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Persistence and Nematicidal Efficacy of Carbosulfan, Cadusafos, Phorate, and Triazophos in Soil and Uptake by Chickpea and Tomato Crops under Tropical Conditions

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The productivity of chickpea, *Cicer arietinum* (L.), and tomato, *Solanum lycopersicum* (L.), is adversely affected by root-knot nematode, *Meloidogyne* species. Nematode-resistant chickpea and tomato are lacking except for a few varieties and therefore grower demand is not met. The available nematicides, namely, carbosulfan, cadusafos, phorate, and triazophos, were, therefore evaluated for their efficacy and persistence in soil and crops to devise nematode management decisions. In alluvial soil, cadusafos was the most persistent nematicide followed by phorate, carbosulfan, and triazophos in that order. The percent dissipation of cadusafos was greater ($P < 0.05$) in chickpea than in tomato plots, which influenced its half-life in soil. Nematicide residues were differentially taken up by chickpea and tomato plant roots with active absorption continuing for up to 45 days. Cadusafos and triazophos were absorbed to greater extent ($P < 0.05$) in tomato than in chickpea. The translocation of residues to shoot was highest by day 15 for cadusafos and at day 45 for other nematicides, with carbosulfan residues translocated the most. Nematicide residue concentrations in shoots never exceeded those in roots, with residues in both roots and shoots persisting beyond 90 days. Nematicide residues in green seeds of chickpea and tomato fruits were all below the Codex/German MRLs of 0.02, including the Indian tolerances of 0.1 μg/g in fruits and vegetables. Cadusafos was found to be the most effective nematicide followed by triazophos against *Meloidogyne incognita* and reniform nematode, *Rotylenchulus reniformis*. Application of cadusafos (Rugby 10 G) or, alternatively, spray application of triazophos (Hostathion 40 EC) in planting furrows, both at 1.0 kg of active ingredient/ha, followed by light irrigation is recommended for the effective control of *M. incognita* and *R. reniformis* infestations on chickpea and tomato.

KEYWORDS: Carbosulfan; cadusafos; phorate; triazophos; nematicidal efficacy; persistence; residues; translocation; *Cicer arietinum* (L.); *Solanum lycopersicum* (L.)

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is the second most important grain legume crop worldwide after beans (*Phaseolus vulgaris* L.) It is a major source of protein for millions of families in developing countries. It is grown in 33 countries and is an important component of diet in the Indian subcontinent, West Asia, and North Africa. The average chickpea yield in major producer countries such as India stagnates at 0.6−0.7 Mt, far below the 3−5 Mt/ha of earlier years. Likewise, productivity of tomato, *Solanum lycopersicum* (L.), a high-value horticultural fruit crop of major economic importance, is also offset by the narrowing of its genetic base, resulting in increasing susceptibility to biotic and abiotic stresses.

Meloidogyne incognita (Kofoid & White) Chitwood and *Meloidogyne javanica* (Treub) Chitwood are the major nematode pests of chickpea in the tropics (*1*). Estimated annual yield losses of 13.7% of chickpea crop (*1*) and 22−70% of tomato crop in tropical and subtropical regions (*2*) have been reported. Growing of resistant cultivars is a more effective economic strategy than applying nematicides to contain nematode problems. However, there is a paucity of nematode-resistant chickpea (*3*) and tomato cultivars (*4*). Breaking of resistance to other pathogens, for example, *Fusarium* wilt resistance in chickpea by *Meloidogyne* spp., can have serious implications for management of chickpea wilt. In such situations, use of a nematicide becomes a necessary adjunct for successful crop cultivation (*5*).

Application of a nematicide is required in each growing season of a susceptible crop. Nematicide persistence in soil for 6−8 weeks is desired for effective initial plant protection (*6*). A few nematicides exist and, currently, are not used for control of nematodes in India. Several insecticides used for insect control, such as carbofuran, carbosulfan, cadusafos, phorate, and triazophos, possess nematicidal activity, of which cadusafos has been reported to be the most effective (*6*−*9*). Carbosulfan [2,3-dihydro-2,2-dimethyl-7-benzofuranyl[(di-*n*-butylamino)thio] methyl carbamate ($LD_{50,rat}$ = 209 mg/kg), triazophos [*O*,*O*-diethyl-*O*-(1-phenyl-1*H*-1,2,4-triazol-3yl] phosphorothioate ($LD_{50,rat}$ = 68 mg/kg), and cadusafos [(*S*,*S*-di-*sec*-butyl *O*-ethyl phosphorodithioate)] ($LD_{50,rat}$ = 37.1 mg/kg) are

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less toxic compared to phorate [*O*,*O*-diethyl *S*-ethylthiomethyl phosphorodithioate] ($LD_{50,rat}$ = 3.2 mg/kg), carbofuran [2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate] ($LD_{50,rat}$ = 8−12 mg/kg), and even fenamiphos [ethyl 3-methyl-4-(methylthio)phenyl (1-methylethyl) phosphoramidate] ($LD_{50,rat}$ = 16−19 mg/kg). Cadusafos is used in Greece (*6*), Italy (*7*), and South Africa (*9*) against nematodes attacking banana, citrus, maize, potato, tobacco, and tomato (*6*−*10*). In India, none of these nematicides are registered for use against nematodes due to the paucity of data on their residues and bioefficacy. Available information regarding their soil residence and uptake by plants under tropical conditions (*10*−*14*) is meager.

Therefore, the present study was conducted to evaluate the efficacy and persistence of the nematicides available in India, namely, carbosulfan, cadusafos, phorate, and triazophos, in soil and in two important Indian crops, chickpea and tomato, following furrow applications at recommended rates in winter for effective economic and judicious nematode management. Tomato and chickpea were selected in this study as the crops to be tested in view of the extensive nematode damage observed in these crops. The current study objective was to mitigate nematode damage in these crops by promoting sudden suppression of nematode populations in soil. As nematicides act in both soil and plant phases, their absorption, translocation, and persistence were also studied.

MATERIALS AND METHODS

Technical Grade Nematicides, Formulated Products, Reagents, and Solvents. Technical grade carbosulfan (98%), cadusafos (98%), triazophos (97.6%), and phorate (91.7%) were obtained from respective manufacturers. Emulsifiable concentrate (EC) of the carbosulfan (Marshal 25%) was procured from Rallis India Ltd. and triazophos (Hostathion 40%) from Hoestch India Ltd. Granular formulation of cadusafos (Rugby 10 G) was obtained from Rallis India Ltd. and phorate (Thimet 10G) from Insecticides India Ltd. All reagents were of analytical grade. Solvents for liquid chromatography were of HPLC grade and degassed prior to use. All other solvents were glass-distilled before use.

Field Experiments. The experiments were conducted in October 2007 at the Indian Agricultural Research Institute, New Delhi, in field microplots of 6 m^2 size. The plots were naturally infested with root-knot nematode *M. incognita* (Kofoid & White) Chitwood and reniform nematode *Rotylenchulus reniformis* (Linford and Olivera) besides other ectoparasitic nematodes. The soil was alluvial with pH 8.2, cation exchange capacity of 2.10 me/110 g, 73.2% sand, 7.6% silt, 19.0% clay, and 0.91% organic carbon. The experiment was conducted in a factorial design with four nematicide treatments (carbosulfan, cadusafos, phorate, and triazophos) at three rates of application, 0 (control), 1, and 2 kg of active ingredient (ai)/ha, and five replications of each treatment. Carbosulfan (Marshall 25% EC) and triazophos (Hostathion 40% EC) were applied as soil spray; cadusafos (Rugby 10 G) and phorate (Thimet 10 G) were applied in planting furrows at the time of transplanting of tomato cv. Pusa Ruby and sowing of chickpea cultivar Pusa 362. Spray applications of carbosulfan and triazophos in planting furrows were done by hand sprayer to reduce the toxicant load in the soil and reduce the cost by restricting the use of chemicals in the rhizosphere soil. This was followed by light irrigation to distribute the toxicant in the soil. The plots receiving no nematicide served as control. The recommended application rate and double the recommended rate were selected to evaluate soil and crop contamination in case of accidental overapplication.

A single application of recommended fertilizer (25:50:25 NPK kg/ha) was applied 1 day prior to all nematicidal treatments. Thirty-five-day-old seedlings of tomato were transplanted to soil plots at inter- and intra row spacings of 50 and 30 cm, respectively. Chickpea seeds were sown to soil plots at inter- and intra row spacings of 30 and 15 cm, respectively.

The tomato plots were flood irrigated (5 cm) at intervals of 20 days. Similarly, chickpea plots also received irrigation but at 30 day intervals. The weeds from the plots were subsequently removed manually.

Nematicidal Efficacy. Nematicidal efficacy was assessed in terms of soil population and root-knot index. Soil samples were taken from the plow layer (15 cm deep) by a soil sampling auger (45 × 2.5 cm) representing approximately 30−35 cores taken from each treatment. Nematode populations in soil were estimated on 0, 55, and 110 days after sowing chickpea/transplanting tomato by processing 200 cm^3 soils by standard Cobb's modified decanting and sieving techniques. Root-knot indices for both tomato and chickpea roots were estimated on the 110th day (*15*).

Sample Preparation for Residue Analysis. Twenty gram soil samples were processed from each control and treatment plot for nematicide residues, adopting single-step extraction and cleanup procedures (*16*). Charcoal (0.5 g) and florisil (0.5 g) preactivated at 120 °C were added to each soil sample. The soil was then filled into a column (32 × 2 cm) over a layer of anhydrous sodium sulfate on cotton plug at the bottom of the column and compacted over a rubber pad. Another layer of sodium sulfate and a cotton wool plug were then applied at the column head. The column was eluted with 150 mL of chloroform in a 6 h elution. The eluant was dried at 40 °C using a Buchi type rotary vacuum evaporator. The residues were dissolved in 2 mL of acetone for gas chromatography and 2 mL of acetonitrile for liquid chromatography.

All plant root and shoot samples (3−25 g) were taken after 15, 30, 45, 60, 90, and 120 days and fruit samples after 90, 100, and 120 days of treatment. The root, shoot, and fruit samples were separately extracted three times with 150, 100, and 75 mL of acetone in a Waring blender, partitioned with 100, 75, and 50 mL of chloroform, and the chloroform extract was cleaned up in a charcoal/florisil (1:3) column (32 × 2 cm) (*17*). The chloroform column eluant was then vacuum evaporated to dryness at 40 °C using a Buchi type rotary evaporator, dissolved in 2 mL of acetone for gas chromatography (GC) or in 2 mL of acetonitrile for liquid chromatography (LC).

Residue Analysis. Residues of cadusafos and triazophos were determined as parent compounds. Residues of phorate were quantified as phoratoxan (phorate sulfone) after potassium permanganate oxidation, which was also adopted for estimation of fenamiphos residues (*18*). Residues of carbosulfan were determined as a total residue of the parent compound and its major degradation product carbofuran.

Gas Chromatography. GC was performed on a Hewlett-Packard 6890 gas chromatograph equipped with a flame photometric detector and a 15 m HP-5 capillary column (15 m, i.d. = 0.53 mm, and film thickness = 5 μm) and a Chemstation for analysis of residues of cadusafos, phorate, and triazophos. The injection volume was 3 μL. The temperature (°C) of the injection port was 260; column, 180; and detector, 260. Nitrogen, hydrogen, and air flow rates were 60, 150, and 110 mL/min, respectively. On this column the retention time of cadusafos was 2.1 min, that of phorate 3.7 min, and that of triazophos 4.0 min. The total analysis time for all of the compounds was 8 min. The peak areas for each compound were found to be linear in the test concentrations range of ∼0.1−1.0 μg/mL.

Liquid Chromatography. LC was carried out on a Hewlett-Packard binary gradient high-pressure liquid chromatograph series 1100, equipped with a Rheodyne manual injector 20 μL and a UV−visible variable-wavelength detector set at λ_{max} = 210 nm. A 4.6 × 200 mm Lichrosorb 5 μm C-18 reverse phase column was used for analysis of carbosulfan and its main degradation product, carbofuran. Column mobile phase was acetonitrile and water (90:10 v/v). The flow rate was 0.7 mL/min. Carbofuran eluted at a retention time of 4.8 min, and carbosulfan eluted at 10.3 min. The peak areas for carbosulfan and carbofuran were linear in the test concentrations range of ∼1.0−10.0 μg/mL.

Limits of Detection (*LOD*) *and Quantification* (*LOQ*). The LOD and LOQ were determined as the concentrations at which signal-to-noise ratios of 3:1 and 10:1, respectively, were routinely obtained. The LOD of cadusafos, phorate, and of triazophos by GC was 0.001 μg/mL and the LOQ was 0.002 μg/g in soil/plant matrices. The LOD of carbofuran and carbosulfan by LC was 0.01 μg/mL and the LOQ was 0.03 μg/g in soil/plant matrices.

Recovery. The average recoveries of nematicides from soil following fortification at 0.01 and 1.0 μg/g were as follows: cadusafos, 95 ± 6.3%; phorate, 91 ± 8.2%; triazophos, 92 ± 5.8%; and carbosulfan, 89.4 ± 4.9%. The recoveries from plant samples fortified at the same levels were carbosulfan, 85.4 ± 4%; cadusafos, 90 ± 7.4%; phorate, 82 ± 9.2%; and triazophos, 88 ± 5.7%. Because recoveries (> 85%) of the test nematicides were similar to those reported earlier (*16*, *17*, *19*−*21*), no recovery correction factor was used in the final residue calculations.

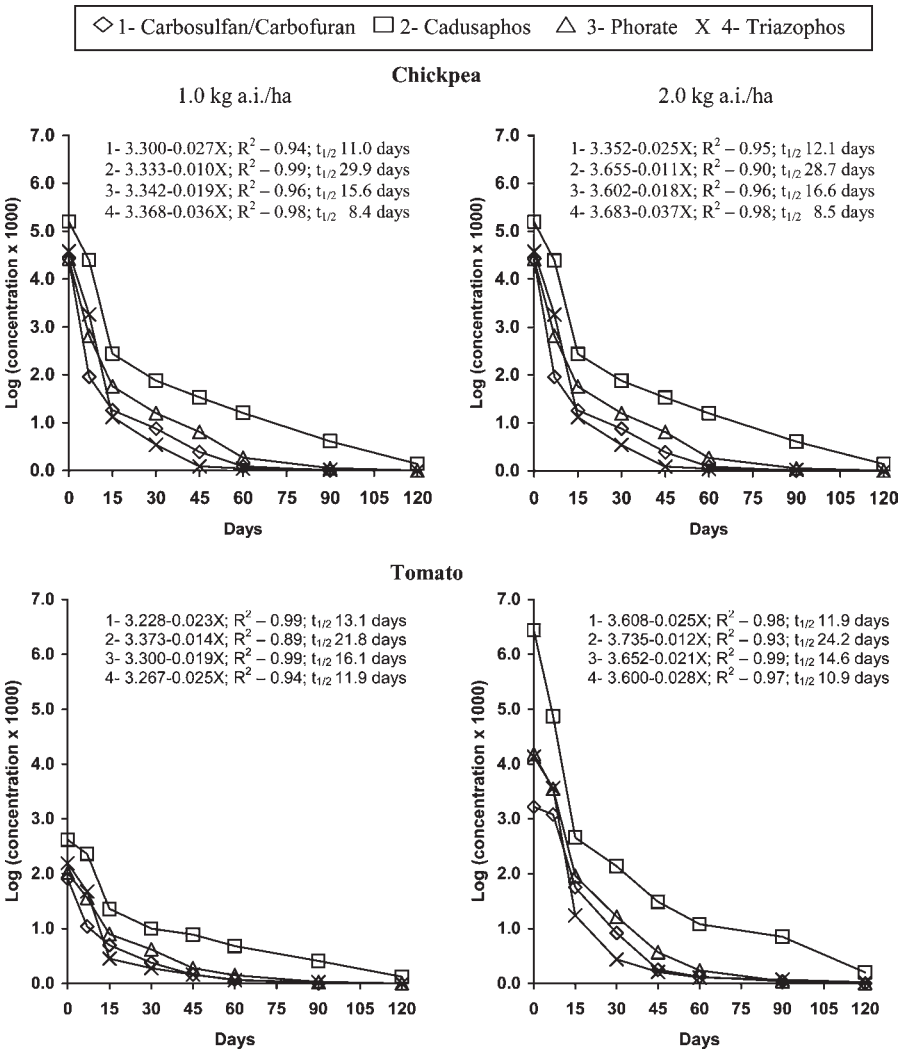

Figure 1. Persistence of nematicides in soil under chickpea and tomato crops.

Statistical Analysis. Multivariate analysis of variance (MANOVA) and multiple correlation regression analysis were performed by the Statistical Package for Social Scientists (SPSS) for data analysis and interpretation.

RESULTS AND DISCUSSION

Persistence of Nematicides in Soil. The initial concentration of all nematicides tested in soil varied from 1.91 to 2.23 μg/g and from 4.42 to 6.44 μg/g following applications at 1.0 and 2.0 kg of ai/ha, respectively. Residues of carbosulfan were determined as the total residue of the parent compound plus its major degradate, carbofuran. The residues of carbosulfan and phorate persisted for up to 90 days and those of cadusafos and triazophos beyond 120 days (**Figure 1**). Carbosulfan was rapidly converted to carbofuran, which became the major metabolite from the seventh day onward. The residues of carbosulfan (*22*) have been reported to persist less than cadusafos (*13*), triazophos (*19*), and phorate (*21*).

The dissipation of nematicides from soil followed first-order kinetics. The dissipation was not influenced by the rates of application ($P > 0.05$). The half-lives (days) of nematicides were 11−12 for carbosulfan, 29−30 for cadusafos, 16−17 for phorate, and 8−9 for triazophos in chickpea soil. The corresponding half-lives in soil cropped with tomato were 12−13, 22−24, 15−16, and 11−12 days, respectively. Triazophos dissipated most quickly, followed by carbosulfan, phorate, and cadusafos (**Table 1**). The dissipation rate of residues from soil was more rapid in chickpea than tomato plots. This could be due to the differential plant population and uptake. The plant populations/plot were more for

Table 1. Means and Least Significant Differences (LSD) of Percent Dissipation of Nematicides in Soils Cropped with Chickpea and Tomato Following Application at 1.0 and 2.0 kg of Active Ingredient/ha

	mean of % dissipation[a]	LSD ($P = 0.05$)
nematicide		0.65
carbosulfan	64.68	
cadusafos	55.11	
phorate	63.99	
triazophos	70.61	
dose		ns
1 kg/ha	64.38	
2 kg/ha	64.82	
crop		0.46
chickpea	65.46	
tomato	63.74	
days		0.87
7	29.25	
15	50.84	
30	60.07	
45	68.74	
60	75.32	
90	88.84	
120	87.11	

[a] Angular transformed values.

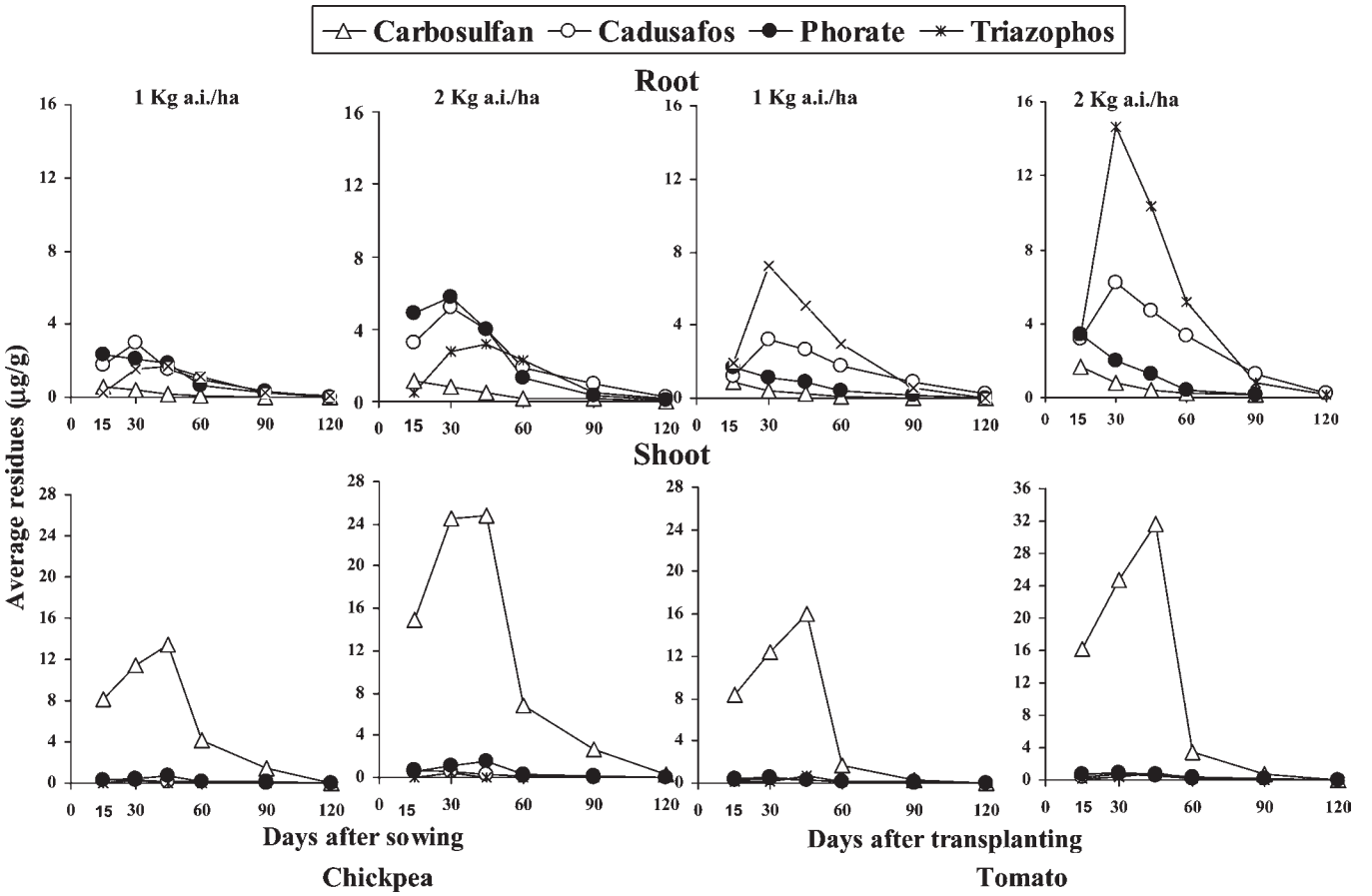

Figure 2. Uptake of nematicides in chickpea and tomato.

chickpea than tomato. A first-order dissipation has been reported previously for cadusafos (*13*), carbosulfan (*22*), phorate (*21*), and triazophos (*19*), with half-lives of 18, 9.1, 10.4, and 7.93 days, respectively, which are similar to the present observations.

Residues in Root. The root absorption of all nematicides tested from soil was rapid, and concentrations in root attained a peak in 15−45 days (**Figure 2**). The residues of carbosulfan were determined as the total residue of the parent compound plus its major degradate, carbofuran. In 15 days, the concentrations of carbosulfan (0.53 μg/g) and phorate (2.31 μg/g) in chickpea roots and that of phorate in tomato roots (1.69 μg/g) reached maximum levels. Carbofuran was the major metabolite in roots from 15 days onward in carbosulfan treatment. Root absorption of cadusafos (3.23 μg/g) and triazophos (7.22 μg/g) residues attained a peak by day 30 in tomato. Maximum absorption of triazophos (1.72 μg/g) in chickpea root occurred by 45 days. The absorption of all nematicides almost doubled at the higher rate of application. The data showed differential accumulation of all nematicide residues in roots of chickpea and tomato. Whereas carbosulfan/carbofuran did not accumulate in either tomato or chickpea roots, the other nematicides tested did accumulate. A good correlation (r = 0.84*) existed between rate of application and residue concentrations in roots. The mean tomato root concentration of residues was highest for triazophos, followed by cadusafos, phorate, and carbosulfan (**Table 2**). Absorption of carbosulfan was fast ($P < 0.05$) compared to the other nematicides tested. However, it was similar ($P > 0.05$) for cadusafos and phorate, but absorption of triazophos was greater ($P < 0.05$) than that of phorate. The two-way interaction between crop and nematicide revealed that absorption of triazophos was greater ($P < 0.05$) in tomato than in chickpea roots, whereas other nematicides were similarly absorbed ($P > 0.05$) in these crops. This could be attributable to persistence of the nematicides in the soil. Active root absorption took place up to 45 days and declined thereafter, concomitant with the residue levels in soil. In roots, the residues of carbosulfan and phorate persisted beyond 90 days, whereas those of cadusafos and triazophos persisted beyond 120 days. The decline of the root residue level was due to upward translocation and dilution factor of plant growth.

Residues in Shoot. The translocation of residues from root to shoot was highest for carbosulfan ($P < 0.05$) compared to cadusafos, phorate, and triazophos (**Table 2**). The residues of carbosulfan quantified as the parent compound and its major degradate, carbosulfan, were highest by 45 days in both chickpea (24.8 μg/g) and tomato (31.6 μg/g) shoots (**Figure 2**). In comparison, the maximum residues of cadusafos observed by 15 days in chickpea shoots (0.34 μg/g) and 30 days in tomato shoots (0. 44 μg/g) were much lower. The residue levels of phorate in chickpea shoots (0.68 μg/g) and triazophos in tomato shoots (0.63 μg/g) were highest by 45 days. The residues of triazophos in chickpea shoots peaking by 30 days following application were the least (0.25 μg/g). There was a remarkable increase in the translocation of triazophos by tomato compared to chickpea concomitant with the root absorption of residues with residue levels in shoots declining along with the reduction of the levels in roots. The concentration of carbosulfan residues in chickpea and tomato shoots at a higher rate of application was significantly greater, and the resultant residue levels at both rates of application correlated well (r = 0.88*). The data show a rapid translocation of the residues of carbosulfan compared to a much slower translocation of cadusafos, phorate, or triazophos in either chickpea or tomato shoots.

Interestingly, the residue concentrations of the test organophosphates in shoots never exceeded those in roots. The translocated residues of nematicides in shoots persisted for up to 90 days at lower (1.0 kg of ai/ha) and beyond 120 days at higher (2.0 kg of ai/ha) application rates (**Figure 2**).

A good correlation ($r = 0.78$*) existed between root and shoot concentrations of all nematicide residues. The decline in residue levels in shoots could be mainly due to dilution factor of plant growth and to some extent due to differential plant metabolism of the xenobiotics.

The residues of the test nematicides in plant parts persisted beyond 90 days. More or less similar observations on absorption and translocation of cadusafos residues in brinjal (*17*) and tomato (*23*) are on record. The persistence of carbofuran in chickpea and pea, and of triazophos in chickpea and wheat has been recorded beyond 90 days of application (*12*, *19*, *23*, *24*). Although triazophos has been claimed by the manufacturer as a contact nematicide and not systemic, we observed high concentrations of triazophos in tomato roots (7.22−14.66 μg/g). Similarly, very high concentrations of triazophos even in the shoots of wheat plants (44.5 μg/g) has been observed (*19*). On the other hand, triazophos levels in both root and shoot of chickpea were far less compared to that in tomato. The differential absorption and translocation of nematicides in chickpea and tomato crops could be due to inherent characteristics of the compound, water solubility, and plant population (*25*, *26*). The water solubility of carbofuran (the major metabolite of carbosulfan) is 700 μg/mL, that of cadusafos 248 μg/mL, that of phorate 50 μg/mL, and that of triazophos 30−40 μg/mL. Nonpolar compounds tend to be adsorbed on the plant surface and polar ones readily absorbed and translocated, with water solubility affecting their concentration in plants (*26*). Furthermore, the rhizosphere dynamics, sorption−desorption of nematicides and plant population, probably influenced persistence and bioavailability of the nematicides in soil solution and thereby differential uptake by chickpea and tomato crops. In fact, the percent dissipation was greater ($P = < 0.05$) in chickpea than in tomato plots.

Table 2. Means and Least Significant Differences (LSD) of Uptake of Nematicides at Predetermined Intervals by Chickpea and Tomato Crops Following Application at 1.0 and 2.0 kg of Active Ingredient/ha

	absorption		translocation	
	mean (μg/g)	LSD ($P = 0.05$)	mean (μg/g)	LSD ($P = 0.05$)
nematicide		1.05		0.54
carbosulfan	0.36		9.52	
cadusafos	2.18		0.25	
phorate	1.45		0.41	
triazophos	2.77		0.14	
dose		0.75		0.38
1 kg/ha	1.13		1.75	
2 kg/ha	2.24		3.41	
crop		0.58		0.38
chickpea	1.35		2.53	
tomato	2.03		2.63	
days		1.29		0.66
15	2.00		3.22	
30	3.57		4.95	
45	2.65		5.75	
60	1.43		1.13	
90	0.43		0.40	
120	0.07		0.04	
crop × nematicide		1.10		0.76
chickpea × carbosulfan	0.33		6.45	
× cadusafos	1.93		0.17	
× phorate	1.94		0.27	
× triazophos	1.18		0.11	
tomato × carbosulfan	0.39		12.59	
× cadusafos	2.42		0.33	
× phorate	0.96		0.55	
× triazophos	4.35		0.18	

Residues in Green Seeds of Chickpea and Tomato Fruit. Only traces of carbosulfan/carbofuran residues were detectable in green seeds of chickpea and fruits of tomato after 90 days of nematicidal application (**Table 3**). By 90 days the residues (μg/g) measured 0.009−0.016 for cadusafos, 0.020−0.056 for phorate, and 0.011−0.018 for triazophos in green seeds of chickpea and 0.021−0.040, 0.014−0.022, and 0.002−0.004, respectively, in fruits of tomato. A higher order of residues of cadusafos in tomato and phorate and triazophos in chickpea was observed. The residues of the nematicides in green seeds of chickpea and fruits of tomato declined with time at different picking intervals, finally leaving behind only trace to nondetectable levels by the 120th day.

The residues of the test nematicides in plant parts persisted beyond 90 days. More or less similar observations on absorption and translocation of cadusafos residues in brinjal (*17*) and tomato (*23*) are on record. However, Wang et al. (*27*) reported as high as 0.0398 μg/g phorate residues in Chinese cabbage. The residues of carbosulfan and triazophos in green seeds of chickpea grown from seeds treated at 100−400 μg/mL were only in trace to nondetectable levels (*24*). However, the residues of the nematicides in green seeds of chickpea and tomato fruits were below the prescribed maximum residue limit (MRL) of 0.02 μg/g for

Table 3. Residues of Carbosulfan/Carbofuran, Cadusafos, Phorate, and Triazophos in Green Pods of Chickpea and Fruits of Tomato ($n = 5$)[a]

	average residues (μg/g) in green seeds of chickpea and tomato fruits							
	chickpea				tomato			
days	carbosulfan/carbofuran	cadusafos	phorate	triazophos	carbosulfan/carbofuran	cadusafos	phorate	triazophos
				1 kg/ha				
90	TR	0.009	0.020	0.011	TR	0.021	0.014	0.002
100	TR	0.003	0.008	0.004	TR	0.006	0.010	ND
120	TR	ND	0.003	ND	TR	0.002	0.003	ND
				2 kg/ha				
90	TR	0.016	0.056	0.018	TR	0.040	0.022	0.004
100	TR	0.005	0.019	0.007	TR	0.010	0.014	ND
120	TR	TR	0.006	ND	TR	0.003	0.004	ND

[a] ND, nondetectable; TR, <0.03 for carbosulfan and carbofuran and <0.002 for cadusafos, phorate, triazophos.

Table 4. Nematicidal Efficacy of Carbosulfan, Cadusafos, Phorate, and Triazophos against Root-Knot and Reniform Nematodes in Soil and Root-Galling in Chickpea and Tomato ($n = 5$)

		nematode population/cm^3 of soil						
		initial[a]		midseason[a]		final[a]		
nematicide	dose (kg/ha)	root-knot nematode	reniform nematode	root-knot nematode	reniform nematode	root-knot nematode	reniform nematode	gall index
				Chickpea				
control	0.0	3.15	2.40	4.65	4.20	4.00	3.25	3.7
carbosulfan	1.0	3.65	2.55	3.10	2.65	3.40	2.50	2.6
	2.0	2.85	3.15	1.85	2.00	1.00	1.00	2.0
cadusafos	1.0	3.50	2.00	1.60	2.15	0.85	1.75	1.6
	2.0	3.20	1.80	1.05	0.25	0.55	0.75	1.2
phorate	1.0	2.85	1.80	2.60	3.00	3.95	3.22	2.8
	2.0	2.45	2.00	1.80	2.85	2.70	3.20	2.1
triazophos	1.0	4.30	2.60	1.70	2.60	2.25	2.25	2.5
	2.0	3.90	1.95	1.10	1.40	1.50	1.25	1.5
				Tomato				
control	0.0	2.96	1.54	4.70	5.23	5.25	6.44	4.2
carbosulfan	1.0	3.12	2.11	2.22	4.03	2.86	2.66	2.2
	2.0	3.32	1.44	1.51	3.05	1.90	2.32	1.8
cadusafos	1.0	2.24	1.62	2.02	3.21	2.11	1.12	2.1
	2.0	3.51	1.85	1.34	1.89	1.13	0.72	1.5
phorate	1.0	3.27	1.55	2.58	3.32	4.36	3.57	3.0
	2.0	3.34	1.43	1.78	2.64	3.00	2.66	2.6
triazophos	1.0	2.62	1.38	2.11	3.67	3.24	4.44	2.5
	2.0	2.84	1.57	1.64	2.59	2.01	2.20	2.0

[a] Initial, pretreatment; midseason, 55 days of treatment; final, 110 days after treatment.

cadusafos on potato and for triazophos on broad bean (*28*) and 0.1 μg/g for carbofuran on fruits and vegetables (*29*) or the German MRL of 0.02 μg/g for carbofuran and 0.01 μg/g for triazophos for plant products (*30*).

Nematicidal Efficacy. The predominant plant parasitic nematode populations of the soils tested consisted of *M. incognita* and *R. reniformis*. Prior to nematicidal application, the *M. incognita* population measured 2.45−4.30 second-stage juveniles (J2)/g of soil and that of *R. reniformis* 1.80−3.15 juveniles and vermiform females/g of soil in chickpea plots (**Table 4**). The populations of these nematodes in tomato plots were comparatively less: 2.24−3.51 *M. incognita* (J2)/g of soil and 1.38−2.11 *R. reniformis* juvenile and vermiform females/g of soil. At midseason, about 55 days after nematicidal application, the population reductions of *M. incognita* were 33−60, 66−77, 44−61, and 63−76% in chickpea soil receiving carbosulfan, cadusafos, phorate, and triazophos, respectively, at the two rates of application. In control, there was a 47% increase in *M. incognita* population at 55 days. The corresponding soil population declines in field cropped with tomato were 52−67, 57−71, 45−62, and 55−65% against an increase of 58% in control. By 110 days, the percent reductions of *M. incognita* were 15−75, 79−86, 1−32, 44−62 in chickpea soil and 45−64, 60−78, 17−43, 38−62 in tomato soil. In control, the final population increase was 27% in chickpea soil and 77% in tomato soil.

The effects of the treatments on *R. reniformis* were similar to those on *M. incognita* but less pronounced. The midseason (day 55) population reductions were 37−52, 49−94, 28−32, 38−67%, and final population reductions were 23−69, 45−77, 0.9−1.5, 30−61% in chickpea soil following treatment with carbosulfan, cadusafos, phorate, and triazophos, respectively. Similar declines of 23−42, 39−64, 36−49, 30−50% at midseason (day 55) and final (day 110) population reductions of 59−64, 83−89, 45−59, 31−66%, respectively, were observed in tomato soil. In control soil, the population increases of *R. reniformis* were 75 and 239% at midseason (day 55) and 35 and 318% at harvest (day 110) of chickpea and tomato, respectively. In general, nematicidal treatments were more effective in reducing soil population of *M. incognita* than of *R. reniformis*.

Multivariate analysis of variance revealed that all of the test nematicides were effective against both *M. incognita* and *R. reniformis*. Nematicidal effectiveness increased with dosage and continued for up to 110 days. The nematode population buildup was greater in tomato than in chickpea crops, indicating tomato as the more preferred host over chickpea (**Table 5**).

Estimation of root-galling in chickpea on a 0−5 scale (*15*) showed root gall indices of 1.2−1.6 in cadusafos, 1.5−2.5 in triazophos, 2.0−2.6 in carbosulfan, and 2.1−2.8 in phorate compared to a high root-gall index of 3.7 in control (**Table 4**). The root-galling in tomato was least in cadusafos (1.5−2.1) followed by carbosulfan (1.8−2.2), triazophos (2.0−2.5), and phorate (2.6−3.0) in comparison to 4.2 in control. This suggests that cadusafos was the most effective and phorate the least effective in reducing the root-galling of crops.

A good correlation between concentration of nematicides in soil and root ($r = 0.68$*) as also nematode population in soil and

Table 5. Means and Least Significant Differences of Nematode Populations in Chickpea and Tomato Cropping Seasons Following Soil Application of Nematicides at 1.0 and 2.0 kg of Active Ingredient/ha

	nematode population/cm^3 of soil	
	mean	LSD (P = 0.05)
nematicide		0.09
carbosulfan	3.00	
cadusafos	2.52	
phorate	3.21	
triazophos	2.94	
dose		0.07
control	4.06	
1 kg/ha	2.67	
2 kg/ha	2.03	
crop		0.06
chickpea	2.71	
tomato	3.13	
nematode		0.06
root-knot	3.05	
reniform	2.79	
soil population level		0.07
initial	2.51	
midseason	3.05	
final	3.19	

root-galling (r = 0.74*) of crops suggests that the decline in nematode population and resultant reduction in hazard indices were due to persistence of nematicides in soil and their absorption by roots. Cadusafos was the most persistent nematicide in soil followed by phorate, carbosulfan, and triazophos. Yet, with regard to nematicidal efficacy, cadusafos was followed by triazophos, phorate, and carbosulfan. This was due to greater absorption and persistence of cadusafos and triazophos over carbosulfan and phorate in roots. The nematicidal efficacy could be attributable to nematostatic action of the toxicant against the most vulnerable second-stage juveniles (J2) of *M. incognita* and both juveniles and preadult females of *R. reniformis* in soil, adversely affecting their invasion into crop roots (*31*). The decline in soil infestation levels and root-galling was due to the adverse effect of the nematicides on invasion, development, reproduction, and fecundity of the nematode (*32*). The better nematicidal action against root-knot compared to reniform nematodes was probably because of lesser degradation and greater inhibition of acetylcholine esterase in root-knot than in reniform nematodes (*33*) and differential root absorptions as observed in the present studies. A better nematostatic action of cadusafos probably accounted for its superiority over carbosulfan, phorate, or triazophos. In fact, cadusafos has been reported to affect hatching, migration, movement, and root invasion by J2 of the potato cyst nematode *Globodera pallida* Stone at concentrations as low as 0.002−0.004 μg/mL (*34*).

The results on nematicidal efficacy in this study are in congruence with the documented literature on better nematicidal potential of cadusafos over several nematicides including 1,3-D, MBr, aldicarb, carbofuran, and phorate (*6*−*9*, *35*). Higher reduction of *M. incognita* soil population under phorate treatment (117 nematodes/200 g of soil) than under carbofuran treatment (126.7 nematodes/200 g of soil) treatment (*36*) and suppression of *Tylenchulus semipenetrans* soil population to nondetectable levels with three applications of cadusafos at 2 g of ai/m^2 at 2 month intervals on lemon (*35*) have been reported.

From the present findings, it is concluded that application of cadusafos (Rugby 10 G) at 1.0 kg of ai/ha or alternatively spray of triazophos (Hostathion 40 EC) at the same application rate in planting furrows, followed by light irrigation, can be recommended for controlling root-knot nematode *M. incognita* and reniform nematode *R. reniformis* infestation of chickpea and tomato.

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