PA-ABC-652

IRRI RESEARCH PAPER SERIES

Number 17 May 1978

RESIDUES OF CARBOFURAN APPLIED AS A SYSTEMIC INSECTICIDE IN IRRIGATED WETLAND RICE: IMPLICATIONS FOR INSECT CONTROL

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RESIDUES OF CARBOFURAN APPLIED AS A SYSTEMIC INSECTICIDE IN IRRIGATED WETLAND RICE: IMPLICATIONS FOR INSECT CONTROL[1]

ABSTRACT

The behavior of carbofuran residues in rice plants treated by broadcast, soil incorporation, and root-zone application, and by seedling root-soak and root-coat technique was studied. Placement of insecticide in gelatin capsules in the root zone gave good persistence (about 60 days) and leaf residue (as much as 45 ppm at 10 days after treatment). Among the methods tested it also controlled early season pests best and gave the highest grain yields. Soil incorporation and root-zone placement with a liquid-band applicator was also more efficient than paddy-water broadcast in getting insecticide to the plant; soil incorporation provided slightly longer persistence (60 days) and less insect damage. Soaking seedling roots in carbofuran solution just before transplanting (root soak) gave high residues at 10 days after treatment (DAT) but rapid dissipation and little residue by 20 DAT. Addition of gelatin or perlite sticker to the root-treatment medium (root coat) extended the persistence of 0.2 to 1.0 ppm residues by about 10 days.

Carbofuran applied to a wetland rice crop to function as a systemic insecticide is primarily absorbed through the rice roots and translocated to the leaves. The consistently higher carbofuran residue in the leaves than in the stems and leaf sheaths may partially explain the chemical's greater efficacy in controlling green leafhoppers than in controlling brown planthoppers; the planthoppers congregate and feed at the base of rice tillers whereas leafhoppers feed on the leaves. Carbamate metabolites are formed and localized primarily in the leaves but their residues do not reach more significant levels than those of the parent chemical. No residues of carbofuran or its carbamate metabolites from plants treated by soil incorporation or root-zone placement with the liquid-band applicator exceeded the 0.2-ppm tolerance allowed in whole grains by the United States Environmental Protection Agency standards. Residues above 0.2 ppm were found only in whole grains from plants that received 6 broadcast applications of carbofuran at 14-day intervals throughout the season.

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A lag of as long as 5 days occurs before enough of the carbofuran applied in the soil as gelatin capsules transfers to the leaves to provide adequate control of the brown planthopper. Carbofuran applied as a perlite root-coat treatment kills all insects 1 day after treatment. A treatment sequence including root-soak or root-coat for early protection against virus, and root-zone application at 20 days after transplanting appears best to provide insect control through the first half of the growing season. However, the possible hazards to transplanters handling treated seedlings, the lack of availability of suitable commercial formulations, and the techniques for root-zone application limit the implementation of the sequence. The techniques for applying carbofuran reported here have advantages over paddy-water broadcast because they use less chemical, give improved insect control, and are less likely to harm fish in a paddy or adjacent waterways.

RESIDUES OF CARBOFURAN APPLIED AS A SYSTEMIC INSECTICIDE IN IRRIGATED WETLAND RICE: IMPLICATIONS FOR INSECT CONTROL

The use of systemic insecticides for controlling insect pests in rice has increased recently. In Southeast Asian countries particularly, hand application of such chemicals (usually formulated as granules) is often simpler and safer to carry out, and gives more uniform and longer lasting control than comparable foliage sprays (Pathak and Dyck 1973). Systemic chemicals are primarily absorbed through the plant roots and leaf sheaths and act as stomach poisons, but they may also move by capillary action to act as contact poisons, or, through their vapors, kill insects by fumigation (Koyama 1971; Pathak and Dyck 1973).

In the Philippines, research at the International Rice Research Institute (IRRI) from 1969 to 1977 has shown systemic N-methylcarbamate insecticides, particularly carbofuran, to be effective against such important rice pests as whorl maggot (*Hydrellia philippina)*, Asiatic rice borer *(Chilo suppressalis)*, brown planthopper *(Nilaparvata lugens)*, and green leafhopper *(Nephotettix virescens)*, when applied to the paddy soil or water. Treatments that place carbofuran within or near the root zone of the rice plant favor absorption through the roots, and provide more effective and longer lasting insect control than that obtained with broadcast applications onto paddy water (Aquino and Pathak 1976). An alternate application method, designed primarily to control rice insects for 15 to 20 days after transplanting (DT), involves soaking seedling roots in a solution of carbofuran in water for 12-24 hours before transplanting (Pathak and Dyck 1973). Addition of sticker to the soak solution (root-coat treatment) may prolong residual activity because a reservoir of insecticide coats the seedling roots and remains available for uptake after transplanting.

Root-zone, root-soak, and root-coat treatments are promising advances toward increasing the efficiency of relatively expensive insecticides such as carbofuran. It is estimated that a single gelatin-capsule, root-zone application of carbofuran a few days after transplanting will control normal populations of rice insects as effectively as three of four broadcast applications of the insecticide to the paddy water or five to six foliage spray treatments (Pathak et al 1974). We analyzed carbofuran residues in rice plants to determine the influence of the aforementioned application techniques and their variations. Residues in plant tissues were analyzed and pest damage was observed in conjunction with several greenhouse and field trials at IRRI during 1975-77. The goal was to obtain better understanding of the major factors underlying control of rice insects with the new technology, and to facilitate the technology's incorporation into an efficient pest control program.

GENERAL EXPERIMENTAL PROCEDURES

Individual experiments varied in experimental details, but had certain features in common.

Field experiments

Field experiments were in thoroughly puddled paddies with a 25- x 25-cm plant spacing and an average of 3 seedlings/hill. Treatments were replicated three or four times in randomized block designs with 40-m^2 plots. Fertilization, irrigation, and weed control were according to standard agronomic practices.

Insectary experiments

Three seedlings were maintained under 5 cm of water in 25-cm diameter porcelain pots in an air-conditioned insectary at 27 ± 1°C, 60-70% relative humidity, and a 12-hour photoperiod. When insect mortalities were to be recorded, plants were covered with 10- x 60-cm plastic cylinders with nylon screen windows.

Plant sampling

At least 10 hills were sampled at random from field plots; plants were separated into component parts (leaf blades, leaf sheaths, and stems either together or separated, roots, and grain), which were composited with a Hobart food chopper. The composites were stored at -10°C before extraction of carbofuran residues. Potted plants from insectary experiments were handled similarly.

Determination of insect control

In insectary studies 10 adult brown planthoppers and 10 adult green leafhoppers were placed on treated plants at various days after treatment (DAT); insect mortality was recorded 48 hours after infestation.

In field studies, ratings of damage by the whorl maggot were recorded and counts of the green leafhopper and brown planthopper were made by net sweepings during the first 30 days, and with a D-Vac suction machine in the later stages of plant growth. Stem borer damage was based on percentage of tillers with deadheart; tungro virus incidence was based on the percentage of hills with disease symptoms.

Residue analysis of leaf and stem tissue

The procedures of Aquino and Pathak (1976) and Fullmer (FMC Corporation, Richmond, CA., pers. comm. 1976) were modified and used in residue analysis. Samples (10 g) of composited plant parts were stirred and refluxed with 100 ml of 0.25 N HCl for 1 hour at 100°C. The mixture was cooled for 15 to 30 minutes and combined with 100 ml of additional 0.25 N HCl used to wash the condenser, chilled to 0°C and filtered through glass wool, after which the residue was washed with 10 ml of additional 0.25 N HCl. The filtrate was extracted by shaking it vigorously with 3 x 50 ml of redistilled methylene chloride, using 2-3 ml of a 1% (saturated) solution of sodium lauryl sulfate in water, as necessary, to break emulsions. The combined methylene chloride layers were dried over sodium sulfate and evaporated by concentration on a rotary evaporator to about 5 ml; the remaining solvent was evaporated to a near dryness under vacuum in a nitrogen stream.

When 3-hydroxycarbofuran was to be determined, 25 ml of absolute ethanol and 2 drops of concentrated hydrogen chloride were added to the residue and the resulting solution was refluxed for 45 minutes. That converted 3-hydroxycarbofuran to its ethyl ether derivative. The solution was cooled in an ice water bath and combined with 100 ml of ice water added through the condenser. The combined organic phases were extracted from the solution with 3 x 50 ml redistilled methylene chloride, dried, and evaporated almost to dryness.

The residue was cleaned by column chromatography. A column was prepared by first adding 0.75 g Nuchar-Attaclay (Kensington Scientific) as a slurry in redistilled chloroform, and then 10 g of alumina (Fisher A 540 adsorption grade) deactivated with 5% water and capped with 2 cm sodium sulfate. The column was prewashed with 30 ml chloroform, then the sample was introduced in 10 ml chloroform and eluted with 100 ml chloroform. The eluate was evaporated to near dryness, and the residue was determined by one or both of the following methods.

Direct determination of carbamates by N-selective detector gas chromatography. The residue was constituted to 2 ml in redistilled acetone and determined by a gas chromatograph equipped with an NP-FID detector (Burgett et al 1976) and a 1- x 2-mm glass column packed with 3% Apiezon L on 80/100 mesh chromosorb W HP. Injector, column, and detector temperatures were 200, 165, and 300°C, respectively. Nitrogen carrier gas, hydrogen,and air followed at 20, 30, and 60 ml/minute, respectively.

Determinations of carbamates by electron-capture gas chromatography of their 2,4-dinitrophenyl ether derivatives. The residue was dissolved in 50 ml acetone and 25 ml pH 9.0 aqueous borax buffer. One ml of 1% 1-fluoro-2,4-dinitrobenzene in acetone and several glass beads were added. The solution was heated for 1 hour on a steam bath using a 3-ball Snyder air condenser, after which the solution was cooled to room temperature and 25 ml redistilled hexane was extracted from it. The hexane phase was determined with a Varian Model 2700 gas chromatograph equipped with a ^{63}Ni electron capture detector and a 1.5- x 2-mm column packed with either 5% DC 200 on 80/100 mesh Gas Chrom Q or 1.5% OV 17 on 100/120 mesh Chromosorb G HP. Injector, column, and detector temperatures were 260°, 225° (DC 200), or 250° (OV 17), and 270°C, respectively. Nitrogen carrier gas flowed at 25 ml/minute.

For leaf and stem tissues fortified at 1.0 ppm before acid hydrolysis, recoveries determined through N-selective detector averaged 75% for carbofuran, 65% for 3-ketocarbofuran, and 52% for 3-hydroxycarbofuran; those determined through electron-capture averaged 60, 55, and 32% for the same three compounds.

Typical chromatograms are shown in Figure 1. Interference encountered in occasional samples in one method was usually overcome by use of the other method. Estimated detection limits were 0.1 ppm in the N-selective determination and 0.02 ppm in the electron-capture determination.

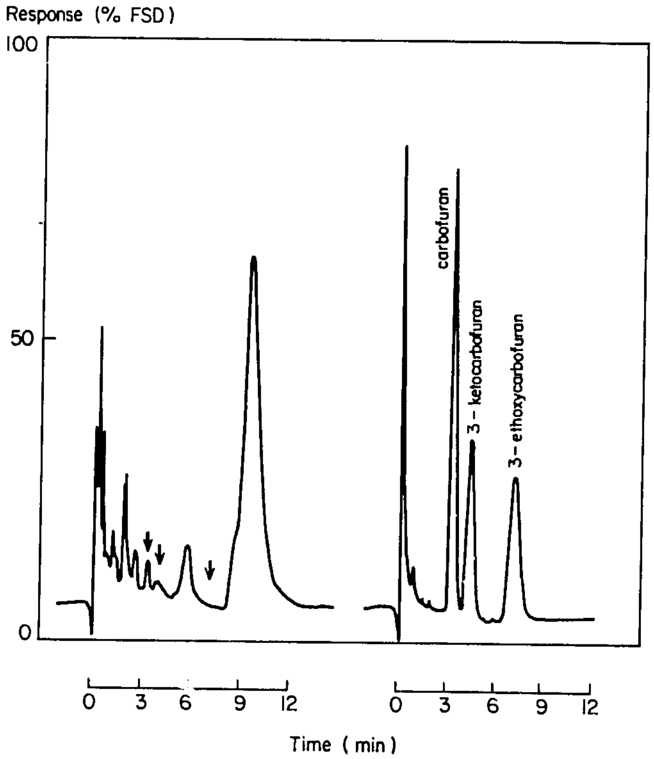


Fig. 1. Gas chromatograms with N-selective detector of (left) untreated rice stem extract, 19 mg of crop equivalent injected, and (right) 10 mg each of carbamate standards. Arrows indicate the retention times of carbamates determined.

Residue analysis of whole grain

Samples (4 g) of finely ground whole grain were stirred and refluxed for 1 hour with 100 ml 0.25 N HCl. The mixture, plus 10 ml hot 0.25 N HCl used to wash the condenser, was slightly cooled and filtered through glass wool. The glass wool containing the residue was slurried with 25 ml hot 0.25 N HCI and filtered again. The slurry-filtration was repeated twice. The combined filtrates were cooled (5°C) for 1 hour, saturated with sodium chloride to which 0.75 ml saturated sodium lauryl sulfate solution (1%) had been added, and extracted with 3 x 50 ml methylene chloride. The filtrates were shaken vigorously during extraction. The combined methylene chloride layers were dried over sodium sulfate and evaporated, first to 5 ml on the rotary evaporator and then to 2 ml under a nitrogen stream. The solution was constituted in benzene by adding 5 ml benzene and concentrating to 2 ml.

The residue was cleaned by adsorption chromatography using a 1-cm diameter column plugged with glass wool. The column was packed, first with 2 g acid Woelm alumina (W 202 Grade I) deactivated with 3% water, then with 1 g Analabs Nuchar-Attaclay; the latter was added as a slurry in about 20 ml hexane while applying a mild vacuum. The column was capped with 2 cm sodium sulfate. The sample was added to the column along with 2 x 2 ml benzene used to wash the sample container. The hexane-benzene effluents were discarded. The column was eluted with 30 ml ethyl acetate. The ethyl acetate solution was concentrated to 1.0 or 0.5 ml under nitrogen gas. The N-selective gas chromatographic technique described in the previous section was used, except that, in this case, 3-hydroxycarbofuran was determined directly, not as its ethyl ether derivative. Recoveries for the whole grain, spiked just before hydrolysis, were: 91% for carbofuran, 92% for 3-ketocarbofuran, and 97% for 3-hydroxycarbofuran at 0.2 ppm.

CARBOFURAN TREATMENT METHODS AND RESULTING RESIDUES

Residues from three basic treatment methods were studied -- root-zone, paddy water broadcast, and soil incorporation.

Root-zone soil treatments

Liquid and granular manual applicators were tested as alternatives to the highly effective but time-consuming gelatin capsule root-zone treatment.

Liquid-band applicator. A two-row, push-type, liquid-band applicator delivered a suspension of carbofuran (2,2-dimethyl-2, 3 dihydrobenzofuranyl-7 N methyl-carbamate) flowable (20.3% active ingredient in water from a back-mounted reservoir (by gravity) through tubes mounted on a skid. A flow-metering orifice in a flexible connecting tube maintained the desired rate of application. The formulation was laid in a band between 3 and 5 cm below the soil surface and about 6 cm from the plants.

Granular applicator. In a separate field test, the granular root-zone applicator treatment was compared with the paddy water broadcast treatment. A push-type applicator with a rotary, fluted, feed mechanism was used to place carbofuran granules in a band 8 to 10 cm deep in furrows between rows (10 to 12 cm from plants in the rows) at 1 kg active ingredient/ha.

Gelatin capsules. Carbofuran 3G granules in gelatin capsules were placed 2 to 3 cm below the soil surface and 2 to 3 cm laterally from each hill.

In one field experiment carbofuran was applied at two rates (0.5 and 2 kg active ingredient/ha) in gelatin capsules and with a liquid-band applicator. Residues of carbofuran in the leaves and stems in the capsule treatment averaged 5 to 10 times higher than those in the liquid-band applicator treatment (Table 1). That was expected because the band applicator puts the insecticide in a continuous band adjacent to hills in a row. The capsule

Table 1. Residues of carbofuran and 3-hydroxycarbofuran (in parentheses) in leaves and leaf sheaths of IR20 plants that received carbofuran by gelatin capsule and liquid-band applicator root-zone treatments. IRRI, 1976 wet season.

Treatment[a]	Rate (kg a.i./ha)	Residue[b] (ppm) at 10 DT		21 DT		30 DT		39 DT		50 DT	
		Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Gel capsule	2.0	44.4 (5.4)	2.53 (0)	34.5 (4.8)	0.25 (0)	7.4 (0.34)	0.89 (0)	2.2 (0.22)	0.49 (0)	0.56 (0.15)	n.a. (n.a.)
Liquid applicator	2.0	10.3 (1.2)	0.63 (0)	5.3 (0.62)	0.27 (0)	0.81 (0.07)	0.085 (0)	0.51 (0.10)	n.a. (n.a.)	0.12 (0)	n.a. (n.a.)
Gel capsule	0.5	19.7 (0.54)	1.30 (0)	6.9 (0.60)	0.27 (0)	0.49 (0.10)	0.067 (0)	0.10 (0)	n.a. (n.a.)	0.23 (0)	n.a. (n.a.)
Liquid applicator	0.5	2.7 (0)	0.22 (0)	0.47 (0)	0.44 (0)	0 (0)	0 (0)	0 (0)	n.a. (n.a.)	0 0	n.a. (n.a.)

[a]Insecticide applied once at 5 days after transplanting (DT). Control values were 0.3 ppm for all sampling dates. [b](0) = <0.1 ppm. n.a. = not analyzed.

concentrates the insecticide at each hill. There was, however, no statistical difference in insect damage between the two treatments at 2 kg active ingredient /ha, and only small differences at 0.5 kg/ha (Table 2). All four treatments gave significantly less insect damage and higher yields than the controls. Highest yield resulted from the gelatin capsules at 2 kg active ingredient/ha.

Soil incorporation

Carbofuran granules were broadcast by hand after the last harrowing and incorporated into puddled soil with a power tiller 1 day before transplanting. In insect control and grain yield soil incorporation was among the best of several application methods tested in the field (Table 3). At 1 kg active ingredient/ha, carbofuran incorporated into the soil provided better control of whorl maggot, stem borer, tungro virus, and brown planthopper than it did when applied with the liquid-band applicator at a similar rate. Pest control from soil incorporation was generally superior to that from repeat broadcast applications to the paddy water -- even when the latter treatment used 2 kg active ingredient/ha -- and far surpassed results from repeated foliar sprays with carbofuran, decamethrin (Decis), or methyl parathion.

Paddy water broadcast treatment

Carbofuran granules (3% active ingredient) were broadcast by hand into paddy water.

Leaf and stem residues in plants that received the broadcast treatment were higher at the first sampling (10 DAT) than at the second (20 DAT), but residues in plants that received the granular root-zone application were considerably higher at 20 and 30 DAT (Fig. 2). The lag before the attainment of maximum foliage residues in the granular applicator treatment resembled that previously reported for leaves and stems of plants treated by soil incorporation with carbofuran (Aquino and Pathak 1976). The broadcast treatment in this experiment controlled the whorl maggot at 10 DAT; at 30 DAT, however, the granular applicator treatment provided better control.

Residue distribution

When a liquid formulation of carbofuran was injected directly into the root zone of 45-day-old plants in the greenhouse, the insecticide was efficiently transferred to the leaves within 2 days (Table 4). Moreover, there was about three times more carbofuran in the leaves of plants after the liquid injection than in the plants treated at the same rate by paddy water broadcast of granules. As liquid injection in the root zone is unlikely to transfer residue to the leaves by fumigation or any mechanism other than uptake through the roots, entry through the roots must be a highly efficient means of carbofuran movement to the leaves.

Table 2. Insect control and yields[a] of variety IR20 in carbofuran root-zone treatments using gelatin capsules and a liquid-band applicator. IRRI, 1976 wet season.

Treatment[b]	Rate (kg a.i./ha)	Whorl maggot damage 27 DT	Insects (no./10 sweeps) Brown planthopper 36 DT	45 DT	Green leafhopper 36 DT	45 DT	Tungro virus (%) 99 DT	Deadheart (%) 67 DT	Yield (t/ha)
Gel capsule	2.0	0 a	9 a	1 a	0 a	0 a	4 a	0.3 a	3.0 d
Liquid applicator	2.0	0 a	8 a	6 a	1 a	0 a	7 a	0.7 ab	2.6 c
Gel capsule	0.5	0 a	13 ab	34 b	1 a	1 a	5 a	1.3 bc	2.5 bc
Liquid applicator	0.5	3 b	32 b	71 b	7 b	1 a	15 b	1.1 bc	2.2 b
Control		9 c	59 c	302 c	80 c	43 b	38 c	2.1 c	1.3 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level.
[b]Insecticide applied once at 5 days after transplanting (DT). [c]Based on a scale of 0-9; 0 = no damage and 9 = more than 50% of leaves damaged.

Table 3. Effects of soil incorporation, liquid-band application in the root zone, and paddy water broadcast of carbofuran, and foliar sprays with decamethrin, methyl parathion, and carbofuran on insect control and yields[a] of variety IR22. IRRI, 1976 wet season.

Treatment[b]	Whorl maggot[c] damage 20 DT[d]	Whorl maggot[c] damage 29 DT	Dead hearts[e] (%) 60 DT	Tungro virus[f] (%) 60 DT	Brown planthoppers[g] 61 DT	Brown planthoppers[g] 78 DT	Predators (no./10 m) *Cyrtorhinus lividipennis* 78 DT	Predators (no./10 m) Spiders 78 DT	Hopperburn (%) 92 DT	Grain yield (t/ha)
1.0 kg C (SI) 1x	1 a	1 ab	1.5 bc	0 a	135 a	1584 a	1 ab	69 a	14 ab	3.7 a
2.0 kg C (SI) 1x	1 a	0 a	0.6 a	0 a	143 a	2329 a	1 ab	58 a	16 ab	3.6 a
1.0 kg C (RZ) 1x	4 bc	3 c	2.0 c	0 a	189 a	3461 a	5 bcd	54 a	0 a	3.2 a
2.0 kg C (RZ) 1x	3 b	2 b	0.7 ab	1 ab	245 a	2802 a	4 bc	52 a	21 ab	3.5 a
1.0 kg C (B_{14}) 6x	5 c	4 cd	1.0 ab	1 ab	292 a	5097 ab	0 a	76 a	13 ab	3.5 a
1.0 kg C (B_{20}) 4x	5 c	5 d	0.8 ab	1 ab	261 a	1744 a	1 ab	45 a	4 a	3.3 a
2.0 kg C (B_{20}) 4x	4 bc	4 cd	0.5 a	1 ab	181 a	3500 a	1 ab	51 a	25 ab	3.5 a
0.05 kg Decamethrin (F_{14}) 6x	5 c	4 cd	0.7 ab	1 ab	2494 b	78908 c	1 ab	83 a	100 c	1.5 c
0.75 kg methyl parathion (F_{20}) 4 x	7 d	8 e	0.9 ab	2 b	349 a	22276 bc	17 d	91 a	51 b	2.3 b
0.50 kg C (F_{20}) 4x	6 d	7 e	1.2 abc	1 ab	1228 b	29964 c	16 cd	75 a	97 c	1.9 bc
Control	9 e	9 f	4.9 d	13 c	264 a	4812 ab	16 cd	60 a	8 ab	1.7 c

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]C = carbofuran, SI = soil incorporation, RZ = root-zone application with liquid-band applicator, B_{14} = broadcast every 14 days, B_{20} = broadcast every 20 days, F_{14} = foliar application every 14 days, F_{20} = foliar application every 20 days. [c]*Hydrellia philippina*. Based on a scale of 0 to 9; 0 = no damage; 9 = more than 50% of leaves damaged. [d]DT = days after transplanting. [e]Percentage of tillers attacked by stem borer. [f]Percentage of hills showing disease symptoms. [g]Collected with D-Vac suction machine per 10 linear meters of row sampled.

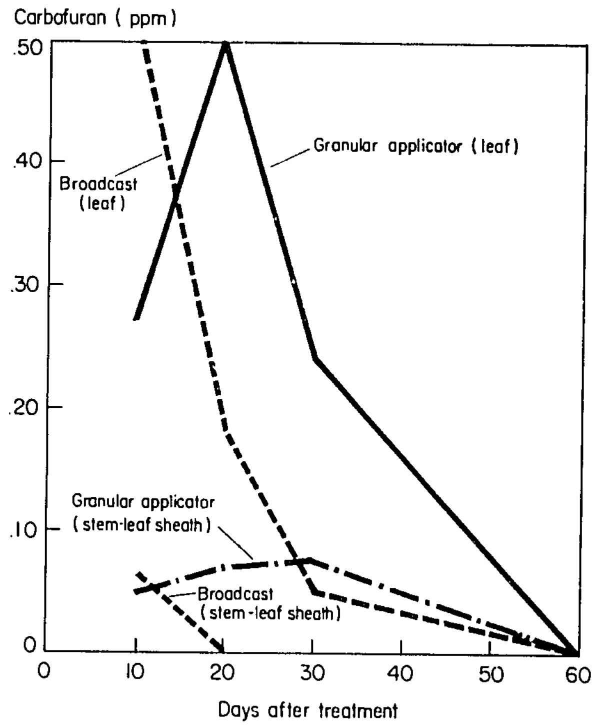


Fig. 2. Granular application for root zone treatment and paddy water broadcast of carbofuran, both at 1 kg/ha at 3 days after transplanting. Residues in leaves and stems are averages of five varieties (TN1, IR28, IR30, IR32, and IR34). IRRI, 1975 wet season.

Table 4. Paddy water broadcast *vs* liquid injection. Residues in leaves and stems of 45-day-old TN1 seedlings sampled 2 days after treatment. IRRI greenhouse, 1977.

Treatment	Rate (kg a.i./ha)	Residue[a] (ppm) Carbofuran	3-keto-carbofuran	3 hydroxy-carbofuran
Leaves				
Control	0.0	0.0	0.0	0.0
Paddy water broadcast	0.5	4.3	0.5	0.5
Paddy water broadcast	2.0	12.1	2.6	2.0
Paddy water broadcast	6.0	55.3	4.1	4.8
Liquid injection	2.0	37.2	6.7	4.8
Stem - leaf sheaths				
Control	0.0	0.0	0	0
Paddy water broadcast	0.5	0.8	0	0
Paddy water broadcast	2.0	2.2	0	0
Paddy water broadcast	6.0	9.2	0	0
Liquid injection	2.0	2.9	0	0

[a]0 = <0.5 ppm.

In the three experiments discussed above, and in one reported previously (Aquino and Pathak 1976), leaves of plants that received systemic application had considerably higher carbofuran residues than the stems. Leaf-to-stem residue ratios calculated 10 DAT averaged 9. Stems apparently serve primarily as a conduit for carbofuran transfer, rather than as a site for localization of the chemical. That may explain the better control of leaf-feeding insects than of stem and leaf sheath feeders consistently observed in plants receiving the systemic treatments.

The ability of carbofuran to translocate was checked in 35-day-old rice plants treated in the greenhouse by root-zone injection and foliar sprays directed at either the leaves or the stems (Table 5). For the root-zone treatment with liquid injection, a hypodermic syringe was used to inject a water suspension of 20.3% flowable carbofuran directly in the plant's root zone. For the foliage spray treatment, 20.3% flowable carbofuran or 16.8% EC monocrotophos was diluted in water and sprayed at 2 kg active ingredient/ha until it almost ran off either the leaf or leaf sheaths. Nontarget plant parts were protected by a plastic film.

The order of residue distribution in the rice plant (on a ppm basis) following the root-zone treatment was leaves > leaf sheaths > stems > roots. Spray application to the leaves gave little downward movement to the sheaths, stems, and roots, but spray application to the stems gave considerable upward movement to the leaves. This result agrees with Bowling's (1970) results which he based on insect mortality determined after the carbofuran was locally applied to the stems of rice plants. It is also similar to the translocation behavior we noted for monocrotophos, a systemic organophosphate. Monocrotophos was, however, less persistent than carbofuran, and less effectively controlled brown planthoppers (Fig. 3).

Table 5. Translocation of carbofuran in rice treated by root, systemic, and topical applications. Residues of carbofuran in plant parts. Variety TN1. IRRI greenhouse, 1977.

Treatment[a]	Residue of parent insecticide[b] (ppm)					
	3 DAT			23 DAT		
	Leaf	Leaf sheath	Stem	Leaf	Leaf sheath	Stem
Root zone injection	11.5	3.8	1.8	5.2	5.0	0.4
Spray on leaves	608	52.4	11.5	210	6.0	1.2
Spray on stems	26	33.0	4.7	11.2	63.3	3.1

[a]All treatments were applied at 2 kg active ingredient/ha on 35-day-old plants. Foliar sprays were directed at indicated part of plant and nontarget parts were covered with plastic film. Leaf sheaths were on the stem during spraying, but were removed before analysis. [b]Residues in roots were 1.0 ppm for all three treatments at both sampling intervals. DAT = days after treatment.

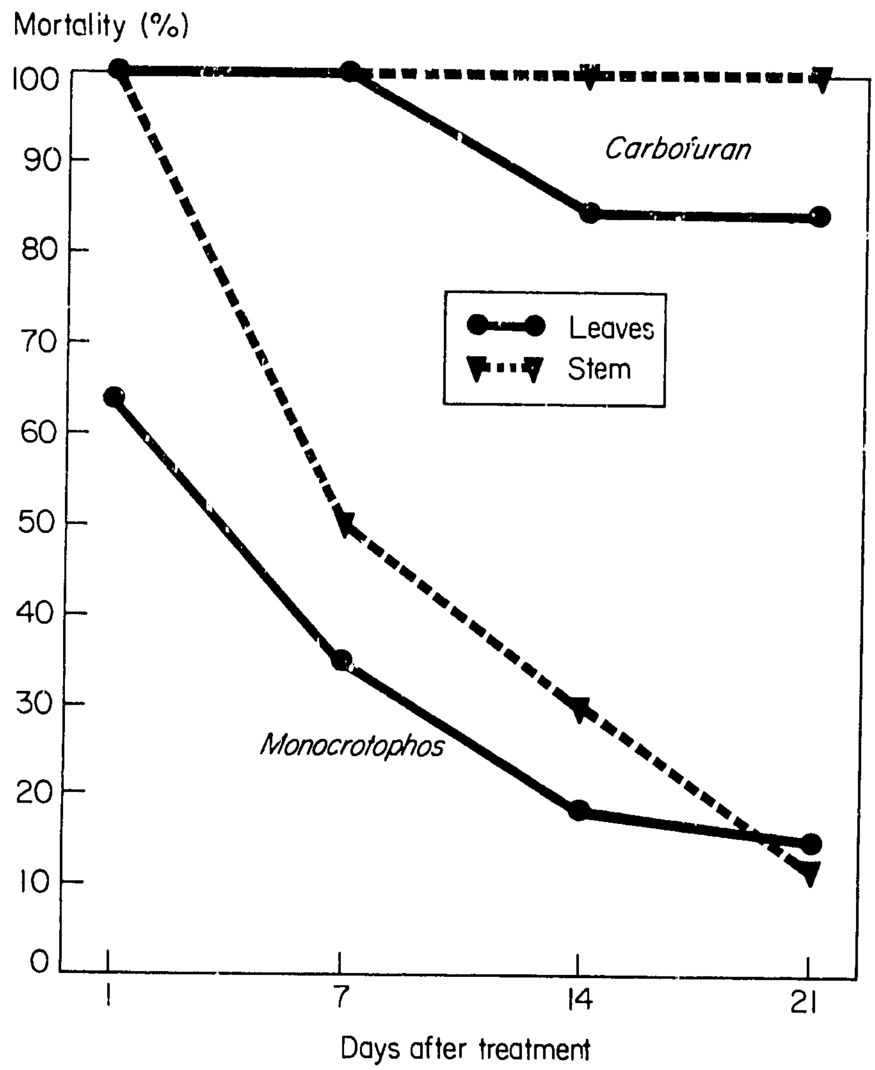


Fig. 3. Mortality of the brown planthopper adults at various days after treatment of rice plants with carbofuran and monocrotophos sprays directed at the stem and leaf portion of the plant. IRRI, 1977.

Residues of carbofuran and its principal metabolite, 3-hydroxy-carbofuran, were analyzed in whole grain following:

- soil incorporation,
- root-zone placement with the liquid-band applicator,
- paddy water broadcast, and
- foliar spray.

Only in the broadcast applications did residues exceed the background level observed for control rice plants (0.06 ppm) (Table 6). The highest residues were in grain from plants treated six times at 14-day intervals; in fact, the combined uncorrected residues of carbofuran and 3-hydroxycarbofuran, the chemicals on which the U.S. Environmental Protection Agency (EPA) tolerance of 0.20 ppm is based, were 0.46 ppm for this treatment. In the grain from

Table 6. Residues of carbofuran and 3-hydroxycarbofuran in whole grain of rice plants treated by different application techniques. IR22. IRRI, wet season 1976-77.

Treatment[a]	Residues[b] (ppm)		
	Rate[c] (kg a.i./ha)	Carbofuran	3 hydroxy-carbofuran
Soil incorporation	1.0	0.08	0.06
Root zone with liquid-band applicator	1.0	0.08	0.02
Broadcast at 14-day intervals 6 times	1.0	0.34	0.12
Broadcast at 20-day intervals 4 times	1.0	0.11	0.05
Foliar spray at 20-day intervals 4 times	0.5	0.04	<0.02
Control		0.06	<0.02

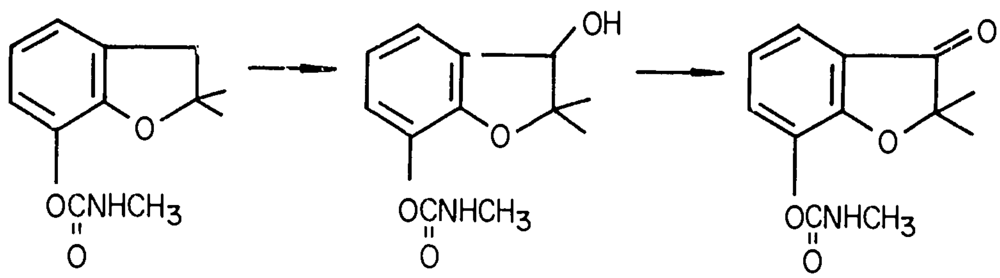
[a]The broadcast and foliar spray applications were begun 5 days after transplanting. Flowering occurred at 70-80 days after transplanting; thus one application in both broadcast treatments and the foliar spray treatment occurred during flowering. [b]Values were not corrected for percentage recoveries, which were 91 and 97% for carbofuran and 3-hydroxycarbofuran, respectively. [c]Refers to amount of insecticide per application. a.i. = active ingredient.

rice treated four times at 20-day intervals, the combined uncorrected residue was 0.16 ppm. Residues in grain from plots treated by soil incorporation, root zone, and foliar spray were negligible. Carbofuran thus undergoes appreciable translocation to rice grain only after frequent or high-dosage applications that continue well into the second half of the growing season. This observation agrees with observations made on corn, in whose grain negligible residues were found when carbofuran was applied to the soil at high rates early in the growing season (Caro et al 1973).

Metabolites

We observed that 3-hydroxycarbofuran and 3-ketocarbofuran, the two principal metabolites of carbofuran, are formed shortly after treatment with the parent compound, and are principally localized in the leaves (Table 4).

Metabolic side-chain oxidation of carbofuran thus occurs in rice leaves, as



Carbofuran 3-hydroxy metabolite 3-keto metabolite

reported previously for corn leaves, cotton leaves, and intact cotton plants (Metcalf et al 1968). But in corn, 3-hydroxycarbofuran was the principal carbamate residue, at the immature silage stage and at harvest, from either soil incorporation or root-zone band placement (Caro et al 1973). The ratio of carbofuran to 3-hydroxycarbofuran in leaves was no greater at 10 DAT than at 39 DAT after the root-zone treatment with 2 kg carbofuran/ha in gelatin capsules (Table 1). It appears that while metabolism of carbofuran follows a similar course in corn and rice, in rice the concentration of metabolites is not related to that of the parent as it is in corn.

Effect of fertilizer and herbicide

Because of the increased efficiency of fertilizer applied in the root zone (IRRI 1974), it may be desirable to apply fertilizer simultaneously with insecticide. Nitrogen fertilizer at 60 kg N/ha and 20.3% flowable carbofuran at 1 kg active ingredient/ha were mixed in 516 liters water to treat 1 ha. The pest control, yield, and leaf residues that resulted when the solution was applied to the root zone with a liquid band applicator were not significantly lower than those that resulted from applying carbofuran and fertilizer separately (Table 7). This was true for both urea and ammonium sulfate. It was noted, however, that leaves sampled at 20 and 40 DAT had higher residues when the fertilizer applied was ammonium sulfate than when it was urea. Prolonged contact with urea, which is basic, may cause more rapid hydrolysis of residual carbofuran in the soil than prolonged contact with ammonium sulfate, which renders soils slightly acidic after treatment. The same experiment showed that 2,4-D herbicide could be added to the root-zone liquid formulation with no adverse effect on insect control, yield, or carbofuran leaf residue.

Table 7. The effectiveness against the green leafhopper *Nephottetix virescens* of carbofuran when mixed with nitrogen fertilizer and herbicide applied simultaneously in the root zone or separately as a broadcast application.[a] Variety 22. IRRI, 1976 dry season.

Treatment[b]	Green leafhoppers (no./10 sweeps) 41 DT	Virus (%) 113 DT	Weeds (no./m²) 30 DT	Yield (t/ha)
Carbofuran (RZ) urea (RZ)	2 a	8 a	10 cde	4.1 a
Carbofuran (RZ) + urea (B)	2 a	6 a	22 de	3.7 a
Carbofuran (RZ) + urea (RZ) + 2,4-D (RZ)	0 a	7 a	4 bcd	4.1 a
Carbofuran (RZ) + urea (RZ) + 2,4-D (B)	1 a	6 a	0 a	4.0 a
Control /urea (RZ)/	65 b	62 b	9 bcde	0.6 b

[a]In a column, all means followed by a common letter are not significantly different at the 5% level. [b]All treatments: root-zone (RZ) and broadcast (B) were applied at 3 days after transplanting (DT). Carbofuran was applied at 1 kg a.i./ha, urea at 60 kg N, and 2,4-D at 0.8 kg.

Effect of mechanical weeding

In a separate experiment, the effect of weeding by hand and with the rotary weeder on root-zone applied carbofuran was studied to determine whether weeding decreased degree of insect control by bringing the insecticide from the root zone to the soil surface. It was determined that use of the rotary weeder did not interfere with uptake of carbofuran applied to the root zone with the liquid-band applicator (Table 8). There was no statistical difference in carbofuran residues among plant leaves when weeding was done with the rotary weeder or by hand after insecticide application.

Seedling root treatments

Soaking rice seedlings for as long as 24 hours in a 1,300-ppm solution of carbofuran in water rendered the plants toxic to green leafhoppers and brown planthoppers for as long as 50 DT in an air-conditioned greenhouse (IRRI, 1971). The effects of this root-soak treatment were, however, greatly reduced and quite erratic when it was tried with transplants in the field. An alternate treatment, in which seedling roots were dipped in carbofuran solution containing methyl cellulose or flour (root coat), improved residual toxicity (IRRI 1972). In the field, both root-soak and root-coat treatments effectively controlled green leafhoppers for 10 DT, but beyond that period the root-soak treatment

Table 8. Effect of hand and rotary weeding on the effectiveness of carbofuran applied in the root zone of rice plants at 0.5 kg active ingredient/ha. IRRI, 1976.

Treatment[a]	Whorl maggot[b] 27 DT	Deadhearts (%) 46 DT	Grain yield (t/ha)
1.0 kg carbofuran + RW 1x	4 a	0.7 a	3.6 ab
1.0 kg carbofuran + RW 2x	5 a	0.7 a	3.5 ab
1.0 kg carbofuran + HW 1x	4 a	0.5 a	3.8 a
No insecticide + RW 1x	9 b	1.8 b	3.1 bc
No insecticide + RW 2x	9 b	1.6 b	2.9 c
No insecticide + HW 1x	9 b	1.8 b	3.4 abc

[a]RW = rotary weeding; HW = hand weeding. The first rotary weeding and hand weeding were done at 14 days after transplanting (DT) and the second rotary weeding at 22 DT. [b]Based on a scale 0-9. 0 = no damage; 9 = more than 50% of leaves damaged.

was only half as effective, or less effective, than the root-coat treatment. Gelatin was by far the best root-coat treatment (IRRI 1975); seedlings dipped in a gel containing carbofuran equivalent to a rate of 2 kg/ha were protected against tungro virus.

Root soak and gelatin root coat. The effects of several control measures, including root-soak and root-coat, on plant residues and insect control were compared in a field experiment. In the seedling root-soak, seedlings were placed in galvanized trays containing a solution of 1,000 ppm carbofuran in water. A solution of 740 ml of carbofuran (20.3% flowable) in 150 liters of water was sufficient to treat seedlings for planting 1 ha. In seedling root-coat with gelatin, a gel was made by mixing 5 parts gelatin and 12 parts carbofuran (20.3% flowable) in 83 parts water. Roots of seedlings were dipped for 10-20 minutes just before transplanting. The highest early leaf residues at 10 DAT were from the gelatin root-coat and the overnight seedling root-soak treatments (Table 9). Residues from the root-coat treatment were more persistent than those from the root-soak; they lasted through at least 20 DAT. In fact, residues from the root-coated plants were higher at 20 DAT than those from broadcast, liquid root-zone, and seedling-soak treatments.

The residue data matched biological observations (Table 10). Seedling root coat gave the best control of whorl maggot at 20 DAT and was among the best treatments.

Table 9. Seedling root soak and root coat treatments. Carbofuran residues in leaves. Variety IR22, IRRI, 1976 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Leaf residue (ppm) after 10 days	20 days	40 days	60 days
Broadcast at 5 DAT	1	0.61	0.03	0.02	trace[c]
Seedling root soak + broadcast at 20 DT	0.15+0.50	33.79	0.16	0.02	trace
Root coat with gelatin	1	73.17	1.01	0.02	trace
Root zone at 5 DT	1	0.99	0.23	0.04	trace
Control	–	0.13	trace	trace	trace

[a]DT = days after transplanting. [b]a.i. = active ingredient. [c]Trace = 0.02 ppm.

Perlite root-coat. Both the root-soak and the root-coat treatments require an extra operation for the grower. The root-coat gelatin mixture is difficult to prepare and somewhat expensive. We investigated an alternate seedling treatment with the advantage of compatibility with seedbed technology at no extra labor.

A root-coat medium consisting of a suspension of 5 g perlite (SiO_2, 73%; Al_2O_3, 15%, Na_2O, 4%; K_2O, 4%; Fe, Ca, and Mg oxides, 2%) (Sun Chemical 1976) and 0.5 ml of carbofuran (20.3% flowable) in 100 ml of water was used as a soak for seedlings for 16 hours before transplanting in the greenhouse. Much of the insoluble perlite coated the roots and served as a carbofuran reservoir after transplanting. The perlite root-coated seedlings gave 100% mortality of brown planthoppers immediately after transplanting (Fig. 4) and controlled brown planthoppers for 30 days. In comparison a gelatin-capsule root-zone treatment at a much higher carbofuran rate (2 kg/ha *vs* 0.15 kg/ha for the perlite root coat) took about 5 days to kill all insects but its effect persisted through almost 50 DT.

The carbofuran residues in leaves of the gelatin-capsule-treated plants remained high at 50 DT while those from the perlite root coat treated plants declined to 10% of the values measured at 20 DT (Table 11). Residues in the stems were much lower than those in the leaves, but followed the same trend. A somewhat striking additional observation was made 50 DT; plants receiving the perlite treatment weighed twice as much as those treated with gelatin capsules. Perlite may be beneficial for plant growth and development.

Table 10. Effect of eight insecticide application techniques on insect control and yield of variety IR22.[a] IRRI, 1976 dry season.

Treatment (carbofuran)	Whorl maggot damage[b]		Green leafhoppers (no./10 sweeps)		Virus (%)	Yield[c] (t/ha)	Increased income[d] (US$)
	20 DAT	30 DAT	20 DAT	30 DAT	98 DAT		
1 kg broadcast 1 x	6 c	7 d	7 bc	4 bc	5 a	2.5 d	103
1 kg root zone 1 x	3 b	3 a	1 a	0 a	1 a	2.5 cd	90
1 kg broadcast 4 x	7 c	5 bc	4 abc	0 a	3 a	2.9 ab	76
0.25 kg root zone 4 x	6 c	5 bc	3 ab	1 ab	1 a	2.9 ab	142
0.5 kg root zone 2 x	5 c	3 a	2 a	0 a	1 a	2.8 abc	157
Seedling soak + 0.5 kg broadcast (20 DAT)[b]	5 c	6 cd	9 c	2 ab	4 a	2.6 bcd	133
Seedling soak + 0.5 kg root zone at 5 DAT	5 c	6 cd	5 d	0 a	2 a	2.6 bcd	120
1 kg root coat	1 a	4 ab	2 a	1 ab	2 a	3.1 a	171
Untreated control	9 d	9 e	9 c	6 c	44 b	1.5 e	

[a]In a column, means followed by the same letter are not significantly different at the 5% level. DAT = days after treatment. [b]Based on a rating of 0-9; 0 = no damage and 9 = more than 50% leaves damaged. [c]Typhoon occurred during early flowering stage. [d]Increased income due to insect control = (value of insecticide treatment as based on yield at a value of US$0.136/kg - value of untreated control) - cost of insect control.

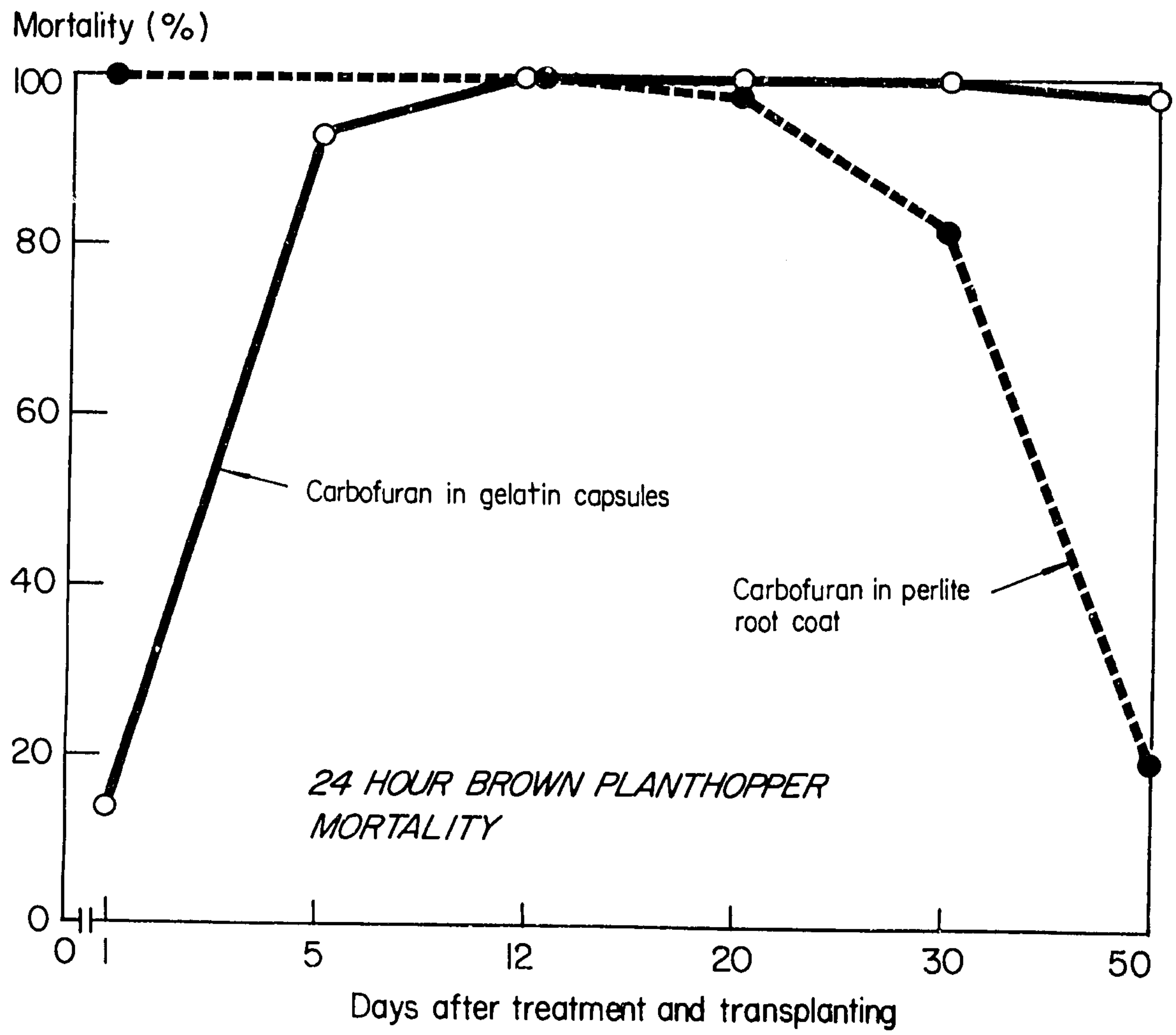


Fig. 4. Gelatin-capsule root-zone and perlite root-coat treatments. Percent mortality of brown planthopper caged on rice plants treated with gelatin capsules in the root zone (2 kg active ingredient carbofuran/ha) and those soaked for 16 hours in a perlite root-coat mixture (0.15 kg active ingredient carbofuran/ha) prior to transplanting. IRRI greenhouse, 1977.

The results with perlite were encouraging, considering the low rate of carbofuran employed. In a field experiment, seedlings treated with perlite root coat (0.15 kg/ha or 1,000 ppm) were protected against green leafhoppers for less than 10 days. Results indicated the need for a higher rate.

In another field experiment a modification of the above perlite root coat -- termed the perlite-dapog root coat -- was tested at the rate of 0.5 kg active ingredient carbofuran/ha. Two hundred liters (dry measure) of perlite was distributed evenly on a concrete surface and moistened with water. Rice seeds (30 kg) were spread on top of the perlite and covered with an additional 100 liters of perlite. The seedbed was watered twice daily. After 14 days a carbofuran (flowable) solution of 0.5 kg active ingredient in 180 liters of water was used to thoroughly wet the bed.

Seedlings were removed from the seedbed and transplanted 15 days after sowing. Results indicated residues of carbofuran in the leaves were quite high at 4 (530 ppm) and 10 (185 ppm) DT, and remained at significant levels (0.95 ppm) at 20 days. Whorl maggot and tungro virus damage was low throughout the season in both treated and control plots. The efficacy of this treatment remains to be compared with that of other treatments under similar conditions.

Table 11. Effect of gelatin capsule root-zone treatment applied at 2.0 kg a.i./ha and perlite root coat treatment applied at 0.15 kg a.i./ha on residues of carbofuran and its metabolites in leaves and stems[a] of TN1, IRRI greenhouse, 1977.

Treatment	Rate (kg a.i./ha)	Residue[b] (ppm)					
		Carbofuran		3-keto carbofuran		3 hydroxy-carbofuran	
		20 DAT	50 DAT	20 DAT	50 DAT	20 DAT	50 DAT
Leaves							
Gelatin capsules	2.00	120	297	6.1	36	9.8	49
Perlite root coat	0.15	266	30	0[c]	4.4	6.4	7.8
Stems							
Gelatin capsules		5.4	9.3	0[c]	1.2	0[c]	2.1
Perlite root coat		1.2	0.5	0[c]	0.1	0[c]	0.3

[a]Stems include both stems and leaf sheaths. Treatments are the same as those noted in Figure 4. [b]DAT = days after treatment. [c]Less than 0.3 ppm.

DISCUSSION

The experiments described have furnished data on insecticide residues and insect control that are useful for evaluating alternative methods of carbofuran application. Figure 5 summarizes information on carbofuran residues in leaves expected from different treatments. In the following discussion we assumed that at least 0.2 ppm of carbofuran is needed to provide significant insect control and that control is primarily directed at pests encountered during the first half of the growing season.

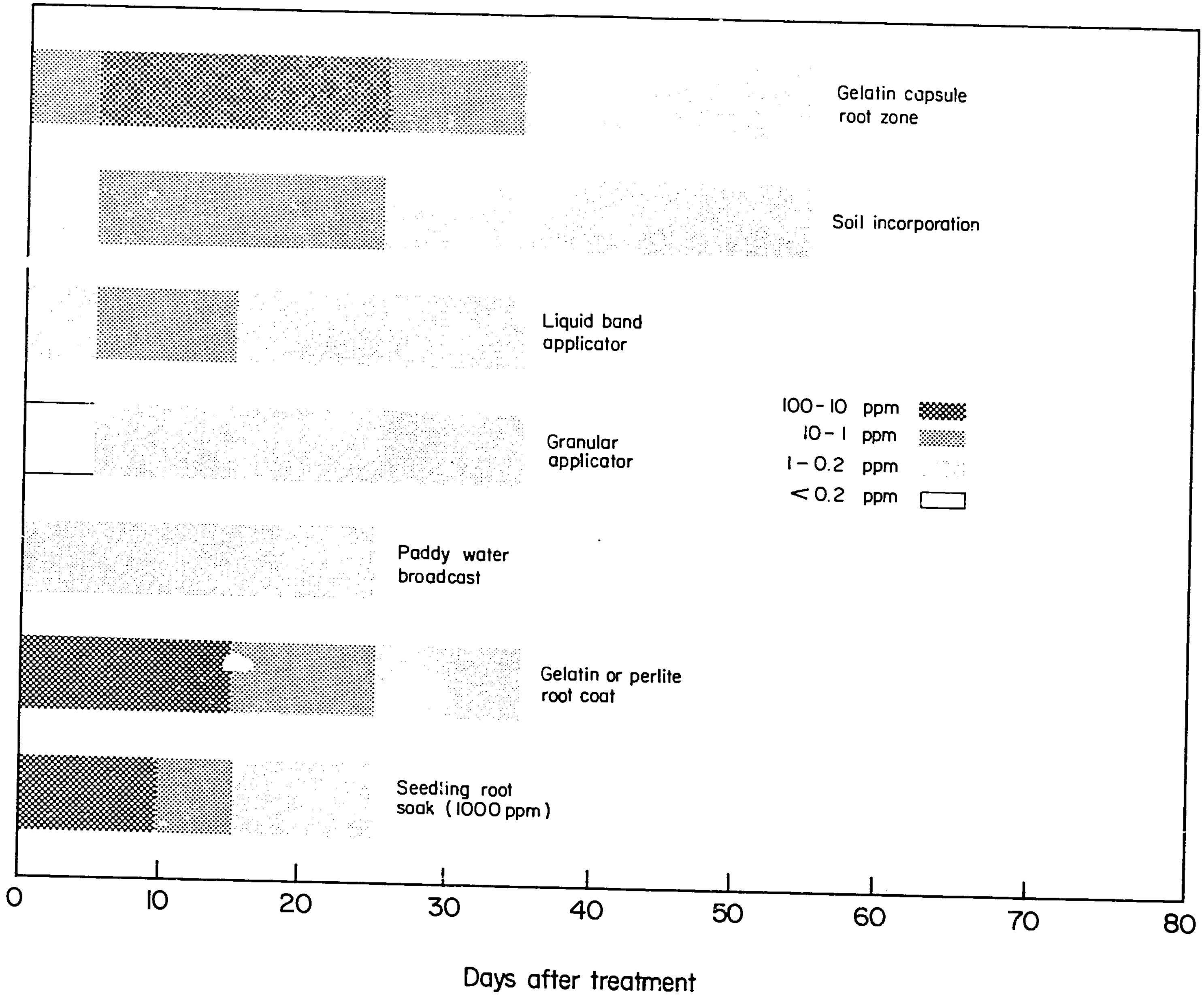


Fig. 5. Magnitude and duration of leaf residues of carbofuran from different treatments. Figures are estimates based on available residue data from rice treated in the field with 1 kg active ingredient/ha, except for seedling root-soak (0.15 kg active ingredient/ha). IRRI greenhouse, 1977.

The gelatin-capsule, root-zone treatment just after transplanting couples excellent carbofuran persistence (50 to 60 days) with high carbofuran content in plant in the 30-40 DT. During this period rice plants are most susceptible to damaging infestations of whorl maggot and insect-transmitted virus diseases. In field experiments this treatment provided the highest grain yield (Table 2).

The efficacy of gelatin-capsule, root-zone placement results from two factors. Insecticide is concentrated in the root zone of rice plants and in an environment (soil) where degradation is relatively slow. The field half-life of carbofuran is estimated as 10 to 30 days in IRRI soils (Siddaramappa et al 1977). Uptake of the insecticide after gelatin-capsule treatment is apparently limited only by the release of insecticide from the source. Two separate dissolve-release processes, involving the gelatin cover and the granule coating, explain the lag in uptake observed in both field and greenhouse experiments. But the insecticide, once dissolved, is in the site most favorable for prolonged uptake by the plant (Fig. 6).

Incorporation of carbofuran in the topsoil provides persistence comparable to that of the gelatin-capsule treatment, but residues have lower magnitude. Aquino and Pathak (1976) found that the persistence of carbofuran in leaves after a 2-kg/ha soil incorporation treatment was nearly the same as that resulting from a similar rate of granular insecticide placed in capsules in the root zone of each rice hill. In both cases leaf residues were greater than 0.1 ppm at 80 DAT, but much less in the soil-incorporation treatment than in the capsule root-zone application at 10, 20, and 40 DAT. Because the incorporated granules are evenly dispersed in the topsoil, insecticide is available for continual uptake at several stages of root elongation (Fig. 6). Uptake is eventually limited when plants are large -- and the carbofuran absorbed is insignificant compared with plant bulk -- or after carbofuran is degraded in the soil.

The granular-applicator treatment is less efficient than soil incorporation in delivering and maintaining carbofuran in the leaves. The granular applicator places the insecticide too far away from the plant's root zone -- 8 to 10 cm below the soil surface and 10 to 12 cm to the side of the plants. The liquid-band applicator promotes higher residues than the granular applicator because it places the insecticide closer to the plant's root. The insecticide, however, is in a continuous narrow band rather than concentrated, as in capsule placement at each hill, or uniformly distributed, as with soil incorporation. Thus the residue magnitude from liquid-band application is much less than that in the capsule treatment, and duration of leaf residues is less than that in soil incorporation.

Carbofuran applied as a paddy-water broadcast (Fig. 6) dissolves and is evenly distributed in the water within 24 hours. Insecticide applied to the water can physically move onto the plant surfaces by capillary action (Pathak and Dyck 1973), and perhaps be absorbed directly through the stems (Bowling 1970) for rapid effectiveness. But the dissolved insecticide must diffuse into the soil before a major systemic effect can be exerted, which may take several days. It is important to note that carbofuran degrades much more rapidly in the paddy water (half-life of 1 to 3 days in slightly alkaline field waters) (Siddaramappa et al 1977) than in the soil (half-life of 10 to 30 days). Thus

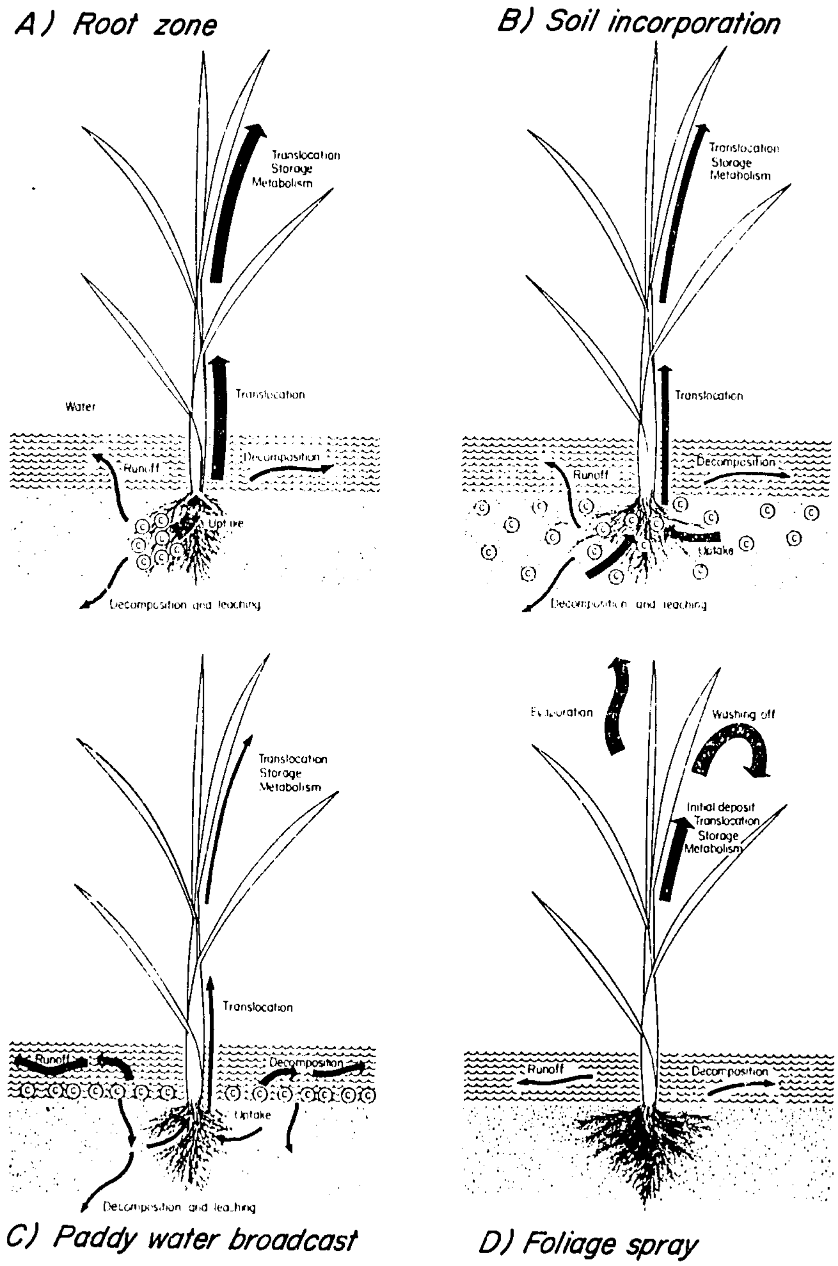


Fig. 6. Schematic diagram of the behavior of granular carbofuran ((c)) in the rice paddy. A. Concentration of granules in the root-zone, such as occurs with gelatin-capsule root-zone application. Uptake is facilitated by the closeness of roots and insecticide. B. Incorporation of granules in the top soil. Uptake is gradual but continuous as root elongation places root and insecticide in contact for extended periods of time. C. Broadcast of granules to the water. Much of the insecticide dissolves in the paddy water and is lost by decomposition and runoff. Only a small part of the insecticide that penetrates the soil surface reaches the roots for uptake. D. Foliage spray. Much of the initial insecticide deposit on the surface of the plants is lost by wash-off or evaporation. Some of the surface deposit is absorbed by the plant but movement during translocation is primarily from lower to upper plant parts.

much of the broadcast carbofuran is degraded in the water before it reaches the roots of rice plants.

In both the root-soak and root-coat treatments, the seedlings absorb a complement of insecticide before transplanting, and unabsorbed insecticide adhering to the roots is in the form and proximity most favorable for uptake after transplanting. In the root soak, however, insecticide residue is rapidly depleted by plant growth dilution, by metabolic degradation, and perhaps by evaporation. Addition of a root-coating agent prolongs the period of useful insecticidal residue in the leaves because more insecticide adheres to the root surface and is available for uptake after transplanting. Even under the most favorable root-coat conditions, however, the insecticide does not persist nearly as long as in the root-zone gelatin-capsule placement, or soil incorporation.

The initial insecticide deposit after foliage spray treatment lies on the surface of rice plants. It is subjected to losses from evaporation and wash-off by rain (Fig. 6), which are much less important in systemic applications. Some of the initial spray deposit is absorbed and metabolized in the leaves but little is translocated to the base of the plant.

The residue estimates in Figure 5 allow for predictions of the efficacy of various combinations of treatments. For example, a favorable sequence might involve seedling root-soak or root-coat followed by root-zone application with either the liquid band or capsule technique 20 DT.

The use of seedling root treatment in these two cases might be beneficial because the lag between application and uptake of root-zone and soil-incorporated carbofuran occurs at a period during which seedlings are susceptible to tungro virus. The seedling treatment should protect young plants during the uptake lag period.

Our hypothetical schedules assume that all treatments are equally acceptable to, and suitable for, rice growers. Gelatin capsules containing carbofuran are not commercially available, and would be extremely time-consuming for individuals to prepare. That, coupled with the extra labor associated with capsule placement in the field, make the treatment one unlikely to be used by rice farmers.

The liquid-band applicator works well only in well-prepared paddies. In farmer's fields clogging of the applicator often causes uneven delivery of the insecticides. This method may not be widely accepted unless the delivery problem is overcome.

Soil incorporation of carbofuran is most likely to gain immediate and widespread acceptance. It uses a commercially available formulation and requires no special equipment, but it is prophylactic (as all the treatments described here are); growers may not invest the capital and extra time associated with a pesticide application that may, under favorable circumstances, be unnecessary.

The root-soak and root-coat methods require an extra step before transplanting, except when done as the perlite root-coat dapog. In addition, such methods place fairly concentrated insecticide on the seedling roots, and thus present a hazard for workers who handle the treated seedlings. Even though carbofuran has a low dermal toxicity (LD_{50} 10,200 mg/kg in the rabbit), workers handling seedlings for prolonged periods of time, as with rice transplanters, may suffer exposure to the insecticide from a combination of dermal, inhalation, and oral routes. Carbofuran is highly toxic by oral ingestion (LD_{50} 11 mg/kg) in the rat. Safety considerations need careful study before seedling root treatments can be recommended for general use.

On the positive side, all the described methods have major advantages over paddy-water broadcast aside from improved insect control. There was no evidence that the early season treatments caused the presence of adverse residues of carbofuran or its carbamate metabolites in whole grain at harvest. But broadcast treatments made late in the growing season gave carbofuran residues in grain that exceeded the EPA tolerance. Also, none of the root-zone or root-soak or root-coat treatments release carbofuran to the paddy water in amounts large enough to directly kill, or contribute harmful residues to, fish in the paddies or in runoff waterways (Argente et al 1977). This is an important consideration in the Philippines and other Asian countries where fish culture within or near paddies is widely practiced (Grover 1975).

The systemic treatments are mainly designed for controlling early and midseason rice pests. Insects infesting rice later in the growing season, such as brown planthopper, would be controlled by these techniques only if early season generations are prevented from developing and no later migration occurs. Furthermore, systemic carbofuran does not tend to concentrate in the stems and leaf sheaths at the tiller base where brown planthoppers congregate, oviposit, and feed (Heinrichs 1978). A foliage spray with carbofuran (or some other contact insecticide) directed at the base of the plant is necessary when high infestations of hoppers occur late in the season. That should be particularly effective during the dry season when rain is less likely to wash the surface residue from the plant.

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