofuran on grain and straw yield are represented in Fig. 26. While 20 DAT applications and 20 and 50 DAT applications reduced the grain yield highly over control, the reduction was not so high with 50 DAT applications, the reduction by 20 as well as 50 DAT applications being highest (60.3 per cent over control). However, the straw yield showed an increase of 10.9 to 19.0 per cent over control by the carbofuran treatments at 20, 50 and 20 and 50 DAT.

4.2.10. Effect on grain filling attributes

4.2.10.1. Kharif 1989

The data on different grain filling attributes and the results of statistical analysis of the same are presented in Table 32.

The 1000 grain weight of filled grains and half-filled grains did not show any treatment differences, the 1000 grain weight of filled grains being 28.98 g and that of half-filled grains being 13.14 g, respectively.

Table 32. Effect of different rates and timings of carbofuran application on grain filling (kharif, 1989)

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Mean number per earhead			1000 grain weight (g)	
			Filled grains	Half-filled grains	Chaff	Filled grains	Half-filled grains
Carbofuran 3G	0.50	20	23.73f	31.23a	50.40a	27.50a	12.49a
,,	0.75	,,	31.23e	17.97bcd	35.63c	27.05a	12.22a
,,	1.00	,,	38.80d	21.70bcd	40.17bc	26.87a	12.63a
,,	0.50	50	48.07c	24.83ab	42.87abc	28.68a	12.92a
,,	0.75	,,	47.13c	20.70bcd	43.40abc	29.77a	13.31a
,,	1.00	,,	56.47b	23.63abc	36.43c	28.47a	12.83a
,,	0.50	20&50	36.47d	19.80bcd	44.90abc	26.38a	12.77a
,,	0.75	,,	38.93d	14.37d	44.33abc	27.63a	13.04a
,,	1.00	,,	38.03d	18.33bcd	49.43ab	27.80a	14.42a
Untreated control			67.77a	15.27cd	40.20bc	28.98a	13.14a

The mean number of filled grains/earhead was highest in untreated control (67.77). This was followed by 56.47 in 1.00 kg ai/ha at 50 DAT, 47.13 in 0.75 kg ai/ha at 50 DAT and 48.07 in 0.50 kg ai/ha at 50 DAT and were signicantly inferior to that in untreated control. The carbofuran treatments applied at 20 DAT showed low filled grains ranging from 36.47 to 38.93 and these treatments were on par. The lowest grain filling was in 0.50 kg ai/ha at 20 DAT (23.73) followed by 0.75 kg ai/ha at 20 DAT (31.23).

The number of half-filled grains was highest in 0.50 kg ai/ha treatment of carbofuran at 20 DAT (31.23) followed by application of 0.50 and 1.00 kg ai/ha at 50 DAT. The lowest number of half-filled grains was recorded from 0.75 kg ai/ha treatment applied twice (14.37) and was on par with untreated control, 0.50 and 1.00 kg ai/ha applied twice, 0.75 kg ai/ha given at 50 DAT and 0.75 and 1.00 kg ai/ha at 20 DAT.

In the case of number of chaff/earhead, the highest number (50.40) was in 0.50 kg ai/ha application of carbofuran at 20 DAT followed by 49.43 in 1.00 kg ai/ha applied twice. All the other treatments were on par with untreated control with lower chaff.

4.2.10.2. Rabi 1989

The data on different grain filling attributes and the results of statistical analysis are presented in Table 33. The 1000 grain weight of filled grains and half-filled grains did not show any significant variations between treatments.

Table 33. Effect of different rates and timings of carbofuran application on grain filling (rabi, 1989)

Treatment	Rate (kg ai/ ha)	Time of appli-cation (DAT)	Mean number per earhead			1000 grain weight (g)	
			Filled grains	Half-filled grains	Chaff	Filled grains	Half-filled grains
Carbofuran 3G	0.50	20	61.35c	23.10bc	50.11ab	28.51a	13.69a
,,	0.75	,,	59.53c	27.19b	55.46ab	28.06a	13.42a
,,	1.00	,,	54.55cd	35.89a	41.13bc	28.11a	13.48a
,,	0.50	50	104.85a	7.51f	16.01d	27.74a	13.90a
,,	0.75	,,	86.93b	14.67de	23.81cd	28.60a	13.63a
,,	1.00	,,	78.50b	28.78b	25.78cd	27.87a	14.49a
,,	0.50	20&50	41.99e	25.46bc	71.96a	27.65a	14.47a
,,	0.75	,,	39.25e	20.16cd	70.17a	27.81a	11.39a
,,	1.00	,,	45.22de	14.23e	68.84a	28.41a	14.19a
Untreated control			109.18a	8.24f	17.02d	27.31a	12.45a

The highest number of filled grains (109.18) was recorded in untreated control followed by 104.85 in 0.50 kg ai/ha application of carbofuran at 50 DAT and were on par with each other. This was followed by 0.75 and 1.00 kg ai/ha applied at 50 DAT which were on par with each other but significantly different from untreated control. The lowest number of filled grains was recorded in the applications twice at 20 as well as 50 DAT. Comparatively higher number of filled grains was recorded in the applications at 20 DAT than the applications twice.

The number of half-filled grains was highest (35.89) in carbofuran treatment at 1.00 kg ai/ha at 20 DAT and was significantly higher than all the other treatments. The lowest number of half-filled grains was in 0.50 kg ai/ha applied at 50 DAT (7.51) and was on par with untreated control. The applications at 1.00 kg ai/ha at 50 DAT followed by 0.75 kg ai/ha at 20 DAT, 0.50 kg ai/ha at 20 and 50 DAT (twice) and 0.50 kg ai/ha at 20 DAT which were on par had the number of half-filled grains per earhead ranging from 28.78 to 23.10.

In the case of the mean number of chaff/earhead, all the treatments except those applied at 50 DAT were showing significantly higher chaff than the untreated control which had 17.02 chaff/earhead. Higher numbers of chaff were recorded in applications of carbofuran given twice at 20 and 50 DAT followed by those applied at 20 DAT. The highest number of chaff was 71.96 recorded in application of 0.50 kg ai/ha applied at 20 as well as 50 DAT.

4.2.11. Effect on the residues and metabolites of carbofuran in whole grain and straw

4.2.11.1. Kharif 1989

The data on the residues of carbofuran and its metabolites in whole grain and straw are presented in Tables 34 and 35. The residues of carbofuran, 3-OH-carbofuran, 3-CO-carbofuran, 3-OH-7-phenol, 3-CO-7-phenol and 7-phenol in the whole grains were below detectable levels in all the treatments.

Similarly, the residues of carbofuran, 3-OH-7-phenol, 3-CO-7-phenol and 7-phenol were also below detectable levels in straw. However, in straw, the carbofuran + 3-OH carbofuran residues which are accounted for determining the maximum residue limits, were lower than the accepted MRL of 1.0 µg/g in straw.

Total residues of carbofuran and metabolites in straw showed variation between treatments. The 20 DAT applications and untreated control showed only zero levels of residues. The residues in 1.00 kg ai/ha applied twice had the highest residue (0.52 µg/g) followed by other treatments depending on the rate and number of applications, in the descending order.

4.2.11.2. Rabi 1989

During rabi, none of the treatments led to the presence of detectable levels of residues and metabolites of carbofuran.

Table 34. Effect of different rates and timings of carbofuran application on the residue and metabolites of carbofuran in whole grain (kharif, 1989)

Treatment	Rate (kg ai/ ha)	Time of application (DAT)	Carbofuran residue ($\mu g/g$)	Metabolites of carbofuran ($\mu g/g$)				
				3-OH-cabofuran	3-CO-carbofuran	3-OH-7-phenol	3-CO-7-phenol	7-phenol
Carbofuran 3G	0.50	20	ND	ND	ND	ND	ND	ND
,,	0.75	,,	ND	ND	ND	ND	ND	ND
,,	1.00	,,	ND	ND	ND	ND	ND	ND
,,	0.50	50	ND	ND	ND	ND	ND	ND
,,	0.75	,,	ND	ND	ND	ND	ND	ND
,,	1.00	,,	ND	ND	ND	ND	ND	ND
,,	0.50	20&50	ND	ND	ND	ND	ND	ND
,,	0.75	,,	ND	ND	ND	ND	ND	ND
,,	1.00	,,	ND	ND	ND	ND	ND	ND
Untreated control			ND	ND	ND	ND	ND	ND

Table 35. Effect of different rates and timings of carbofuran application on the residue and metabolites of carbofuran in straw (kharif, 1989)

Treatment	Rate (kg ai/ ha)	Time of appli- cation (DAT)	Carbofu- ran residue (μg/g)	Metabolites of carbofuran (μg/g)							Total resi- dues of carbofuran and metabo- lites(μg/g)
				3-OH- carbo- furan		3-CO- carbo- furan		3-OH-7- phenol	3-CO-7- phenol	7- phenol	
Carbofuran 3G	0.50	20	ND	ND		ND		ND	ND	ND	0.00e
,,	0.75	,,	ND	ND		ND		ND	ND	ND	0.00e
,,	1.00	,,	ND	ND		ND		ND	ND	ND	0.00e
,,	0.50	50	ND	0.10		ND		ND	ND	ND	0.10de
,,	0.75	,,	ND	0.02		0.11		ND	ND	ND	0.13cd
,,	1.00	,,	ND	0.07	Data not analysed	0.12	Data not analysed	ND	ND	ND	0.19c
,,	0.50	20&50	ND	0.08		0.24		ND	ND	ND	0.32b
,,	0.75	,,	ND	0.07		0.37		ND	ND	ND	0.44a
,,	1.00	,,	ND	0.10		0.42		ND	ND	ND	0.52a
Untreated control			ND	ND		ND		ND	ND	ND	0.00e

Means followed by a common letter in a column are not significantly different at 5% level (DMRT)

4.3. Path coefficient analysis of the factors (X) inducing resurgence influencing various attributes of *C. medinalis* populations

4.3.1. Effect on weight of larvae of third instar

The results of analysis are presented in Table 36 and illustrated in Fig. 27. The factors considered explained 55.6 per cent influence to weight of third instar as evidenced by the residual effect. The highest positive direct effect was by $chlorophyll_b$ followed by $chlorophyll_a$, 3-OH-7-phenol and 7-phenol contents. But the correlation coefficients of chlorophyll contents with weight of larvae were not significant. The 3-CO-carbofuran had positive indirect effects through other metabolites and $chlorophyll_{a+b}$ which was more pronounced through 3-OH-7-phenol and 7-phenol residues. The 3-OH-7-phenol showed highest positive indirect effect through 7-phenol. The indirect effects of different parameters through $chlorophyll_a$ or $chlorophyll_b$ were found nullified by the combinant effects of $chlorophyll_{a+b}$. The indirect effect of 3-CO-7-phenol through 3-OH-7-phenol was even higher than its direct effect on weight of third instar larvae. The 7-phenol showed good positive indirect effect through 3-OH-7-phenol residue while total residues of carbofuran and metabolites had high indirect positive effects through 3-OH-7-phenol and 7-phenol residues.

Through 3-OH-7-phenol all the metabolites and total residues of carbofuran and metabolites had high indirect

Table 36. Correlation between weight of 20 larvae of III instar (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of								Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	3-CO-7 phenol residue (X_3)	7-phenol residue (X_4)	Total residues of carbofuran and metabolites (X_5)	Chlorophyll$_a$ (X_6)	Chlorophyll$_b$ (X_7)	Chlorophyll$_{a+b}$ (X_8)	
X_1	0.511**	-0.060	0.216	0.057	0.260	0.028	-0.020	-0.059	0.088	0.666
X_2	0.667**	-0.039	0.332	0.125	0.252	0.031	0.147	0.167	-0.349	
X_3	0.533**	-0.018	0.221	0.187	0.143	0.022	0.118	0.094	-0.234	
X_4	0.660**	-0.048	0.258	0.083	0.325	0.029	-0.065	-0.053	0.131	
X_5	0.666*	-0.050	0.309	0.122	0.283	0.034	0.133	0.152	-0.316	
X_6	-0.132	0.001	0.061	0.128	-0.027	0.006	0.798	0.993	-1.992	
X_7	-0.144	0.003	0.053	9.017	-0.017	0.005	0.754	1.050	-2.010	
X_8	-0.141	0.003	0.057	0.022	-0.021	0.005	0.783	1.040	-2.029	

** Significant at one per cent level

* Significant at 5 per cent level

Unlerlined figures are the direct effects positive effects on weight of third instar larvae. Chlorophyll$_a$ recorded highest indirect positive effect through 3-CO-7-phenol followed by 3-OH-7-phenol. The indirect effects of total residues of carbofuran and metabolites, 3-CO-carbofuran and 3-OH-7-phenol were positive through 7-phenol.

4.3.2. Effect on weight of larvae of fourth instar

The results of analysis are presented in Table 37 and illustrated in Fig. 28. The residual effect of 0.542 showed that the different factors influence the weight of fourth instar larvae to the extent of 70.6 per cent. The highest positive direct effect on larval weight was from the total residues of carbofuran and metabolites followed by that from chlorophyll$_b$. At the same time chlorophyll$_{a+b}$ showed highest negative direct effect. The different metabolites of carbofuran showed negative direct effects on weight of fourth instar larvae. The correlation coefficients of all the metabolites of carbofuran and total residues of carbofuran and metabolites were significant and positive.

All the metabolites of carbofuran showed high positive indirect effects through total residues of carbofuran and metabolites. All the parameters tested showed negative indirect effects through 3-OH-7-phenol and 3-CO-7-phenol residues but these effects were low. The effects of chlorophyll$_a$ and chlorophyll$_b$ were found nullified by the effects of chlorophyll$_{a+b}$. Through 3-CO-carbofuran, the other metabolites and total residues of carbofuran and metabolites showed negative indirect effects. The 3-OH-7-phenol, 7-phenol and total residues of carbofuran and

Table 37. Correlation between weight of 20 larvae of IV instar (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of								Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	3-CO-7-phenol residue (X_3)	7-phenol residue (X_4)	Total residues of carbofuran and metabolites (X_5)	Chlorophyll$_a$ (X_6)	Chlorophyll$_b$ (X_7)	Chlorophyll$_{a+b}$ (X_8)	
X_1	0.684**	<u>-0.326</u>	-0.086	-0.066	-0.142	1.291	-0.017	-0.058	0.088	0.542
X_2	0.751*	-0.212	<u>-0.133</u>	-0.144	-0.138	1.434	0.127	0.164	-0.346	
X_3	0.480*	-0.099	-0.088	<u>-0.217</u>	-0.078	1.000	0.102	0.092	-0.232	
X_4	0.727*	-0.260	-0.103	-0.096	<u>-0.178</u>	1.343	-0.057	-0.052	0.130	
X_5	0.798*	-0.273	-0.123	-0.141	-0.155	<u>1.541</u>	0.115	0.149	-0.314	
X_6	-0.093	0.008	-0.024	-0.032	0.015	0.256	<u>0.689</u>	0.972	-1.977	
X_7	-0.105	0.018	-0.021	-0.019	0.009	0.223	0.652	<u>1.028</u>	-1.995	
X_8	-0.101	0.014	-0.023	-0.025	0.012	0.240	0.677	1.018	<u>-2.015</u>	

** Significant at one per cent level

* Significant at 5 per cent level

Underlined figures are the direct effects

Fig. 27. Path diagram representing the cause (X) - effect (Y) relationship.

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	3-CO-7-phenol residue	X_4	7-phenol residue
X_5	Total residues of carbofuran and metabolites	X_6	$Chlorophyll_a$
X_7	$Chlorophyll_b$	X_8	$Chlorophyll_{a+b}$

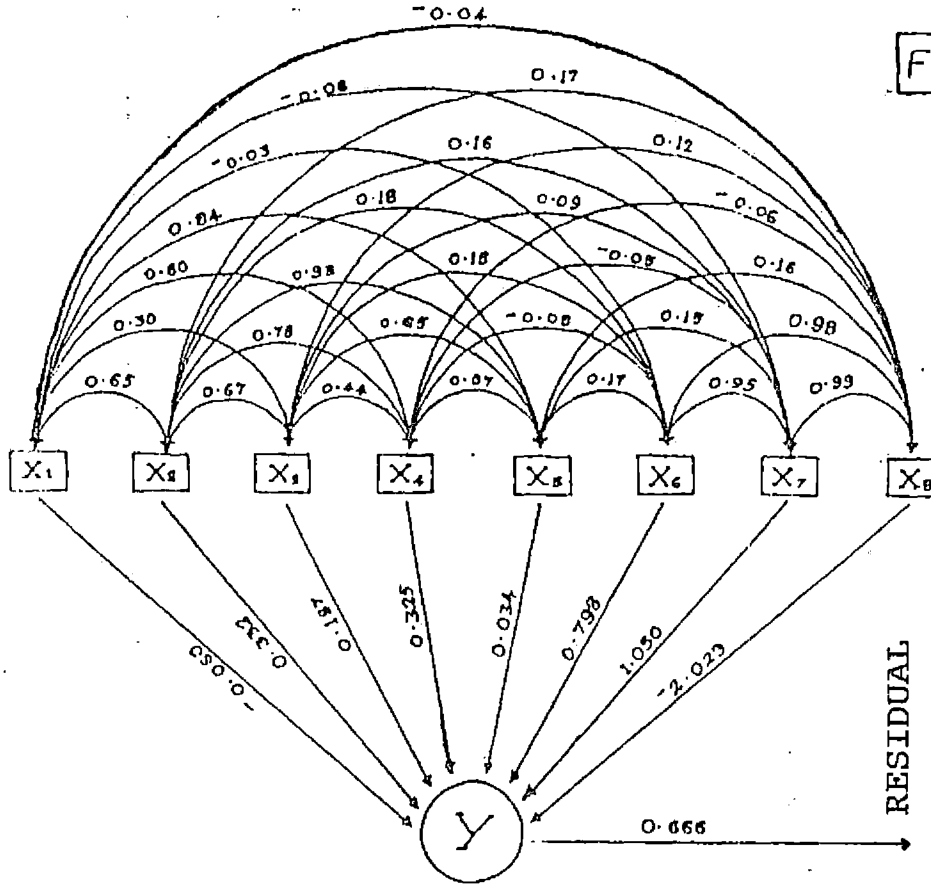
Y Weight of 20 larvae of third instar

Fig. 28. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	3-CO-7-phenol residue	X_4	7-phenol residue
X_5	Total residues of carbofuran and metabolites	X_6	$Chlorophyll_a$
X_7	$Chlorophyll_b$	X_8	$Chlorophyll_{a+b}$

Y Weight of 20 larvae of fourth instar

FIG-27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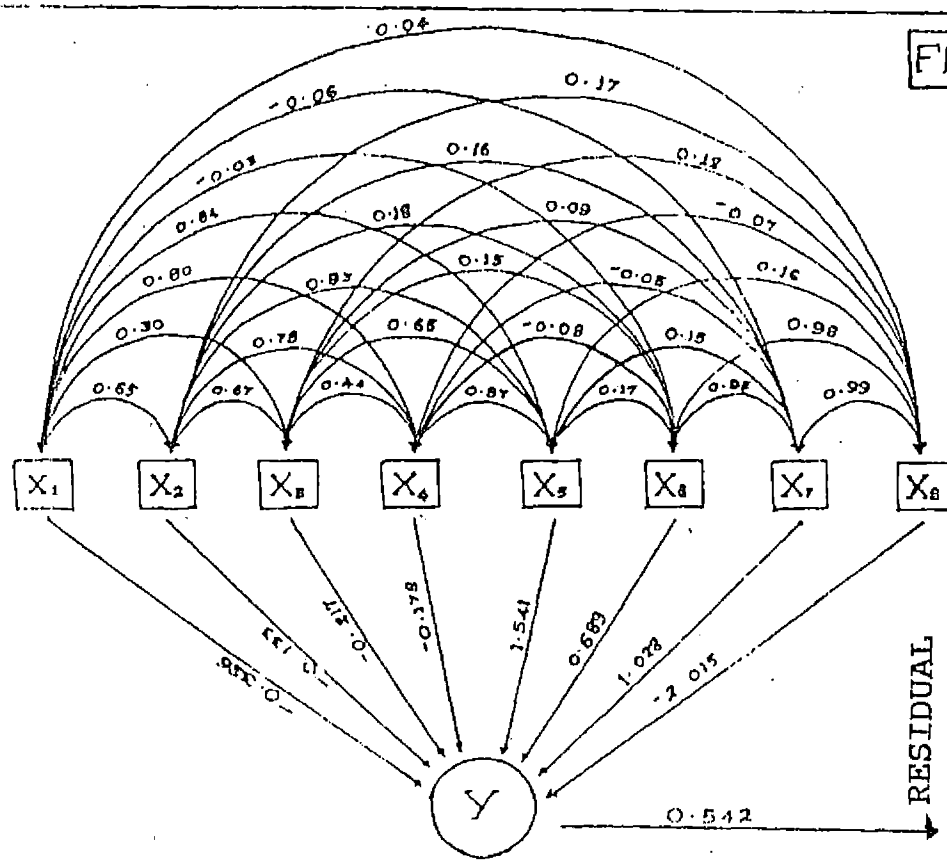
-0.06
0.84
0.18
-0.08
0.16
0.60
0.93
0.30
0.78
0.65
-0.08
0.15
0.98
0.65
0.67
0.44
0.87
0.17
0.95
0.99
X1
X2
X3
X4
X5
X6
X7
X8
-0.053
0.332
0.187
0.325
0.034
0.798
1.050
-2.029
Y
0.666
RESIDUAL

FIG-28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0.16
0.80
0.93
0.30
0.78
0.65
-0.08
0.15
0.98
0.65
0.67
0.44
0.87
0.17
0.98
0.99
X1
X2
X3
X4
X5
X6
X7
X8
-0.338
-0.133
-0.217
-0.178
1.541
0.689
1.078
-2.015
Y
0.542
RESIDUAL

metabolites showed comparatively higher negative indirect effects through 3-CO-carbofuran residue.

4.3.3. Effect on weight of larvae of fifth instar

The results of path coefficient analysis are presented in Table 38 and illustrated in Fig. 29. The correlation coefficients of all the metabolites of carbofuran and the total residues of carbofuran and metabolites were significant and positive. The residual effect of 0.614 indicated that the factors considered explained 62.3 per cent of variation in weight of fourth instar larvae. The highest positive direct effect on weight of fifth instar larvae was from $chlorophyll_{a+b}$ followed by total residues of carbofuran of metabolites and the highest negative effect was for $chlorophyll_{a}$. The effects of different parameters through $chlorophyll_{a}$ and $chlorophyll_{b}$ were found nullified by the effects through $chlorophyll_{a+b}$.

The indirect effects of all the metabolites of carbofuran through total residues of carbofuran and metabolites were positive and higher than the corresponding direct effects. Through 7-phenol, negative indirect effects were shown by 3-CO-carbofuran, 3-OH-7-phenol, 3-CO-7-phenol and total residues of carbofuran and metabolites. The indirect effects of $chlorophyll_{a}$, $chlorophyll_{b}$ and $chlorophyll_{a+b}$ were higher through total residues than through other metabolites.

Table 38. Correlation between weight of 20 larvae of V instar (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

	Correlation coefficients between Y and X factors	Direct and indirect effects of								Residual effect
		3-CO carbo-furan residue (X_1)	3-OH-7-phenol residue (X_2)	3-CO-7-phenol residue (X_3)	7-phenol residue (X_4)	Total residues of carbofuran and metabolites (X_5)	Chlorophyll a (X_6)	Chlorophyll b (X_7)	Chlorophyll a+b (X_8)	
X_1	0.583**	0.230	-0.005	0.012	-0.489	0.869	0.048	0.033	0.049	0.614
X_2	0.589**	0.150	-0.008	0.026	-0.475	0.965	-0.356	0.093	0.194	
X_3	0.404*	0.070	-0.005	0.039	-0.270	0.673	-0.285	0.052	0.130	
X_4	0.544**	0.184	-0.006	0.017	-0.611	0.904	0.159	-0.030	-0.073	
X_5	0.654**	0.193	-0.007	0.025	-0.533	1.037	-0.322	0.085	0.176	
X_6	-0.051	-0.006	-0.001	0.006	0.050	0.172	-1.936	0.554	1.110	
X_7	0.046	-0.013	-0.001	0.004	0.031	0.150	-1.831	0.586	1.120	
X_8	0.005	-0.010	-0.001	0.005	0.041	0.162	-1.900	0.580	1.131	

** Significant at one per cent level

* Significant at 5 per cent level

Underlined figures are the direct effects

4.3.4. Effect on weight of larvae of sixth instar

The results of analysis are presented in Table 39 and illustrated in Fig. 30. The correlation coefficients of all the metabolites of carbofuran and total residues of carbofuran and metabolites were positive and significant. The percentage influence of the tested factors on larval weight was 59.6 as evidenced by the residual effect. The highest positive direct effect on weight of sixth instar larvae was recorded by $chlorophyll_b$ followed by $chlorophyll_a$ and total residues of carbofuran and metabolites. The effects shown by $chlorophyll_a$ and $chlorophyll_b$ were nullified by the effects of $chlorophyll_{a+b}$.

With regard to different metabolites, all the metabolites had high indirect positive effects through total residues of carbofuran and metabolites. Through 3-OH-7-phenol, the negative indirect effects of other metabolites were more prominent.

4.3.5. Effect on weight of pupae

The results of analysis are presented in Table 40 and illustrated in Fig. 31. As the residual effect was high (0.899), the effects of the parameters considered was only 19.2 per cent on the weight of pupae of C. medinalis. The correlation coefficients of mean length of first three leaves and residue of carbofuran were negative and significant. The effects of $chlorophyll_a$ and $chlorophyll_b$ were found nullified by the effects of $chlorophyll_{a+b}$ and their

Table 39. Correlation between weight of 20 larvae of VI instar (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

	Correlation coefficients between Y and X factors	Direct and indirect effects of								Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	3-CO-7-phenol residue (X_3)	7-phenol residue (X_4)	Total residues of carbofuran and metabolites (X_5)	Chlorophyll$_a$ (X_6)	Chlorophyll$_b$ (X_7)	Chlorophyll$_{a+b}$ (X_8)	
X_1	0.671**	-0.044	-0.208	-0.015	-0.197	1.113	-0.046	-0.106	0.174	0.636
X_2	0.616**	-0.029	-0.320	-0.034	-0.191	1.237	0.340	0.301	-0.687	
X_3	0.457*	-0.013	-0.213	-0.051	-0.109	0.863	0.272	0.169	-0.461	
X_4	0.617**	-0.035	-0.249	-0 023	-0.246	1.158	-0.151	-0.096	0.259	
X_5	0.704**	-0.037	-0.298	-0.033	-0.214	1.329	0.307	0.274	-0.624	
X_6	-0.115	0.001	-0.059	-0.008	0.020	0.221	1.848	1.790	-3.928	
X_7	-0.172	0.002	-0.051	-0.005	0.013	0.192	1.747	1.893	-3.964	
X_8	-0.150	0.002	-0.055	-0.006	0.016	0.207	1.813	1.874	-4.002	

** Significant at one per cent level

* Significant at 5 per cent level

Underlined figures are the direct effects

Table 40. Correlation between weight of 20 pupae (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of					Residual effect
		Chlorophyll$_a$ (X_1)	Chlorophyll$_b$ (X_2)	Chlorophyll$_{a+b}$ (X_3)	Mean length of first three leaves (X_4)	Residue of carbofuran (X_5)	
X_1	0.111	0.403	1.333	-1.945	0.322	-0.002	0.899
X_2	0.072	0.381	1.410	-1.963	0.246	-0.001	
X_3	0.090	0.395	1.396	-1.982	0.282	-0.001	
X_4	-0.404*	-0.235	-0.628	1.011	-0.553	0.001	
X_5	-0.014*	0.078	0.221	-0.346	0.042	-0.008	

* Significant at 5 per cent level

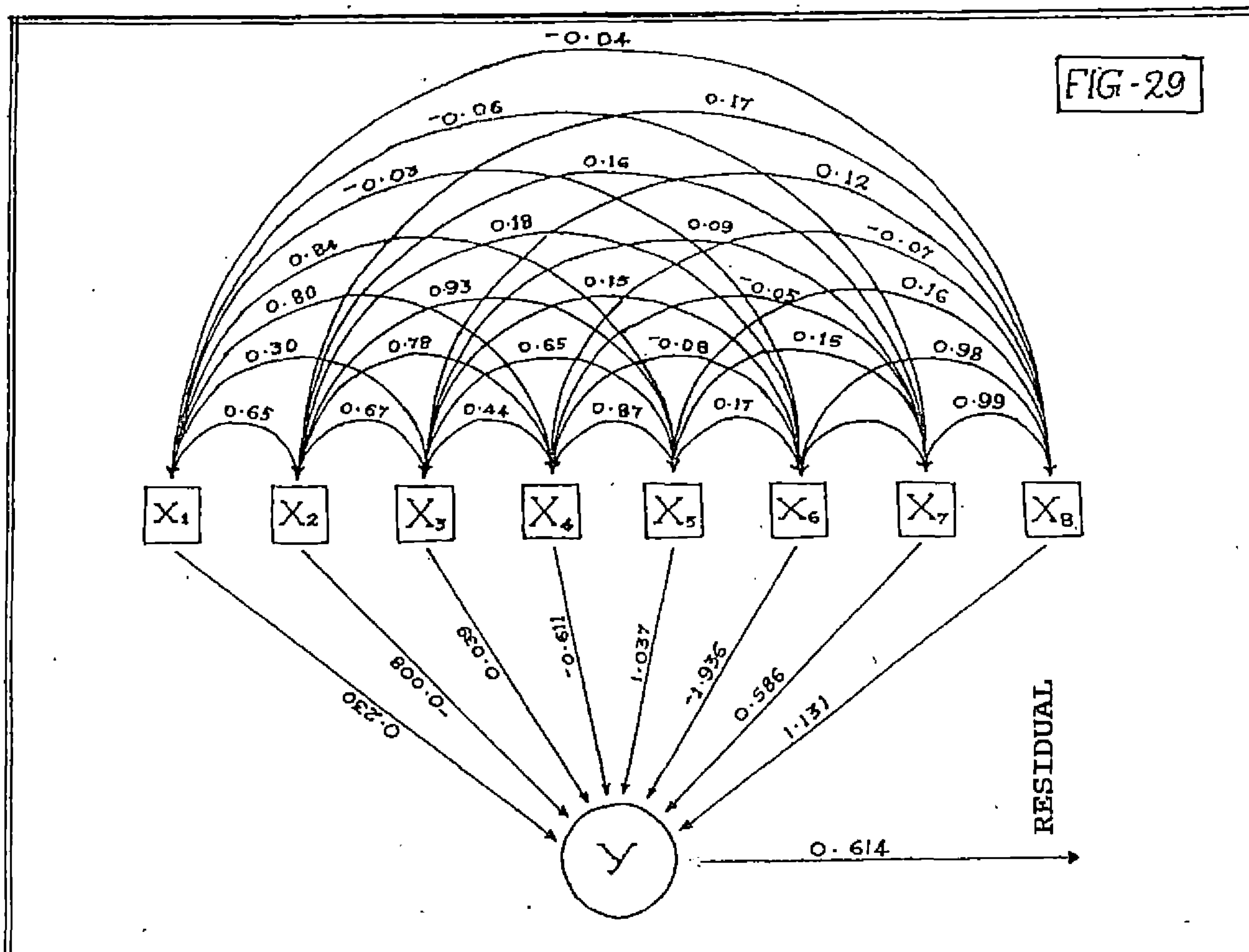
Underlined figures are the direct effects

Fig. 29. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	3-CO-7-phenol residue	X_4	7-phenol residue
X_5	Total residues of carbofuran and metabolites	X_6	$Chlorophyll_a$
X_7	$Chlorophyll_b$	X_8	$Chlorophyll_{a+b}$
Y	Weight of 20 larvae of fifth instar		

Fig. 30. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	3-CO-7-phenol residue	X_4	7-phenol residue
X_5	Total residues of carbofuran and metabolites	X_6	$Chlorophyll_a$
X_7	$Chlorophyll_b$	X_8	$Chlorophyll_{a+b}$
Y	Weight of 20 larvae of sixth instar		



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0.09
0.84
-0.07
0.80
0.93
0.15
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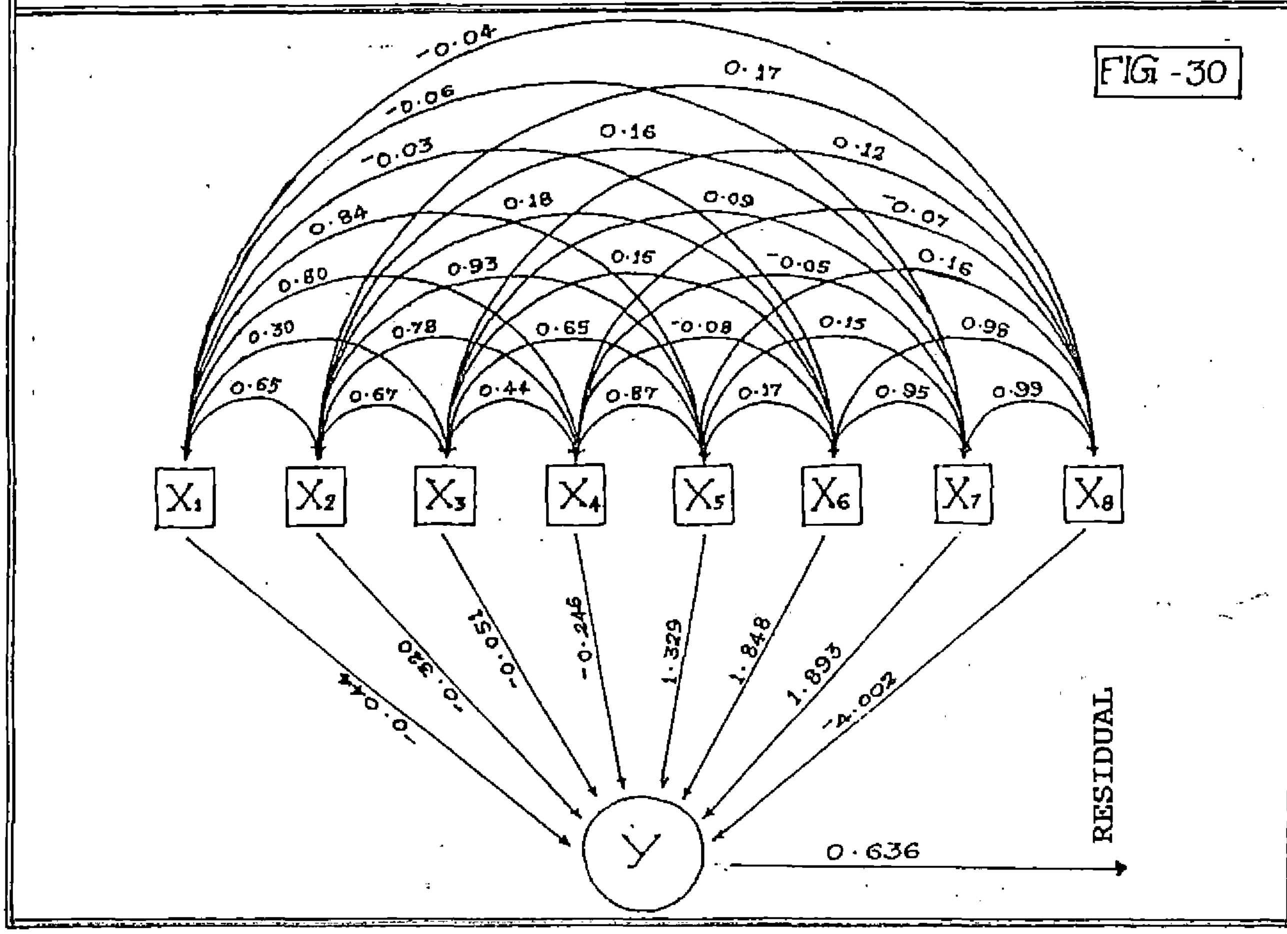
0.16
0.30
0.78
0.65
-0.08
0.15
0.98
0.65
0.67
0.44
0.87
0.17
0.99
X1
X2
X3
X4
X5
X6
X7
X8
-0.230
-0.008
0.039
-0.611
1.037
-1.936
0.586
1.131
Y
0.614
RESIDUAL

FIG-29



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0.93
0.15
-0.05
0.16
0.30
0.78
0.65
-0.08
0.15
0.96
0.65
0.67
0.44
0.87
0.17
0.95
0.99
X1
X2
X3
X4
X5
X6
X7
X8
-0.04
-0.320
-0.051
-0.246
1.329
1.848
1.893
-4.002
Y
0.636
RESIDUAL

FIG-30

correlation coefficients were not significant. However, the chlorophyll contents showed comparatively higher positive indirect effects through mean length of first three leaves. The indirect effect of residue of carbofuran through $chlorophyll_b$ was positive while that through $chlorophyll_{a+b}$ was negative.

4.3.6. Effect on per cent mortality of first instar larvae

The results of analysis are presented in Table 41 and depicted in Fig. 32. The 3-OH-7-phenol, 7-phenol, total residues of carbofuran and metabolites and total nitrogen recorded negative significant correlation coefficients with mortality of first instar larvae. The factors explained 48.3 per cent influence on mortality of first instar larvae. Among the different factors, $chlorophyll_b$ had highest positive direct effect followed by $chlorophyll_a$ and total residues of carbofuran and metabolites. The highest negative direct effect was by $chlorophyll_{a+b}$ followed by 3-OH-7-phenol residue and total nitrogen. The effects of different factors through $chlorophyll_a$ and $chlorophyll_b$ were nullified by their effects through $chlorophyll_{a+b}$.

Through total residues of carbofuran and metabolites, the 3-OH-7-phenol and 7-phenol recorded higher indirect positive effects. Through 3-OH-7-phenol, total residues of carbofuran and metabolites and 7-phenol showed high negative indirect effects. In the case of total nitrogen, the direct effect was negative and higher than its indirect effects through other parameters studied.

Table 41. Correlation between per cent mortality of first instar larvae (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of							Residual effect.
		3-OH-7 phenol residue (X_1)	7-phenol residue (X_2)	Total residues of carbofuran and metabolites (X_3)	Chlorophyll$_a$ (X_4)	Chlorophyll$_b$ (X_5)	Chlorophyll$_{a+b}$ (X_6)	Total nitrogen (X_7)	
X_1	-0.441*	-0.607	-0.032	0.265	0.127	0.190	-0.269	-0.115	0.719
X_2	-0.420*	-0.472	-0.042	0.248	-0.057	-0.061	0.102	-0.139	
X_3	-0.387*	-0.565	-0.036	0.285	0.115	0.173	-0.244	-0.114	
X_4	0.154	-0.112	0.003	0.047	0.693	1.127	-1.539	-0.067	
X_5	0.133	-0.096	0.002	0.041	0.655	1.192	-1.553	-0.108	
X_6	0.143	-0.104	0.003	0.044	0.680	1.181	-1.568	-0.092	
X_7	-0.530**	-0.138	-0.011	0.064	0.092	0.255	-0.286	-0.506	

** Significant at one per cent level

* Significant at 5 per cent level

Underlined figures are the direct effects

Fig. 31. Path diagram representing the cause (X) - effect (Y) relationship

X_1 Chlorophyll$_a$

X_2 Chlorophyll$_b$

X_3 Chlorophyll$_{a+b}$

X_4 Mean length of first three leaves

X_5 Carbofuran residue

Y Weight of 20 pupae

Fig. 32. Path diagram representing the cause (X) - effect (Y) relationship

X_1 3-OH-7-phenol residue

X_2 7-phenol residue

X_3 Total residues of carbofuran and metabolites

X_4 Chlorophyll$_a$

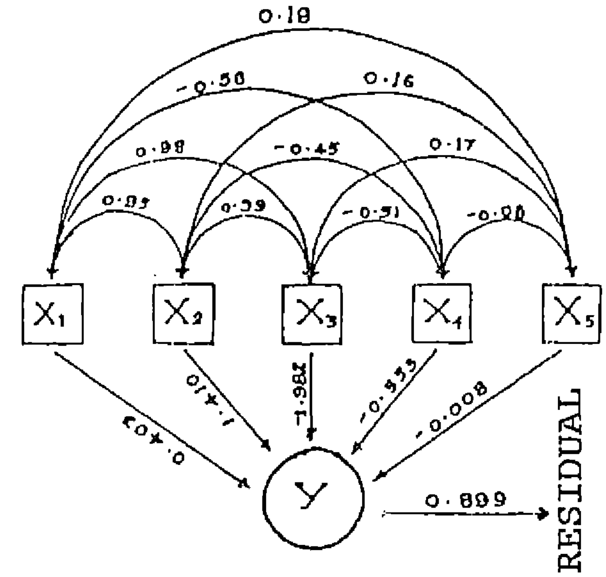
X_5 Chlorophyll$_b$

X_6 Chlorophyll$_{a+b}$

X_7 Total nitrogen

Y Mortality of first instar larvae

FIG-31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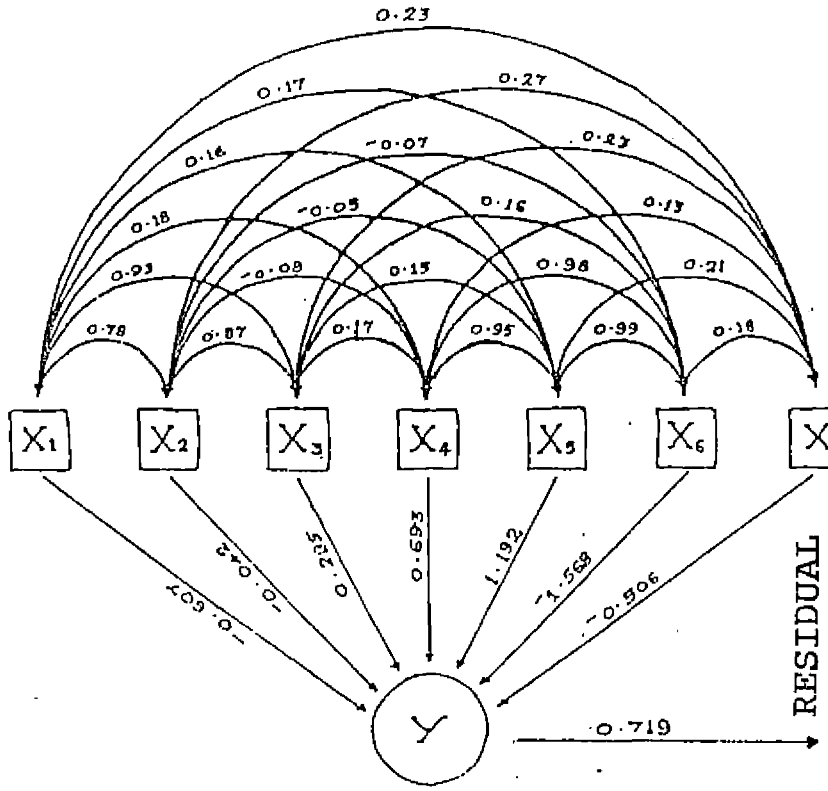
0·16
0·98
-0·45
0·17
0·85
0·39
-0·51
-0·08
X₁
X₂
X₃
X₄
X₅
1·982
-0·553
-0·008
Y
0·899
RESIDUAL

FIG-32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-0·07
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-0·05
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0·17
0·95
0·99
0·18
X₁
X₂
X₃
X₄
X₅
X₆
X₇
0·235
0·693
1·192
-1·568
-0·506
Y
0·719
RESIDUAL

4.3.7. Effect on mean larval mortality

The results of analysis are presented in Table 42 and graphically represented in Fig. 33. The residual effect of the factors considered was 0.591 which indicated that 65.1 per cent influence on mean larval mortality is attributed by the factors studied. The 3-CO-carbofuran, 3-OH-7-phenol, 7-phenol, total residues of carbofuran and metabolites, residue of carbofuran and total nitrogen showed negative and significant correlation coefficients with mean larval mortality. Chlorophyll_b showed highest positive direct effect followed by total nitrogen and 3-OH-7-phenol residue. The correlation coefficients of chlorophyll pigments were not significant.

The indirect effects of different factors through 3-OH-7-phenol, total residues of carbofuran and metabolites and total nitrogen were negative. Through 3-OH-7-phenol, highest negative indirect effect was shown by total residues of carbofuran and metabolites followed by residue of carbofuran. Through total nitrogen, the indirect effects of other factors were lower as compared to its direct negative effect.

The 3-CO-carbofuran and 7-phenol showed highest negative indirect effect through 3-OH-7-phenol. The residue of carbofuran recorded highest negative indirect effect through 3-OH-7-phenol, while total nitrogen showed indirect positive effect through chlorophyll_b and indirect negative effect through chlorophyll_{a+b}.

Table 42. Correlation between mean larval mortality (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of									Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	7-phenol residue (X_3)	Total residues of carbofuran and metabolites (X_4)	Chlorophyll$_a$ (X_5)	Chlorophyll$_b$ (X_6)	Chlorophyll$_{a+b}$ (X_7)	Residue of carbofuran (X_8)	Total nitrogen (X_9)	
X_1	-0.401*	0.194	-0.280	-0.150	-0.090	-0.022	-0.086	0.085	0.045	-0.097	0.591
X_2	-0.531**	0.126	-0.430	-0.146	-0.100	0.163	0.245	-0.338	0.060	-0.112	
X_3	-0.567**	0.155	-0.334	-0.187	-0.094	-0.073	-0.078	0.127	0.051	-0.135	
X_4	-0.494**	0.162	-0.400	-0.163	-0.108	0.147	0.223	-0.306	0.062	-0.111	
X_5	-0.275	-0.005	-0.079	0.015	-0.018	0.886	1.457	-1.930	0.014	-0.065	
X_6	0.251	-0.011	-0.068	0.010	-0.016	0.837	1.540	-1.947	0.011	-0.105	
X_7	0.265	-0.008	-0.074	0.012	-0.017	0.869	1.526	-1.966	0.012	-0.090	
X_8	0.407**	0.124	-0.366	-0.137	-0.094	0.172	0.241	-0.343	0.071	-0.074	
X_9	-0.527**	0.038	-0.098	-0.051	-0.024	0.117	0.330	-0.359	0.011	-0.492	

** Significant at one per cent level

* Significant at 5 per cent level

Underlined figures are direct effects

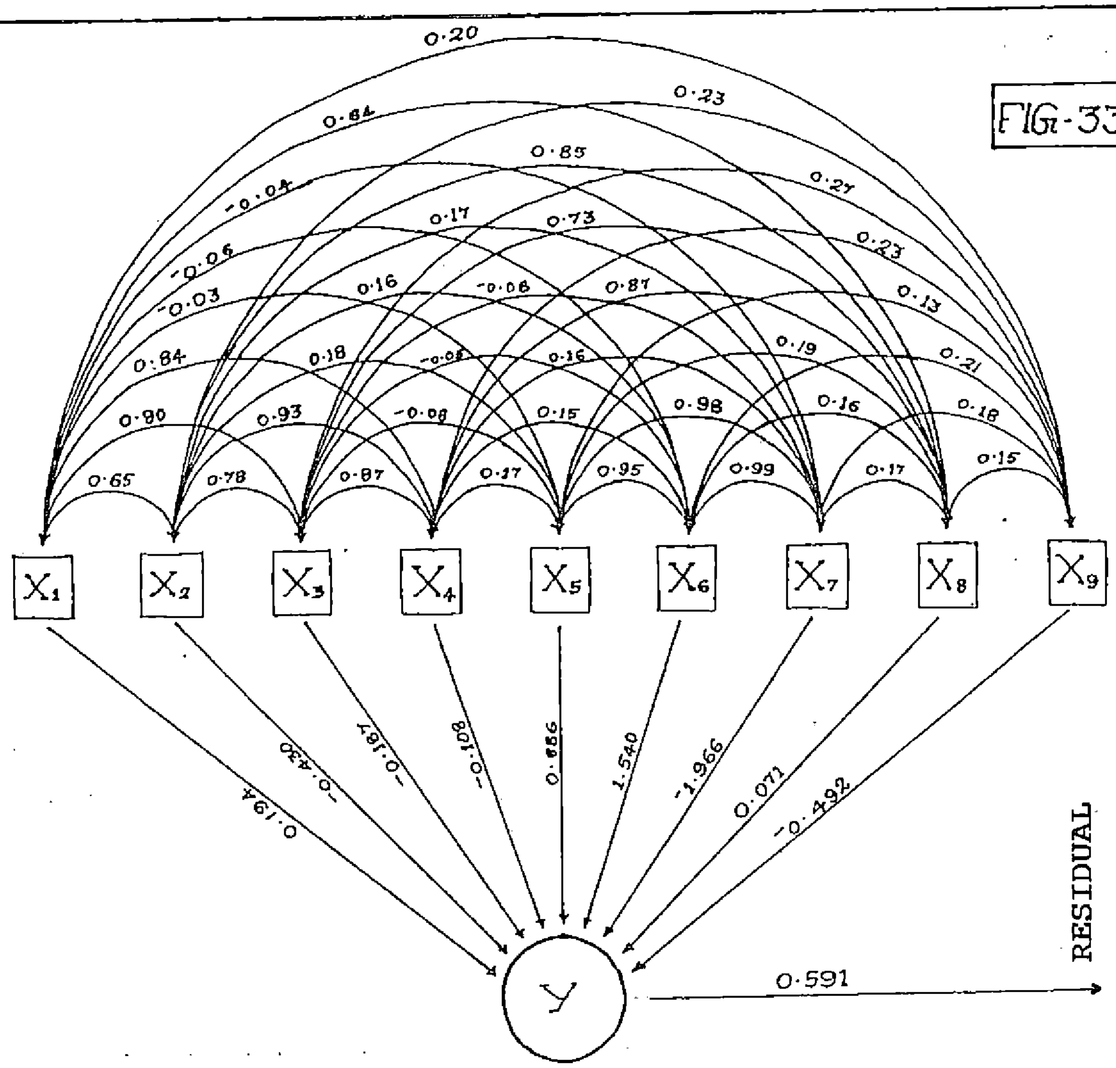
Fig. 33. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	7-phenol residue	X_4	Total residues of carbofuran and metabolites
X_5	$Chlorophyll_a$	X_6	$Chlorophyll_b$
X_7	$Chlorophyll_{a+b}$	X_8	Carbofuran residue
X_9	Total nitrogen		
Y	Mean larval mortality		

Fig. 34. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-OH-phenol residue	X_2	Total residues of carbofuran and metabolites
X_3	$Chlorophyll_a$	X_4	$Chlorophyll_b$
X_5	$Chlorophyll_{a+b}$		
Y	Pupal mortality		

FIG-33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0·18
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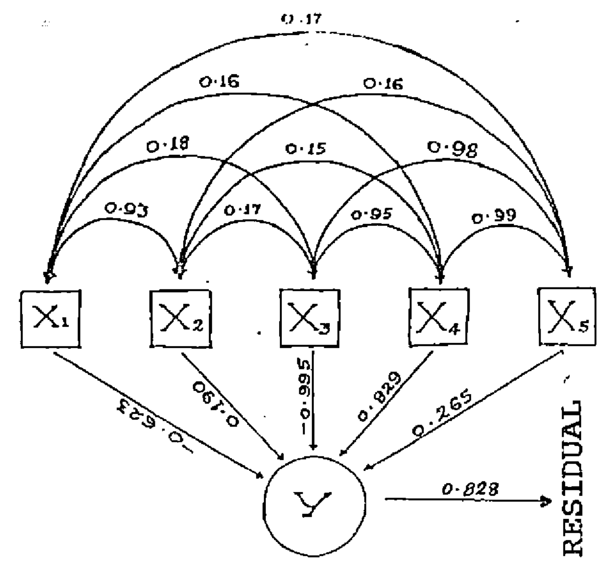
0·80
0·93
-0·08
0·15
0·98
0·16
0·18
0·65
0·78
0·87
0·17
0·95
0·99
0·17
0·15
X1
X2
X3
X4
X5
X6
X7
X8
X9
0·194
-0·430
-0·187
-0·108
0·886
1·540
-1·966
0·071
-0·492
Y
0·591
RESIDUAL

FIG-34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0·16
0·16
0·18
0·15
0·98
0·93
0·17
0·95
0·99
X1
X2
X3
X4
X5
-0·623
0·190
-0·995
0·829
0·265
Y
0·828
RESIDUAL

4.3.8. Effect on pupal mortality

The results of analysis are presented in Table 43 and illustrated in Fig. 34. The correlation coefficients of 3-OH-7-phenol and total residues of carbofuran and metabolites were negative and significant. However, the residual effect was high (0.828) indicating low effects of the factors considered on pupal mortality. The highest positive direct effect was by $chlorophyll_b$ and negative direct effect was manifested by $chlorophyll_a$ followed by 3-OH-7-phenol residue. The effects of different factors through $chlorophyll_a$ were found to be nullified by their effects through $chlorophyll_{a+b}$ and $chlorophyll_b$. Through 3-OH-7-phenol, total residues of carbofuran and metabolites showed high negative indirect effect.

4.3.9. Effect on female/male ratio

The results of analysis are presented in Table 44 and illustrated in Fig. 35. In the case of 3-CO-carbofuran, 3-OH-7-phenol and total residues of carbofuran and metabolites, the correlation coefficients were positive and significant. As the residual effect was high (0.893), the factors considered explained only 20.3 per cent effects on the female/male ratio. Among the different factors, highest direct effect was for total residues of carbofuran and metabolites. Only 3-CO-carbofuran and 3-OH-7-phenol showed comparatively higher indirect positive effects and their indirect effects were through total residues of carbofuran and metabolites.

Table 43. Correlation between pupal mortality (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of					Residual effect
		3-OH-7-phenol residue (X_1)	Total residues of carbofuran and metabolites (X_2)	Chlorophyll$_a$ (X_3)	Chlorophyll$_b$ (X_4)	Chlorophyll$_{a+b}$ (X_5)	
X_1	-0.452*	<u>-0.623</u>	0.177	-0.183	0.132	0.046	0.828
X_2	-0.394*	-0.580	<u>0.190</u>	-0.166	0.120	0.041	
X_3	-0.035	-0.115	0.032	<u>-0.995</u>	0.784	0.260	
X_4	-0.078	-0.099	0.028	-0.941	<u>0.829</u>	0.262	
X_5	-0.031	-0.107	0.030	-0.977	0.821	<u>0.265</u>	

* Significant at 5 per cent level

Underlined figures are the direct effects

Table 44. Correlation between female/male ratio (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of						Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	Total residues of carbofuran and metabolites (X_3)	Chlorophyll$_a$ (X_4)	Chlorophyll$_b$ (X_5)	Chlorophyll$_{a+b}$ (X_6)	
X_1	0.383*	0.019	-0.004	0.368	-0.000	-0.000	0.001	0.893
X_2	0.416*	0.012	-0.007	0.409	0.003	0.001	-0.003	
X_3	0.450*	0.016	-0.006	0.440	0.003	0.001	-0.003	
X_4	0.077	-0.001	-0.001	0.073	0.018	0.005	-0.016	
X_5	0.067	-0.001	-0.001	0.064	0.017	0.005	-0.016	
X_6	0.072	-0.001	-0.001	0.069	0.017	0.005	-0.017	

* Significant at 5 per cent level

Underlined figures are the direct effects

4.3.10. Effect on first instar larvae emerged in F_1 generation

The results of analysis are presented in Table 45 and illustrated in Fig. 36. The correlation coefficients were significant and positive in the case of 3-CO-carbofuran, 3-OH-7-phenol, total residues of carbofuran and metabolites and total sugars. However, only 32.8 per cent influence on first instar emergence of F_1 generation could be attributed to the different factors studied as the residual effect was high. Among the different factors, highest positive direct effect was by $chlorophyll_b$ followed by $chlorophyll_a$ and 3-OH-7-phenol. The highest negative direct effect was by $chlorophyll_{a+b}$ followed by total residues. The effects of different factors through $chlorophyll_a$ and $chlorophyll_b$ were found nullified by their effects through $chlorophyll_{a+b}$.

For 3-CO-carbofuran, the highest indirect positive effect was through 3-OH-7-phenol and indirect negative effect through total residues of carbofuran and metabolites. The total residues of carbofuran and metabolites showed highest positive indirect effect through $chlorophyll_b$ followed by 3-OH-7-phenol and highest negative indirect effect through $chlorophyll_{a+b}$. The $chlorophyll_a$ and $chlorophyll_b$ had highest negative indirect effects through $chlorophyll_{a+b}$ while the former had highest indirect positive effect through $chlorophyll_b$ and the latter showed it through $chlorophyll_a$. The total sugars had highest nega-

Table 45. Correlation between F_1 first instar larvae emerged (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of							Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	Total residues of carbofuran and metabolites (X_3)	Chlorophyll$_a$ (X_4)	Chlorophyll$_b$ (X_5)	Chlorophyll$_{a+b}$ (X_6)	Total sugars (X_7)	
X_1	0.371*	<u>0.423</u>	0.379	-0.429	-0.063	-0.256	0.302	0.015	0.820
X_2	0.385*	0.276	<u>0.582</u>	-0.477	0.468	0.727	-1.195	0.005	
X_3	0.405*	0.355	0.542	<u>-0.513</u>	0.423	0.662	-1.084	0.021	
X_4	0.121	-0.011	0.107	-0.085	<u>2.544</u>	4.322	-6.827	0.071	
X_5	0.148	-0.024	0.093	-0.074	2.406	<u>4.571</u>	-6.889	0.066	
X_6	0.139	-0.018	0.100	-0.080	2.497	4.527	<u>-6.956</u>	0.069	
X_7	0.366*	0.017	0.007	-0.029	0.495	0.829	-1.318	<u>0.364</u>	

* Significant at 5 per cent level

Underlined figures are the direct effects

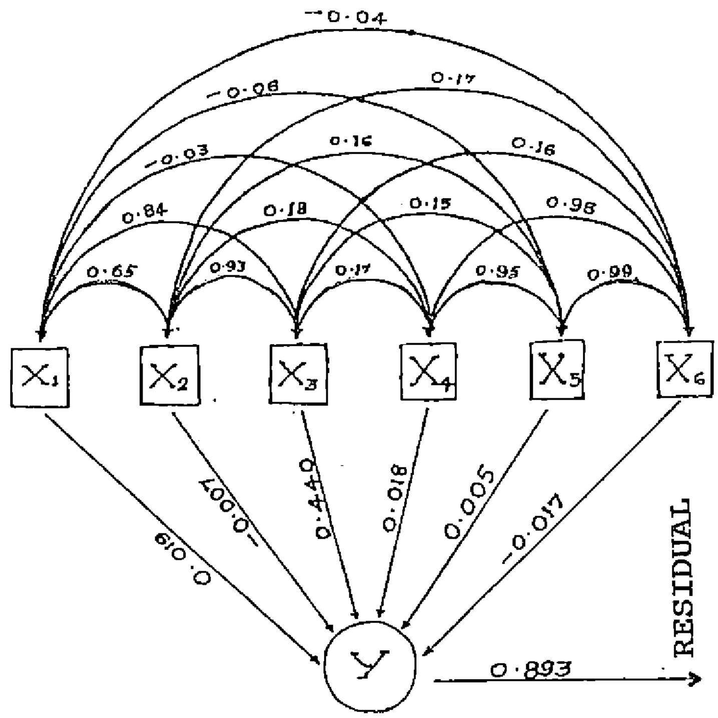
Fig. 35. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	Total residues of carbofuran and metabolites	X_4	$Chlorophyll_a$
X_5	$Chlorophyll_b$	X_6	$Chlorophyll_{a+b}$
Y	Female/male ratio		

Fig. 36. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	Total residues of carbofuran and metabolites	X_4	$Chlorophyll_a$
X_5	$Chlorophyll_b$	X_6	$Chlorophyll_{a+b}$
X_7	Total sugars		
Y	First instar larvae emerged in F_1		

FIG-35



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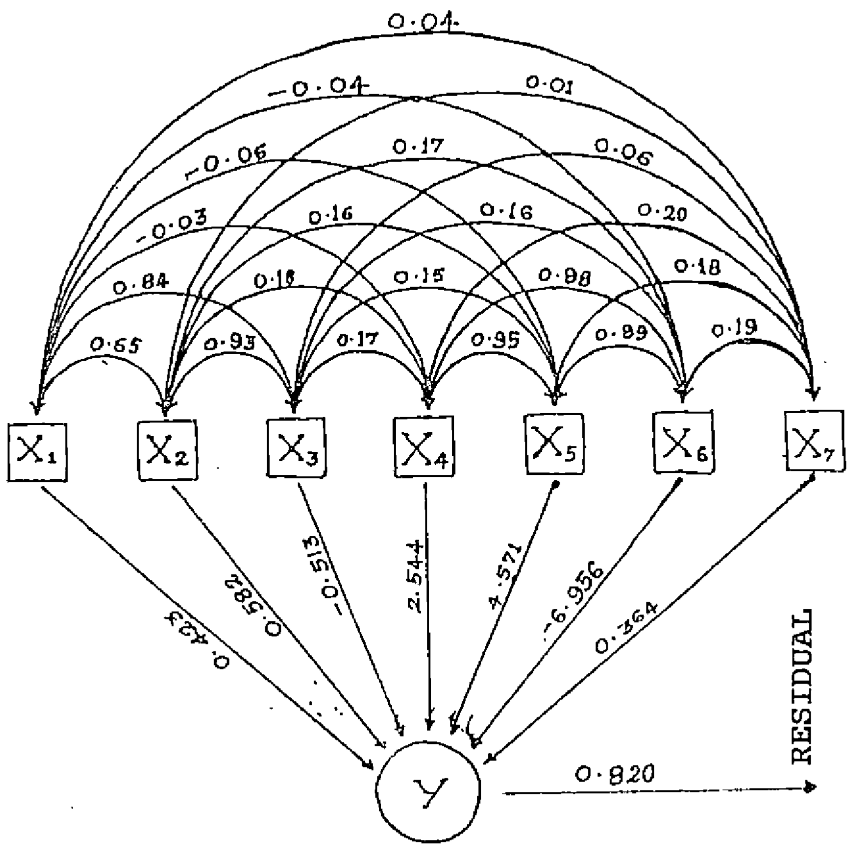
RESIDUAL

FIG-36



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RESIDUAL

tive indirect effects through $chlorophyll_{a+b}$ and the effects through $chlorophyll_b$ and $chlorophyll_a$ were positive.

The highest negative indirect effects through total residues was shown by 3-OH-7-phenol and 3-CO-carbofuran residues. Through 3-CO-carbofuran, 3-OH-7-phenol and total residues of carbofuran and metabolites had positive indirect effects. Similarly, through 3-OH-7-phenol, total residues and 3-CO-carbofuran had indirect positive effect. Through total sugars other factors had no effect on the F_1 first instar larval emergence.

4.3.11. Effect on ovipositional preference on treated plants

The results of analysis are presented in Table 46 and illustrated in Fig. 37. As the factors considered, explained 78.7 per cent to ovipositional preference, it was evident that the ovipositional preference was mostly controlled by the direct and indirect effects of the factors studied. The correlation coefficients of all the factors were positive and significant. The highest positive direct effect was for 3-OH-7-phenol followed by 3-CO-carbofuran and 7-phenol residues. Negative direct effect was shown only by total residues of carbofuran and metabolites.

The 3-CO-carbofuran had high positive indirect effects through 3-OH-7-phenol and 7-phenol. The 3-OH-7-phenol showed high positive indirect effects through

Table 46. Correlation between ovipositional preference on treated plants (Y) and the factors inducing resurgence (X) in insectary studies and the direct and indirect effects of the different factors assessed through path coefficient analysis

Correlation coefficients between Y and X factors		Direct and indirect effects of						Residual effect
		3-CO-carbofuran residue (X_1)	3-OH-7-phenol residue (X_2)	3-CO-7-phenol residue (X_3)	7-phenol residue (X_4)	Total residues of carbofuran and metabolites (X_5)	Mean leaf hair number/cm^2 (X_6)	
X_1	0.769**	0.677	0.534	0.078	0.346	-0.955	0.088	0.462
X_2	0.733**	0.441	0.821	0.171	0.336	-1.061	0.025	
X_3	0.402*	0.205	0.546	0.258	0.191	-0.740	-0.058	
X_4	0.800**	0.541	0.638	0.114	0.432	-0.993	0.068	
X_5	0.799**	0.567	0.764	0.167	0.377	-1.140	0.063	
X_6	0.391*	0.187	0.063	-0.047	0.091	-0.223	0.320	

** Significant at one per cent level

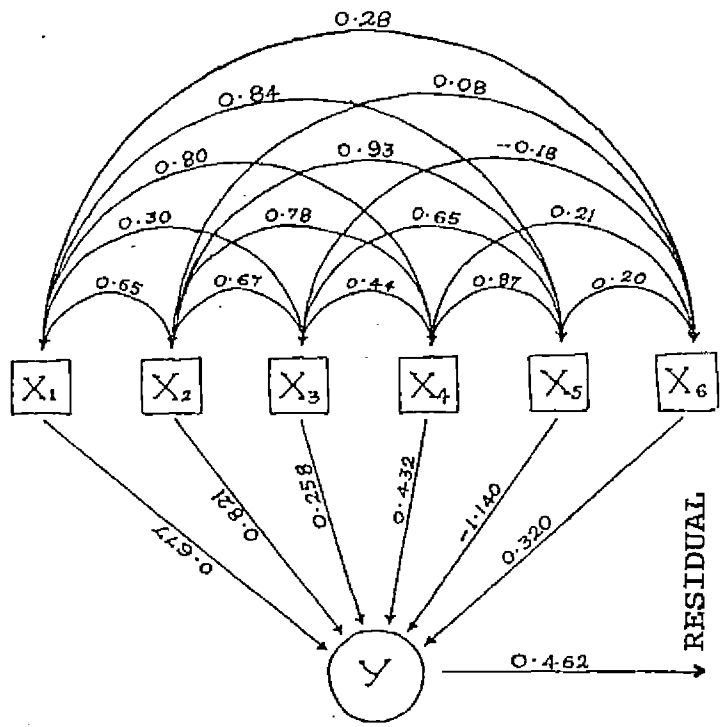
* Signficant at 5 per cent level

Underlined figures are the direct effects

Fig. 37. Path diagram representing the cause (X) - effect (Y) relationship

X_1	3-CO-carbofuran residue	X_2	3-OH-7-phenol residue
X_3	3-CO-7-phenol residue	X_4	7-phenol residue
X_5	Total residues of carbofuran and metabolites	X_6	Mean leaf hair number/cm^2
Y	Ovipositional preference on treated plants		

FIG-37



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X3
X4
X5
X6
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0·821
0·258
0·432
-1·140
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RESIDUAL

3-CO-carbofuran and 7-phenol. For 3-CO-7-phenol, high positive indirect effects through 3-OH-7-phenol was followed by 3-CO-carbofuran. The indirect effects of all the factors through total residues of carbofuran and metabolites were negative and high. The 7-phenol showed highest indirect positive effects through 3-OH-7-phenol followed by 3-CO-carbofuran. The indirect effects of total residues of carbofuran and metabolites through the metabolites of carbofuran were high and positive. Comparatively higher indirect positive effect was recorded by mean leaf hair number/cm^2 through 3-CO-carbofuran residue while through total residues of carbofuran and metabolites, the indirect effect was negative.

Through 3-CO-carbofuran, total residues and 7-phenol recorded high indirect positive effects. The different metabolites and total residues of carbofuran and metabolites showed indirect positive effects through 3-OH-7-phenol. Through 3-CO-7-phenol, highest indirect positive effect was manifested by 3-OH-7-phenol. The total residues of carbofuran and metabolites, 3-CO-carbofuran and 3-OH-7-phenol recorded positive indirect effects through 7-phenol, in that order. Through total residues, highest negative indirect effect was for 3-OH-7-phenol. The carbofuran metabolites or the total residues of carbofuran and metabolites did not show substantial indirect effects through mean leaf hair number/cm^2.

Discussion

5. DISCUSSION

The effects of soil application of graded doses of carbofuran granules (3 per cent) at 0.50, 0.75 and 1.00 kg ai/ha given at 20, 50 and 20 and 50 days after transplanting (DAT) on the development and survival of the rice leaf folder, <u>Cnaphalocrocis medinalis</u> Guen. through biochemical and biophysical changes in the rice plant were assessed under insectary and field conditions with a view to generate information on the insecticide-induced resurgence potential of the insect. Chatterjee and Rao (1974) have implicated natural enemy mortality as a factor responsible for the flare-up of <u>C. medinalis</u>. In a survey conducted in Kerala State, Abraham <u>et al</u>. (1973) could record only a few parasitoids in association with <u>C. medinalis</u> and the biotic pressure from these were not strong enough to regulate host populations. Therefore, the natural enemy complex associated with the stages of the leaf folder cannot be considered as a key factor regulating the pest populations and therefore, the involvement of natural enemies in resurgence is ruled out.

The results obtained in the present studies are discussed in this chapter.

5.1. <u>INSECTARY STUDIES</u>

5.1.1. <u>Effect of carbofuran on feeding rate, mortality, duration and sex-ratio of C. medinalis</u>

5.1.1.1. <u>Rate of feeding of larval stages</u>

In terms of the leaf area consumption (section 4.1.1.1) it was found that the damage inflicted was highest in the case of the fourth instar larvae, but such variations were not significant. In terms of the length of the linear patch involved in laminar feeding by first instar larvae, the treatment effects were not significant. This finding clearly shows that none of the carbofuran treatments influenced the extent of feeding by C. medinalis. The results of studies on the effect of soil application of carbofuran on the extent of feeding by the leaf folder have not been reported in literature earlier.

The extent of feeding by C. medinalis on leaves of treated rice plants is relevant in the case of those larvae which survive the toxic stimulus of carbofuran and the variations, if any, in the feeding activity can be ascribed mainly to the influence of non-toxic metabolites which may either stimulate or inhibit gustatory receptors. Such effects could be logically dose-dependant. The present studies have clearly established that for the rates of carbofuran tested, the surviving C. medinalis larvae did not show any marked changes in their feeding activity due to the residues/metabolites of carbofuran. Increased feeding by Nilaparvata lugens as influenced by application of foliar sprays of decamethrin, methyl parathion and diazinon have already been reported (Chelliah and Heinrichs, 1980 and 1984). Investigations by Raman (1981) showed that the resurgence inducing insecticides such as quinalphos, cypermethrin, fenthion, permethrin and fenvalerate increased the feeding rate of the brown plant hopper. Mathew (1989) reported that there was increased feeding of BPH receiving sub-lethal doses of deltamethrin, methyl parathion, fenthion and fenitrothion foliar sprays. On the other hand, Liu and Wilkins (1987) gave an account of the reduced feeding of the white backed plant hopper, Sogatella furcifera on rice plants as a result of topical application of carbofuran. Such variations in different species of insects are quite expected.

5.1.1.2. Weight of different stages of larvae and pupae of C. medinalis

The larvae of C. medinalis developing on rice plants which received carbofuran treatments showed significant weight gain in the third, fourth, fifth and sixth instar (section 4.1.1.2), whereas in the case of the first and second instars such weight gains were not manifested. The weight gains were particularly pronounced in the treatments which received the doses of 0.75 and 1.00 kg ai/ha applied at both 20 and 50 DAT. In the first and second instars, larval mortality were relatively higher (Table 4) and the adverse impact of the toxicant on these instars would normally be relatively more severe due to the sharpness of the toxic stimulus from carbofuran in that form itself. But the survivors reaching the third instar will certainly reveal the effects of the metabolites of carbofuran and the present results are to be viewed in this context.

It will be found that as the larvae develop from the third to the sixth instar, the extent of their weight gain as compared to under control tended to decrease in the successive instars (Table 3 and Fig. 2). The results of path analysis given in section 4.3.1 to 4.3.4 clearly show that the weight of different larval instars is highly and positively correlated with the residues of carbofuran and its metabolites. The sum total effect of the direct and indirect effects of these factors has contributed to the weight gain. The results of the path coefficient analysis corroborate the finding that in successive instars, the rate of weight gain showed a reduction. This is explicable on the basis of progressive reduction in residues and metabolites of carbofuran following treatments.

In the case of pupae also, the general trend of weight gain under carbofuran treatments was quite similar, except for the highest weight of those pupae developing from larvae fed on rice plants receiving the carbofuran application at 0.75 kg ai/ha at 20 DAT only, as compared to the case of larvae in which similar influence was highly perceptible in the same dose applied twice at 20 and 50 DAT. The data relating to the mean weight of pupae are obviously an overall reflection of the cumulative impact of the metabolites on the third, fourth, fifth and sixth instars rather than the effect of pupae per se, in view of the fact that when once the pupae are formed, further substantial gain in weight cannot be normally expected. Therefore, the finding brings into focus the favourable impact of carbofuran treatment at 0.75 kg ai/ha, even if it is given once at 20 DAT on the pupal development.

In the case of the castor semilooper (Achaea janata), Ramdev and Rao (1980) reported that the larvae gained weight on account of the treatment with DDT, even though the food intake was reduced. This was due to the better efficiency of conversion of ingested food to body matter due to lipid digestibility improvement. In the case of the gypsy moth (Lymantria dispar) also, Deecher et al. (1990)

found that treatments with avermectin and milbemycin at 10, 5 or 1 ppm increased their weight gain compared to untreated control. Sithananantham *et al*. (1973) found that the size and weight of aphids, *Aphis gossypii* were greater in plants treated with disulfoton, phorate, dimethoate and lindane granules. But they have attributed the gain in weight to the nutritional changes in host plants. But in the present investigations, nutritional status of treated plants did not show any impact on the weight of larvae of leaf folder as there was no correlation between weight of larvae and the normal biochemical components of leaves of treated plants. Therefore, the increased gain in weight in carbofuran treated larvae and pupae of *C. medinalis* could be attributed to the favourable influence of residues and metabolites of carbofuran through better digestion and conversion of ingested food. This is further evidenced by the fact that larvae did not show any significant variations in respect of the food intake in terms of the area of lamina eaten up.

Even though there was weight gain in larvae and pupae due to the treatments, it is interesting to note that there was no corresponding increase in fecundity as well as favourable changes in larval and pupal durations or mortality levels.

5.1.1.3. Larval and pupal mortality

The results on the effect of carbofuran treatments on the larval and pupal mortality show that the treatment differences are not significant (section 4.3.6) for all the six larval instars. But in respect of the overall mean larval mortality and pupal mortality levels, such differences are found to be significant, but since the insecticidal treatments are on par with untreated control, the results bring to focus the weak action of soil applied carbofuran against the rice leaf folder larvae. The results of path analysis show that there is a significant negative relationship between the 3-OH-7-phenol, 7-phenol, total residues of carbofuran as well as metabolites and total nitrogen on the one hand and mortality of first instar larvae, but such a relationship is lacking in the case of the other larval instars (section 4.3.6). In the case of overall mean larval mortality for all the six instars, a negative relationship was obtained (section 4.3.7).

In the case of pupal mortality, even though significant differences between carbofuran treatments were manifested, all these treatments were on par with untreated control (Table 4). This is further substantiated by the effects of 3-OH-7-phenol, which showed high negative direct effect on pupal mortality and its correlation was negative and significant (section 4.3.8).

In rice, carbofuran is widely recommended and used for the control of several tissue boring and sucking insects. In the earlier studies, fairly good control of the rice leaf folder by the soil application of carbofuran granules have been reported (Jayaraj et al., 1976; Rao et al., 1976; Chaturvedi and Mathur, 1981; Krishnamurthy et al., 1985). The recent reports of outbreaks of the pest (Chelliah and Heinrichs, 1984; Kushwaha and Singh, 1984; Qadeer et al., 1988; Panda and Shi, 1989) despite application of carbofuran granules brings out the possibility for insecticide-induced resurgence or development of resistance in the insect to the toxic stimulus of carbofuran. In the present study development of resistance in field populations has not been assessed, but the trend of mortality clearly shows that outbreaks are quite possible as a result of very feeble toxic stimulus of carbofuran against the C. medinalis and its uninterrupted multiplication without any insecticidal pressure.

5.1.1.4. Larval and pupal duration

The results presented in section 4.1.1.4 show that none of the insecticidal treatments are significantly different from untreated control, in respect of their effect on the larval and pupal durations. These results are not in consonance with the trends reported by Chelliah and Heinrichs (1978 and 1980) as well as Heinrichs and Mochida (1984). They found that there was a reduction in the length of nymphal stages of the brown plant hopper, Nilaparvata lugens due to application of foliar sprays of resurgence - inducing insecticides. Increase in the longevity of adult females have been reported in the case of Diabrotica virgifera Le Conte due to the topical application of carbofuran at sub-lethal levels (Ball and Su, 1979). But in the case of lepidopterous pests, the effects of sub-lethal doses have been mainly deleterious (Adkisson and Wellso, 1962; Chauthani and Adkisson, 1966; Tan, 1981).

In the present studies on the rice leaf folder, the effects on larval and pupal durations were not pronounced. Such a trend is perhaps due to the relatively weak toxic stimulus of carbofuran against the larvae (section 4.1.1.2).

5.1.1.5. Male and female adult emergence and sex-ratio

The male and female adult emergence and the female/male ratio in different treatments did not show much variations as compared to control (section 4.1.1.5). But the highest dose of carbofuran (1.00 kg ai/ha) applied twice at 20 as well as 50 DAT showed significantly higher female emergence as compared to untreated control. The rest of the doses were on par with control in respect of adult emergence. That the adult emergence in the rest of the doses of carbofuran is on the lower side shows that the development of resistance to carbofuran cannot be the main factor involved in the phenomenon of greater adult emergence at a particular dose. The finding clearly shows that two applications of carbofuran at 20 and 50 DAT, each at 1.00 kg ai/ha favourably influenced insect development up to the adult stage.

Lucky's (1968) hormoligosis concept in which sub-harmful quantities of any stressing agent will be stimulatory to the organism by providing it increased sensitivity to respond to changes in the environment and increased efficiency to develop new or better systems to fit a sub-optimum environment can be expected to operate in the present studies, since all the doses of carbofuran tested in the present studies were found to be near sub-lethal levels. The pronounced improvement in adult female emergence at the dose of carbofuran at 1.00 kg ai/ha applied twice at 20 and 50 DAT as compared to the rest of the doses is explicable on the basis of build up of adequate quantities of the metabolites of carbofuran which selectively confers developmental advantages to females of *C. medinalis* through physiological changes in insects. The results of path analysis corroborate this hypothesis. Lack of such favourable influence on the males indicates that the hormoligosis effect is not operating on the males. Such differential effects on sexes are quite possible but not reported so far.

In respect of female/male ratio, the treatment effects were not significant. The results of path analysis (section 4.3.9) showed that the different factors such as 3-CO-carbofuran, 3-OH-7-phenol and total residues of carbofuran and metabolites have only low influence on the female/male ratio even though a positive significant correlation was seen involving these factors on the one hand and the female/male ratio on the other. This trend is indicative of lack of influence of the residues and metabolites of carbofuran on the sex ratio. Dittrich *et al*. (1974) reported increased proportion of females of *Tetranychus urticae* due to treatment with carbaryl and DDT. Sheila (1989) also observed similar effects due to topical application of the LD_5 and LD_{10} of decamethrin and carbaryl on *Amrasca biguttula biguttula*. Singh and Lal (1966) did not observe any significant difference in the sex-ratio of the first and second generations of *Dysdercus koenigii* developing from adults surviving exposure to various doses of DDT and endrin. Chelliah and Heinrichs (1980) also did not observe any change in the sex-ratio due to foliar applications of resurgence-inducing insecticides on *Nilaparvata lugens*. But Rosenheim and Hoy (1988) recorded the production of more males by sub-lethal doses of chlorpyriphos in the parasitoid *Aphitis melinus*. In the present studies, however, differential effects on the sexes were not found in the case of carbofuran. In respect of different insecticides, their impacts can naturally be expected to be quite divergent.

5.1.2. Fecundity and F_1 progeny production of *C. medinalis* moths reared on different treatments

The results presented in section 4.1.2 show that in respect of mean number of eggs laid/female and mean number of first instar larvae/female, the treatment differences were not significant. In the case of the percentage emergence of the first instar larvae, the treatments with 0.50 kg ai/ha and 1.00 kg ai/ha applied twice on 20 and 50 DAT showed improvement as compared to control. In respect of the per cent emergence of the first instar larvae, the path analysis (section 4.3.10) showed significant positive influence of the residue of 3-CO-carbofuran, 3-OH-7-phenol as well as the total residues and it can be surmised that the overall effect on percentage emergence of first instar larvae is due to the impact of the direct and indirect effects of the factors tested, but the influence of these factors is found to be relatively weaker. Increased percentage emergence of the first instar larvae without any improvement in fecundity shows that the better progeny production is mainly due to improvement in the egg hatch by factors mediated by carbofuran metabolites which tend to favourably influence the processes involved in embryonic and post-embryonic development.

There are many reports of stimulatory effects of insecticide applications on reproductive potential of insects (Atallah and Newsom, 1966; Hart and Ingle, 1971; Dittrich *et al*., 1974; Chelliah and Heinrichs, 1978; Heinrichs *et al*., 1982 a; Gajendran *et al*., 1986; Mathew, 1989; Sheila, 1989). On the contrary, reports on the reduction of reproductive potential due to insecticide applications have also been made (Adkisson and Wellso, 1962; Georghiou, 1965; Kumar and Chapman, 1984; Krishnaiah and Kalode, 1987).

In studies conducted on some coleoptera, diptera and orthoptera, Roan and Hopkins (1961) suggested that sub-lethal doses might positively stimulate neural activity to bring about a favourable neurohormonal influence on insect reproduction. The present studies do not conform to the above results, since fecundity improvement was not realised. Krishnaiah and Kalode (1987) reported that in N. lugens resurgence induction could not be due to improvement of their fecundity and the present results are in consonance with this finding. But it is possible that such an influence got manifested at a later stage after oviposition during the process of embryogenesis.

Increase in size of the insect was attributed as the cause for increased fecundity of Aphis gossypii (Sithanantham, 1968), but in the present study fecundity variations were not detected despite the size variations (section 5.1.1.2). A similar influence is ruled out in the case of C. medinalis. Sithanantham et al. (1973) established the role of sub-lethal concentrations of the toxicant in plant as a factor that induces higher reproduction of A. gossypii in treated cotton plants. A similar influence is not found in the present case relating to C. medinalis.

5.1.3. Fecundity and egg laying preference of C. medinalis females (untreated) on treated and untreated plants

In the no-choice test to determine the mean fecundity and ovipositional preference, if any, (section 4.1.3) of the normal adult females, they did not show any preference to rice plants which previously received carbofuran at graded doses, as compared to untreated control. However, in the multiple-choice test in which the different treatments were all offered simultaneously, the adult females showed preference for oviposition on the carbofuran treated plants. This preference for egg laying was quite marked in the case of those treatments which received carbofuran application at all the doses given twice at 20 and 50 DAT. These results show that the resurgence of C. medinalis on rice plants receiving carbofuran treatments is mainly due to the preference of such plants for oviposition resulting in the higher larval loads on preferred plants. The plants receiving carbofuran at 1.00 kg ai/ha (Fig. 7) showed maximum ovipositional stimulus and the treatments given on 20 and 50 DAT were definitely more attractive than single application of carbofuran.

The results of path analysis (section 4.3.11) also clearly established high positive correlation of the factors such as 3-CO-carbofuran, 3-OH-7-phenol, 3-CO-7-phenol, 7-phenol, total residues of carbofuran and metabolites as well as leaf hair density. As the residual effect was low the aforesaid factors are relatively of considerable importance in deciding the ovipositional preference of moths on treated plants. The effects of these factors on ovipositional preference is the sum total of the direct and indirect effects of the factors involved. Among these factors, the effect shown by leaf hair density is very much pronounced by its direct positive effect and this brings into focus the strong involvement of the leaf hair density on the lamina as a key regulatory factor in the acceptance of treated plants for oviposition. The effect of different rates and timings of application of carbofuran on the leaf hair number is found to be significant, but the trend showed inconsistencies in the first three leaves. However, the mean leaf hair density on the first three leaves of treated plants was found to be on par with that in untreated control (Table 12).

In respect of mean leaf hair density for the first three leaves taken together, those plants which received carbofuran at 1.00 kg ai/ha at 20 as well as 50 DAT showed higher density than those which received 0.50 kg ai/ha at 20 DAT. The ovipositional preference of plants receiving the 1.00 kg ai/ha treated twice at 20 and 50 DAT is thus quite likely to be due to the higher leaf hair density on the first three leaves which are generally preferred for oviposition. Denser disposition of leaf hairs on the lamina of cotton plants has been reported to be a factor that decides the ovipositional stimulus to females of *Heliothis armigera* Hubner and *H. punctigera* Wallengren (Hasan *et al*., 1990). They attributed the ovipositional preference to the better grip and effective foothold of the moth's pre-tarsal claws on a substrate with denser trichomes. Regarding the insecticide-induced variations in leaf hair on the lamina of treated plants, there are no previous reports at all, but such biophysical changes are quite likely to be mediated by carbofuran which possesses phytotonic properties. The phytotonic effects have been widely reported in the case of carbofuran (Venugopal and Litsinger, 1980; Balasubramaniyan and Morachan, 1981; Pillai *et al*., 1985; Thakur *et al*., 1988), mainly through suppression of IAA oxidase titres in treated plants.

That the odour emanating from plants receiving insecticidal treatment, was not attractive to the brown plant hopper, N. lugens has been reported by several workers (Aquino et al., 1979; Chelliah and Heinrichs, 1980; Balasubramaniyan and Morachan, 1981 and Raman, 1984). The results of the multiple-choice experiment conducted in the present study are at variance with these reports. The plants which received carbofuran treatments definitely elicited ovipositional preference as compared to untreated control and this is obviously due to the positive olfactory stimuli emanating from treated plants, in the form of vapour-phase admixture of the residues/metabolites from carbofuran. The report by Siddaramappa (1978) that carbofuran and its metabolites are transported acripetally to the leaf tips by transpiring water and is lost by evaporation lends support to the above possibility.

5.1.4. Effect of carbofuran treatments on biophysical characters of rice plants

5.1.4.1. Length and width of leaves

In respect of the mean leaf length, significant differences were found under carbofuran treatments as compared to control, but the variability was not quite consistent in the first, second and third leaves (section 4.1.4.1;Table 9). When the mean length of the first three leaves was considered together, the carbofuran treatment at 1.00 kg ai/ha applied twice at 20 and 50 DAT caused more elongation as compared to the control and both the doses of 0.50 and 0.75 kg ai/ha given only once at 50 DAT caused lowest elongation. The elongation of leaves due to carbofuran treatment is a manifestation of the phytotonic effect of the toxicant.

In respect of mean width of leaves, treatment effects were significant for the first, second and third leaves, but when the mean values of width were taken for all the three leaves, the differences failed to attain statistical significance over control. The trend of leaf width increase was not consistent for the three leaves. It is only in the first leaf, that carbofuran treatment at 1.00 kg ai/ha on 50 DAT showed higher leaf width than the control. In the case of the third leaf, the width was higher in the treatment of 0.75 kg ai/ha twice at 20 and 50 DAT as compared to control. The second leaf did not show striking variations in leaf width as compared to control.

These results show that the time of application of carbofuran has a good deal of influence on leaf width. Yoshida (1981) reported that in rice, one leaf emerges in about 4-5 days before panicle primordia development and once in 7-8 days thereafter. It can thus be found that the first leaf emerged at 53 to 55 days after planting and the second leaf emerged by 44 to 47 days after planting and the third leaf emerged by 35-38 days after planting. As the panicle primordia would have started initiation at about 30 to 35 DAT, the effect of applying carbofuran at 50 DAT would not have influenced the leaf width as the leaf width is mostly determined well before emergence of the leaf, particularly in the case of second and third leaves. In the case of first leaf there could be some effect of the 50 DAT application as this leaf emergence should have started only by 53 DAT, after the receipt of the insecticidal treatments at 50 DAT. Therefore, the changes in width of the first leaf are naturally expected. As the second leaf emerged only after about 24 to 27 days of application of carbofuran, the residues of carbofuran or its metabolites might not have been present in the plant in adequate quantities to cause any positive influence on the width of second leaf. That the residues of carbofuran at three weeks of application decreased to very low levels has been reported by Mohamed Ali (1978). But in the case of the third leaf, the residues of the insecticide applied at 20 DAT could have favourably influenced the leaf width.

Increased plant height in rice plants as a result of increase in leaf length was reported to be due to application of 1.00 kg ai/ha of carbofuran (Chelliah and Heinrichs 1978). Venugopal and Litsinger (1984) as well as Heinrichs and Mochida (1984) have also reported similar effects with methyl parathion. Increase in tiller production, leaf area index, root production and grain yield was reported as a result of soil application of carbofuran granules at 0.75 and 1.00 kg ai/ha (Abdul Salam, 1989). Such phytotonic effects of carbofuran on rice plants have been attributed to the physiological changes in the plant, enhanced absorption of nutrients or to the changes taking place in the soil which facilitates better nutrient availability for the plant.

5.1.4.2. Height of plants and leaf thickness

The mean thickness of the three youngest leaves did not show any variations due to the carbofuran treatments (section 4.1.4.2 and Table 10) but the height of plants showed significant variations on this account. The mean height was highest in the plants which received carbofuran treatment at 1.00 kg ai/ha applied twice at 20 and 50 days after transplanting as compared to control. This is an indication of the positive influence of carbofuran treatments on the growth of plants. For this particular treatment of carbofuran, the length of first and second leaf also was relatively higher (section 4.1.4.1) than in untreated control. According to Yoshida (1981), the height of the rice plants is mainly dependent on the length of second or third leaves from the top. Increase in plant height is, therefore, mostly the result of elongation of these two leaves under influence of carbofuran at 1.00 kg ai/ha applied twice on 20 and 50 DAT. Balasubramaniyan and Morachan (1981) have also observed significant increase in rice plant height as a result of carbofuran applied at 0.50 kg ai/ha on 20 and 45 days after planting.

The non-significant correlations involving plant height and the factors such as weight of larvae/pupae, area of leaf consumed, larval and pupal mortality and the duration of life stages brings out that as a factor regulating leaf folder growth and development, plant height is of no concern. This is quite expected because a mere increase in the plant height in itself cannot confer any advantages to the insect.

5.1.4.3. Thickness of different transverse layers of the second leaf

For studying the thickness of different transverse layers, the second leaf from the top was selected because this particular leaf would be the most preferred one for feeding by leaf folder larvae and since this leaf would be the youngest one which is physiologically mature at 60 DAT. The paired 't' test conducted for determining the preference of leaves for feeding by leaf folder larvae (section 5.2.8) justified the selection of second leaf for this study as maximum preference of the leaf folder larvae for feeding at 60 DAT was for the second leaf.

In transverse sections, difference of thickness was noticed only in the case of the upper epidermis of the second leaf consequent on the application of carbofuran granules (section 4.1.4.3). The results show that the lower rate of 0.50 kg ai/ha applied at 50 DAT and 20 and 50 DAT as well as the median dose of 0.75 kg ai/ha at 20 DAT were the most effective in increasing the thickness of the upper epidermis, while the other rates could not cause such a change as compared to untreated control. The total thickness of the second leaf as well as the thickness of other layers such as lower epidermis, vascular bundle, mesophyll, bulliform cells and fibrous patch on the upper surface did not show any variations in their thickness as a result of carbofuran treatments.

Generally the leaf folder larva feeds within a folded leaf and hence the feeding is mostly on the upper leaf lamina. But occasionally it feeds from the lower surface also (Fraenkel *et al* ., 1981). The larvae of *C. medinalis* feed from one side of the lamina to the other up to the epidermal layer on the opposite side and as such the thickness of the epidermal layer *per se* without any increase in overall leaf thickness does not appear to be a factor which can be expected to influence feeding by the larvae. The proliferation of cells in the upper epidermis under influence of carbofuran treatments is quite likely to be due to the phytotonic effects.

5.1.4.4. Leaf hair density and length

The leaf hair density in rice plants which received carbofuran at 1.00 kg ai/ha at 20 and 50 DAT (twice) was distinctly higher in the second leaf than in the treatments which received 0.50 and 1.00 kg ai/ha once either at 20 DAT or 50 DAT as well as the untreated control (section 4.1.4.4: Table 12). In the third leaf as well as in all the three leaves taken together the trends were quite similar in respect of carbofuran treatments, but in this case the treatments failed to attain statistically significant variations from that of the control. Variations in leaf hair density due to phytotonic effects of carbofuran have not been reported. As already discussed, such changes towards increase in density of leaf hairs might have provided tactile stimuli favourable for host plant acceptance for oviposition. The results of the multiple choice test in which the rice plants which received carbofuran at 1.00 kg ai/ha at 20 and 50 DAT have already indicated the involvement of positive olfactory stimulus from metabolites probably in the vapour phase.

Those moths which are attracted to the carbofuran treated plants (1.00 kg ai/ha at 20 and 50 DAT) must have had the required tactile stimuli for host plant acceptance for oviposition. In the insectary studies, though fecundity variations were not recorded under various treatments, there was improved larval emergence in carbofuran treatments. This is a pointer to the possibility of better egg hatch as already discussed. The denser disposition of leaf hairs must have provided optimal microenvironmental conditions for development of the eggs. It is also possible that such a condition provides mechanical protection to the eggs and perhaps better protection from natural enemies. It is also probable that the physiological changes brought about by carbofuran were more favourable to the process of egg hatch as reported by Van Der Laan (1961) in the case of cotton white fly, *Bemisia tabaci* Gennadius.

5.1.5. Influence of carbofuran treatments on biochemicals in rice plants

In respect of nitrogen and crude protein contents, the carbofuran treatments were not significantly different as compared to untreated control (section 4.1.5). However, dose and time of application dependency was manifested in regulating these constituents. Thus, application of carbofuran at 1.00 kg ai/ha at 20 and once again at 50 DAT led to significant increase of these two components as compared to the treatment receiving 0.50 kg ai/ha only once at 20 DAT. Higher plant absorption of Nitrogen was reported by Thakur *et al*. (1989) following soil application of carbofuran. Similar results were also reported by Abdul Salam (1989). The present results are in consonance with the earlier reports, but the lack of variation from untreated control is somewhat unexpected. Singh and Jotwani (1980) observed a positive relationship with nitrogen content in leaf and degree of damage by the sorghum shoot fly, Atherigona soccata (Rond.). Similar reports on the influence of nitrogen on sucking insects are legion but such reports on lepidoptera are very scanty. In the present study, it is found that at least in the case of the leaf folder increase in nitrogen, mediated by carbofuran application cannot be considered a major factor which predisposed rice plants to their infestation.

Increase in carbohydrate content in rice plants receiving carbofuran at 0.50 kg ai/ha given at 50 DAT was quite pronounced as compared to untreated control. In the case of organic carbon, total sugars and silica (SiO_2), the treatments failed to attain any statistical significance. Sithananthan et al. (1973) reported that the treatment with granules of disulfoton, phorate, dimethoate and lindane led to reduction in carbohydrate content in cotton which in turn favoured infestation by Aphis gossypii. Regupathy and Jayaraj (1974) also obtained similar results with phorate granules in cotton which favoured infestation by Aphis gossypii and Amrasca devastans. In the case of carbofuran, which belongs to the carbamate group, similar results are unexpected. That higher carbohydrate content was implicated in the resistance of corn varieties to infestation by the European corn borer, Pyrausta nubilalis (Hubner) was reported by Beck (1956). The effect of total carbohydrate content in rice plants to infestation by C. medinalis cannot be expected to be similar, but such a trend cannot be ruled out altogether.

5.1.6. Chlorophyll content in leaf

The results relating to the chlorophyll content in leaf presented in section 4.1.6 showed an increase over control only in the case of carbofuran treatment given at 50 DAT at 0.50 kg ai/ha. Between the different rates of application, $chlorophyll_a$ did not show any variations. But the $chlorophyll_b$ and $chlorophyll_{a+b}$ components showed substantial variations among the treatments of 0.50, 0.75 and 1.00 kg ai/ha. In the case of timings of applications, the $chlorophyll_a$, $chlorophyll_b$ and $chlorophyll_{a+b}$ were higher in the 50 DAT applications of carbofuran. Even though the $chlorophyll_a$ and $chlorophyll_b$ contents showed direct and indirect effects on different attributes regulating growth and population build-up of the leaf folder as evidenced by the results of path coefficient analysis (Fig. 27-36), the direct and indirect effects of $chlorophyll_{a+b}$ have been found to nullify the effects of $chlorophyll_a$ and $chlorophyll_b$ components. It can, therefore be concluded that chlorophyll do not have any influence on the growth and development as well as attraction of the leaf folder moths for oviposition. This result is a variation from the earlier reports of Singh and Jotwani (1980), Venugopal and Litsinger (1984), Abdul Salam (1989) and Mathew (1989), but such differences are expected for insects belonging to different groups.

5.1.7. Residue and metabolites of carbofuran in leaf

The data relating to the residue and metabolites of carbofuran in leaf presented in section 4.1.7 indicate that the residues are relatively higher in accordance with the rate and number of applications of the toxicant. The lower residues were detected in carbofuran treatment of 0.50 kg ai/ha given only once and highest was in the treatment of 1.00 kg ai/ha given twice. Such results are quite expected. The effects of different metabolites and residues of carbofuran on the different growth and development attributes and attraction of moths for oviposition was studied through path coefficient analysis (Fig. 27-37). These results showed that the highly toxic carbofuran residue and the 3-OH-carbofuran residue had no adverse effects on the different biological traits of *C. medinalis*. The larval and pupal mortality data (section 4.3.6) support the above finding. However, in the Philippines, development of resistance to carbofuran has been reported in *Nilaparvata lugens* (Heinrichs and Valencia, 1978).

The other metabolites which normally possess very low insecticidal property have been found to influence leaf folder development (Fig. 27-37). Among these metabolites, phenol metabolites were found to be more important. The plant phenols are often implicated in host plant resistance (Uthamasamy *et al*., 1976). But in the case of leaf folder, the phenol metabolites of carbofuran did not show any antagonistic influence. This may be explained on the basis of a very low titre of the metabolic phenols as compared to plant phenols. The carbofuran phenols might not have any influence as a resistance fator.

5.2. FIELD EXPERIMENTS

5.2.1. Effect of carbofuran treatments and pest infestation trends

5.2.1.1. Leaf folder

The results presented in section 4.2.1.1 and 4.2.1.2 showed that there was variation in the extent of damage by the leaf folder *C. medinalis* in the different treatments in the kharif and rabi seasons, which could be attributed to the variations in the climate during the two seasons. In the kharif season, the general level of pest infestation was relatively heavier. This is in accordance with the effect of seasonal variations on *C. medinalis* which are principally contributed by a favourable environment mainly higher rainfall and associated microclimatic relative humidity levels in the kharif season as compared to the rabi season in which these conditions are not that favourable (Appendix II).

In the field experiments conducted in both seasons the leaf folder damage was strikingly higher for all the three observations at 50, 60 and 70 DAT, in the treatment which received carbofuran at 1.00 kg ai/ha at both 20 and 50 DAT as compared to control. The lower dose of 0.75 kg ai/ha also showed such heavy incidence in the kharif season, but not in the rabi season. The first set of observations taken on 30 DAT failed to show any significant variation in leaf folder incidence as compared to control.

This is normally expected, since the carbofuran treatments were given only 10 days before and this short span is inadequate to cause any impact on the pest population. Another aspect of interest is to note that the treatment differences were manifested in a more pronounced manner during the rabi season which is characterised by a relatively dry weather and higher atmospheric temperature levels.

Multiple-choice experiments have already established the ovipositional preference of C. medinalis moths to rice plants which received carbofuran at 1.00 kg ai/ha applied at 20 as well as 50 DAT. Heavy damage in plants receiving this particular dose of carbofuran under field conditions is in perfect agreement with the results of the multiple choice experiments. Chelliah and Heinrichs (1984) also attributed the resurgence of Nilaparvata lugens due to the attraction of adult macropterous forms to rice plants treated with resurgence-inducing insecticides. As already discussed, the ovipositional attraction could be due to vapour phase mixture of carbofuran and its metabolites available close to the lamina of treated plants. The vapour phase emission from treated leaves will be higher during the dry hot rabi season than in damp murky conditions of the kharif season. The effect of temperature and light on the vaporisation loss of carbofuran is reported by several workers (Huynh et al., 1974; Talekar et al., 1977; Ferreira and Seiber, 1981).

The present study has clearly established that carbofuran when applied at 1.00 kg ai/ha against pests of rice, led to pronounced resurgence in leaf folder C. medinalis.

The results of the insectary studies particularly those relating to larval/pupal weight, larval/pupal mortality rates, rate of emergence of first instar larvae and adult emergence lend solid support to the results obtained from the field studies.

In the present study increased effect of higher rates and more number of applications of carbofuran was also manifested (Fig. 13-16). Heinrichs et al.. (1982 a) and Raman and Uthamasamy (1983) attributed the number of application of resurgence-inducing insecticides as a factor in resurgence of N. lugens. In trials conducted by Heinrichs et al. (1982 b) decamethrin at higher rates of application induced BPH resurgence and the present studies are in conformity with early reports.

5.2.1.2. Yellow stem borer damage

The carbofuran treatments did not cause any significant variations in the incidence of the stem borer, Scirpophaga incertulas (Walker) (section 4.2.2). In the kharif season experiment, the stem borer incidence was very low even at 50 DAT and also at harvest and the impact of carbofuran treatments on control of stem borer was not therefore, very pronounced. In the rabi season, the insecticidal treatments were not found to be effective at 30 and 50 DAT in reducing the incidence of the stem borer.

Carbofuran is widely recommended for control of yellow stem borer and is recommended in the Kerala State also (KAU., 1986 and 1989). In the light of the present studies, particularly the resurgence of the leaf folder, these recommendations need to be reviewed carefully.

5.2.1.3. Rice gall midge damage

The result on the damage by gall midge, *Orseolia oryzae* presented in section 4.2.3 shows that the level of damage during the kharif and rabi seasons in different treatments was very low . in all the observations. The pest incidence in different treatments were' on par with untreated control. Trials on the control of gall midge with carbofuran showed its effectiveness (AICRIP, 1982; 1984 and 1987). However, Panda and Shi (1988) could not get adequate control of rice gall midge from basal application of carbofuran applied at 1.00 kg ai/ha alone or in combination with quinalphos spray given @ 0.50 kg ai/ha at 25 DAT. They attributed poor control due to improved plant health in rice as a result of carbofuran.

5.2.1.4. Rice whorl maggot damage

The results of the field studies during kharif and rabi on the damage by rice whorl maggot, *Hydrellia sasakii* presented in section 4.2.4 show that the levels of damage in different treatments including control were below economic threshold level. In the rabi experiment, for the observation at 30 DAT, the treatment effects were pronounced. From the results, it could be seen that the treatment at 0.50, 0.75 and 1.00 kg ai/ha of carbofuran is effective in controlling the whorl maggot damage when applied at 20 DAT. The effectiveness of carbofuran in controlling whorl maggot is well documented by the earlier reports also (Abraham and Thomas, 1977; Bandong and Litsinger, 1979; Arceo and Heinrichs, 1980; Singh and Rizvi, 1983).

5.2.2. Plant growth attributes

In respect of height of plants and tiller production carbofuran treatments failed to show any favourable influence as in the insectary studies (section 4.2.5). Balasubramaniyan and Morachan (1981) observed significantly higher number of productive tillers/hill by carbofuran at 0.50 kg ai/ha applied at 20 and 45 days after planting. Venugopal and Litsinger (1984) also reported similar effects in a hydroponic culture study with carbofuran, 3-hydroxy carbofuran and 3-keto carbofuran, applied at 1.00 ppm levels. With 0.50, 0.75 and 1.00 kg ai/ha applied basally, Bhattacharya et al. (1988) recorded highly significant increase in the number of tillers/hill at flowering, productive tillers/hill and number of panicles/m^2. In the present field studies, the leaf folder incidence was very heavy and under such a situation it is only natural that the phytotonic effects of carbofuran failed to attain perceptible levels. Moreover in field studies, a number of factors involving edaphic, climatic and biotic stresses will be influencing the treatment plants and hence the direct impact cannot be expected with reasonable accuracy, while under insectary studies the impact is more accurately assessed.

5.2.3. Number, length and width of leaves

In respect of the number of leaves, all the carbofuran treatments were on par with untreated control during kharif and there was some difference during rabi. Similar results were obtained in the case of length and width of leaves also. It is found that in respect of these traits, carbofuran did not show any favourable influence due to any phytotonic effects in contrast to the insectary studies. Such a result is normally expected in a situation where the plants are subjected to heavy biotic stress from pests.

5.2.4. Leaf area of different leaves

The results of the mean leaf area of first, second and third leaves and mean of first three leaves showed no variations between the carbofuran treated and the untreated plants during the kharif and rabi seasons. In the case of the total area of the first three leaves in the net plot also, there was no such variation during rabi (section 4.2.7). The expression of phytotonic effects must have been obscured due to heavy incidence of the leaf folder in these treatments. However, in the case of total area of first three leaves in the net plot, in the treatments with 0.75 and 1.00 kg ai/ha given at 20 and 50 DAT there was a positive response due to phytotonic effects on the length and width of leaves and number of tillers/hill.

5.2.5. Leaf area damage by *C. medinalis* larvae

The results of the leaf area damage by *C. medinalis* presented in section 4.2.8 showed that there was very high differences between carbofuran treatments and the untreated control. During kharif and rabi, the damage in the carbofuran treatments given twice on 20 and 50 DAT recorded highest damage followed by single applications given either at 20 DAT or at 50 DAT. Leaf area damage is a direct result of the larval population density and improved feeding stimulus.

In the insectary trials in which fixed number of larvae were confined on treated leaves, such feeding differentials were not manifested. Therefore, it can be surmised that the larval population loads per unit area should have led to more foliar damage. The higher larval population loads are explicable on the basis of ovipositional attraction of leaf folder moths to treated plants and the positive influence of laminar hairs as on host plant acceptance.

5.2.6. Yield attributes and yield

The results on the yield attributes and yield during kharif and rabi seasons are presented in section 4.2.9. In the mean length of earhead, the treatments showed differences only during the kharif season. The carbofuran treatments were not found to differ within themselves.

With regard to the weight of panicle during kharif and rabi, it could be seen that the weight of panicles in treatments given at 20 DAT and 20 and 50 DAT is very much reduced as compared to untreated control. The total grains/earhead showed significant variations between treatments during kharif but not during rabi. This difference between the seasons must be mostly due to the variations in the general intensity of leaf folder damage.

In the case of grain yield during kharif and rabi, the untreated control recorded highest grain yield and the 0.75 and 1.00 kg ai/ha treatments with carbofuran at 50 DAT were equal to grain yield in control, statistically and the other treatments showed low yields.

The straw yield during kharif did not show any variation between carbofuran treatments and untreated control, inspite of heavy damage by leaf folder in different treatments. During rabi season, higher straw yields were obtained from the 0.75 and 1.00 kg ai/ha treatments at 50 DAT. All these results are indicative of the influence of leaf folder damage in different treatments.

Balasubramaniyan and Morachan (1981) observed 4682 kg of grain yield with 0.50 kg ai/ha of carbofuran applied at 20 and 45 DAT, while in untreated control it was 3931 kg/ha. Venugopal and Litsinger (1984) also observed increased grain yield/plant by carbofuran application. Pandya et al. (1988) reported 289.0 grains/panicle, 8.9 tonnes/ha yield and 8.7 tonnes/ha of straw yield as compared to 196.0 grains/panicle and 5.8 tonnes each of grain and straw yield per hectare in untreated control, respectively, due to control of major rice pests by insecticides.

5.2.7. Grain filling characters

There was no significant difference between treatments in the case of 1000 grain weight during kharif and rabi (section 4.2.10). In the case of filled grains all the carbofuran treatments were showing reduction in both the seasons. These reductions were more prominent in the case of 20 DAT applications during kharif but during rabi, the trend was found in the treatment at 20 as well as 50 DAT. With regard to the number of half-filled grains during kharif and rabi, the effect of carbofuran treatments was not consistent. The chaff production was higher in the lowest dose of 0.50 kg ai/ha applied at 20 DAT and all the doses applied at 20 as well as 50 DAT and the 0.50 and 0.75 kg ai/ha of carbofuran applied at 50 DAT were also equal with it during kharif. During rabi, all the doses applied twice recorded a higher chaff along with the lower doses of 0.50 and 0.75 kg ai/ha of carbofuran applied at 20 DAT, these results showing the influence of timing and rate of application of carbofuran on chaff production. Such results are normally expected when the damage by C. medinalis is higher in these treatments.

5.2.8. Residues and metabolites of carbofuran in whole grain and straw

The results of the residues and metabolites of carbofuran presented in section 4.2.11 show that the grains from the carbofuran treated plots contained no detectable levels of residues of carbofuran or metabolites such as 3-OH-carbofuran, 3-CO-carbofuran, 3-OH-7-phenol, 3-CO-7-phenol and 7-phenol. These results are expected due to the long time lag between the last application and harvest of the crop. The straw also contained only very low residues of carbofuran or its metabolites and their totals were well below the maximum residue limits of 1.00 ppm for straw.

Rajukkannu et al. (1976) reported 0.06 and 0.15 ppm of carbofuran in grain and straw, respectively in the rice variety IR-20 by two applications of 1.25 kg ai/ha at 15 and 45 DAT. Mohamed Ali et al. (1980) reported non-detectable levels of carbofuran in the rice variety Triveni as a result of soil application of 0.54 kg ai/ha of carbofuran.

Summary

SUMMARY

Studies under insectary and laboratory conditions were conducted at the Regional Agricultural Research Station, Pattambi (Kerala Agricultural University) to assess the changes taking place in the extent of feeding, growth and development of the rice leaf folder, *Cnaphalocrocis medinalis* Guen. on rice plants receiving soil application of carbofuran granules at graded doses of 0.50, 0.75 and 1.00 kg ai/ha at 20 and 50 DAT as well as at both timings of 20 and 50 DAT, with a view to generate information on the insecticide-induced resurgence potential of the pest. In these experiments, the feeding rate, mortality, duration of development, sex-ratio, fecundity, F_1 progeny production of *C. medinalis* as well as ovipositional preference of adult females on treated and untreated rice plants were determined. The biophysical changes in rice plants due to carbofuran application such as length, width and thickness of leaves, anatomical variations of leaf tissues, height of plants as well as the density and length of leaf hairs were ascertained. The biochemical factors such as organic carbon, total nitrogen, chlorophyll, total carbohydrates as starch, total sugars and silica in leaves of carbofuran treated and untreated rice plants at 60 DAT were also assayed in these experiments. The residues and metabolites of carbofuran in the treated and untreated leaves were estimated.

The results of feeding studies did not reveal any changes in the extent of larval feeding on leaves of plants as a result of carbofuran application. In the case

of weight of different larval stages and pupae also, the treatment effects were not found to be significant in the first and second instars, whereas in the third, fourth, fifth and sixth larval instars, there was pronounced increase in weight even though the extent of feeding remained without changes. The weight gain was found to be positively correlated to the quantum of carbofuran metabolites. The study indicated that the weight gain in larvae and pupae is due to the possible enhancement of the digestibility and more efficient conversion of ingested food into body matter under influence of the metabolites of carbofuran.

In respect of the mean larval mortality and pupal mortality, most of the insecticidal treatments were found to be on par with untreated control, indicating the weak toxic stimulus of carbofuran against the C. medinalis. The larval and pupal mortality levels showed significant negative correlation with the metabolites of carbofuran. The larval and pupal durations did not show any perceptible changes as a result of insecticidal treatments.

An increase in the female emergence at the 1.00 kg ai/ha of carbofuran applied at 20 as well as at 50 DAT showed the possible operation of hormoligosis effect due to improvement in female emergence from pupae due to the favourable physiological influence of carbofuran metabolites on their growth and development. Lack of such influence on males indicates that the hormoligosis effect is not operating on males.

Regarding the emergence of the first instar larvae belonging to the F_1 generation, there was significant positive correlations with the factors 3-CO-carbofuran, 3-OH-7-phenol, total residues of carbofuran and metabolites and total sugars. This brings into focus the positive influence of these factors on progeny production and the likely resurgence of pest on that account.

In a no-choice test, the fecundity of adult females on carbofuran treated and control plants did not show any change, but in the multiple choice test, the moths showed clear preference towards the carbofuran treated plants for egg laying. The maximum number of eggs were laid on plants receiving carbofuran treatment at 1.00 kg ai/ha twice at 20 and 50 DAT. This shows that the treated rice plants provide positive orientational stimulus to the females of C. medinalis. Positive orientation towards treated rice plants for oviposition is quite likely to be due to positive short-range olfactory stimuli from the vapour-phase mixture of the metabolites of carbofuran while the density of leaf hairs might influence the acceptance of plants thus selected. The density of leaf hairs had only a lesser influence as compared to the metabolites as indicated by the results of path coefficient analysis (Section 4.3.11).

The length of leaves showed significant variations between treatments and the higher doses led to increase in the length of leaves. But in the case of width of the first, second and third leaves from the top, the variations were inconsistent. The plant height also showed an increase due to carbofuran applications. The thickness of the first three leaves also did not show any variations due to carbofuran treatments. Although there were some phytotonic effects due to carbofuran applications, such changes were not found to be of any favourable influence on *C. medinalis*.

In respect of leaf hair density and leaf hair length, only leaf hair density showed the influence of carbofuran application and such variation was very pronounced in the second leaf. The leaf hair density was found to be drastically reduced in the treatment with the lower dose of carbofuran (0.50 kg ai/ha) and single applications (20 DAT or 50 DAT) and was found to increase with an increase in the dose and number of applications of carbofuran. However, none of the treatments showed any variations in this respect as compared to untreated control. In multiple choice tests, the ovipositional attraction towards rice plants receiving carbofuran application has been well established. This shows the possible involvement of the carbofuran metabolites in the vapour phase as olfactory stimuli in eliciting positive orientational stimulus towards treated plants. The path analysis established positive correlation of leaf hair density on the one hand and the ovipositional preference on the other, thereby bringing out the importance of tactile stimuli provided by leaf hairs in the acceptance of host plants for oviposition.

The biochemical components such as organic carbon, total nitrogen, total carbohydrates, total sugars and silica (SiO_2) in carbofuran treated rice plants did not show any variations from that of untreated control even though total nitrogen and total sugars showed correlations with the growth and developmental attributes of *C.*

medinalis. Even though the $chlorophyll_a$, $chlorophyll_b$ and $chlorophyll_{a+b}$ showed increase at the lower dose of 0.50 kg ai/ha applied at 50 DAT, the chlorophyll content did not show any influence on the resurgence of the rice leaf folder by means of their influence on the rate of feeding, gain in weight, reduction in mortality or larval and pupal duration of *C. medinalis*.

As per expectations, the residues and metabolites of carbofuran were found to be influenced by the rates and timings of its application. Higher residues were recorded in the higher doses and increased number of applications. The toxic residues of carbofuran and the 3-OH-carbofuran did not show any deleterious effects on the growth and development of leaf folder larvae and pupae. On the contrary, the metabolites showed a positive influence on the insect. The most striking influence was in bringing about a positive orientational response of the adult moths to the treated plants for oviposition.

In the field experiments conducted during the kharif (July-November) and rabi (October-January) seasons, the effects of carbofuran treatments on the intensity of damage caused by major pests including the leaf folder, the effects on the growth attributes and grain/straw yield were studied. The terminal residues of carbofuran and its metabolites left in the grain and straw at harvest were also assayed. The leaf folder damage was found to increase at higher doses of carbofuran, particularly at 1.00 kg ai/ha applied twice on 20 and 50 DAT. Increase in the intensity of damage was found to be caused by increase in larval population loads which in turn is the expression of positive ovipositional preference to carbofuran treated plants and also due to enhanced egg hatching under better mechanical protection provided by leaf hairs and also probably due to insecticide-induced physiological changes which are favourable to embryonic and post-embryonic development. A higher rate of increase in C. medinalis populations and the resultant increase in the intensity of damage over control was experienced during the rabi season than in the kharif season. As weather was more favourable for increase of leaf folder during the kharif season, the leaf folder populations increased heavily under the influence of carbofuran metabolites causing severe damage, thereby obscuring the treatment differentials. However, during rabi season, since the plant damage was lower, the treatment differentials became clearly manifested.

The damage by the stem borer, Scirpophaga incertulas (Walker) and the gall midge, Orseolia oryzae (Wood-Mason) was low during both the kharif and rabi seasons and the carbofuran treatments did not show any influence on their field damage levels. Carbofuran treatments effectively reduced damage caused by the rice whorl maggot, Hydrellia sasakii (Y.I.)

Even though phytotonic effects were manifested by carbofuran treatments in the insectary, such results were not obtained in the field experiments mainly due to severe stress by the leaf folder which tended to mask the phytotonic effects.

In respect of the crop yield and yield attributes, the general trend on the effect of carbofuran treatments was negative. At higher doses and more number of applications, there was decrease in grain yield, indirectly through heavy leaf folder damage under carbofuran application.

The residues of carbofuran and its metabolites in the whole grains and straw at the time of harvest were well below the maximum residue limits.

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* Originals not seen

APPENDIX I

Recovery of carbofuran, 3-OH carbofuran, 3-CO-carbofuran, 7-phenol, 3-OH-7-phenol and 3-CO-7-phenol in thin layer chromatographic techniques

	μg/g added	Recovery					
		Leaf		Straw		Grain	
		μg/g	%	μg/g	%	μg/g	%
Carbofuran	2	1.72	86.00	1.61	80.50	1.83	91.50
,,	4	3.88	97.00	4.01	100.00	3.88	97.00
,,	6	5.85	97.50	5.68	94.66	5.51	91.83
,,	8	7.96	99.50	7.54	94.25	7.74	96.75
,,	10	9.63	96.30	9.37	93.70	9.63	96.30
Mean			95.26		92.62		94.68
3-OH-carbofuran	2	1.83	91.50	1.73	86.50	1.73	86.50
,,	4	3.51	87.75	3.63	90.75	3.51	87.75
,,	6	5.71	95.17	5.55	92.50	5.71	95.17
,,	8	7.72	96.50	7.72	96.50	7.72	96.50
,,	10	9.90	99.00	9.90	99.00	9.63	96.30
Mean			93.98		93.05		92.44
3-CO-carbofuran	2	1.83	91.50	1.64	82.00	1.64	82.00
,,	4	3.45	86.25	3.45	86.25	3.03	75.75
,,	6	5.23	87.16	4.77	79.50	5.47	91.16
,,	8	6.96	87.00	7.76	97.00	6.96	87.00
,,	10	8.87	88.70	9.16	91.60	8.87	88.70
Mean			88.12		87.27		84.92

Contd..

Appendix I (contd.)

7-phenol	2	1.91	95.50	1.56	78.00	1.73	86.50
,,	4	3.38	84.50	3.61	90.25	3.61	90.25
,,	6	5.75	95.83	5.29	88.17	5.59	93.17
,,	8	7.76	97.00	7.55	94.38	7.35	91.88
,,	10	9.46	94.60	9.19	91.90	9.46	94.60
Mean			93.49		88.54		91.28
3-OH-7-phenol	1	0.80	80.00	0.95	95.00	0.84	84.00
,,	2	1.75	87.50	1.85	92.50	1.70	85.00
,,	3	2.59	86.33	2.88	96.00	2.52	84.00
,,	4	3.70	92.50	3.70	92.50	3.93	98.25
,,	5	4.44	88.80	4.58	91.60	4.58	91.60
Mean			87.03		93.52		88.57
3-CO-7-phenol	2	1.46	73.00	1.68	84.00	1.57	78.50
,,	4	3.04	76.00	3.17	79.25	3.30	82.50
,,	6	4.93	82.16	4.46	74.33	4.77	79.50
,,	8	6.13	76.62	6.31	78.87	6.13	76.62
,,	10	7.92	79.20	7.92	79.20	8.14	81.40
Mean			77.40		79.13		79.70

APPENDIX II

Weather parameters recorded during April 1989 to March 1990 at Pattambi

Year, month and date	Temperature (°C) Maximum	Temperature (°C) Minimum	Relative Humidity(%) Maximum	Relative Humidity(%) Minimum	Sun-shine hours	Rainfall (mm)
1989						
April 2-8	36.4	25.0	84	49	8.7	9.6
9-15	37.6	25.5	83	50	9.1	0.0
16-22	35.0	24.3	88	53	6.5	78.2
23-29	34.8	24.8	84	55	7.5	0.0
30-6 May	35.3	24.7	88	57	9.7	49.0
7-13	34.0	24.4	94	58	8.6	12.0
14-20	34.6	25.3	87	56	8.5	11.0
21-27	33.2	24.4	91	61	5.3	19.6
28-3 June	33.9	24.0	94	50	7.2	16.6
4-10	30.0	22.1	94	78	3.4	217.0
11-17	29.6	22.3	95	78	2.3	183.6
18-24	29.4	22.3	95	80	2.0	312.2
25-1 July	28.9	22.8	95	79	2.9	106.8
2-8	31.2	23.8	94	65	6.7	31.8
9-15	30.2	23.7	91	70	6.3	1.2
16-22	29.2	23.0	95	88	1.1	159.2
23-29	28.1	22.0	94	84	1.4	245.4
30-5 August	30.5	21.2	92	70	8.1	53.4
6-12	29.7	23.0	94	75	5.6	31.8
13-19	28.5	22.6	95	81	3.2	113.4
20-26	29.2	22.6	94	78	5.2	48.6
27-2 Sept.	30.2	22.8	93	69	6.6	23.2
3-9	31.3	22.7	94	70	6.7	12.6
10-16	30.1	22.4	95	73	7.3	69.6

Contd..

Appendix II (contd.)

17-23	30.0	23.4	94	75	3.7	55.6
24-30	29.6	22.9	93	75	3.5	96.6
Oct. 1-7	31.4	22.7	92	69	7.6	15.0
8-14	30.5	23.4	95	73	5.1	66.4
15-21	31.1	23.7	94	74	6.6	56.2
22-28	22.7	22.5	93	69	6.4	33.8
29-4 Nov.	30.8	23.0	94	69	5.2	158.1
5-11	32.7	22.6	89	55	8.7	11.8
12-18	32.6	22.8	88	62	7.0	0.0
19-25	32.4	19.1	90	47	9.6	0.0
26-2 Dec.	32.7	21.6	80	44	10.2	0.0
3-9	33.1	22.5	81	47	9.9	0.0
10-16	32.7	19.5	80	42	8.9	0.0
17-23	23.9	20.1	84	45	9.5	0.0
24-31	33.6	21.0	84	58	8.9	0.0
1990						
January 1-7	32.7	21.4	81	63	7.3	0.0
8-14	32.1	14.6	84	49	6.9	0.0
15-21	34.4	14.8	91	41	10.0	0.0
22-28	34.5	17.4	91	50	10.0	0.0
29-4 Feb.	34.8	16.4	86	48	10.4	0.0
5-11	35.3	18.8	78	36	10.4	0.0
12-18	35.6	19.2	85	37	9.7	0.0
19-25	34.1	15.9	92	41	10.1	0.0
26-4 March	35.7	17.6	86	62	9.1	0.0
5-11	35.8	18.5	92	42	9.5	0.0
12-18	36.3	19.1	90	41	8.6	0.0
19-25	36.7	19.5	89	42	8.5	0.0
26-1 April	36.2	19.6	87	45	9.0	0.0

RESURGENCE POTENTIAL OF THE RICE LEAF FOLDER, *Cnaphalocrocis medinalis* Guen. AS INFLUENCED BY THE SOIL APPLICATION OF CARBOFURAN GRANULES

By

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ABSTRACT OF THESIS

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ABSTRACT

In investigations on the changes taking place in the extent of feeding, growth and development of the rice leaf folder, *Cnaphalocrocis medinalis* Guen. on rice plants receiving soil application of carbofuran granules at 0.50, 0.75 and 1.00 kg ai/ha/application at 20, 50 and 20 and 50 days after transplanting, the extent of larval feeding on leaves did not show any variations as a result of carbofuran treatments. In the third, fourth and fifth larval instars and pupae, carbofuran treatments led to their weight gain due to possible enhancement of the digestibility and more effective conversion of ingested food into body matter, under influence of factors mediated by the metabolites of carbofuran in leaf tissues. In respect of mean larval and pupal mortality, the insecticidal treatments did not show any impact, but the metabolites showed a negative correlation with the mortality levels thereby indicating the favourable influence of the metabolites on the development of *C. medinalis*.

There was improvement in female emergence as a result of treatment with 1.00 kg ai/ha of carbofuran applied at 20 as well as 50 DAT as compared to untreated control, but the sex-ratio variations as a result of treatments were not pronounced. The first instar larval emergence (F_1 generation) showed a positive influence by different metabolites of carbofuran.

Carbofuran treated plants showed distinctly positive orientational stimulus to *C. medinalis* adults due to positive olfactory stimuli probably due to emission of

vapour-phase admixture of carbofuran metabolites, but there was no improvement in fecundity under such treatments. There was distinct improvement in progeny production from females developing from carbofuran treated rice plants. This is mainly due to the ingress of more female moths and the resultant increase in overall ovipositional output rather than increase in fecundity. Carbofuran treatments caused increase in the density of leaf hairs in a dose-dependent manner, but such variations were not significant as compared to untreated control. The positive relationship between ovipositional preference on the one hand and leaf hair density of treated plants on the other brings to focus the role of tactile stimuli provided by leaf hairs in the acceptance of host plants for oviposition.

The residues and metabolites of carbofuran in leaves favourably influenced most of the growth and developmental attributes of the rice leaf folder. None of the plant biochemicals showed any changes under influence of carbofuran treatments.

The results of field experiments conducted during the kharif and rabi seasons were in general conformity to the results generated in the insectary studies. Considerable increase in the damage by C. medinalis was recorded as a result of carbofuran application and it was dose-dependent. Increase in the intensity of damage was found to be due to increase in larval population loads which in turn is the result of ovipositional preference of leaves of carbofuran treated rice plants. Enhanced egg hatching under better mechanical protection provided by the leaf hairs and also due to insecticide-mediated physiological changes in the insect are other factors responsible for increasing the population loads of C. *medinalis*.

In respect of length of leaves and plant height, phytotonic effect due to carbofuran treatments was recorded under insectary conditions but in the field experiments, such effects were obscured by heavy incidence of leaf folder populations.

The residues of carbofuran and its metabolites in the whole grain were below detectable levels, but the residues in straw were detectable but well below the maximum residue limit of 1.00 ppm fixed for rice straw.

The study clearly established the resurgence induction of the leaf folder, C. *medinalis* due to application of carbofuran granules, particularly at 1.00 kg ai/ha/application either at 20 DAT or 50 DAT or at both stages. The implications of the various findings relating to the use of carbofuran granules for rice leaf folder control have been discussed.