EFFECT OF PHORATE APPLIED FOR THE CONTROL OF BUNCHY TOP VECTOR OF BANANA, *Pentalonia nigronervosa* Coq. ON THE PLANT AND IN THE SOIL ENVIRONMENT

BY

D. SITARAMA RAO

THESIS

Submitted in partial fulfilment of the requirement

for the degree

DOCTOR OF PHILOSOPHY

Kerala Agricultural University

Faculty of Agriculture

DIVISION OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI — TRIVANDRUM

1989

DECLARATION

I hereby declare that this thesis entitled "Effect of phorate applied for the control of bunchy top vector of banana Pentalonia nigronervosa Coq., on the plant and in the soil environment" is a bona-fide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles of any other University or Society.

D.SITARAMA RAO

Vellayani,
29th April 1989.

CERTIFICATE

Certified that this thesis entitled "Effect of phorate applied for the control of bunchy top vector of banana Pentalonia nigronervosa Cog., on the plant and in the soil environment" is a record of research work done independently by Sri. D. SITARAMA RAO 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.

Dr. N. MOHAN DAS
Chairman

Advisory Committee
Professor and Head
Department of Agricultural Entomology.

Vellayani,
29th April 1989.

APPROVED BY

CHAIRMAN

Dr. N. MOHAN DAS

MEMBERS

Dr. (Mrs.) A. VISALAKSHY

Dr. K. SASIDHARAN PILLAI

Dr. M. CHANDRASEKHARAN NAIR

Dr. R. SUBRAMONIA AIYER

24/2/90

ACKNOWLEDGEMENTS

I wish to express at indebitedness and gratitude to Dr. N. Mohan Das, Professor and Head, Department of Agricultural Entomology, for suggesting this problem, for his valuable guidance and constant encouragement throughout the period of study and for his sustained interest during the preparation of the manuscript.

I gratefully acknowledge the encouragement given by Dr. (Mrs.) A. Visalakshy, Professor of Agricultural Entomology, as a member of the Advisory Committee particularly during the standardisation of techniques. I am grateful to Dr. R. Subramonia Aiyer, Professor and Head, Department of Agricultural Chemistry and member of the Advisory Committee for the encouragement, valuable advice and good will extended to me in the course of the work. I am thankful to Dr. M. Chandrasekharan Nair, Professor of Plant Pathology and Dr. K.Sasidharan Pillai, Professor of Agricultural Entomology, members of the Advisory Committee for their advice and encouragement.

I wish to thank Dr. N.Sadanandan, former Dean, College of Agriculture, Vellayani (presently Director, P.G.Studies), Dr. P.K.Gopalakrishnan, Associate Dean (Retd.), Dr. C.Sreedharan, former Associate Dean, College of Horticulture, Vellanikkara

(Presently, Dean, College of Agriculture, Vellayani) Dr. P.A.Waheed, Professor (Radio Tracer), Sri. S.Balakrishnan, Associate Director of Research (Plg) and Sri. P.G.Veeraraghavan, Professor of Agronomy, Cashew Research Station, Madakkathara, for extending the facilities for conducting the study.

I wish to gratefully acknowledge the wholehearted cooperation extended to me by Sri. C.Krishnankutty, Sri. A. Narayanan Master, and Sri M. Kandaswami Gounder, cultivators, my friends and collegues in the conduct of the study.

I wish to acknowledge the help rendered by Dr. K.C. George, Professor of Statistics, College of Veterinery and Animal Sciences, Sri. P.V. Prabhakaran, Professor of Agricultural Statistics, College of Agriculture, Vellayani and members of staff, Computer Centre, Vellanikkara in processing the data.

I thank The Indian Council of Agricultural Research, New Delhi, for awarding me a Senior Fellowship.

I thank my wife and family members for their support and inspiration. I dedicate this work to the loving memory of my late parents.

(D. SITARAMA RAO)

C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

INTRODUCTION

Banana, (Musa paradisiaca L.) is one of the important fruit crops cultivated extensively in the tropics. Its original home is believed to be India, but is now a widely cultivated, highly commercial crop in many countries, including Ecquador, Honduras, Panama, Columbia, Costa Rica, Jamaica, Mexico, Hawaii, Fiji, Srilanka, India and several other Far Eastern Countries (Magee, 1927, Wardlaw, 1972). In India banana is cultivated in over two lakh hectares, mostly in the Southern States. In Kerala it is an essential daily requirement as a vegetable and as a fruit.

Of the diseases affecting the plant, the virus disease, bunchy top is the most serious one. It is widespread in all the banana growing tracts of the world except the western hemisphere (Wardlaw, 1972). The disease was first recorded in 1879 from Fiji and in India from Kerala in 1940. It had later spread to Tamil Nadu, Karnataka, Andhra Pradesh, Maharastra, Orissa, Assam, West Bengal, Bihar and other States (Rangaswamy, 1972). The virus is transmitted solely by an insect vector, Pentalonia nigronervosa Coq. (Magee, 1927, Kolkaila and Soliman, 1954, Wardlaw, 1961, Stover 1972).

Bunchy top disease has the potential to wipe out banana cultivation. In Australia banana industry suffered heavily due to the out break of the disease during 1920-'27. In India banana cultivation was completely wiped out from Palani hills in Tamil Nadu due to the spread of the disease. Banana aphid, P. nigronervosa acquires the virus with a minimum of 17 hours of continuous feeding on the infected plants. The incubation period varies from 90 minutes to 48 hours and the aphids remain infective for 13 days (Rangaswamy, 1972). The only method for limiting the havoc caused by the disease is by the control of the vector in the field. Spraying of monocrotophos @ 0.05 per cent at monthly intervals had been recommended by Regupathy et al., (1983). But the increased incidence of the disease necessiated more frequent sprayings which rendered the technology economically nonviable.

Experiments conducted earlier at the College of Agriculture, Vellayani, Trivandrum had revealed that the susceptibility of the crop was greater during the early stages which resulted in the death of the plant while in the latter stages the crop was more tolerant to the disease (Anon. 1973). Application of phorate @ 1.25 g ai/plant at the time of planting controlled the aphid

upto 60 days after treatment (Nair et al., 1973). Later studies showed that the application of phorate @ 2.50 g ai/plant each at the base at planting and then at 75 and 165 days after planting gave adequate control of the vector and the incidence of bunchy top disease in banana. This method is being extensively practiced for containing the disease in Kerala.

Application of granular insecticides though relatively less hazardous than sprays, their repeated application may cause persistent adverse effects in the soil environment and leave undesirable residues in the plant and bunches.

The absorption, translocation and metabolism in different plants have been studied earlier (Bowman and Casida, 1957, Metcalf et al., 1957, Getzin and Chapman 1960, Lichtenstein et al., 1974). Its persistence and metabolism in soil also have been reported (Getzin and Chapman, 1960, Getzin and Shanks, 1970, Menzer et al., 1970, Suett, 1971, Lichtenstein et al., 1973, Waller and Dahm, 1973, Harris and Chapman, 1980 and Chapman et al., 1982).

Eventhough many insecticides are known to have little effect on soil micro organisms under certain conditions some of the chemicals may reduce microbial growth rate,

reproduction and basic activity in metabolism (Tu and Miles, 1975). At recommended field doses insecticides may not cause significant reduction in the indigenous microbial activity that is important to soil fertility. But cumulative effect may be depressive. Certain microbes get adopted to the insecticides and they reach high numbers utilizing the dead cells of the organisms killed by the chemicals (Tu and Miles, 1975, Walter-Echols and Lichtenstein, 1977). These aspects relating to the long term effects of phorate in banana fields have not been studied and hence investigations were carried out with a view to studying:

(1) the uptake, translocation, metabolism and persistence of phorate in banana plant when applied to the root zone/leaf axil of the plant at different intervals after planting.

(2) the persistence of phorate when applied to the soil at different growth stages of banana and the waiting periods required to keep the residues in bunches below tolerance limits.

(3) the uptake, translocation, persistence and bio-efficacy of phorate applied at different doses as influenced by rainy/summer seasons.

(4) the persistence and metabolism of phorate in different soil types and the effect of soil types on the absorption and metabolism of phorate in banana plants, and

(5) the effect of phorate on the soil micro organisms.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Phorate is widely used as a soil insecticide for the control of bunchy top disease of banana and on a wide variety of crops for the control of pests. The literature available on aspects related to its prolonged use as a soil systemic insecticide have been briefly reviewed here:

2.1 Absorption, translocation and persistence of phorate in plants

Phorate being a systemic insecticide is absorbed by plants and translocated to aerial parts following its application in soil. The absorbed insecticide persisted at various levels in different plant parts in different crops.

2.1.1 Vegetables

According to Getzin and Chapman, (1960), phorate was readily absorbed by peas when grown in treated soils. The initial uptake ranged from 94 ppm in plants grown in quartz sand to 7 ppm in those grown in muck soil at 4 days after treatment. The plants continued to absorb the radio active insecticide upto 24 days after application giving residue concentrations of 90 and 10 ppm, respectively.

Chisholm and Specht, (1967) obtained similar results with canning peas. They reported that phorate persisted in peas in measurable quantities at 76 days after application in soil.

Galley and Foerster, (1976) found that absorbed labelled phorate persisted more in the leaves than in the roots of broad beans. They attributed the absorption and its subsequent translocation to the combined effects of transpiration and action of transfer cells in the plant.

Talekar et al., (1977 a) found that mung beans and soy beans were efficient in the absorption and translocation of ^{14}C labelled phorate following foliar and soil applications. At two weeks after application radio carbon was detected in the stem, roots and leaves. At harvest, leaves contained more radio phorate than the seeds.

Carrots were reported to absorb and translocate phorate readily when grown in contaminated soils (Lichtenstein et al., 1965, Suett, 1971). Lichtenstein et al., (1973) found that carrots grown in surface treated soils contained 0.12 ppm phorate at harvest while those grown in soils where the insecticide was incorporated, contained a higher lavel of residue (0.50 ppm).

Getzin and Chapman, (1960) found that phorate emulsions when applied at the rate of two and six lb ai/acre

in irrigation water was absorbed and translocated by cabbages as evidenced by the increased anticholinesterase activity of tissue extracts of the plants. Higher dose resulted in greater anticholinesterase activity than the lower dose even at 60 days after treatment.

Phorate applied in soil was effectively absorbed and translocated by sugar beets as evidenced by the control of aphids and reduced buildup of mites and leaf hoppers on the treated plants. The aerial parts were found to contain high concentration of residues at eight days after application while the roots contained no detectable residues. Insecticides persisted in the tops for 24 days (0.07 ppm) while no detectable residues were found in either the tops or roots at 68 days after application, when the plants were harvested (Reynolds et al., 1960).

Absorption and translocation of phorate by potato was reported by several workers. Bacon, (1960) found that phorate was readily absorbed and it persisted in the aerial parts in sufficiently lethal quantities to give good protection against aphids for 86 days and leaf hoppers for 97 days when applied to cut seed pieces of potato at planting. The insecticide was found to be absorbed and translocated more efficiently when applied as granules

than as emulsion (Getzin and Chapman, 1960). Similar findings were reported by Kathpal et al., (1983) who found that phorate persisted in potato tubers for 70 days after soil application @ 1.5 Kg ai/ha either in a single dose or in split doses. No detectable residues were found in tubers at harvest in both the treatments.

2.1.2 Cereals

Lilly et al., (1958) reported that wheat absorbed and translocated phorate applied in soil and no detectable residues were found in samples collected at early dough stage and in mature grains. Bhatia et al., (1973) did not find detectable residues in barley grains at harvest following furrow applications of phorate granules @ 1.0 and 2.0 Kg ai/ha at sowing. Corn plants were found to be less efficient in absorbing and translocating phorate from soil. Lichtenstein et al., (1973) applied abnormally high dose of 10 lb ai/acre as emulsions and found that corn plants showed detectable residues during the first year after treatment but not during the second year while crops like carrot showed residues. Plants grown in soils treated with ^{32}P labelled phorate were found to contain the insecticide both in foliage and roots at 17 days after treatment (Lichtenstein et al., 1974). The aerial parts contained more radio active phorate than the roots.

2.1.3 Rice

The absorption and translocation of phorate from treated soils and its persistence in rice were investigated by several workers. The insecticide was applied at doses ranging from 0.50 to 2.50 Kg ai/ha either at the time of transplantation or at tillering or at booting stages of the crop.

Narayanaswamy et al., (1975) found that application of phorate granules @ 1.25 Kg ai/ha at planting resulted in the accumulation of a residue of 2.16 ppm in plants at three days after application. The residues declined to 1.88 ppm at 15 days after application. Similar residue pattern was observed by Garg and Sethi, (1982ω) who found that the plant residues increased from 1.84 ppm one da after tre tment to 2.30 ppm at three days after treatment. The residues declined there after to 1.98 and 1.29 ppm, respectively at 5 and 10 days after application. However, after this initial decline the residues gradually increased to the maximum level of 14.59 ppm at 60 days after application.

The author also investigated the relative distribution of phorate residues in different plant parts at 20, 30, 45 and 60 days after treatment. While the roots contained higher concentrations of residues (1.02 ppm) than the shoots

(0.85 ppm) at 20 days after treatment, the relative concentration declined in roots as compared to the concentration in shoots at 30, 45 and 60 days. The highest total concentration of residues was obtained at 60 days at which stage the roots, stems, leaves and earheads contained 3.34, 4.60, 4.82 and 1.83 ppm respectively.

The informations available on the pattern of terminal residues in rice plants following application of phorate in fields at different doses and at different crop phases are summarized below:

Time of application	Dose Kg ai/ha	Residues of phorate (ppm) in Ear-heads	Grains	Straw	Bran	Reference
At planting	0.25	0.360	-	-	-	Pandian, (1975)
	1.00	0.610	-	-	-	"
	1.25	-	0.057	0.192	-	Rajukkannu et al., (1977)
	1.25	-	0.080	0.150	-	Rajukkannu and Krishnamoorthy, (1979)
	1.50	ND	-	-	-	Jain et al., (1980)
	2.00	1.830	0.250	-	-	Garg and Sethi, (1982a)
At tillering	1.25	-	0.070	0.150	ND	Rajukkannu et al., (1976)
	1.25	-	0.150	0.220	-	Prasad and Mani, (1979)
	1.50	-	0.200	0.330	-	"
	2.00	-	0.240	0.390	-	"
	2.00	-	0.048	0.048	-	Pillai, (1981)
At booting	1.25	0.080	0.080	0.150	ND	Rajukkannu et al., (1976)
	1.25	-	0.240	0.240	-	Visalakshy et al., (1979)
	2.00	-	0.099	0.910	-	Pillai, (1981)
	2.50	-	0.38	0.85	-	Visalakshy et al., (1979)
15 days prior to harvest	1.00	-	0.11	-	-	Rao et al., (1986)

ND: Non detectable

\- Not reported

2.1.4 Other field crops

Metcalf et al., (1957) reported that when the base of cut leaves of cotton and lemon plants were placed in solution containing ^{32}P labelled phorate, the absorption was very rapid. Highest absorption (95 ppm) was found at four days after treatment beyond which the residues declined.

Mustard plants absorbed phorate applied in soil rapidly. Maximum residue of 2.10 ppm was detected at 20 days after application which declined there after resulting in complete dissipation of residues at harvest. However, flag leaves contained 2.40 ppm phorate at 95 days after application (Jain et al., 1974 b). Of the various plant parts, leaves contained the highest concentration of insecticide followed by flowers, stem and roots. No detectable residue of phorate was found in seeds at harvest (Agnihotri et al., 1975).

Alfalfa plants treated with phorate granules @ 1.0 and 4.0 lb ai/ac contained 390 and 520 ppm of insecticide respectively at three days after application. However, at 27 days after treatment no detectable residues were found in air dried hay. Cholinesterase activity of the blood of cattle fed with air dried hay made from treated plants was not found to be appreciably affected (Dobson et al., 1960).

2.2 Metabolism of phorate

Phorate when applied to soil undergoes a series of structural changes which affect its efficacy as an insecticide. It is metabolized to various products through chemical and biochemical transformations. When absorbed by plants grown in treated soils these changes are found to occur in them also. Bull, (1972) reviewed the mechanisms involved in the metabolism of organophosphates and the relative importance of various pathways in plants, soils, insects and higher animals. He broadly classified the mechanisms as biological oxidations brought about by enzymes in biological systems, nonenzymatic chemical reactions and hydrolytic reactions mediated by enzymes.

2.2.1 Oxidative metabolism

The oxidative metabolic reactions can be classified as desulfuration which enhance the anticholinesterase activity and oxidation of thioether moiety further enhancing the anticholinesterase activity (Bull, 1972). He further states that desulfurations are found to be quantitatively lesser in certain plants as compared to insects, while thioether oxidation is more common in plants, insects and mammals. The oxidation of thioether moiety is a two step reaction wherein the oxidation of sulfides to sulfoxides is rapid while the oxidation of sulfoxides to sulfones is

relatively slower (Bowman and Casida, 1957, Metcalf et al., 1957, Bull, 1972). Menn and McBlain, (1974) further stated that higher plants possess a microsomal oxidase system similar to that present in mammals and insects and a peroxidase system both of which have a potential for catalyzing the oxidative transformations.

2.2.2 Hydrolytic metabolism

Phorate and five of its oxidative metabolites undergo hydrolytic metabolism in plants, insects and mammals thus causing loss of their insecticidal activity. Bowman and Casida, (1958) detected the presence of five hydrolytic metabolites of which four could be identified. The relative concentration of these metabolites, diethylphosphorodithioic acid, diethylphosphorothioic acid, diethylphosphoric acid and phosphoric acid varied within plants, insects and mammals.

2.2.3 Nature and extent of metabolism of phorate in plants

Bowman and Casida, (1957) found that phorate was rapidly metabolized to five compounds following absorption and translocation in vegetables grown in soils treated with ^{32}P labelled insecticide @ 2.0 lb ai/ac.

Bowman and Casida, (1958) studied the extent of metabolism of phorate in bean plants. They found that 79 percent of extractable insecticide was in the form of toxic

metabolites at one day after treatment while the hydrolysed metabolites accounted for 21 per cent of the residues. At 12 days after treatment the proportion of toxic metabolites decreased (73 per cent) while that of the hydrolytic metabolites increased to 27 per cent of the residues. They also reported that phorate sulfoxide and phorate sulfone constituted 76.2 per cent of the total metabolites at one day after treatment, while at 12 days after treatment these metabolites continued to constitute the bulk of total metabolites (64.0 per cent). Oxyphorate sulfoxide and oxyphorate sulfone accounted for 8.5 per cent of the total residue at that stage.

Peas grown in phorate treated soil showed the highest concentration of toxic metabolites at eight days after treatment. The hydrolysed metabolites constituted 43,45and 61 per cent of the total metabolites at 8, 16 and 24 days after treatment (Getzin and Chapman, 1960).

Carrots metabolized the absorbed phorate to phorate sulfoxide and phorate sulfone (Suett, 1971). Carrots grown in soils one year after treatment (as indicator crop) contained 0.04 ppm phorate sulfone at harvest (Lichtenstein et al., 1973). Phorate sulfoxide and phorate sulfone were detected along with parent compound at harvest in carrots grown in treated soils (Suett, 1974). Carrots

grown as indicator plants in soils treated one year prior to planting contained traces of phorate sulfoxide and 0.13 ppm of phorate sulfone at harvest (Chapman and Harris, 1980).

Sugar beet tops contained 0.77, 0.30 and 0.07 ppm phorate sulfoxide at 8, 16 and 24 days after application of phorate while no detectable residues of parent compound or its metabolites were present in the roots at the same periods (Reynolds et al., 1960).

Radish grown in treated soils contained 0.07 and 0.14 ppm of phorate sulfoxide and phorate sulfone at harvest while no detectable residues of metabolites could be found when the radish was grown in the same plot a year later (Chapman and Harris 1980).

Menzer and Ditman, (1968) found that most of the terminal residues of phorate recovered from treated spinach plants were in the form of phorate sulfone and oxyphorate sulfone.

Phorate when applied to seed furrow at planting resulted in residues of 1.6 and 0.05 ppm in potato tubers at 70 and 80 days after planting. Phorate sulfoxide was the only metabolite detected at both these stages apart from the parent compound (Kathpal et al., 1983).

From soil ^{14}C labelled phorate was absorbed and metabolized by mung bean plants. Leaves contained measurable quantities of phorate sulfoxide and phorate sulfone while no metabolites could be detected in seeds. Similar residue pattern was found in soy bean plants. However, the seeds contained measurable quantities of radio carbon but those were in the form of hydrolysis products (Talekar et al., 1977a).

Brassica plants treated with granular phorate contained four metabolites phorate sulfoxide, phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone along with the phorate precursor. The main metabolites detected at 15 days after application were phorate sulfoxide and its sulfone while oxyphorate sulfoxide and oxyphorate sulfone accounted for 0.26 ppm residue at that time (Krishnaiah and Kalra, 1978).

Lilly et al., (1958) reported that a mixture of oxidative metabolites was present in wheat, oats and barley at 4 and 6 leaf stages. The mixture was found to be 10 to 100 times more cholinesterase inhibitory than the parent compound.

Phorate sulfoxide, phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone were detected in corn plants

14 days after soil application of insecticide. While the parent compound was present oxyphorate could not be detected in any of the plant samples. (Leuk and Bowman, 1970). Silage prepared from corn grown in phorate treated soil contained 0.03 to 0.18 ppm phorate sulfone. However no mortality of Drosophila melanogaster (Meigen) was obtained when the flies were exposed to extracts of the silage for 96 hours (Lichtenstein et al., 1973). Corn plants grown in treated soils were found to metabolize phorate to phorate sulfoxide and sulfone. At seventeen days after treatment greens contained higher amounts of both the metabolites (0.36 and 0.44 ppm respectively) than roots which contained 0.30 and 0.08 ppm respectively (Lichtenstein et al., 1974).

Khajuria et al., (1973) found phorate sulfoxide and phorate sulfone in sorghum plants at levels ranging from 1 to 2 ppm at 35 days after application. No detectable residues of either the parent compound or any of its metabolites were found at 45 days.

Bermuda grass, Cynodon dactylon (L.) grown in treated soils contained phorate sulfoxide, phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone at 21 days after treatment (Leuk and Bowman, 1970).

Saunders and Getzin, (1973) studied the nature and extent of metabolism of phorate by Scots pine (Pinus sylvestris L.) seedlings. Five months after application phorate, phorate sulfoxide and phorate sulfone were detected in the stem, bark, needles, buds and roots of the seedlings, while the needles and bark additionally contained oxyphorate sulfoxide and oxyphorate sulfone Highest concentration of phorate, phorate sulfoxide and phorate sulfone were found in roots and needles, intermediate levels were found in bark and buds while the lowest amounts were found in stem. Phorate sulfoxide was the most predominant metabolite followed by phorate sulfone whereas phorate was present in the lowest amount. Application @ 2.0 g ai/plant resulted in higher amounts of phorate and metabolites in all the plant parts than application @ 1.0 g ai/plant. The authors concluded that the presence of higher concentration of phorate sulfoxide and phorate sulfone was due to the continuous absorption of these metabolites from the soil and from the metabolism of absorbed phorate within the plant tissues.

2.2.4 Factors affecting the metabolism and persistence of phorate in plants.

2.2.4.1 Soil type.

Appleman and Sears, (1946) and Foster et al., (1946) pioneered the idea that soil type influenced the effectiveness of insecticides applied in soil there by affecting their uptake by plants. They observed that when crops were grown in treated soils more insecticide was available in light soils than in heavy clays, mucks and peats. A similar finding was reported by Getzin and Chapman, (1960) who found that pea plants absorbed and translocated more phorate from sandy and silt loam soils than from muck soil. Lindley, (1963) obtained comparable biological efficiency with lesser amount of phorate in mineral soils than in soils with high organic matter content.

2.2.4.2 Soil moisture.

Soil moisture influences the persistence of pesticides in the soil since it can affect the adsorption of pesticides by various soil fractions. Water can compete with pesticides for adsorption sites resulting in the release of adsorbed pesticide molecules which in turn enhances the availability of the toxicants to plants (Barlow and Hadaway, 1959). Greater water solubilities of oxidative metabolites of phorate coupled with higher moisture might enhance uptake of the toxicants by plants (Getzin and Chapman, (1960).

Reynolds and Metcalf, (1962) reported that irrigation markedly increased the uptake of disulfoton and phorate from granules by cabbage. Similar observations were reported by Jefferson et al., (1964) in carnations and Ridgeway et al., (1965) in cotton. However Agnihotri et al., (1975) found that phorate persisted for longer (60 days) periods both in plants and soil in unirrigated conditions than under irrigated conditions (45 days). Brassica plants retained 10.7 per cent more residue under unirrigated condition than in irrigated condition.

2.2.4.3 Seasons

VanMiddlem and Baranowski, (1962) found that highest concentration of phorate in tomato plants usually coincided with preceding periods of relatively high temperature and rainfall.

2.2.4.4 Methods of application and doses of insecticide used

Application of higher doses of insecticide resulted in higher residues in wheat, barley and oats (Lilly et al., 1958). Persistence of residues was more in cabbage plants treated at higher doses of phorate when applied to both sandy and silt loams (Getzin and Chapman, 1960).

Longer residual toxicity due to higher rates of phorate application was noticed in barley as evidenced by lesser incidence of leaf aphid (Bhatia et al., 1973).

Methods of application were reported to influence the availability of insecticide and its biological activity in plants. Bowman and Casida, (1957) obtained higher uptake and persistence of phorate when the insecticide was applied as a foliar spray. While the insecticide persisted for 32 days under this method of application the persistence was 17 days when the plants were treated with soil drenches at the same dose. Higher rates of insecticides would be required for soil treatments than for foliar application but at the same time one granular application to soil would replace several foliar sprays (Getzin and Chapman, 1960). Topical applications to leaf whorls of sugar beets with granular phorate was found to be more effective than foliar sprays (Reynolds et al., 1960). Phorate applied by fluid drilling gel method left 3-9 times more residue in spring grown quick maturing carrots than when applied under bow wave method at the same dose (Suett and Whitefield, 1983).

2.3 Persistence and metabolism of phorate in soils

Kearney et al., (1969) defined persistence as the time required to reduce the pesticidal concentration to 75 to

100 percent of the amount initially applied to the soil.

Metabolism of phorate in soils can be rather rapid. Getzin and Shanks, (1970) could detect the conversion of 13 per cent of applied phorate to phorate sulfoxide in zero day samples. Menzer et al., (1970) recovered large amounts of phorate sulfoxide phorate sulfone and oxyphorate sulfoxide from phorate treated soils. They also recovered minute quantities of oxyphorate and oxyphorate sulfone. Waller and Dahm, (1973) reported that two days after incubation with labelled phorate the soil samples contained phorate, phorate sulfoxide and phorate sulfone which accounted for 21, 50 and 29 per cent of recovered radio activity.

2.3.1 Factors affecting the persistence and metabolism of phorate in soil

Factors responsible for the persistence and degradation of insecticides applied in the soil were classified by Edwards, (1966) according to their relative importance. He identified the structure, intrinsic stability solubility and volatility of the chemical as primary factors; type of soil, organic matter content, clay content, rainfall, irrigation leading to leaching as secondary factors, soil

temperature and microbial composition as tertiary factors and those like formulation, concentration of applied insecticide, mineral content and acidity of soil and plant cover as quartenery factors.

Phorate was considered to be chemically stable in neutral and acidic soils but prone to hydrolysis in alkaline soils. Phorate was reported to be relatively insoluble in water (17.9 ppm) and has a moderately low vapour pressure of 2.3×10^{-3} at 30°C. Thus the biological effectiveness of the insecticide mainly depends on the secondary, tertiary and quartenery factors.

2.3.1.1 Soil type.

Heavier soils and those with more organic matter retained amounts of pesticides for longer periods as compared to light soils. Getzin, (1958) found that drenches of phorate resulted in higher mortality of aphids on plants grown in treated sandy soils. The insecticide remained active for a longer period in sand and sandysoils than in silt loams, clay looms and muck soils. Patterson, (1962) observed that soil organic matter restricted the absorption of applied phorate by plants. According to Getzin and Rosefield, (1966) the time taken for the disappearance of 50 percent of applied dose was 10,6,4 and 1.5 weeks respectively in organic, sandy loams, silt loams and clay

loam soils. Mechanical composition of soil had the main influence on soil structure which in turn influenced the persistence of insecticides in soil (Yaron et al., 1967). Phorate persisted for only 2 - 4 weeks in fine sandy loams while the persistence was 4 weeks in muck soil as evidenced by toxicity to Acheta pennsylvanicus Burmeister, (Harris, 1969). Read, (1969) however could not obtain significant variations in persistence of phorate in sandy soils and fine sandy loams as evidenced by assay with first instar cabbage maggot. Suett, (1971) obtained longer persistence of phorate in peaty soil than in sandy loam. He reported that the time taken for the dissipation of residues to less than one per cent of the initially applied dose was 14 weeks in peaty soils as compared to 7 weeks in a sandy loam. Phorate was more mobile in brown forest soils than in degraded 'Chernozem' and black marsh soils indicating that soil adsorbency was important for the translocation of pesticides (Ostogic et al., 1972). Radio labelled phorate persisted more in plain field sand than in quartz sand giving residues of 0.46 and 0.01 ppm respectively when water was percolated through the treated soil for 17 days. Under non-percolating conditions the residues were 0.53 and 0.01 ppm respectively in the two soils (Lichtenstein et al., 1974). Laterite soil retained more phorate residues than red, black and kari soils

(Mithyantha and Perur, 1974). Under flooded conditions the degradation of phorate was observed to be fast in black clay loams when applied @ 1.25 kg ai/ha (Rajukkannu et al., 1977). Persistence of phorate was longer in forest soil followed by alluvial, red laterite and sandy soils under upland conditions (Visalakshy, 1977). She also reported the half life values of 48.5, 30.2, 16.8, 15.7 and 13.4 days, respectively, in these soils. Phorate was more persistent in muck soils than in sandy soils, the residues one year after application were 4.3 and 2.0 ppm, respectively (Chapman and Harris, 1980). More than 99 and 90 per cent of the initial concentration dissipated from sandy and muck soils, respectively, within a year after application (Harris and Chapman, 1980). Wang, (1980) reported lower persistence of phorate in quartz sand as compared to those in fine sand and silt loam.

However, Chapman et al., (1982) could not find significant differences in the persistence of phorate residues in different soil types. They found that phorate disappeared more rapidly in natural soils than in sterile soils, irrespective of the soil type.

2.3.1.2 Soil moisture

Gerolt, (1961) stated that soil humidity, which was directly related to the soil moisture content, could

influence the persistence of pesticides by influencing their initial adsorption or the rate at which they would be diffused into soil or the rate at which the adsorbed toxicants would be released from the soil constituents. Edwards, (1966) opined that soil moisture prevented the adsorption of the pesticide to the soil fractions by competing for the adsorption sites. In dry soil the insecticide cide would more readily be retained and bound in an inactive form until freed by moisture. This phenomenon would be more pronounced in lighter soils than in heavier soils. Chiou et al., (1979) on the other hand suggested an alternative theory that the effectiveness of the insecticide in soil depended on the solubility of insecticide which in turn decided the extent to which it was partitioned between the soil organic matter and soil solution. Thus more soluble insecticides persisted less in the soil. Sharma et al., (1980) reported a reduction in the toxicity of phorate with a reduction in moisture levels when white grubs (Lachnosterna consanguinea Blanch) were exposed to treated soil.

Soil moisture could affect the persistence of pesticides in soil by influencing the microbial activity. Chapman and Harris, (1980) found that contrary to expectation phorate persisted in sandy soil for a longer period than in

a muck soil since the sandy soils dried up quicker than mucks between irrigations thus curtailing the microbial degradation.

However significant differences in toxicity of phorate applied in soil could not be obtained by Read, (1969) under different levels of moisture in green house.

2.3.1.3 Solubility and leaching.

Getzin and Chapman (1960) using ^{32}P labelled phorate demonstrated the oxidation and subsequent leaching of metabolites from treated soils. Irrigation water leached significant amounts of the insecticide from the top layers to the lower layers. Getzin and Shanks, (1970) observed that all the oxidative metabolites were more water soluble than the parent compound and hence were liable to be leached by excess moisture. Schulz et al., (1973) studied the vertical and horizontal movement of phorate applied in soil and found significant amounts of phorate sulfoxide and phorate sulfone in the soil cores below the zone of application. Phorate sulfone constituted 95 per cent of the total recovered residues from this zone. Lichtenstein et al., (1974) later confirmed these findings. They found that when water was percolated through phorate treated soil, the lower layers contained 3.30 times higher concentration of phorate sulfone than the upper layers. Percolated water also contained

significant amounts of phorate sulfoxide and phorate sulfone. Talekar et al.,(1977 a) estimated ^{14}C labelled phorate in treated soil and in plants grown in the soil and attributed the vast portion of the unaccounted residue to loss by leaching.

2.3.1.4 Temperature.

Increased soil temperature accelerates the disappearance of insecticides applied in soil by increasing conversion to metabolites, volatilization and desorption. Higher temperature causes more rapid break down of insecticides in tropics than in temperate soils especially during wet season During dry season the break down could be considerably slowed (Edwards, 1966). Soil applied phorate disappeared after two months in summer while it persisted for longer period in autumn. There was almost no loss of residue during winter when the soils were frozen. Persistence of biological activity of phorate was slightly higher at 24°C than at 13°C. Phorate persisted for just more than a week after application in soil (Thompson, 1973). Longer persistence of phorate in winter was noted by Suett, (1975). Talekar et al., (1977 b) found that degradation of phorate applied in soil was rapid resulting in the recovery of 0.4 per cent of the applied dosage at the end of autumn season while the breakdown was further accelerated during hot rainy spring and summer

seasons. Phorate residues completely dissipated in 128, 117 and 109 days when the treated soil was incubated at 15, 30 and 45°C respectively (Verma, 1979). Srinivas et al., (1985) reported the half-life values for phorate were 18.47 and 32.02 days during summer and winter seasons respectively, when applied at a dose of 2.5 kg ai/ha in the soil for the control of groundnut pests.

2.3.1.5 Soil microbes

Ahmed and Casida, (1958) were the first to study the effect of micro organisms on the metabolism of phorate in soils. They reported that green alga, Chlorella and yeast, Torulopsis oxidized phorate to its sulfoxide at a fast rate. The conversion of phorate sulfoxide to oxyphorate sulfoxide was found to be slow. Both phorate sulfoxide and oxyphorate sulfoxide were found to be more stable than phorate and oxyphorate. The bacteria Psuedomonas fluorescens and Thiobacillus thiooxidans failed to oxidize phorate, but were effective in hydrolysing the compound. Getzin and Chapman, (1960) attempted to define the exact role of soil microbes in the metabolism and degradation of phorate applied to natural organic soils. They concluded that since soils could not be sterilized totally without affecting their structure it was difficult to define the exact role played by the microbes. According to the authors

the magnitude of phorate oxidation was not affected by a large reduction of microbial population by partial sterilization. Apart from oxidation a small but significant reduction of phorate sulfoxide to phorate was reported by Getzin and Shanks, (1970). The authors attributed the phenomenon to the action of soil microbes. This finding was later confirmed by Walter-Echols and Lichtenstein, (1977) who reported significant reduction of phorate sulfoxide to phorate in treated loam soils overlaid with lake mud. They also found that the metabolite was oxidized to its sulfone in the same microcosm. Since both the oxidation and reduction reactions failed to occur in autoclaved treated soil- lake mud-water microcosm they concluded that microbes were responsible for these conversions. Addition of glucose to non sterile system resulted in increased recovery of phorate confirming the role of soil microbes. Chapman et al., (1982) found that phorate, phorate sulfoxide and phorate sulfone disappeared at a relatively slower rate in sterile organic and mineral soils than in natural soils, further confirming the importance of soil microbes in degradation and metabolism of soil applied phorate.

2.3.1.6 Doses of insecticide used.

Way and Scopes, (1968) found that phorate when applied at 10 ppm, half the insecticide disappeared in 68 days whereas it persisted for nearly two years when applied at an abnormally high dose of 250 ppm in the same soil, indicating that the rate of degradation was slower at higher doses. Similar degradation pattern was reported by Schulz et al., (1973). They found that 0.6 and 2.70 per cent of the initial deposits were recovered at 4½ months after granules were incorporated in soil at 5 and 10 lb ai/ac.

Suett and Padbury, (1980) however found no differences in rate of decline of initial residues when phorate was applied to soil in continuous logarithmically changing doses ranging from 0.9 to 16 kg ai/ha. The initial residue declined by 35 per cent in all the doses.

2.3.1.7 Method of application

Parker and Dewey, (1965) found that phorate was lost more slowly when mixed thoroughly with soil than when applied to the soil surface. Lichtenstein et al., (1973) found that fifty per cent of the phorate applied to the soil surface disappeared in six days while 32 days were required for similar dissipation when the insecticide was mixed with the top 4-5 inch soil.

2.3.1.8 Volatilization.

Getzin, (1958) found that sandy soil, silt loam and muck soils lost 25, 20 and 18 per cent of applied radio active phorate within an hour of treatment. After this initial loss little or no volatalization occurred. Getzin and Chapman, (1960) reported that phorate volatilized rapidly from quartz sand and a steel surface with less than 10 per cent of applied radio activity remaining 24 hours after treatment. Harris, (1961) found that phorate was lost from treated soils due to volatilization as indicated by the fall in mortalities of the exposed fruit fly, D.melanogaster. Greater volatility of phorate and disulfoton was responsible for their movement through soil in a gaseous state (Burt et al., 1965). Lichtenstein et al., (1973) observed that the very rapid initial decline of residues of phorate in a soil surface treatment was due to volatilization. Considerable amounts of radio active phorate was lost from the plant and soil surface which could be due to volatilization. However, loss of residue due to volatilization was reported to be negligible by Ahmed et al., (1979). They found that phorate when applied at 1.1 and 19 kg ai/ha to soil resulted in disappearance rate constants of 0.053 and 0.043 respectively. In

contrast higher initial disappearance rates of 0.230 and 0.204 per day were reported by Chapman and Harris, (1980), when phorate was applied to sandy and muck soils, respectively. In an identical study Harris and Chapman, (1980) observed that the rate constants of phorate were 0.131 and 0.095 respectively. In both cases volatilization was reported to be responsible for the loss irrespective of soil type. Similar conclusions were drawn by Chapman et al., (1982) who observed that the initial loss of residue was greater due to volatilization than the subsequent rate of decline of residues which was due to other factors.

2.3.1.9 Conjugations and bindings of residues in soil and plants

Several workers have reported that a part of the phorate applied in soil got bound in soil and became unavailable for up take by plants. Similar bindings were also reported to occur in plant tissues following uptake and translocation of the pesticide. Getzin and Chapman, (1960) found the presence of bound residues in peas grown in treated soils. These unextractable factions constituted nearly seven per cent of the total residues on the fourth day to 29 per cent on the 24th day after treatment. They also found that

14-25 per cent of the applied radio active phorate was bound in sandy soil. Muck soils exhibited the highest rate of binding of 40 to 82 per cent. Conjugation with glycosides was reported to be the process by which organophosphates were bound in the soil (Bull, 1972). Binding was least in quartz sand. It was 1.81 per cent of applied radio active phorate while in sandy soils the rate of binding was 4.3 per cent (Lichtenstein et al., 1974). Talekar et al., (1977a) reported that 5.75 and 7.89 per cent of labelled (^{14}C) phorate was found in bound form in the tissues of mung beans and soybeans following soil treatments. Foliar application resulted in the binding of 5.75 and 4.80 per cent of the residue in these plants, respectively.

2.3.2 Toxicity of phorate and oxidative metabolites

2.3.2.1 Cholinesterase inhibition.

Bowman and Casida, (1957) demonstrated that phorate undergoes a series of enzymatic oxidations in cotton plants following uptake from soil. They reported that these metabolites had greater cholinesterase inhibitory properties than the parent compound. Similar findings were reported by Metcalf et al., (1957) with lemon plants. Changes in

the structure of insecticide resulted in higher anti-cholinesterase activity. Lilly et al., (1958) determined the extent of cholinesterase inhibition by phorate and five of its oxidative metabolites. They reported 50 per cent inhibition values expressed in μg per 50 ml blood plasma as 0.63, 2.5, 7.7, 32.5, 74 and 553 for oxyphorate sulfone, oxyphorate sulfoxide, oxyphorate phorate, phorate sulfone, phorate sulfoxide and phorate respectively. Thus the oxidative metabolites were 7.5 to 880 times more active anticholinsterase agents than the parent compound.

2.3.2.2 Toxicity to house fly

Bowman and Casida, (1958) studied the relative toxicities of phorate and its metabolites to house fly by topical application. They reported that oxyphorate was most toxic to house flies followed by oxyphorate sulfone, phorate, phorate sulfone, phorate sulfoxide and oxyphorate sulfoxide in the order of decreasing toxicity.

2.3.2.3 Toxicity to Drosophila melanogaster Meigen.

Lichtenstein, (1966) reported that phorate and some of its metabolites were not equi-toxic to D. melanogaster. The median lethal times of insects upon exposure to 2 μg quantities of toxicants were 3, 6 and 10 hrs. for phorate, phorate sulfone and phorate sulfoxide respectively. Schulz et al., (1973)

found that exposure of D. melanogaster to films containing a mixture of phorate (60.5 per cent), phorate sulfoxide (14.7 per cent) and phorate sulfone (24.8 per cent) resulted in a LT50 of 0.2 h while a similar exposure to films containing phorate sulfoxide (4.95 per cent) and phorate sulfone (95.05 per cent) resulted in a very high median lethal time of 30.5 h confirming that the parent compound was more toxic to the flies than the metabolites. This observation was later confirmed by Walter-Echols and Lichtenstein, (1977) who found that reduction of phorate sulfoxide to phorate in incubated soil resulted in a significant increase in toxicity to the flies.

2.3.2.4 Toxicity to field cricket, Acheta pennsylvanicus Burmeister

Relative toxicities of phorate and five of its metabolites to the first instar nymphs of A. pennsylvanicus were studied by Getzin and Shanks, (1970). They reported that when the insects were exposed to soils treated with these compounds, phorate and oxyphorate were found to be highly toxic followed by phorate sulfone and phorate sulfoxide. Oxyphorate sulfoxide and oxyphorate sulfone were least toxic. However, when topically applied to the insects oxyphorate sulfone and oxyphorate sulfoxide were found

to be most toxic metabolites followed by phorate sulfone, phorate sulfoxide and phorate. None of the oxidative metabolites exhibited fumigant action. Similar results were reported by Harris and Bowman, (1981) who found that phorate sulfone and phorate sulfoxide were more toxic than phorate to the cricket when applied topically.

2.3.2.5 Toxicity to aphids

Ho and Galley, (1982) studied the relative toxicicities of phorate (14c) and its oxidative metabolites to Aphis fabae (Scop.) after incorporation into artificial diets. Phorate was found to be the most toxic one to the aphids followed by phorate sulfone, phorate sulfoxide and oxyphorate sulfoxide. They also reported that aphids released on diets containing large amounts of oxyphorate sulfone were found wandering indicating that the acceptibility of the diet changed by the presence of metabolite.

2.4 Effect of phorate on the soil microflora

The application of phorate to the soil for the control of foliage feeding insects was reported to be stimulatory, harmful and harmless to different groups of soil microflora by different workers. It was reported in the comprehensive Technical Manual on

Thimet (Cyanamid International, 1970) that the use of phorate in soil would not affect soil fertility as rapid reestablishment of microbial equilibrium, after a temporary set back, seemed to occur as soon as the effect of insecticide was lost from the soil.

2.4.1 Effect on soil fungi

Tewari et al., (1972) reported an increase in the fungal population during the first three weeks following soil application of phorate. The increase was found to be significant (Kandaswamy et al., 1975) while a significant negative correlation was obtained between the fungal populations and concentration of phorate residue in soil (Visalakshy, 1977).

Chelliah, (1972) found that application of phorate @ 2.0 Kg ai/ha was toxic to soil fungi. Satpathy, (1974) on the other hand could find a mild antifungal effect due to the application of the insecticide to the soil around egg-plant seedlings. Similarly slightly depressive effects were reported by Murthy et al., (1976) in soils grown to okra while a 50 per cent reduction was reported by Gupta et al., (1985). Treatment in red loam soil also resulted in similar reductions (Das, 1986).

Fungal populations were not affected when the insecticide was applied at lower doses only (Chelliah, 1972) though similar result was obtained at even higher dose of 3.0 Kg ai/ha (Visalakshy et al., 1981) Varshney and Rana, (1987) also reported that fungal population was unaffected in treated sandy loams (@ 1.68 Kg ai/ha).

2.4.2 Effect on bacteria

Significant increase in the soil bacterial population was reported by Kandaswamy et al., (1975) following phorate application to paddy soil. Pandian and Balasubramanian, (1978) found the increase in bacterial population was proportional to the dose of phorate applied to soil. Visalakshy et al., (1981) also found similar stimulation seven months after application. Increase in bacterial population in treated red loam was reported by Das, (1986).

Azotobactor population were found to be adversely affected by phorate application by Chelliah, (1972). Singh and Gulati, (1972) reported on initial adverse effect of the insecticide on ammonification and nitrification bacteria, which was overcome during the later stages. Azotobactor populations were affected in groundnut soils (Tewari et al., 1972). A 50 per cent

reduction in bacterial colonies was reported by Satpathy, (1974). Rhizobial and bacterial populations were adversely affected by phorate when applied at 5.0 Kg ai/ha (Chendrayan and Prasad, 1976). Non rhizospheric bacterial populations also were adversely affected at three days after application (Murthy et al., 1976), and in cowpea soils (Visalakshy, 1977). The bacteriostatic effects of the insecticide persisted for four months (Gupta et al., 1985).

Application of phorate had no influence on the total soil bacteria (Chellaiah, 1972), and on Rhizobium in soils grown to okra (Murthy et al., 1976). Varshney and Rana, (1987) also obtained similar results in treated sandy loam soils.

2.4.3 Effect on actinomycetes

Tewari, et al., (1972) reported that phorate significantly increased the population of actinomycetes in soil throughout the season. A significant positive correlation between the actinomycete populations and residue levels was reported by Kandaswamy et al., (1975) in rice soils. Pandian and Balasubramanian, (1978) found that the increase in the actinomycete population was more in clay soils followed by black cotton, red and

sandy loams in a decreasing order. Visalakshy et al., (1981) reported that phorate applied to pepper vines stimulated populations of actinomycetes for seven months.

A negative correlation between the levels of residue and population of actinomycetes was reported by Visalakshy (1977). The reduction in population was as high as 50 per cent and it was noticed upto four months after application (Gupta et al., (1985). A significant initial reduction and subsequent increase in red loams (Das, 1986) alluvial, sandy and lateritic loam soils was noticed (Naseemabeevi, 1987).

Chellaiah, (1972) however did not find any relationship between the concentrations of phorate residues and actinomycete population which was confirmed later by Varshney and Rana, (1987).

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 Raising of banana crop

Field experiments were conducted at the Kerala Agricultural University, Vellanikkara Campus and in farmers' fields during 1983-87.

3.1.1 Variety

The banana cultivar Robusta with a duration of eleven months was used in the experiments.

3.1.2 Land preparation

Land was cleared of weeds followed by surface scraping. Pits of size 50 x 50 x 50 cm were dug at a spacing of 2.40 x 1.80 m for planting.

3.1.3 Selection of suckers

Three month old sword suckers of uniform size (60 cm height and 15-20 cm girth) were used. The uniformity of the age of suckers was ensured by labelling the suckers as they emerged around the mother plants. Care was taken to select pest and disease free suckers.

3.1.4 Planting

The suckers were planted upright in the centre of the pits with at least five cm pseudostem remaining

above ground level. Top soil was added to the pit around the sucker and pressed to avoid hollow air spaces.

3.1.5 Fertilizers

Fertilizers were applied at the rate of 160 : 160 : 320 g of N, P_2O_5 and K_2O per plant in two splits at two and four months after planting. The fertilizers were added to the soil in a band 60 - 75 cm around the base of plants.

3.1.6 Cultural operations

The plants were irrigated by pot watering on need basis during dry spells. Fields were weeded regularly by surface scraping. Side suckers were destroyed periodically upto 8 months. The bunches were harvested at maturity ie. eleven months after planting.

3.2 Culturing of test insect *P. nigronervosa*

Water suckers, which were unsuitable for normal planting, were planted in mud pots filled with potting medium. The plants were kept in the open and watered regularly. One month after potting, the pots were transferred and placed under partial shade. Twenty to 30 adult aphids collected from field were released on each potted plant which were then kept covered with fine

nylon nets to prevent the entry of predators. The adult females reproduced parthenogenetically and were viviparous too. They reproduced at the rate of 6-8 nymphs per female per day. There were four nymphal instars and the nymphs moulted as adults in 8-10 days. The females started laying nymphs two days after emergence. Adult longevity was observed to be 22-27 days. The population consisted of apterous forms initially. Alate forms appeared after one month when the population reached high density leading to over crowding. Fourth instar nymphs were used for bioassay. Direct collection of sedentary insects from the plants resulted in heavy mortality which was caused by the damage done to their mouth parts. Hence the aphids were disturbed by blowing air over the colony prior to collection and the moving insects were collected using a camel hair brush.

3.3 Assessment of the uptake, metabolism, persistence of phorate in the banana plant and the bio efficacy of the toxicant to *P. nigronervosa* when the insecticide was applied at the root zone/leaf axils of the plant

3.3.1 Layout

The experiment was laid out at the Kerala Agricultural University Campus at Vellanikkara during August 1983. A randomised block design was adopted and there

were nine treatments (vide Table 1) and each treatment was replicated six times. Each plot consisted of four plants planted as described in para 3.1.4.

3.3.2 Treatments

The treatments consisted of phorate applied at 1.25 or 2.5 g ai/plant at planting followed by 2.5 g ai/plant applied at 75 or 165 days after planting or 1.25 g ai/plant applied in the leaf axils at 75 or 165 days after planting. At planting the granules were evenly distributed around the sucker in the planting pit and were covered with top soil. At 75 or 165 days after planting the required quantity of insecticide was applied around the base of plants and it was raked into the soil and plants were watered. For the treatment at leaf axils the required quantity of Thimet 10 G to treat a plant (1.25 g ai) was equally distributed in five leaf axils at the crown at 75 or 165 days after planting.

3.3.3 Assay of the persistent toxicity of phorate to P. nigronervosa

Feeding cages were specially designed to confine P. nigronervosa to the feeding sites on the treated plants. The cage was made out of a transparent plastic tube of 2.5 cm dia cut at 10 cm length. The two ends of the tube were given slanting cuts. One end of the tube was closed with a

piece of muslin cloth fixed permanently in position using an adhesive. A ring like sponge piece was pasted to the other end of the cage using the adhesive to ensure that there was no gap between the cage and the plant when it was fixed on the curved surface of the leaf base. A pair of nails were provided outside the cage, near the open end, to facilitate the fixing of the same to the plant. Thirty last instar nymphs of P. nigronervosa were carefully transferred into each cage using a camel hair brush and the cages were fixed on the leaf bases using elastic bands as shown in Plate, 1. The insects settled to feed with in an hour after the fixing of feeding cages. The cages were covered with dry banana leaves to prevent direct exposure to sun and consequent heat.

The treated banana plants were exposed to the test insects at fortnightly intervals after treatment. The mortality of the insect was recorded 24 h after exposure. This was repeated till no mortality was observed. The observed mortalities were corrected using Abbot's formula (Finney, 1964) and persistent toxicity was assessed in terms of PT indices following the method of Pradhan, (1967).

3.3.4 Chemical assay of phorate and metabolites in the treated plants.

The content of phorate and four of its known toxic metabolites (phorate sulfoxide, phorate sulfone, oxyphorate

PLATE I Confining last instar nymphs of *P.nigronervosa* on the leaf sheath of treated plant.

PLATE I

sulfoxide and oxyphorate sulfone) were estimated at fortnightly intervals commencing from the fifteenth day after treatment.

3.3.4.1 Collection of plant samples

The third open leaves, counting outwards from the heart leaf, of two plants in each replication of the experiment were cut along with the upper 4 inch portion of the leaf sheath. The lamina was discarded and the petiole and leaf sheath portions were cut into small bits. From this, a 25 g sample was weighed out and stored in polythene bags for further processing.

3.3.4.2 Extraction and clean up of insecticide residue

The extraction and clean up of residues of phorate from the plant samples was done adopting the method described by Jain et al., (1974 a) with some modifications. The 25 g plant sample collected from each of the replications was macerated in an electric blender for three minutes along with 75 ml of a mixture of acetone and water (1:1). The macerate was transferred to a conical flask and shaken for 60 minutes on a mechanical shaker. The content in the flask was then filtered through a Buchner's funnel. The pulp was again extracted twice with 50 ml portions of solvent-water mixture. The filtrates were pooled and concentrated in a Kuderna Danish evaporator till the acetone was completely evaporated.

The concentrate was quantitatively transferred to a separating funnel and was shaken with 50 ml chloroform. The lower chloroform layer was collected. The process was repeated twice with 25 ml portions of fresh chloroform. The three chloroform extracts were pooled and concentrated over a water bath to a volume of 5-10 ml which was then subjected to a chromatographic column clean up.

A glass chromatographic column of 2.0 cm dia and 50 cm length was used. The lower end of the column was plugged with glass wool over which a five cm layer of activated charcoal was placed. Anhydrous sodium sulphate was carefully placed over the charcoal to a height of five cm. About five g of an adsorbent mixture containing a 2:2:1 mixture of activated charcoal, Celite 545 and magnesium oxide was placed over the sodium sulphate layer. The concentrated chloroform extract containing the residues was poured in to the top of the column. The coloumn was then eluted with 150 ml of Analar grade chloroform. The elutant was reduced in volume and made up to 100 ml. Phorate and metabolites present in the elutant were estimated.

3.3.4.3 Preparation of Chromatograms

Forty g silicagel G. (sufficient to draw three plates) was taken in a conical flask and 80 ml of distilled water was added to it. The flask was then shaken vigorously with

a swirling motion for two minutes. Care was taken not to trap air bubbles in the slurry while shaking. The slurry was then poured into the applicator whose exit gate was adjusted at 300 microns. Three clean dry glass plates of size 20 x 20 cm were laid on the base plate. A few drops of water was added under each plate to prevent lateral movement during application of silicagel. Leading edges of the glass plates were adjusted in a straight line to facilitate easy and even motion of the applicator.

The applicator containing slurry was placed over the glass plate, titled and drawn in a smooth motion. The coated plates were allowed to remain on the base plate undisturbed for twelve hours. The air dried chromatograms were activated in a hot air oven for ten minutes at 110°C. Interfering substances in the activated chromotograms were removed by washing in acetone. The lower ends of chromatograms were dipped in redistilled acetone in a chromatographic chamber. When the solvent front reached 15 cm level, the chromatograms were removed and air dried. Using a sharp pencil the level of solvent front was marked at a height of 12 cm from the bottom edge. Vertical colums of two cm width were also scored on the chromatogram.

3.3.4.4 Setting up of chromatographic chamber.

The chromatographic chamber was prepared by pouring 300 ml of a mixture of chloroform and methanol (98.25:1.75)

one hour prior to use. The "edge effect" on the chromatograms was minimized by dipping strips of filter paper in the solvent and fixing the same to the inner walls of the chamber. The chamber was then tightly closed and was kept for an hour.

3.3.4.5 Separation of phorate and metabolites in cleaned up plant extract

The parent compound and four of its metabolites were separated adopting the method suggested by Blinn, (1963).

3.3.4.5.1 Spotting the sample

Twenty ml of cleaned up plant extract (1/5th of 25 g plant sample extracted vide para 3.3.4.2) was pipetted out into a beaker and the solvent was allowed to evaporate completely. The residue was dissolved repeatedly in small quantities of dichloromethane and spotted quantitatively in one column of the prepared chromatogram (vide para 3.3.4.4) at a height of 2.0 cm from the bottom edge. Care was taken to confine the spot at the middle of the column. A similar sample was spotted in the adjacent column on the chromatogram in an identical position. Reference standards of phorate and metabolites were similarly spotted in identical position in five consecutive columns.

3.3.4.5.2 Developing the chromatograms

The spotted chromatogram was gently lowered into the chromatographic chamber so that the bottom edge dipped into

the solvent to a depth of 1.5 cm and the lid was replaced quickly. When the solvent front reached a height of the 12 cm mark the chromatogram was removed from the chamber and allowed to dry.

3.3.4.5.3 Visualization and extraction of residue from chromatogram.

Five ml of a five per cent palladium chloride solution and one ml Conc. HCl were taken in a 100 ml volumetric flask and the volume made up with 95 percent ethanol. The chromogenic solution was sprayed on the developed chromatogram keeping the first column in which the sample of unknown composition was spotted, covered with a polythene sheet. Spots holding the reference standards and the residues in the extract in the second column appeared yellow against a dull background. The parent compound developed colour quickly while the metabolites took about an hour for the development of colour. With reference to the standards spots containing phorate and oxidative metabolites of the extract in the second column could be identified and their Rf values were determined. Since the colour of palladium chloride interfered with the colorimetric quantitative estimation of the identified metabolites the unsprayed first column was used for this purpose. The unstained silicagel in the column corresponding to the stained spots in the second column were

scraped and quantitatively transferred to centrifuge tubes. Five ml of chloroform was added to each of these tubes and after shaking them for five minutes the tubes were centrifuged for three minutes at 3000 rpm. The supernatant was decanted to B19/26 test tubes. The process was repeated twice with two ml portions of chloroform and the supernatants were pooled.

3.3.4.6 Preparation of standard curves

Stock solutions of phorate and four of its oxidative metabolites were prepared by dissolving 100 mg of reference standards in 100 ml redistilled acetone. Different dilutions were prepared from which aliquots containing 2.5, 5, 10, 15, 20 and 25 µg each were pipetted out into separate B 19/26 test tubes. An acetone blank was also maintained simultaneously. A drop of propylene glycol was added to preserve the insecticide and the solvent was removed by blowing hot air. To each tube 0.4 ml of freshly prepared P-nitrobenzyl pyridine (two percent w/v) and cyclohexyl amine (two percent v/v) were added. After fitting air condensers to these tubes the bottom portions of the tubes were dipped into a preheated oil bath maintained at 175-180°C for three minutes. The tubes were then quickly transferred to an ice bath and were held for 30 seconds. The air condensers were then removed and three ml ethyl acetate was

added to each tube. The transmittance was recorded on a spectrophotometer at 540 nm. The absorbence values (y) were plotted against their corresponding concentrations (x) and the regression equations were computed ($y = ax \pm b$).

3.3.4.7 Quantification of residues in the extract

To the test tubes containing residues dissolved in solvent (vide para 3.3.4.5) a drop of propylene glycol was added and the solvent was evaporated completely. The colour was developed and read in a spectrophotometer (vide para 3.3.4.6). From the readings the quantities of residues were estimated using the relevent regression equations (vide para 3.3.4.6).

3.3.5 Recovery studies

Twenty five g each of uncontaminated plant samples collected from the control plants were taken in separate beakers. The samples were fortified, in duplicate, with 0, 2, 4, 6, 8 and 10 ppm of phorate and its oxidative metabolites separately. The insecticides were allowed to penetrate into the tissues for 6 hours and were then extracted and estimated as described in paras 3.3.4.2 and 3.3.4.6 and the recovery percentages computed.

3.4 Assessment of the absorption and translocation of phorate in plants of different growth stages and determining the waiting periods required to keep the residues in banana bunches below tolerance limits.

3.4.1 Layout and treatments

The experiment consisted of eight treatments each replicated eight times (vide Table 5).

The experiment was laid out in a randomized block design. Staggered planting was done so that plants in all age groups could be treated simultaneously. Twenty five g of phorate granules (@ 2.50 g ai/plant) were applied around the base of each plant (excluding control plants) and the insecticide was raked into the soil to a depth of 15 cm. The plants were watered immediately after treatment.

3.4.2 Assay of the persistent toxicity of phorate to *P. nigronervosa*

The treated plants were exposed to the test insect *P. nigronervosa*, as described under para 3.3.3 at intervals of 3, 10, 17, 24, 31, 45, 60 and 90 days after treatment and the mortalities were recorded at 24 hours after each exposure. The percentages of the dead insects were corrected

using Abbot's formula and the persistent toxicity of the insedticide was assessed in terms of PT indices following the method described by Pradhan, (1957).

3.4.3 Assessment of terminal residues in banana bunches

The terminal residues in mature unripe bunches used for culinary purposes and in ripe bunches used for table purpose were determined by chemical assay.

3.4.3.1 Collection of samples

Samples consisting of two fingers each from the top, middle and the bottom hands of the bunch from each plot were collected at harvest and brought to the laboratory. When the bunches ripened, samples of ripe fruits were collected similarly. The samples were used for estimating the residues.

3.4.3.2 Processing of samples and estimation of residues

The fruit samples collected were cut into small bits, mixed well, and composite samples were used for extraction of residues. The procedures followed for the extraction, clean up and estimation of residues and recovery studies described in para 3.3.4.2., 3.3.4.7 and 3.3.5 were adopted for this experiment also.

3.5 Assessment of the effect of seasons on the uptake, translocation and persistence of phorate in banana

3.5.1 Layout

The experiment was laid out at Vellanikkara Campus during the year 1985-86 with three treatments each replicated eight times. A randomized block design was adopted. One experiment was conducted during summer season and one in rainy season.

3.5.2 Treatments

Phorate was applied at the dose of 1.25 and 2.50 g ai/plant, as granules to the root zone at planting an untreated control was also maintained as one treatment. The method of application of granules was as described in para 3.3.2. Life saving irrigation was given during the summer season after the application of insecticide granules.

3.5.3 Assay of the persistent toxicity of phorate to *P. nigronervosa*

The exposures of the test insect on the treated plants were done at intervals of 15, 30, 45, 60, 75, 90 and 105 days after planting as described in para 3.3.3. Observations on the mortality of test insects, confined to the feeding sites,

were recorded at the end of 24 h after exposure.

3.5.4 Estimation of insecticide residues

The insecticide residues were estimated at fortnightly intervals starting from 15 days after application. The methods adopted for collection and processing of plant samples, extraction, clean up and estimation of residues were those described in paras 3.3.4.1, 3.3.4.2 and 3.3.4.7.

3.6 Assessment of the uptake and metabolism of phorate applied at root zone of banana plants grown in four types of soil

3.6.1 Layout and treatments

The influence of soil type on the absorption and metabolism of phorate in banana plants was studied through a series of experiments laid out in farmers' fields during 1987-88. Phorate was applied @ 2.5 g ai/plant at root zone at planting. An untreated control was also maintained. The treatment and control plots were replicated five times in sandy, clay loam (lateritic low land), lateritic upland and black cotton soil.

3.6.2 Description of soils

The physical and chemical properties of the four types of soil were as follows:

Constituents	Soil types			
	Sandy	Clay-loam (Lateritic low land)	Lateritic upland	Black cotton
Coarse sand	54.25%	35.75%	48.25%	15.50%
Fine sand	30.75%	9.75%	3.75%	7.00%
Silt	8.00%	16.50%	8.00%	21.90%
Clay	7.00%	38.00%	40.00%	35.60%
Organic matter	3.77%	7.75%	12.54%	20.46%

3.6.3 Observations

Plant parts were collected at fortnightly intervals starting from 7 days after application and were processed and the parent compound and its four oxidative metabolites present were estimated. The parent compound and its metabolites available in the treated soil at 0,7, 15, 45, 90, 120 and 180 days after treatment also were estimated.

3.6.3.1 Estimation of residues of the insecticide and its metabolites in the plant parts

The plant samples were collected, processed and residues of phorate and its metabolites were estimated as described the paras 3.3.4.1 to 3.3.4.7.

3.6.3.2 Estimation of residues of insecticide and metabolites in the soils

3.6.3.2.1 Collection of soil samples

Soil samples (100 g each) were collected from a depth of 15-20 cm from two locations around the base of each treated plant and the samples were mixed well and brought to the laboratory.

3.6.3.2.2 Processing of the soil samples

Soil samples were air dried, powdered and passed through a two mm sieve.

3.6.3.2.3 Extraction and clean up of residues of phorate

Fifty g of processed soil sample from each replicate was blended in an electrical blender for three minutes along with 150 ml of acetone - water mixture (1:1 v/v). The slurry was filtered through a Buchner's funnel. The filtrate was collected in a beaker and the acetone was completely removed over a hot water bath. The content was transferred to a separating funnel. The residue which may remain in the beaker was washed down into the funnel thrice using chloroform. Fifty ml chloroform was used for each sample. After shaking thoroughly for three minutes the contents were allowed to separate. The lower

chloroform layer was collected. The extraction was repeated twice with 25 ml portions of chloroform. All the chloroform extracts were pooled and concentrated in a Kuderna Danish evaporator to five ml. The extract was cleaned up as described in para 3.3.4.2.

3.6.3.2.4 Separation of metabolites and estimation of residues

An aliquot of cleaned up extract was used for the TLC separation of parent compound and the metabolites and they were quantified through colorimetry following the methods described in paras 3.3.4.4 to 3.3.4.7.

3.6.3.3 Recovery studies

Fifty g of uncontaminated, air dried and powdered samples of sandy, clay loam, lateritic upland and black cotton soils were taken in separate beakers and were mixed with stock solutions of the phorate and metabolites to give 0, 2, 4, 6, 8 and 10 ppm concentrations. To facilitate easy penetration of insecticides about 25 ml of chloroform was added to each sample. The fortified soil samples were extracted, cleaned up and the quantities of insecticide and metabolite present were estimated as described in paras 3.6.3.2.3, 3.3.4.2 to 3.3.4.7 and the recovery percentages were computed.

3.6.4 Assessment of the effect of phorate applied at the base of banana plant on the microflora of the soil

Microbial populations in samples of soils collected at harvest were studied adopting the serial dilution plate method described by Pramer and Schmidt, (1965). The ennumerations of colonies of bacteria, fungi and actinomycetes were done by using soil extract agar medium (Allen, 1953), Martin's rosebengal agar medium (Martin, 1950), and Kuster's agar medium (Kuster and William, 1964) respectively.

3.6.4.1 Preparation of media

The soil extract agar medium consisted of glucose 1.0 g, dipotassium hydrogen phthalate 0.5 g, yeast extract 0.5 g, agar agar 15g, soil extract 100 ml and water 900 ml. Soil extract was prepared by heating 400 g of soil with 400 ml of tap water for 30 minutes in an autoclave. A small amount of calcium carbonate was added and the soil suspension was passed through a double filter paper. The turbid filtrate was poured back into the filter and the process was repeated till the extract became clear. The soil extract was bottled and sterilized for 15 minutes at 20 p.s.i. in an autoclave. To prepare the medium, agar was boiled with

500 ml water and filtered through a muslin cloth. Glucose and dipotassium phthalate were dissolved in 400 ml water. To this 100 ml of soil extract was added and the contents were again boiled. It was transferred to conical flasks which were then plugged with non-absorbent cotton and was sterilized for 15 minutes at 20 p.s.i in an autoclave.

The Martin's rosebengal agar medium consisted of dextrose 10.0 g, peptone 5.0g, potassium dihydrogen phosphate 1.0g, magnesium sulphate 0.5 g, streptomycin 0.03 g, rosebengal one part in 30,000 parts of the medium, agar 15.0g and water 1000 ml. Agar was melted and boiled in a beaker with 500 ml distilled water. All the ingredients except streptomycin were dissolved in 500 ml of boiled water. Both the solutions were mixed and the medium was dispensed into conical flasks. The flasks were plugged with non absorbent cotton and sterilized for 15 minutes at 20 p.s.i. in an autoclave.

Kuster's agar medium consisted of starch 10.0 g, casein 0.3 g, potassium nitrate 2.0 g, sodium chloride 2.0g, dipotassium hydrogen phosphate 2.0g, magnesium sulphate 0.05 g, agar 15.0 g and water 1000 ml. The medium was prepared and sterilized in an autoclave for 15 minutes at 20 p.s.i.

3.6.4.2 Plating

One g each of the soil samples were transferred asceptically to conical flasks containing 100 ml of sterile distilled water. The flasks were shaken on a mechanical shaker for 20 min to achieve complete dispersion of soil. One ml of this suspension was pipetted out from each flask using a sterile pipette and transferred to 99 ml of sterile water each taken in another set of flasks. These flasks were shaken for 20 min on a mechanical shaker. Further one in 100 dilutions of the suspensions were made. The 10^{-4} dilutions were used for fungal counts while 10^{-6} dilutions were used for bacteria and actinomycetes.

One ml of desired dilution was transferred aseptically to a sterile petriplate using a sterile pipette. The petri plate was rotated gently so as to get a uniform spread of solution in the plate. Fourteen ml of the respective medium was poured into each petriplate. Uniform spread was ensured by rotating the plate gently. The petriplates were then incubated at room temperature.

3.6.6.3 Observations

The counts of fungal colonies were taken after one week of plating and 10 and 14 days after the plating the counts of bacteria and actinomycetes were recorded. The number of colonies in the petriplate was used for computing the microbial population in one g of sample based on dilution factor.

RESULTS

RESULTS

4.1 Assessment of the uptake, translocation, bioefficacy, persistence and metabolism of phorate applied at different doses, at the root zone and leaf axils of banana at different intervals after planting and observed at different intervals after treatment

The total phorate available in banana plants at different intervals after the application of the insecticide in the soil and in the leaf axils and the bioefficacy of the insecticide contents of the plants in controlling P. nigronervosa were assessed.

4.1.1 Insecticide content of banana plants at different intervals after treatment

The data and the results of statistical analysis are presented in Table-1 and Annexure 2.

When the insecticide was applied @ 1.25g ai/ plant to the root zone the highest absorption of 2.081 ppm at 15 DAT was observed in plants treated at 75 DAP. The absorption was significantly lower in plants treated at planting and at 165 DAP (1.679 and 1.217 ppm) respectively. At 30 DAT, the insecticide content in plants treated at planting (3.176 ppm) came on par with the plants treated at 75 DAP (3.016 ppm). In the plants

Table 1 Uptake, translocation and persistence of phorate applied at different doses at the root zone and leaf axils of banana observed at different intervals after treatment

Treatments			Total phorate content (ppm) in plant samples collected at different intervals after treatment (days)							
Site of Application	Dose g ai/ plant	Time of Application (DAP)	15	30	45	60	75	90	105	120
Root zone	1.25	0	1.679	3.176	7.502	9.750	5.450	2.337	0.302	ND
Root zone	1.25	75	2.081	3.016	4.799	3.088	1.887	1.133	0.154	ND
Root zone	1.25	165	1.217	2.439	2.085	1.416	0.997	0.054	ND	ND
Root zone	2.50	0	1.817	6.108	9.283	9.942	6.095	2.467	0.315	ND
Root zone	2.50	75	2.883	5.967	6.005	3.206	2.040	1.872	0.173	ND
Root zone	2.50	165	2.667	5.682	5.817	3.308	1.889	1.863	0.186	ND
Leaf axil	1.25	75	1.023	2.210	4.276	2.267	1.059	0.316	ND	ND
Leaf axil	1.25	165	0.846	2.188	2.079	1.043	0.092	ND	ND	ND
C.D.			0.332	0.375	0.354	0.803	1.104	0.284	NS	-

DAP = Days after planting

NS = Treatment effects not significant

ND = Non detectable

treated at 165 DAP phorate content was significantly lower (2.439 ppm). The insecticide level was significantly higher in plants treated at planting, in the observations done at subsequent stages, when compared to the treatments given at 75 and 165 DAP. The insecticide level in plants treated at planting time reached the peak level of 9.750 ppm at 60 days after treatment. The residues declined and reached non-detectable levels at 120 DAT. In plants treated at 75 DAP, the peak level of 4.799 ppm was observed at 45 DAT, after which the residues declined and reached non-detectable levels at 120 DAT. The peak absorption of 2.439 ppm was seen at 30 DAT in plants treated at 165 DAP. Residues fell to non-detectable levels at 105 DAT in this treatment.

When the plants were treated @ 2.50g ai/plant, the highest level of 2.883 ppm was observed at 15 DAT in plants treated at 75 DAP and it was on par with the content in plants treated at 165 DAP (2.667 ppm). Phorate in plants treated at planting was significantly low (1.817 ppm) at this stage. The insecticide content at 30 DAT showed a steep increase in all the treatments. The plants treated at planting contained the highest residue level (6.108 ppm) which was on par with that of the plants treated at 75 DAP (5.967 ppm). The lowest level of insecticide was observed in plants treated at 165 DAP (5.682 ppm). It was

significantly lower than the content in plants treated at the time of planting but was on par with the level in plants treated at 75 DAP.

The contents showed an increasing trend upto 60 DAT in plants treated at planting time reaching highest level of 9.942 ppm after which it declined and reached non-detectable levels at 120 DAT. In plants treated at 75 DAP the highest residue level of 6.005 ppm was seen at 45 DAT. The residues declined gradually and reached non-detectable levels at 120 DAT. The residue levels were least in plants treated at 165 DAP reaching peak level of 5.817 ppm at 45 DAT. The residue dissipated at a slower rate in this treatment and reached non-detectable levels at 120 DAT.

When the plants were treated at two doses of 1.25 and 2.50g ai/plant at planting, the difference in levels of insecticide at 15 DAT was not statistically significant. Significantly higher levels of insecticide residues were found in plants treated at the higher dose at 30 and 45 DAT while the treatments at the two levels were on par at 60, 75, 90 and 105 DAT. The level of residue observed at 30 DAT with the 2.5g dose was double but the difference was considerably reduced at 45 DAT and was least from 60 DAT onwards.

When treated at 75 DAP, significantly higher residue levels were obtained with higher dose at 15 DAT. At 30 DAT the residue in plants treated at higher dose was double of that observed at lower level. The difference reached the level of 50 per cent at 45 DAT and the treatments came on par at 60 DAT.

When treated at 165 DAP the residue levels obtained with the higher dose of 2.50g ai/plant were around 100 per cent more than the residues obtained with 1.25g ai/plant in all the observations.

When the insecticide was applied @ 1.25g ai/plant in leaf axils at 75 and 165 DAP, the uptake was higher (1.023 ppm) in the former treatment at 15 DAT. The content continued to be higher in plants treated at the base at 75 DAP during the entire period of observation. The peak residue level was seen at 45 DAT in plants treated at 75 DAP (4.276 ppm) and at 30 DAT in plants treated at 165 DAP (2.188 ppm). The insecticide residue persisted in plants up to 90 DAT in the former while the residue reached non-detectable levels at 90 DAT in the latter treatment.

4.1.2 Bioefficacy of phorate content of treated banana plants against P. nigronervosa

The data on the corrected mortalites of P. nigronervosa confined on treated plants, observed at different

intervals after treatment, were analysed statistically and the results are presented in Table-2 and Appendix.3.

When applied @ 1.25g ai/plant at 75 and 165 DAP, at the root zone, highest mortality was observed at 15 DAT in plants treated at 75 DAP (49.3 per cent) and it was followed by treatments done at 165 DAP and at planting, the mortality being 27.9 and 13.60 per cent respectively. The differences were significant. Though the mortalites showed an upward trend in all the treatments, the highest mortality (93.55 per cent) was recorded in plants treated at planting at 30 DAT. It was followed by treatments done at 75 and 165 DAP. Peak mortality of 100 per cent was seen at 45 DAT when the aphids were exposed on plants treated at planting. The highest mortalities of 87.80 and 70.9 per cent in plants treated at 75 and 165 DAP were observed at 30 DAT. The persistence of the pesticide was also similar in treatments done at planting and at 75 DAP, whereas the residue came to non-detectable levels earlier when treated at 165 DAP.

The mortality observed at 15 DAT with the increased dose of 2.5g ai/plant was 58.65 per cent in treatment done at 75 DAP and it was on par with the mortality in plants treated at 165 DAP (56.3 per cent) and both were significantly higher than the mortality in plants treated at planting

axils of banana, to P. nigronervosa observed at different intervals after treatment

Treatments			Corrected mortalities of P. nigronervosa exposed on treated plants at different intervals after treatment (days)							P	T	PT	ORE
Site of Application	Dose g ai/ plant	Time of application DAP	15	30	45	60	75	90	105				
Root zone	1.25	0	13.60 (22.61)	93.55 (74.30)	100.00 (90.00	100.00 (90.00)	89.05 (71.09)	29.50 (33.09)	3.30 (10.50)	105	61	6439	2
Root zone	1.25	75	49.30 (44.60)	87.80 (69.57)	75.50 (60.32)	44.75 (41.99)	26.80 (31.19)	9.05 (17.49)	1.70 (7.49)	105	42	4423	5
Root zone	1.25	165	27.95 (31.91)	70.90 (57.35)	61.75 (51.80)	31.85 (34.36)	12.05 (20.33)	1.80 (7.71)	0.00 (0.00)	90	34	3095	7
Root zone	2.50	0	36.10 (36.92)	97.50 (80.94)	100.00 (90.00)	100.00 (90.00)	93.30 (75.00)	30.60 (33.59)	2.45 (9.05)	105	65	6899	1
Root zone	2.50	75	58.65 (49.98)	99.81 (87.51)	95.05 (77.14)	49.80 (45.88)	24.40 (29.06)	12.60 (20.81)	0.00 (0.00)	90	56	5105	4
Root zone	2.50	165	56.25 (48.60)	94.75 (76.73)	99.75 (87.12)	55.80 (48.34)	38.45 (38.32)	17.10 (24.42)	2.45 (9.02)	105	52	5468	3
Leaf axil	1.25	75	14.95 (22.75)	76.40 (60.93)	71.60 (57.80)	26.75 (31.11)	13.95 (21.94)	3.50 (10.96)	0.00 (0.00)	90	34	3107	6
Leaf axil	1.25	165	13.35 (21.42)	68.80 (56.04)	60.25 (50.92)	20.40 (26.84)	3.15 (10.02)	0.00 (0.00)	0.00 (0.00)	75	33	2489	8
C.D.			7.37	5.91	8.46	3.29	8.15	10.41	NS	-	-	-	-

Figures given in parentheses are transformed values (angles)
P = Period (days)
T = Average toxicity (per cent)
PT = Persistent toxicity index
ORE = Order of relative efficacy

(36.1 per cent). At 30 DAT the mortalities in the three treatments came on par. Highest mortality was seen at 45 DAT in treatments done at planting and the mortalities declined sharply between 75 and 90 DAT. The peak mortalities observed in plants treated at 75 and 165 DAP were 99.8 and 99.7 respectively and these were observed at 30 and 45 DAT respectively. The mortality declined sharply between 45 and 60 DAT.

A comparison of mortalities obtained with the two doses of insecticide at planting revealed that the differences were significant in the observations recorded at 15 and 30 DAT only. When applied at 75 DAP, significantly higher mortalities were seen at 30, 45 and 60 DAT at the higher dose (99.8, 95.1 and 49.8 per cent) as compared to those obtained at the lower dose (87.8, 75.5 and 44.8 per cent respectively). However, the increases in mortalities were not proportional to the difference between the doses of the toxicant. When applied at 165 DAP, significantly higher mortalities were recorded with the higher dose throughout the period of the experiment.

In leaf axil filling, differences in the mortalities obtained in treatments done at 75 and 165 DAP were not significant at the early stages. The mortalities were significantly higher in plants treated at 75 DAP in the data recorded at 60, 75 and 90 DAT.

A comparison of the mortalities on plants treated at root zone and leaf axil at 75 DAP revealed that significantly higher mortalities occurred with root zone application at 15, 30, 45 and 60 DAT, while the differences were not significant at 75 and 90 DAT. Treatments done at 165 DAP also showed higher mortalities with root zone application at 15, 30, 75 and 90 DAT than with leaf axil filling.

Application of 1.25g ai/plant at root zone at planting gave an average toxicity of 61.33 per cent as compared to 42.13 and 34.38 per cent respectively in treatments done 75 and 165 DAP respectively. The PT indices showing the persistent toxicity of insecticide were 6439.5, 4423.5 and 3094.5 in the three treatments.

At the higher dose of the insecticide (2.50g ai/plant) the average toxicities were 65.71, 56.72 and 52.08 respectively in plants treated at 0,75 and 165 DAP. The highest PT value (6899.3) was seen in treatment done at the time of planting and it was followed by the treatment done at 165 (5468.3) and at 75 DAP (5404.7). The lowest average toxicity (33.19) and PT index (2489.3) were seen in leaf axil treatments at 165 DAP.

4.1.3 Correlation between the content of phorate in the plant and the mortalities of P. nigronervosa

Each treatment in the experiment (8 treatments vide Table - 1) was replicated six times and the residue content was

assessed at intervals of 15, 30, 45, 60 75 and 90 DAT. The varying residue contents in the above thirty six observations and the corresponding mortalities were statistically correlated. The results of statistical analysis of the data are presented in Table 2a. The highly significant positive correlation indicated that the mortality of the test insect was dependent on the insecticide residue content in the plant.

4.1.4 Dose-mortality relationship between the total phorate content in the plant and the aphid fed on the plant

The residue content of total phorate in the plant had been estimated at six occasions (15, 30, 45, 60, 75 and 90 DAT) after each application done at 0, 75 and 165 DAP. The insecticide was applied at two doses also. The absorption of the insecticide in the plant varied considerably and the residue content was not fully related to the dose of the toxicant applied to the soil or the period after treatment. The mortality of the insect would be caused by the insecticide content of the plant only. Hence an attempt was made to study the relationship between the insecticide content in the plant and the mortality of the test insect. For this purpose, from the basic data, the residue content in individual plants in the eighteen treatments listed in Table 2b were tabulated and the mortality recorded on the corresponding plants were also noted. These were later rearranged in a descending scale. Thus a graded series of doses of pesticide content in plants under each treatment and the mortalities caused by the

Table 2.a Correlation between the total phorate content (x) in banana plant parts, (from plants treated with insecticide at different intervals after planting), collected at different intervals after treatment (15, 30, 45, 60, 75 and 90 DAT) and the corresponding mortalities of P. nigronervosa (y) exposed on the plants

Site of insecticide application	Dose g ai/plant	Time of treatment DAP	Correlation coefficient
Root zone	1.25	0	0.7907 **
Root zone	1.25	75	0.6228 **
Root zone	1.25	165	0.8792 **
Root zone	2.50	0	0.8102 **
Root zone	2.50	75	0.9427 **
Root zone	2.50	165	0.9125 **
Leaf axil	1.25	75	0.8206 **
Leaf axil	1.25	165	0.9563 **

DAT = Days after treatment

DAP = Days after planting

** = Significant at 1% level

toxicant were obtained. These data were subjected to probit analysis (Finney, 1962) and the LD_{50} and LD_{90} values were calculated from the regression equations. The results are presented in Table 2b.

The data showed that the dosage of the total phorate required for causing mortality of P. nigronervosa varied in the observations recorded at different intervals after treatment. These variations were not high upto 60 DAT. In the treatments done at 0, 75, 165 DAP the LD_{50} values upto 60 DAT ranged from 1.624 to 2.196, 2.179 to 2.711 and 1.921 to 2.603 ppm, respectively. In the observations recorded at 75 and 90 DAT, in the above treatments, the LD_{50} values were 3.506 and 3.359, 3.147 and 3.234, 3.239 and 3.614 ppm, respectively.

The data also showed that the LD_{50} values relating to the observations done at different intervals after the treatments given at 0, 75, and 165 DAP, which were at widely varying growth stages of the plant, did not show significant variations. When observations at 15 DAT (application at 0, 75 and 165 DAP) were made on 15, 90 and 180 day old plants, the LD_{50} values relating to the above observations were 2.196 2.533 and 1.985 respectively. The same trend was seen in the observations taken at subsequent intervals after treatment also. The result indicated that the age of the plant was not adversely affecting the toxicity of phorate residues in the plant. The trends seen in the LD_{90} values were similar to those of LD_{50} values.

The LD_{50} of the total phorate in the leaf sheath upto 60 DAT ranged from 1.624 to 2.625 ppm and from 75 to 90 DAT the values ranged from 3.147 to 3.614 ppm. The LD_{90} values of the total phorate upto 60 DAT ranged from 2.544 to 4.406 and from 75 to 90 DAT, they ranged from 4.201 to 5.464 ppm, respectively.

4.1.5 Metabolism of phorate absorbed by banana plants

Data relating to the experiment are presented in Table 3.

When applied at the rate of 1.25g ai/plant at planting, the phorate content obtained at 15 DAT (0.965 ppm) was almost on par with the content in plants treated at 75 DAT (0.863 ppm). But the content in plants treated at 165 DAT was very low (0.489 ppm). The content increased in plants treated at planting at a rapid rate reaching the levels of 1.369, 2.986 and 3.009 ppm at 30, 45 and 60 DAT, while in plants treated at 75 DAP the corresponding residues were 1.286, 1.618 and 0.801 showing a less efficient absorption and in treatment done at 165 DAT the residues were 0.932, 0.472 and 0.116 showing that the absorption was still lesser with advancement of age. While the peak in the content of phorate was seen at 45 DAT in the first two treatments, the peak was seen at 30 DAT in the third treatment. The residue persisted upto 90 DAT in plants treated at planting,

after planting and as observed at different intervals after treatment.

Treatments				Contents of phorate/metabolites (ppm) in samples colle at different intervals after treatment (days)						
Site of application	Dose g ai/ plant	Time of application DAT		15	30	45	60	75	90	105
Root zone	1.25	0	Phorate	0.965	1.369	2.986	3.009	1.095	0.302	ND
			Phorate sulfoxide	0.714	0.984	2.193	1.634	1.173	0.069	ND
			Phorate sulfone	ND	0.596	1.679	1.956	0.895	0.433	ND
			Oxyphorate sulfoxide	ND	0.060	0.483	1.825	1.083	0.651	ND
			Oxyphorate sulfone	ND	0.203	0.161	1.326	1.204	0.882	0.302
Root zone	1.25	75	Phorate	0.863	1.286	1.618	0.801	0.326	ND	ND
			Phorate sulfoxide	0.657	0.755	0.837	0.772	0.842	0.239	ND
			Phorate sulfone	0.087	0.286	0.748	0.625	0.347	0.128	ND
			Oxyphorate sulfoxide	0.318	0.414	0.820	0.412	0.372	0.580	0.074
			Oxyphorate sulfone	0.156	0.275	1.376	0.478	ND	0.186	0.080
Root zone	1.25	165	Phorate	0.489	0.932	0.472	0.116	0.087	ND	ND
			Phorate sulfoxide	0.343	0.846	0.785	0.515	0.132	ND	ND
			Phorate sulfone	0.237	0.348	0.348	0.407	0.286	ND	ND
			Oxyphorate sulfoxide	0.087	0.200	0.262	0.160	ND	ND	ND
			Oxyphorate sulfone	0.061	0.113	0.218	0.218	0.477	0.054	ND
Root zone	2.50	0	Phorate	1.108	2.039	2.979	3.041	1.786	0.224	ND
			Phorate sulfoxide	0.409	1.222	1.425	1.697	1.106	0.353	ND
			Phorate sulfone	0.169	1.336	1.407	1.997	0.995	0.662	0.316
			Oxyphorate sulfoxide	0.131	0.708	1.870	2.683	1.064	0.597	ND
			Oxyphorate sulfone	ND	0.803	1.557	2.221	1.184	0.631	ND
Root zone	2.50	75	Phorate	1.169	1.608	1.318	0.991	0.208	ND	ND
			Phorate sulfoxide	0.808	1.450	1.302	0.548	0.786	0.530	ND
			Phorate sulfone	0.206	0.988	1.046	0.920	0.446	0.510	ND
			Oxyphorate sulfoxide	0.515	0.840	1.188	0.604	0.544	0.682	0.093
			Oxyphorate sulfone	0.185	1.081	1.218	0.143	0.165	0.147	0.080
Root zone	2.50	165	Phorate	0.906	1.492	1.908	0.887	0.538	ND	ND
			Phorate sulfoxide	0.887	1.438	1.667	0.917	0.549	0.530	ND
			Phorate sulfone	0.285	0.942	0.198	0.320	0.336	0.510	0.106
			Oxyphorate sulfoxide	0.238	0.733	1.020	0.361	0.305	0.416	0.080
			Oxyphorate sulfone	0.352	1.077	1.024	0.823	0.131	0.406	ND
Leaf axil	1.25	75	Phorate	0.132	1.062	0.872	0.636	0.187	0.041	ND
			Phorate sulfoxide	0.269	0.286	0.727	0.812	0.497	ND	ND
			Phorate sulfone	0.430	0.604	0.820	0.408	0.110	0.037	ND
			Oxyphorate sulfoxide	0.195	0.258	0.895	0.190	0.139	0.098	ND
			Oxyphorate sulfone	ND	ND	1.034	0.221	0.126	0.140	ND
Leaf axil	1.25	165	Phorate	0.255	0.565	0.605	0.481	ND	ND	ND
			Phorate sulfoxide	0.321	0.678	0.619	0.420	0.092	ND	ND
			Phorate sulfone	0.085	0.397	0.205	0.108	ND	ND	ND
			Oxyphorate sulfoxide	0.185	0.308	0.360	0.034	ND	ND	ND
			Oxyphorate sulfone	ND	0.240	0.290	ND	ND	ND	ND

DAP : Days after planting

ND : Not Dectectable

while in the other two treatments it reached zero level during that period.

The only metabolite observed at 15 DAT, in plants treated at planting (@ 2.50g ai/plant), was phorate sulfoxide while in the other two treatments all the metabolites could be detected. The content of the metabolites showed an increase, parallel with that of phorate and reached the peak at 60 DAT, but the drop in content was faster for phorate sulfoxide than for phorate during 60 to 75 DAT indicating that the absorption of the toxicant from the soil had ceased during the period while the oxidation of the residue in the plant was continuing. Same trend was seen with reference to the content of the phorate and its metabolite, phorate sulfoxide when treated at 75 and 165 DAP. After reaching the peak, the phorate content was falling while the phorate sulfoxide content was maintaining relatively higher levels in subsequent observations.

Phorate sulfone was first detected at 30 DAT in plants treated at planting (0.596 ppm) and it reached the peak at 60 DAT (1.956 ppm) and then declined from 75 to 90 DAT (0.433 ppm). The content of this metabolite in plants treated at 75 DAP was 0.087 ppm at 15 DAT and in subsequent observations upto 45 DAT the same trend as in the plants treated at planting was seen. But the content of phorate sulfone in the former treatment was only half of the latter in observations from 75 DAT.

Oxyphorate sulfoxide was also first detected at 30 DAT and it reached the peak of 1.825 ppm at 60 DAT and declined to non-detectable level at 105 DAT, when treated at the time of planting. When treated at 75 DAP, it was detected in the assay done at 15 DAT but the quantity was only 0.318 ppm. As in the case of the previous metabolites the content increased and reached the peak at 45 DAT and then showed a decline. But here the content was found to increase again at 90 DAT and the residue persisted even at 105 DAT. When treated at 165 DAP the residue showed a sudden increase from 0.087 to 2 ppm between 15 and 30 DAT and it reached the peak of 2.25 ppm at 45 DAT. Then the decline was sudden and the residue became undetectable at 75 DAT.

Oxyphorate sulfone which was first detected at 30 DAT (0.06 ppm) increased to the peak of 1.326 ppm to 60 DAT and it persisted upto 105 DAT in plants treated at the time of planting. When treated at 75 DAP, the increasing trend was seen upto 75 DAT and the residue persisted upto 105 DAT. As in the case of other metabolites the content was lower in the second treatment than in the first in all observations. When treated at 165 DAP, as in the case of oxyphorate sulfoxide, there was a sudden increase in the content of the residue between 15 and 30 DAT and the peak was obtained at 45 DAT. The content remained the same at 60 DAT and then showed

a rise at 75 DAT and suddenly declined at 90 DAT and became non detectable at 105 DAT.

With the increase in dosage of phorate from 1.25 to 2.5g ai/plant the influence of the time of application on the absorption and translocation of the insecticide was seen narrowed down. The phorate content at 15 DAT in plants treated at 0, 75 and 165 DAP were 1.108, 1.169 and 0.906 ppm respectively, at 30 DAT the residues were 2.039, 1.608 and 1.492 respectively and at 45 DAT residues were 2.979, 1.318 and 1.908 ppm respectively. Dissipation of the residue was faster in later treatments than in the treatments done at planting. In the former phorate became non-detectable at 90 DAT while in the latter it reached the non-detectable level only at 105 DAT.

When treated at planting, the content of all the four metabolites rose gradually from 15 DAT and reached the peak at 60 DAT. The dissipation occurred fully at 105 DAT except in the case of phorate sulfone which showed some persistence at 105 DAT.

When treated at 75 DAP, the peak levels of all the metabolites were observed at 45 DAT and the residues of phorate sulfoxide and phorate sulfone reached non-detectable levels at 105 DAT while the residues of oxyphorate sulfoxide and oxyphorate sulfone persisted to the levels of 0.093 and 0.080 ppm respectively during the period.

When treated at 165 DAP also, the metabolites reached the peak at 45 DAT. The residues of phorate and oxyphorate sulfone became undetectable at 105 DAT while the other two metabolites persisted then. The content of the metabolites also showed a narrowing trend with the advancement of the age at which the treatments were made.

With the doubling of dosage of phorate, applied at the time of planting, corresponding increase in the content of phorate or its metabolites were not observed in plants at different intervals after treatment. When treated at planting the phorate content was higher with 2.5g ai/plant dose at 15, 30 and 75 DAT only. At 15 DAT phorate sulfoxide was the only metabolite observed within plants treated at planting @ 1.25g ai/plant while all metabolites except oxyphorate sulfoxide were detected in plants treated with 2.5g ai/plant dose. Phorate sulfoxide was at higher level with lower dose at 15 and 45 DAT and even after that the content remained almost on par at two levels. The content of oxyphorate sulfoxide and oxyphorate sulfone were found at higher levels from 30 to 60 DAT in plants treated with higher dose of phorate indicating a faster metabolic rate in the latter treatment. But at 75 and 90 DAT the differences between the two doses were not maintained.

When the treatment was done at 75 DAP also, the content of phorate and its four metabolites, observed at different intervals after treatment, did not show proportionate increase with the doubling of dosage except in the case of oxyphorate sulfoxide, obtained at 15, 30 and 45 DAT.

When applied at 165 DAP an increase in absorption of phorate and a higher metabolism with the increased dosage were obvious in the data. A longer persistence of the metabolites was observed in plants treated with 2.5g ai/plant of phorate than with 1.25g ai/plant and significant quantities of phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone were detected in the treatment with higher dose at 90 DAT while these metabolites became undetectable at the lower dosage of the pesticide then. Same trend was seen with oxyphorate sulfoxide and oxyphorate sulfone at 105 DAT.

When applied at the leaf axil the treatment done at 75 DAP resulted in the longer persistance of phorate content in plant than when applied at 165 DAP. Residues were detectable at 75 and 90 DAT in the former while it came below detectable level in the latter during that period. When the basal application and leaf axil fillings were compared, the former showed higher content of phorate and all the metabolites at all intervals at which the samples were collected.

4.1.6 Percentage distribution of phorate and its metabolites in banana plants treated with the insecticide at different intervals after planting and as observed at different intervals after treatment

The percentage of phorate and its metabolites in banana plants treated with the insecticide at different intervals after planting are presented in Table - 4.

When treated at the time of planting, at 1.25g ai/plant, percentage of phorate and phorate sulfoxide in the plant showed a gradual decline from 15 DAT (57.47 and 42.53 per cent respectively) to 90 DAT (12.92 and 2.95 per cent). Phorate sulfone showed an increase upto 45 DAT (0 to 22.30 per cent) and gradually declined at 90 DAT (18.53 per cent). Oxyphorate sulfoxide and oxyphorate sulfone, in general, manifested an increasing trend from 30 to 90 DAT. Oxyphorate sulfone alone could be detected at 105 DAT and hence accounted for 100 per cent residue in the plant.

When applied at 75 DAP also the trend in the percentage of phorate and phorate sulfoxide remained the same as in the previous treatment. Percentage of phorate sulfone showed an increasing trend upto 60 DAT (4.18 to 20.24 per cent) and then declined at 90 DAT (11.29 per cent). The percentages of oxyphorate

Table 4 Percentage distribution of phorate and its metabolites in banana plants treated with the insecticide at different intervals after planting and as observed at different intervals after treatment.

Treatments			Percentages of phorate/metabolites in samples collected at different intervals after treatment (days).						
Site of application	Dose g ai/ plant	Time of application DAT		15	30	45	60	75	90	105
Root zone	1.25	0	Phorate	57.47	43.10	39.80	30.86	20.09	12.92	-
			Phorate sulfoxide	42.53	30.98	29.23	16.76	21.52	2.95	-
			Phorate sulfone	-	18.77	22.38	20.06	16.42	18.53	-
			Oxyphorate sulfoxide	-	1.89	6.44	18.72	19.87	27.86	-
			Oxyphorate sulfone	-	6.39	2.15	13.60	22.09	37.74	100
Root zone	1.25	75	Phorate	41.47	42.64	21.21	25.94	17.28	-	-
			Phorate sulfoxide	31.57	25.03	17.44	23.38	44.62	21.09	-
			Phorate sulfone	4.18	9.48	15.59	20.24	18.39	11.29	-
			Oxyphorate sulfoxide	15.28	13.73	17.09	13.34	19.71	51.19	48.05
			Oxyphorate sulfone	7.49	9.12	28.67	15.48	-	16.42	51.95
Root zone	1.25	165	Phorate	38.44	38.21	22.64	7.94	8.73	-	-
			Phorate sulfoxide	26.96	34.69	37.65	35.25	13.24	-	-
			Phorate sulfone	18.63	14.27	16.69	27.86	28.69	-	-
			Oxyphorate sulfoxide	6.84	8.20	12.57	10.95	-	-	-
			Oxyphorate sulfone	4.79	4.63	10.46	14.92	47.84	100	-
Root zone	2.50	0	Phorate	60.98	33.88	32.24	30.59	29.30	9.08	-
			Phorate sulfoxide	22.51	20.31	15.42	17.07	18.15	14.31	-
			Phorate sulfone	9.30	22.20	15.23	20.09	16.32	26.83	100
			Oxyphorate sulfoxide	-	11.76	20.24	26.98	17.46	24.20	-
			Oxyphorate sulfone	7.21	13.34	16.85	22.34	19.43	25.58	-
Root zone	2.50	75	Phorate	40.54	26.95	21.71	30.42	9.69	-	-
			Phorate sulfoxide	28.02	24.30	21.14	16.82	36.61	28.47	-
			Phorate sulfone	7.15	16.56	17.23	28.25	20.77	27.24	-
			Oxyphorate sulfoxide	17.86	14.08	19.56	18.54	25.34	36.43	53.76
			Oxyphorate sulfone	6.42	18.11	20.06	4.39	7.69	7.85	46.24
Root zone	2.50	165	Phorate	33.97	26.29	32.80	26.81	28.48	-	-
			Phorate sulfoxide	33.26	25.31	28.66	27.72	29.06	28.45	-
			Phorate sulfone	10.68	16.58	3.40	9.67	19.38	27.43	56.99
			Oxyphorate sulfoxide	8.92	12.90	17.53	10.91	16.14	22.33	43.01
			Oxyphorate sulfone	13.19	18.95	17.60	24.88	6.93	21.79	-
Leaf axil	1.25	75	Phorate	12.87	45.97	20.39	23.85	17.66	12.97	-
			Phorate sulfoxide	26.22	12.38	17.05	30.45	46.93	0	-
			Phorate sulfone	41.91	26.15	19.18	15.29	10.39	11.71	-
			Oxyphorate sulfoxide	19.01	11.17	20.93	7.12	13.12	31.02	-
			Oxyphorate sulfone	-	-	24.18	8.29	11.89	44.30	-
Leaf axil	1.25	165	Phorate	30.14	25.82	29.10	46.12	-	-	-
			Phorate sulfoxide	37.94	30.99	29.77	40.26	100	-	-
			Phorate sulfone	10.05	18.14	9.86	10.35	-	-	-
			Oxyphorate sulfoxide	21.87	14.08	17.32	3.26	-	-	-
			Oxyphorate sulfone	-	10.97	13.95	-	-	-	-

DAT : Days after treatment

sulfoxide and oxyphorate sulfone did not show a definite trend and both remained detectable upto 105 DAT and then their presence was more or less same (48.05 and 51.95 per cent respectively).

When applied at 165 DAP, the percentages of phorate and phorate sulfoxide were comparatively lower than those observed in treatments done at the time of planting and at 75 DAP. In general, the residues of phorate and phorate sulfoxide showed a declining trend upto 75 DAT (38.44 to 8.73 and 26.96 to 13.24 per cent respectively) and became non-detectable at 90 DAT. The percentages of the remaining metabolites, phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone, showed a broadly increasing trend in the observations made from 15 DAT to 90 DAT.

With an increase in the dosage from 1.25g ai to 2.5g ai/plant the percentage of phorate and phorate sulfoxide residues in the plant did not show corresponding increase in treatments done at the time of planting, 75 DAP and 165 DAP in all the observations recorded at 15 to 90 DAT.

When applied at the time of planting, at 1.25g ai/plant, phorate sulfone was first detected at 30 DAT (18.77 per cent), whereas in the higher dose 9.3 per cent of the residue content was constituted by this metabolite at 15 DAT. The percentages in the subsequent observations did not show noticeable differences between the two doses upto 75 DAT. However, at 90 DAT the content was higher in plants treated with 2.5g ai/plant

(26.83 per cent). With the increase in the dosage of phorate applied to the soil, the percentages of oxyphorate sulfoxide and oxyphorate sulfone residue in the plant showed a significant increase in most of the treatments and observations.

The percentages of phorate and phorate sulfoxide ranged from 12.87 to 45.97 and from 12.38 to 46.93 respectively, when the insecticide was applied in the leaf axils at 75 DAP. When applied at 165 DAP, their percentages ranged from 25.82 to 46.12 and 29.77 to 100 respectively. When applied at 75 DAP, the percentages of phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone were comparatively higher than the percentages of these metabolites in the treatment done at 165 DAP.

4.1.7 Correlation between the content of phorate and its metabolites in banana observed at different intervals after treatment and the mortalities of P. nigronervosa at corresponding periods and the results of path coefficient analysis of data.

The relevant data and the results of statistical analysis of the same are presented in Table-5 and Fig-1.

When phorate was applied at the time of planting at root zone @ 1.25g ai/plant, the correlation coefficient between phorate sulfone and the mortality of aphids (0.826) alone showed a positive and significant trend. The correlation coefficients relating to the remaining factors were positive but not statistically significant.

Table 5 Correlations between the mortality of P. nigronervosa confined to treated plants at different intervals after treatment and the contents of phorate and its metabolites observed at corresponding intervals, and the results of path coefficient analysis of the data.

Treatments			Correlation coefficient between aphid mortality (y) and contents of phorate and its metabolites (x_1 to x_5)	Direct and indirect effects of					
Site of application	Dose g ai/plant	Time of application DAT		Phorate (x_1)	Phorate sulfoxide (x_2)	Phorate sulfone (x_3)	Oxyphorate sulfoxide (x_4)	Oxyphorate sulfone (x_5)	Residual effect
Root zone	1.25	0	(x_1) 0.7551	3.72232	-0.12109	-0.77037	-2.41986	0.34320	0.0134
			(x_2) 0.7998	3.45916	-0.13030	-0.70094	-1.66544	-0.16268	
			(x_3) 0.8258*	3.35791	-0.10695	-0.85397	-3.84709	2.27590	
			(x_4) 0.4648	1.68845	-0.04069	-0.61606	-5.33281	4.76591	
			(x_5) 0.2815	0.24344	0.00404	-0.37037	-4.84326	5.24764	
Root zone	1.25	75	(x_1) 0.9650**	1.24129	0.05738	0.01042	0.01165	-0.35573	0.0181
			(x_2) 0.5737	0.80249	0.08876	0.01752	-0.06359	-0.27148	
			(x_3) 0.3582	0.45257	0.05442	0.02657	0.48473	-0.66209	
			(x_4) 0.1672	0.01701	-0.00664	0.01629	0.85010	-0.70956	
			(x_5) 0.4846	0.53301	0.02909	0.02283	0.72811	-0.82844	
Root zone	1.25	165	(x_1) 0.8694*	0.19198	0.83308	-0.11467	0.00570	-0.04669	0.0077
			(x_2) 0.9837**	0.15355	1.04161	-0.20168	0.00840	-0.01818	
			(x_3) 0.6526	0.08167	0.77934	-0.26955	0.00609	0.05507	
			(x_4) 0.9228*	0.12506	1.00089	-0.18761	0.00874	-0.02427	
			(x_5) -0.1715	-0.06470	-0.13666	-0.10715	-0.00153	0.13853	
Root zone	2.50	0	(x_1) 0.9359*	1.93188	-1.58302	1.00818	-1.82908	1.40789	0.0105
			(x_2) 0.9678**	1.84031	-1.66179	1.14351	-1.92425	1.56997	
			(x_3) 0.8996*	1.60192	-1.56291	1.21585	-1.99901	1.64371	
			(x_4) 0.7540	1.59284	-1.44144	1.09560	-2.21841	1.72536	
			(x_5) 0.7836	1.54551	-1.48248	1.13560	-2.17493	1.75986	
Root zone	2.50	75	(x_1) 0.9580**	0.66573	0.17052	0.02924	0.03241	0.06060	0.0061
			(x_2) 0.8845*	0.49107	0.23099	0.03041	0.05020	0.08182	
			(x_3) 0.6485	0.35058	0.12660	0.05548	0.05250	0.06334	
			(x_4) 0.6599	0.30547	0.16432	0.04127	0.07057	0.07825	
			(x_5) 0.8718*	0.46353	0.21729	0.04040	0.06349	0.08698	
Root zone	2.50	165	(x_1) 0.9939**	1.05113	-0.05619	0.00207	-0.03364	0.03053	0.0104
			(x_2) 0.9683**	1.01507	-0.05818	0.01457	-0.03759	0.03443	
			(x_3) 0.1249	0.02060	-0.00802	0.10572	-0.00603	0.01262	
			(x_4) 0.7788	0.82682	-0.05114	0.01490	-0.04276	0.03099	
			(x_5) 0.8104	0.82251	-0.05135	0.03421	-0.03397	0.03901	
Leaf axil	1.25	75	(x_1) 0.9459**	0.87473	-0.04361	-0.37913	0.84788	-0.35397	0.0001
			(x_2) 0.3509	0.42293	-0.09019	-0.23500	0.75955	-0.50639	
			(x_3) 0.8771*	0.71859	-0.04593	-0.46151	1.20728	-0.54134	
			(x_4) 0.7179	0.49877	-0.04607	-0.37470	1.48698	-0.84708	
			(x_5) 0.5076	0.34289	-0.05058	-0.27667	1.39494	-0.90298	
Leaf axil	1.25	165	(x_1) 0.8792*	-0.18701	0.58560	0.18225	-0.11694	0.41530	0.0042
			(x_2) 0.9427*	-0.18174	0.60259	0.20103	-0.12858	0.44940	
			(x_3) 0.9422*	-0.15354	0.54571	0.22199	-0.12030	0.44835	
			(x_4) 0.9044*	-0.14752	0.52263	0.18014	-0.14825	0.49740	
			(x_5) 0.9480**	-0.14125	0.49250	0.18101	-0.13411	0.54985	

* Significant at 5 per cent level. Under lined figures are direct effects.
** Significant at 1 per cent level. DAT : Days after treatment.

Fig. 1 Path coefficient diagram showing the direct and indirect effects of phorate and its metabolites on P. nigronervosa exposed to treated banana plants at different intervals after treatment.

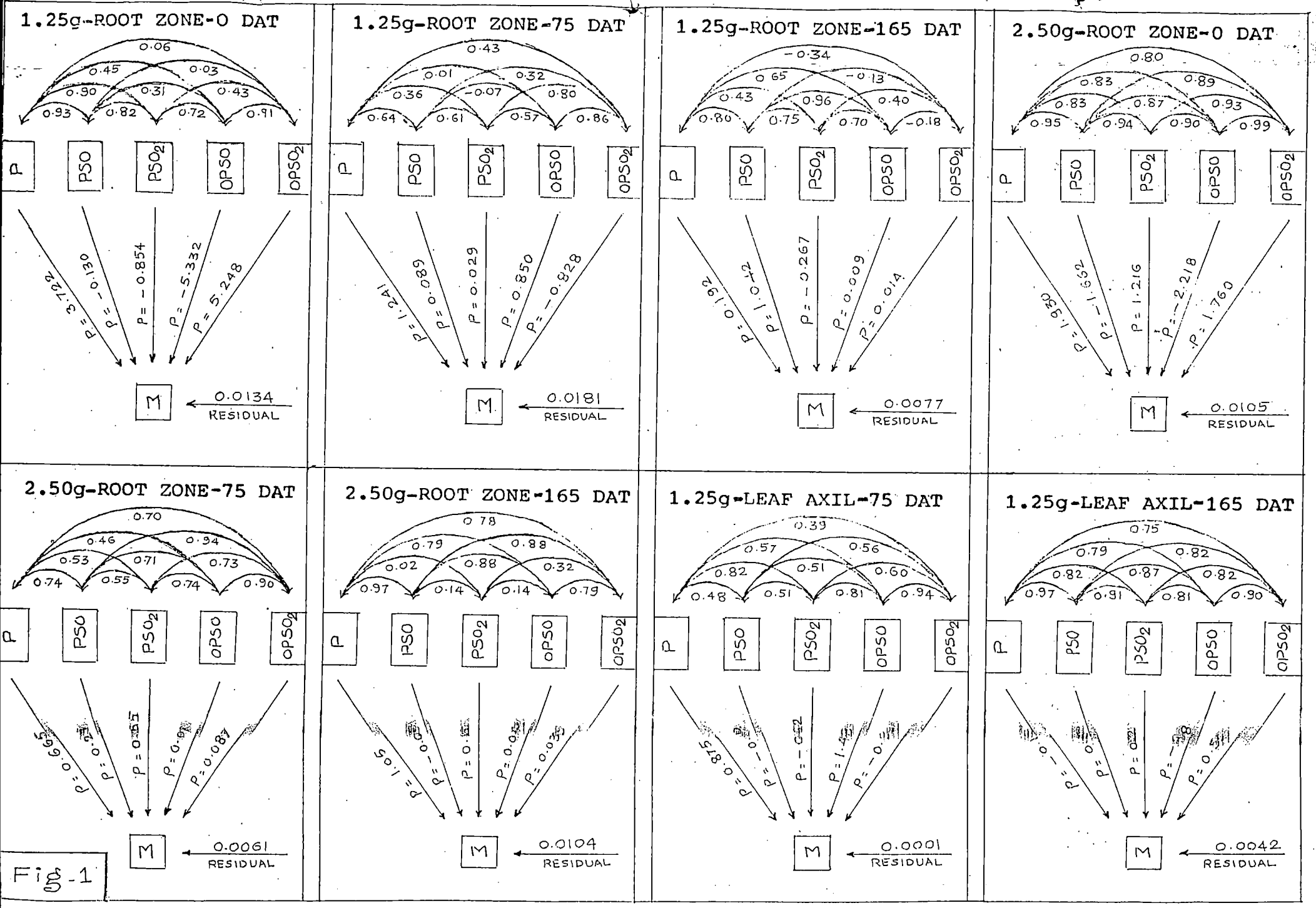
1.25g-ROOT ZONE-0 DAT
0.06
0.45
0.03
0.90
0.31
0.43
0.93
0.82
0.72
0.91
P
PSO
PSO2
OPSO
OPSO2
P = 3.762
P = -0.130
P = -0.854
P = -5.332
P = 5.248
M
0.0134
RESIDUAL
1.25g-ROOT ZONE-75 DAT
0.43
0.01
0.32
0.36
-0.07
0.80
0.64
0.61
0.57
0.86
P
PSO
PSO2
OPSO
OPSO2
P = 1.241
P = 0.089
P = 0.029
P = 0.850
P = -0.928
M
0.0181
RESIDUAL
1.25g-ROOT ZONE-165 DAT
-0.34
0.65
-0.13
0.43
0.96
0.40
0.80
0.75
0.70
-0.18
P
PSO
PSO2
OPSO
OPSO2
P = 0.162
P = 1.042
P = -0.267
P = 0.009
P = 0.014
M
0.0077
RESIDUAL
2.50g-ROOT ZONE-0 DAT
0.80
0.83
0.89
0.83
0.87
0.93
0.95
0.94
0.90
0.99
P
PSO
PSO2
OPSO
OPSO2
P = 1.920
P = -1.652
P = 1.216
P = -2.218
P = 1.760
M
0.0105
RESIDUAL
2.50g-ROOT ZONE-75 DAT
0.70
0.46
0.94
0.53
0.71
0.73
0.74
0.55
0.74
0.90
P
PSO
PSO2
OPSO
OPSO2
P = 0.695
P = 0.055
P = 0.087
M
0.0061
RESIDUAL
2.50g-ROOT ZONE-165 DAT
0.78
0.79
0.88
0.02
0.88
0.32
0.97
0.14
0.14
0.79
P
PSO
PSO2
OPSO
OPSO2
P = 1.501
P = 0.045
P = 0.035
M
0.0104
RESIDUAL
1.25g-LEAF AXIL-75 DAT
0.39
0.57
0.56
0.82
0.51
0.60
0.48
0.51
0.81
0.94
P
PSO
PSO2
OPSO
OPSO2
P = 0.815
P = -0.062
P = 1.411
P = -0.111
M
0.0001
RESIDUAL
1.25g-LEAF AXIL-165 DAT
0.75
0.79
0.82
0.82
0.87
0.82
0.97
0.91
0.81
0.90
P
PSO
PSO2
OPSO
OPSO2
P = 0.411
M
0.0042
RESIDUAL

Fig-1

The path coefficient analysis showed that the direct effect of phorate on mortality in this treatment (3.72) was positive and high. The association of the compound with the mortality was caused by the positive indirect influences through the other metabolites, phorate sulfoxide (0.93) phorate sulfone (0.90) oxyphorate sulfoxide (0.45) and oxyphorate sulfone (0.06). While the association of phorate sulfoxide with mortality was strongly positive, the direct effect was found to be negative (-0.13). The association was rendered positive through the highly positive and indirect effects through other factors, phorate (0.93), phorate sulfone (0.82), oxyphorate sulfoxide (0.31) and oxyphorate sulfone (0.03). Phorate sulfone exhibited significant positive correlation with the mortality. This was rendered so through the indirect positive effects of phorate (0.90), phorate sulfoxide (0.82), oxyphorate sulfoxide (0.72) and oxyphorate sulfone (0.43) even though its direct effect was low and negative (-0.854). The association of oxyphorate sulfoxide with the mortality was positive even though the direct effect of the metabolite was highly negative (-5.333). This was obviously due to its positive indirect effect through oxyphorate sulfone (0.91), phorate sulfone (0.72), phorate (0.45) and phorate sulfoxide (0.31). The association of oxyphorate sulfone with mortality was positive but weak.

Though the direct effect was positive and high (5.248), its indirect effects through oxyphorate sulfoxide (0.91), phorate sulfone (0.43), phorate (0.06) and phorate sulfoxide (0.03) its association with mortality of aphids was weak. Though the correlation coefficients between the different factors and mortality had low statistical significance, the residual effect observed in path analysis was 0.0134 only showing that 98.7 per cent of the mortality was caused by phorate and metabolites in the plant.

In treatment done at 75 DAP (1.25g ai/plant) the correlation coefficient between phorate and mortality of aphids (0.965) was positive and highly significant, while the correlation coefficients relating to other factors, phorate sulfoxide, oxyphorate sulfone, phorate sulfone and oxyphorate sulfone (0.574, 0.485, 0.358 and 9.167 respectively) were positive but not statistically significant.

The direct effect of phorate on the mortality of aphid in this treatment (1.24) was highly positive. The association was rendered positive through the indirect effects of phorate sulfoxide (0.64), oxyphorate sulfone (0.43), phorate sulfone (0.36) and oxyphorate sulfoxide (0.01). The association of phorate sulfoxide with mortality was positive while the direct effect due to the metabolite on mortality (0.089) was low but positive. The association was rendered more positive by the indirect effects through

phorate (0.640), phorate sulfone (0.61) and oxyphorate sulfone (0.32). The association of phorate sulfone with mortality was low and positive (0.029). The direct effect of the metabolite on the mortality was positive but low (0.027). The indirect effects through other metabolites, oxyphorate sulfone (0.80), phorate sulfoxide (0.61), oxyphorate sulfoxide (0.57) and phorate (0.36) influenced the mortality caused by the metabolite. The association of oxyphorate sulfoxide with mortality and its direct effects on mortality were positive. The association was influenced by the indirect effects through oxyphorate sulfone (0.86), and phorate sulfone (0.57) to a larger extent and phorate (0.01) to a smaller extent. The direct effects of oxyphorate sulfone were negative (-0.83) while the association of the metabolite with the mortality was positive. This was due to the indirect positive influence through other factors, oxyphorate sulfoxide (0.86), phorate sulfone (0.80), phorate (0.43) and phorate sulfoxide (0.32). The residual effect observed in the path coefficient analysis in this treatment was 0.0181 only, showing that 98.19 per cent of the aphid mortality was caused by phorate and its metabolites in the plant tissues.

At 165 DAP (application to root zone @ 1.25g) the correlation coefficients between mortality and phorate sulfoxide, oxyphorate sulfoxide and phorate were 0.984,

0.923 and 0.869 respectively. These were positive and significant while the correlation between the mortality and phorate sulfone was positive but not statistically significant (0.653). The correlation coefficient between oxyphorate sulfone and the mortality was negative but not significant. The residual effect found in the path analysis was very low (0.0077) thus showing that the mortality was caused by the combined effects of phorate and metabolites.

The direct effect of phorate on mortality was positive but low. The significant positive association of the metabolite with mortality was due to the indirect effects through phorate sulfone (0.80), oxyphorate sulfoxide (0.65) and phorate sulfone (0.43). The association of phorate sulfoxide with mortality was highly significant and positive. The direct effect was also high and positive. The indirect effects through phorate (0.80), phorate sulfone (0.75) and oxyphorate sulfoxide (0.96) also influenced the association of the metabolite with the mortality. The association of phorate sulfone with the mortality was positive but not significant. The direct effect of the metabolite was low and negative. The association of the metabolite with the mortality was rendered positive by the indirect effects through phorate sulfoxide (0.75), oxyphorate sulfoxide (0.70),

phorate (0.43) and oxyphorate sulfone (0.40). The association of oxyphorate sulfone with mortality was significant and positive while the direct effect of the metabolite on the association was low and positive. This enhancement of the association with mortality was due to the positive indirect effect through phorate sulfoxide (0.96), phorate (0.65) and phorate sulfone (0.70). The association of oxyphorate sulfone with the mortality was negative but not significant, while the direct effect of the metabolite was low and positive. The association was rendered negative by the negative indirect effects through other metabolites oxyphorate sulfoxide (-0.18), phorate sulfoxide (-0.13), and phorate (-0.34).

When applied at the root zone (2.50g ai/plant), at planting, the correlation coefficients between the content of phorate sulfoxide (0.968), phorate (0.936) and phorate sulfone (0.899) and mortalities were significant and positive. The correlation coefficient relating to oxyphorate sulfone (0.784) and oxyphorate sulfoxide (0.754) were also positive but not significant. The residual path coefficient analysis was only 0.0105 in this treatment indicating that 98.95 per cent mortality was brought about by phorate and its metabolites in the plant tissue.

The direct effect of phorate on the mortality of aphids in this treatment (1.93) was high and positive. The

association of the metabolite with the mortality was also influenced by the indirect effects through the other metabolites, phorate sulfoxide (0.95), phorate sulfone (0.83), oxyphorate sulfoxide (0.83) and oxyphorate sulfone (0.80). The direct effect of phorate sulfoxide on the mortality was negative and high (-1.66) while the association with mortality was significantly positive. This positivity was due to the indirect effects of phorate (0.95), phorate sulfone (0.94), oxyphorate sulfone (0.89) and oxyphorate sulfoxide (0.87). The direct effect of phorate sulfone on the mortality was high and positive (1.216). The association was positive which resulted from the indirect effects of phorate sulfoxide (0.94), oxyphorate sulfone (0.93), oxyphorate sulfoxide (0.90) and phorate (0.83). The direct effect of oxyphorate sulfoxide was high and negative while its association with mortality was high and positive. This positive association was by the strong and positive indirect effects through oxyphorate sulfone (0.99), phorate sulfone (0.90), phorate sulfoxide (0.87) and phorate (0.83). The direct effect on oxyphorate sulfone was positive (1.76). Its association with mortality was also positive and high. The indirect effects of metabolites which contributed to this association were oxyphorate sulfoxide (0.99), phorate sulfone (0.93), phorate sulfoxide (0.89) and phorate (0.80).

When the higher dose was applied at 75 DAP, the correlation eoefficients of phorate (0.958), phorate sulfoxide (0.885) and oxyphorate sulfone (0.872) were highly positive and significant while coefficients relating to the other metabolites (0.659 and 0.648) were also positive but not significant. The residual in path coefficient analysis was 0.0061 only.

Direct effect of phorate on mortality of aphid in this treatment (0.665) was high and positive. The association was also influenced by the indirect positive effects through phorate sulfoxide (0.74), oxyphorate sulfone (0.70), phorate sulfone (0.53) and oxyphorate sulfoxide (0.45). The direct effect of phorate sulfoxide was low and positive (0.231) and the correlation coefficient was high and positive. The positive association of the metabolite with the mortality was due to its highly positive indirect effects through oxyphorate sulfone (0.94), phorate (0.74), oxyphorate sulfoxide (0.71) and phorate sulfone (0.55). The direct effect of phorate sulfone and the association with mortality were positive. The association of the metabolite with the mortality was also influenced by the indirect positive effects through oxyphorate sulfoxide (0.74), oxyphorate sulfone (0.73), phorate sulfoxide (0.55) and phorate (0.53). The direct effect of oxyphorate

sulfoxide on the mortality was positive (0.071) and low while the association was positive but not significant. This was the result of the indirect influence through other factors, oxyphorate sulfone (0.90), phorate sulfone (0.74), phorate sulfoxide (0.71) and phorate (0.46). The direct effect of oxyphorate sulfone was low and positive (0.087) while its association with mortality was significantly high and positive. The association was influenced by the indirect effects of phorate sulfoxide (0.94), oxyphorate sulfoxide (0.90), phorate sulfone (0.75) and phorate (0.70).

At 165 DAP (2.50g ai/plant applied at the root zone) the correlation coefficients of phorate (0.994) and phorate sulfoxide (0.968) were positive and significant. The coefficients for oxyphorate sulfone, oxyphorate sulfoxide and phorate sulfone were 0.8104, 0.7788 and 0.1249 respectively. The residual effect of 0.0104 obtained in the path coefficient analysis showed that 98.76 per cent of mortality was caused by the parent compound and its metabolities.

The direct effects of phorate (1.05) was positive and high. The indirect effects through other metabolites, phorate sulfoxide (0.97), oxyphorate sulfoxide (0.79), oxyphorate sulfone (0.78) and phorate sulfone (0.02) also influenced the relationship. The direct effect of phorate sulfoxide (-0.58) was low and negative while its association with mortality was highly significant and positive. This

positivity was caused through the indirect effects of the metabolite through phorate (0.97) oxyphorate sulfoxide (0.88), oxyphorate sulfone (0.88) and phorate sulfone (0.14). The direct effect of phorate sulfone (0.106) was positive and low. Its association with mortality was also positive and low The positivity was caused by its indirect effects through other metabolites, oxyphorate sulfone (0.32), phorate sulfoxide (0.14), oxyphorate sulfoxide (0.14) and phorate (0.02). Direct effect of phorate sulfone was low and positive. The association of the metabolite with mortality was high and positive. The indirect effects have influenced the association. The direct effect of oxyphorate sulfone was low and positive (0.04) while its association with mortality was high and positive. The indirect effects through other metabolites, phorate sulfoxide (0.88), oxyphorate sulfoxide (0.79), phorate (0.78) and phorate sulfone (0.32) rendered the association more positive.

In leaf axil application at 75 DAT the correlation coefficients of phorate (0.9498) and phorate sulfone (0.877) were positive and significant while the correlation coefficients oxyphorate sulfone (0.718) oxyphorate sulfone (0.509) and phorate sulfoxide (0.351) with mortality were not significant. The residual effect of 0.0001 observed in the path coefficient analysis showed that 99.99 per cent

of the mortality of aphids could be attributed to the direct and indirect influences of phorate and metabolites present in the plant.

The direct effect of phorate on the mortality was high (0.875). Its association with mortality was also positive and high. The indirect effects through other metabolites, phorate sulfone (0.82), oxyphorate sulfoxide (0.57), phorate sulfoxide (0.48) and oxyphorate sulfone (0.39) also influenced the association. The direct effect of phorate sulfoxide was low and negative while its association with mortality was positive. Its indirect effects throguh oxyphorate sulfone (0.56), oxyphorate sulfoxide (0.51), phorate sulfone (0.51) and phorate (0.48) rendered the association positive. The direct effect of phorate sulfone on the mortality of aphids was negative (-0.462) while its association with mortality was positive and significant. The positivity was the result of indirect influence through oxyphorate sulfone (0.60), phorate (0.82) and phorate sulfoxide (0.51). The direct effect of oxyphorate sulfoxide was high and positive (1.487) and its association with mortality was also high and positive. The indirect effects through metabolites, oxyphorate sulfone (0.94), phorate sulfone (0.81),

phorate (0.57) and phorate sulfoxide (0.51) also contributed to the association. The direct effect of oxyphorate sulfone was negative while the association with mortality was positive. Its indirect effects through oxyphorate sulfoxide (0.94), phorate sulfone (0.60), phorate sulfoxide (0.56) and phorate (0.39) rendered the association positive.

In the leaf axil application at 165 DAP the correlation coefficients of oxyphorate sulfone (0.948), phorate sulfoxide (0.943), phorate sulfone (0.942) and phorate (0.879) were significant and positive. The residual effect (0.0042) obtained in path analysis was very low which suggested that 99.68 per cent reliability.

The direct effect of phorate on mortality was negative (-0.187) while the association was positive and significant. The indirect effects of phorate sulfoxide (0.97), phorate sulfone (0.82) oxyphorate sulfoxide (0.79) and oxyphorate sulfone (0.75) rendered the association positive. The direct effect of phorate sulfoxide was positive and high. The association with mortality was also high. The association was influenced by the indirect effects of phorate (0.97), phorate sulfone (0.91), oxyphorate sulfoxide (0.87) and oxyphorate sulfone (0.82). The direct effect of phorate sulfone was positive (0.72). The association with

mortality was significant. This was rendered positive by the indirect effects of phorate sulfoxide (0.91), phorate (0.82), oxyphorate sulfone (0.82) and oxyphorate sulfoxide (0.81). The direct effect of oxyphorate sulfoxide was negative and low (-0.148). The indirect effects through oxyphorate sulfone (0.90), phorate sulfoxide (0.87), phorate sulfone (0.81) and phorate (0.79) contributed to the positive association with mortality. The direct effect of oxyphorate sulfone was positive (0.549) and the association with mortality was also positive and significant. The indirect effects of oxyphorate sulfoxide (0.90) phorate sulfone (0.82), phorate sulfoxide (0.82) and phorate (0.75) also influenced its association with the mortality.

4.2 Persistent toxicity of phorate in banana plants treated at different growth stages of the crop and the residues of phorate in harvested banana fruits

4.2.1 Persistent toxicity

The data relating to the experiment and results of statistical analysis of the same are presented in Table-6, Appendix-4 and Fig-2.

At 3 DAT the highest mortality of 38.70 per cent was observed in plants treated at 30 DAP and it was followed by the mortalities in treatment done at 60, 90 and 120 DAP (27.5 to 31.7 per cent). The mortalities

Table 6 Absorption and translocation of phorate (@ 2.5g ai/plant applied at root zone) in banana treated at different growth stages of the crop

Time of treatment (DAP)	Corrected per cent mortalities of *P. nigronervosa* exposed to treated plants at different intervals after treatment (days)								P	T	PT	ORE
	3	10	17	24	31	45	60	90				
0	0.00 (0.00)	0.00 (0.00)	8.10 (16.56)	68.40 (55.78)	90.80 (72.37)	90.80 (72.37)	99.40 (85.55)	38.10 (38.12)	90	67.4	6063	1
30	38.70 (38.45)	58.50 (49.89)	59.35 (50.39)	71.10 (57.47)	92.40 (74.02)	93.50 (82.91)	66.25 (53.48)	30.30 (34.39)	90	64.4	5795	2
60	27.50 (31.61)	30.45 (33.48)	61.10 (51.42)	59.80 (50.65)	91.60 (73.16)	77.90 (61.97)	52.00 (46.14)	26.80 (31.19)	90	53.4	4805	3
90	27.70 (31.76)	33.30 (35.24)	56.60 (48.77)	60.60 (51.13)	91.30 (72.82)	57.50 (49.32)	32.30 (34.64)	12.10 (20.38)	90	46.4	4178	4
120	28.90 (32.54)	32.50 (34.24)	56.25 (48.59)	60.60 (51.12)	68.30 (55.71)	36.35 (37.09)	36.00 (36.86)	13.60 (12.65)	90	41.5	3739	5
150	12.15 (20.39)	40.10 (39.30)	58.80 (50.06)	62.50 (52.23)	47.00 (43.26)	14.80 (22.65)	11.00 (19.36)	10.60 (19.01)	90	31.1	2891	6
180	1.90 (9.78)	30.60 (33.58)	30.75 (33.68)	38.35 (38.26)	36.25 (37.02)	23.00 (28.65)	23.10 (28.74)	4.30 (11.94)	90	23.5	2118	7
210	0.00 (0.00)	10.65 (19.06)	29.10 (32.66)	35.80 (36.77)	31.60 (34.20)	31.00 (33.83)	6.00 (14.20)	4.15) (11.74)	90	21.2	1907	8
C.D.	7.38	5.38	6.53	8.50	9.26	7.20	9.29	9.21				

Figures given in parentheses are transformed values (angles)
P = Period (days)
T = Average toxicity (per cent)
PT = Persistent toxicity index
ORE = Order of relative efficacy

Fig 2 Persistent toxicity of phorate in banana plants, when treated at different growth stages of the crop, to the last instar nymph of *P. nigronervosa*.

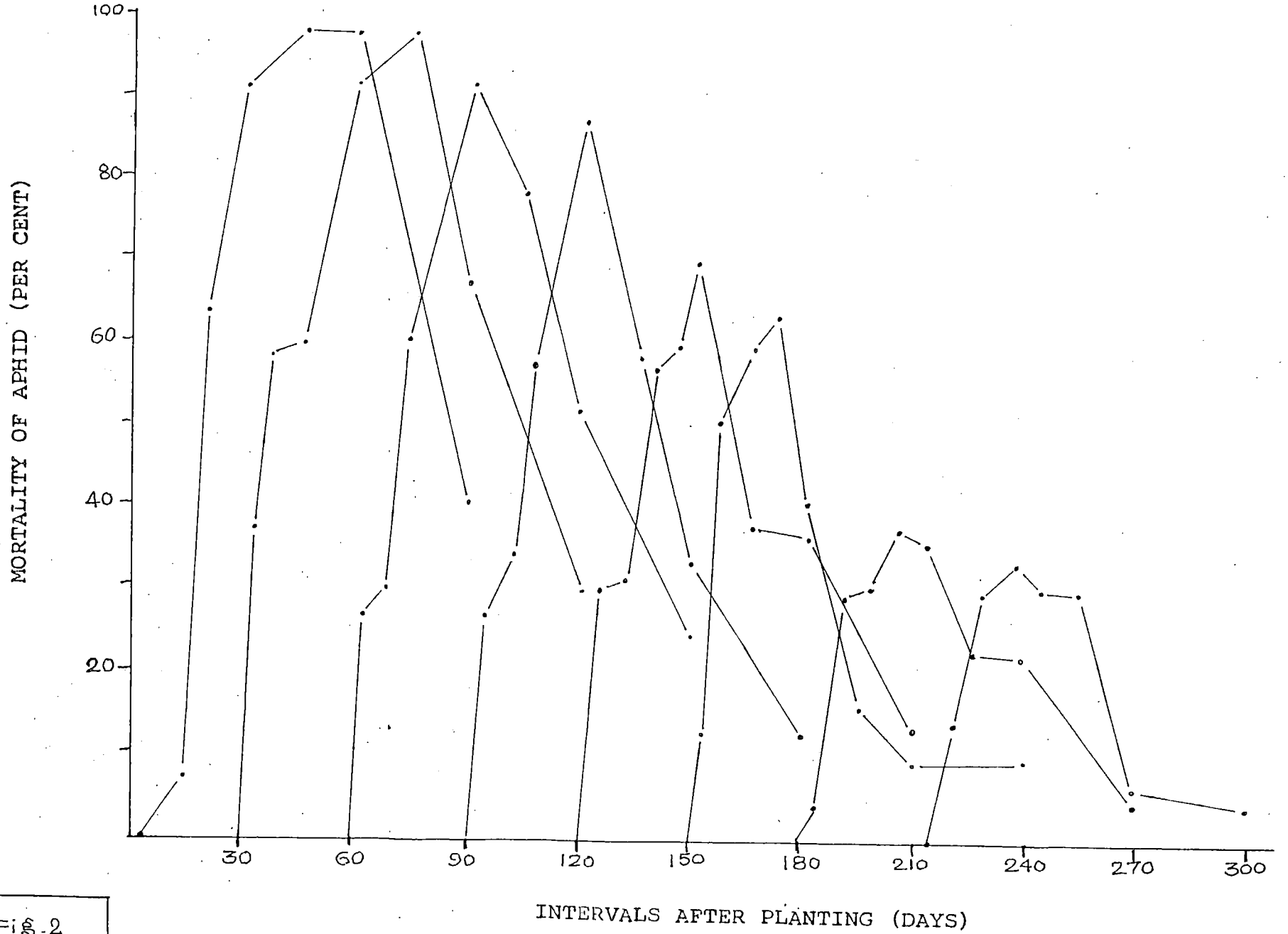
MORTALITY OF APHID (PER CENT)
100
80
60
40
20
30
60
90
120
150
180
210
240
270
300
INTERVALS AFTER PLANTING (DAYS)

Fig.2

in these treatments were statistically on par. On plants treated at 150 DAP, the mortality was significantly lower (12.15 per cent). Plants treated at 180 and 210 DAP showed mortalities of 1.90 and 0.0 per cent respectively.

At 10 DAT the highest mortality (58.5 per cent) was observed in plants treated at 30 DAP which was significantly higher than the mortalities observed in other treatments. The mortalities recorded in treatments done at 60, 90, 120, 150 and 180 DAP came on par while the treatment at 210 DAP continued to give low mortality (10.65 per cent). No mortality was observed on plants treated at the time of planting.

At 17 DAT the mortalities recorded on plants treated at 30, 60, 90, 120 and 150 DAP came on par (56.60 to 59.35 per cent) while the mortalities on plants treated at 180 and 210 DAP were significantly lower (30.75 and 29.10 per cent respectively). Mortality on plants treated at planting was the lowest (8.10 per cent).

At 24 DAT, however, a steep increase in mortality was noticed in plants treated at the time of planting (68.40 per cent) and those in plants treated at different intervals upto 150 DAP came on par. Low mortalities were found in plants treated at 180 and 210 DAP (38.26 and 36.77 per cent respectively).

At 31 DAT mortalities recorded in plants treated at 0, 30, 60 and 90 DAP were high and on par (90.80 to 92.60 per cent) and these were significantly higher than the mortalities observed on plants treated at 120, 150, 180 and 210 DAP. The mortalities obtained on plants treated at 150, 180 and 210 days after planting were on par and very low (31.6 to 47 per cent). At 45 DAT highest mortality (99.39 per cent) was seen in plants treated at planting and it was closely followed by plants treated at 30 DAP (93.5). The mortalities in treatments done at 60, 90 and 120 DAP (77.9, 57.5 and 36.35 respectively) were significantly differing among themselves. In the remaining treatments the mortalities ranged from 14 to 31 per cent only.

At 60 DAT the mortality in plants treated at planting remained the highest (99.40) while the mortalities reached below 50 per cent in treatments done at 90 and 210 DAP.

At 90 DAT the plants treated at 0, 30 and 60 DAP came on par (26.8 to 38.1 per cent) and the remaining treatments were on par and significantly inferior (4.15 to 13.6 per cent).

A comparison of the average toxicity (T) and persistent toxicity indices (P T) of the treatments revealed that highest persistent toxicity (6063-PT value) was found in

plants treated at planting. The PT index relating to the treatment done at 30 DAP also came very close to it (5795). Then the response fell in almost linear scale and in treatments done at 210 DAP the PT index was very low (1907).

4.2.2 Terminal residues in fruits.

The data relating to the residues are presented in Table 7.

Phorate residues (total) in raw and ripe fruits obtained from plants treated at 0, 30, 60, 90 and 120 days after planting were below detectable levels. The mean residue levels in fruits obtained from plants treated at 150, 180 and 210 DAP were 0.048, 0.128 and 0.225 ppm respectively. When ripe fruits had residues 0.27 and 0.197 ppm in treatments in which the insecticide was applied at 180 and 210 DAP respectively.

4.3 The effect of seasons on the uptake, translocation and persistence of phorate and its bioefficacy against *P. nigronervosa*

4.3.1 Effect of seasons on the uptake and persistence.

The data relating to the study were analysed satistically and are presented in Table 8, Fig. 3 and Appendix 5.

Significant effects of seasons on the absorption and persistence of insecticide in the plants were observed

Table 7 Terminal residues of phorate in harvested fruits when applied @ 2.5g ai/plant at the root zone at different growth stages of the crop

Time of treatment (DAP)	Phorate residues (ppm) in	
	mature unripe fruits (at harvest)	mature ripe fruits (at 10 DAH)
0	ND	ND
30	ND	ND
60	ND	ND
90	ND	ND
120	ND	ND
150	0.048	0.0
180	0.128	0.07
210	0.225	0.197

DAH = Days after harvest

DAP = Days after planting

ND = Non detectable level

Table 8 Uptake, translocation and persistence of phorate applied at the root zone of banana in the rainy and summer seasons

Treatments	Dose g ai/ plant	Residues of phorate (ppm) in the plant samples collected at different intervals after treatment (days) 15	30	45	60	75	90	105	120
Rainy Season									
Phorate	1.25	1.79	4.87	7.10	4.11	3.81	1.32	0.61	0.33
Phorate	2.50	2.03	5.99	8.68	7.97	5.37	1.88	0.43	0.31
Mean		1.91	5.43	7.89	6.04	4.59	1.50	0.52	0.32
Summar Season									
Phorate	1.25	1.90	4.49	7.39	6.84	5.51	1.49	0.60	0.30
Phorate	2.50	1.89	6.50	8.39	9.71	8.81	3.41	0.78	0.55
Mean		1.90	5.49	7.89	8.28	7.16	2.45	0.69	0.42
C.D. for comparing seasons		NS	NS	NS	0.82	0.97	0.53	NS	NS
C.D. for comparing doses within season		NS	1.58	1.28	1.15	1.37	NS	NS	NS

Residues reached non detectable levels in all the treatments at 135 DAT

Fig 3 Phorate content in banana plants, treated with the insecticide in rainy and summer seasons, observed at different intervals after treatment and the mortality of *P. nigronervosa* exposed on the plants at corresponding intervals.

A. data relating to rainy season - phorate applied @ 1.25g ai/plant.

B. data relating to rainy season - phorate applied @ 2.50g ai/plant.

C. data relating to summer season - phorate applied @ 1.25g ai/plant.

D. data relating to summer season - phorate applied @ 2.50g ai/plant.

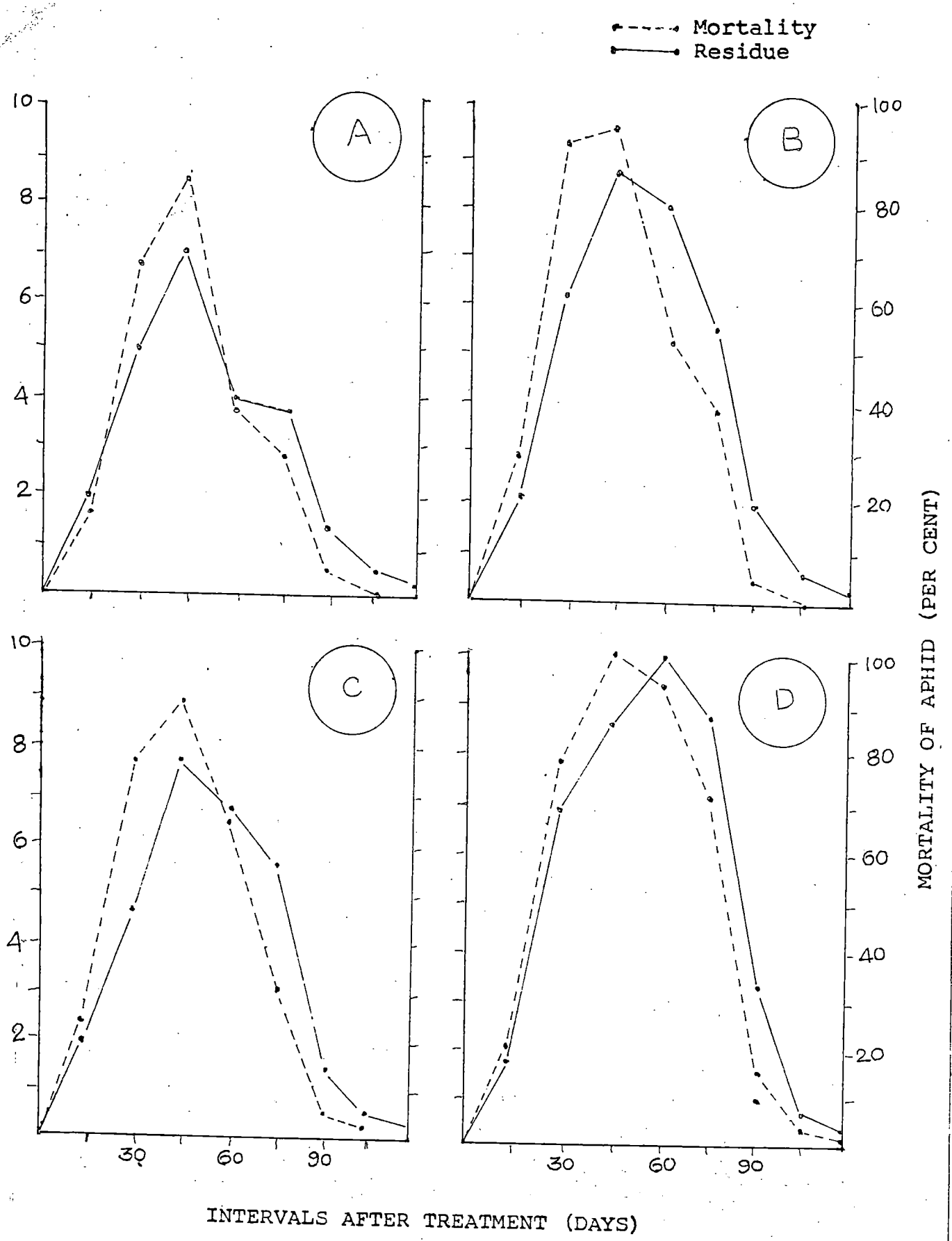
Mortality
Residue
A
B
C
D
10
8
6
4
2
100
80
60
40
20
30
60
90
MORTALITY OF APHID (PER CENT)
INTERVALS AFTER TREATMENT (DAYS)

Fig-3

at 60, 75 and 90 DAT. The mean insecticide contents in summer season at the above periods (8.28, 7.18 and 2.45 ppm respectively) were significantly higher than the corresponding insecticide contents in rainy season (6.04, 4.59 and 1.50). Though the mean residues were higher in summer months at 105 and 120 DAT, than in rainy season the variations were not statistically significant. At the initial stages of absorption (15, 30 and 45 DAT) the mean insecticide contents were not varying in the two seasons.

The increase in the content of total phorate in the leaf sheath, caused by the enhancement of the dose of insecticide from 1.25g ai/plant to 2.5g ai/plant, showed significant difference at 45 (from 7.1 to 8.68 ppm), 60 (4.11 to 7.97) and 75 (3.81 to 5.37) days after the treatment during the rainy season. In summer season such significant differences were observed at 30 (4.49 to 6.50 ppm) 60 (6.8 to 9.71) and 75 (5.51 to 8.81) days after treatment. In the last phase (90 to 120 DAP) slightly higher content of the insecticide were found in plants with the higher doses of insecticides; but the variations in the data were not statistically significant.

4.3.2 Persistent toxicity of phorate to P. nigronervosa in the rainy and summer seasons

The data relating to the mortality of P. nigronervosa confined on the plants at different intervals after treatment and the results of statistical analysis of the same are presented in Table 9, Fig. 3 and Appendix 6.

The bioefficacy of the insecticide content observed in plants in the two seasons showed highly significant variations. At 15 and 30 DAT the mean mortality observed in the summer months (21.05 and 78.5 per cent respectively) did not show significant variations from the corresponding mortalities in the rainy season (20.4 and 78.65). The mean mortalities observed in the rainy season at 45 DAT (95.75 per cent), 60 DAT (83.0), 75 DAT (49.2), 90 DAT (11.20) and 105 DAT (1.40) were significantly higher than the mean mortalities observed in corresponding periods after treatment in summer months (88.9, 43, 31.55, 3.20 and 0 per cent respectively).

The persistence (P) of the insecticidal effect of the residues was upto 90 DAT in rainy season while it extended upto 105 DAT in the summer season (vide Table 8).

The average toxicity (T) worked out for the rainy and summer months relating to the doses of 1.25 kg ai/plant were 37.4 and 40.9 per cent respectively and the corresponding values for the dose of 2.5g ai/plant were 50.7 and 55.2 respectively.

Table 9 Persistent toxicity of phorate applied at the root zone of banana, in the rainy and summer season, to *P. nigronervosa*

Treatments	Dose g ai/ plant	Corrected mortalities (per cent) of *P. nigronervosa*, exposed on treated plants at different intervals after treatment (days)							P	T	PT	ORE
		15	30	45	60	75	90	105				
Rainy Season												
Phorate	1.25	14.75 (22.60)	63.30 (52.63)	81.55 (64.55)	35.60 (36.62)	25.95 (30.61)	3.40 (10.65)	0.00 (0.00)	90	37.4	3368	4
Phorate	2.50	28.10 (32.02)	90.50 (72.03)	94.55 (76.51)	50.60 (45.33)	37.45 (37.73)	2.95 (9.91)	0.00 (0.00)	90	50.7	4561	2
Mean		21.05 (27.31)	78.50 (62.38)	88.90 (70.53)	43.00 (40.97)	31.55 (34.17)	3.20 (10.28)	0.00 (0.00)				
Summer Season												
Phorate	1.25	22.00 (27.95)	75.90 (60.62)	88.50 (70.17)	65.80 (54.20)	28.40 (32.19)	5.45 (13.63)	0.36 (3.42)	105	40.9	4296	3
Phorate	2.50	18.90 (25.78)	81.25 (64.33)	99.52 (86.07)	95.05 (77.12)	70.10 (56.86)	18.45 (25.44)	3.10 (10.14)	105	55.2	5795	1
Mean		20.40 (26.87)	78.65 (62.47)	95.75 (78.12)	83.00 (65.67)	49.20 (44.53)	11.20 (19.53)	1.40 (6.78)				
C.D. seasons		NS	NS	4.89	3.08	2.86	4.47	4.07				
C.D. interaction		3.86	4.43	NS	4.36	3.23	6.32	NS				

Figures given in parentheses are transformed values (angles)

The persistent toxicity of the lower dose (1.25g ai/plant) of phorate, in rainy season, was lower (PT index 3368) than that of the summer season (4296). When treated with phorate at 2.5g ai/plant the PT indices relating to the rainy and summer months were 4561 and 5795 respectively.

4.4 Metabolism and persistence of phorate in different types of soil and the absorption, translocation, metabolism and persistence of phorate in banana plants grown in treated soils

4.4.1 Persistence and metabolism of phorate in plants

4.4.1.1 Effect of soils on content of phorate and metabolites in plants

Data relating to the aspect and results of statistical analysis of the same are presented in Table 10 and Fig. 4.

Total Phorate: The content observed at seven and 15 DAT showed variations among the plants grown in different soil types. The highest level of residues (1.53 and 5.42 ppm) were seen in lateritic low land soil and it was followed by lateritic upland (1.05 and 3.31), black cotton (0.61 and 3.30) and sandy (0.56 and 2.04) soils.

In the plants grown in all the four types of soil, the total residues were remaining high from 30 to 60 DAT. They were in the higher range in plants grown in sandy soil

Table 10 Contents of phorate and its metabolites in banana plants, treated with insecticide at 2.5g at planting, as observed at different intervals after treatment in different soils.

Insecticide/ Metabolite	Residues of phorate and metabolites (ppm) in leaf sheaths observed at different intervals after treatment (days)										C.D. (P=0.05)
	7	15	30	45	60	75	90	105	120	135	
Sandy soil											
Phorate	0.339	0.795	5.246	6.533	3.220	0.303	0.155	0.315	ND	ND	0.848
Phorate sulfoxide	0.158	0.934	2.894	3.393	3.150	0.947	0.671	0.114	ND	ND	1.422
Phorate sulfone	0.067	0.191	1.430	1.827	2.302	0.947	0.682	0.274	ND	ND	0.679
Oxyphorate sulfoxide	ND	ND	0.556	0.806	1.548	0.642	0.311	0.224	ND	ND	0.741
Oxyphorate sulfone	ND	0.119	0.567	1.211	0.117	1.023	0.252	0.235	0.042	ND	0.702
Total	0.564	2.038	10.693	13.771	10.336	3.857	2.071	1.162	0.042	ND	-
Lateritic low land											
Phorate	0.839	1.631	2.179	3.379	2.031	2.478	0.655	0.131	0.063	ND	0.831
Phorate sulfoxide	0.328	1.474	2.162	3.921	3.604	2.424	1.951	0.440	0.158	ND	0.860
Phorate sulfone	0.227	0.667	1.212	1.816	1.493	1.560	1.748	1.119	0.209	ND	0.482
Oxyphorate sulfoxide	0.132	0.763	2.238	0.609	1.681	1.302	2.077	0.995	0.249	0.035	1.015
Oxyphorate sulfone	ND	0.880	1.451	2.321	2.598	2.179	1.792	0.584	0.339	0.021	0.976
Total	1.526	5.421	9.242	12.045	11.408	10.043	8.223	3.270	1.018	0.056	-
Lateritic upland											
Phorate	0.552	1.436	3.212	2.097	2.394	0.241	0.200	0.074	0.051	ND	0.482
Phorate sulfoxide	0.344	0.822	1.102	3.773	3.674	1.125	0.747	0.233	0.110	ND	0.844
Phorate sulfone	0.129	0.464	1.322	3.041	1.632	1.746	1.009	0.319	0.311	ND	0.775
Oxyphorate sulfoxide	0.023	0.219	0.882	0.524	1.065	0.670	1.099	0.478	0.061	0.036	0.638
Oxyphorate sulfone	ND	0.370	0.514	0.648	0.643	0.908	1.349	0.123	0.087	0.036	0.587
Total	1.047	3.311	7.032	10.083	9.408	4.690	4.405	1.226	0.620	0.072	-
Black cotton soil											
Phorate	0.490	1.683	1.343	1.025	0.555	0.489	0.087	0.102	0.072	ND	0.719
Phorate sulfoxide	0.120	0.815	2.305	2.770	1.633	1.429	0.426	0.389	0.180	0.103	0.673
Phorate sulfone	ND	0.561	2.105	1.348	1.017	0.879	0.811	0.563	0.286	ND	0.973
Oxyphorate sulfoxide	ND	0.143	0.766	0.329	1.222	1.209	0.961	0.795	0.506	0.049	0.934
Oxyphorate sulfone	ND	0.093	0.594	0.425	0.450	1.100	0.984	0.668	0.456	ND	0.800
Total	0.610	3.295	7.113	5.909	4.877	5.086	3.269	2.517	1.500	0.150	-

Fig 4 Persistence and metabolism of phorate in banana plants grown in different types of soil and treated with the insecticide @ 2.5g ai/plant at the time of planting.

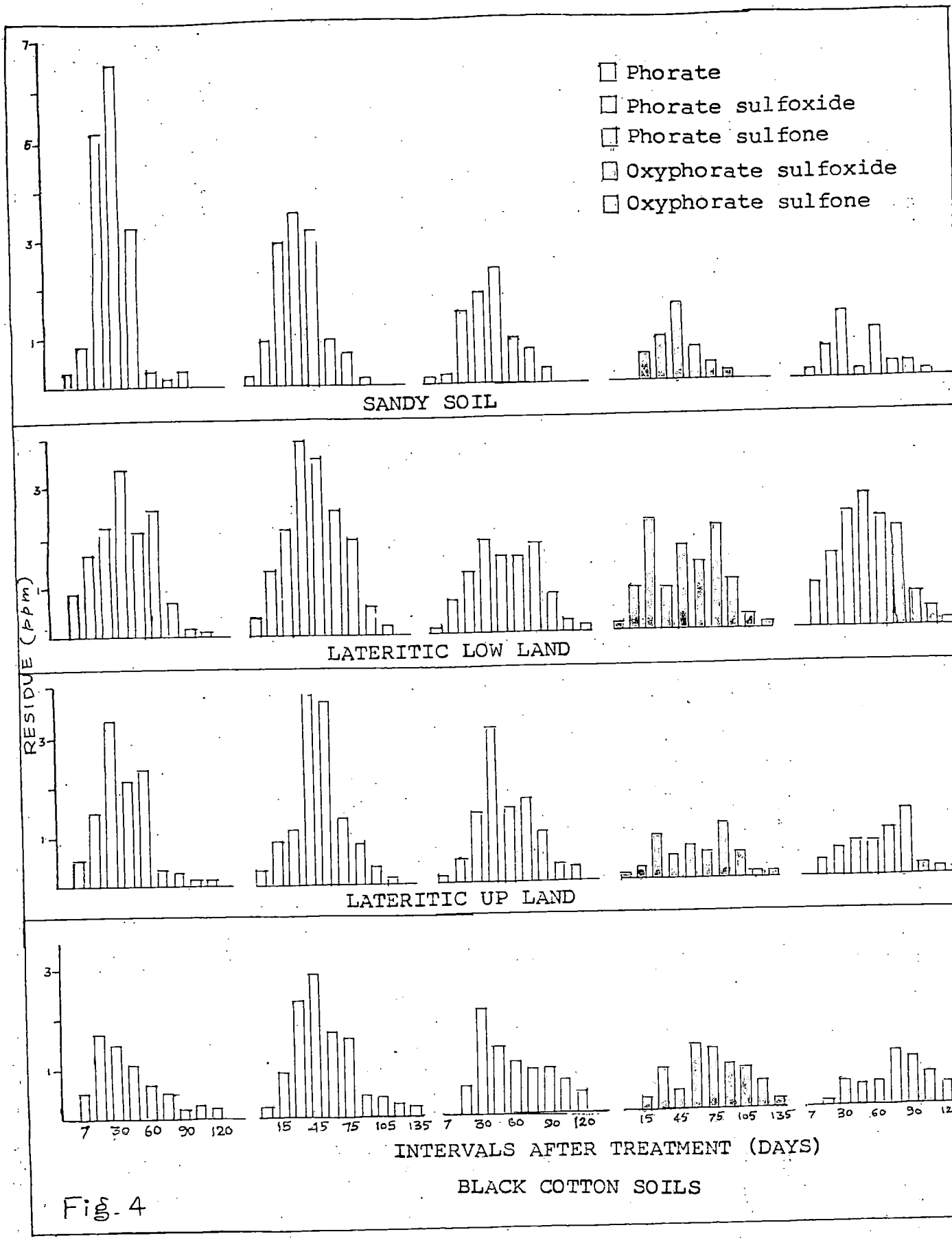
Phorate
Phorate sulfoxide
Phorate sulfone
Oxyphorate sulfoxide
Oxyphorate sulfone
SANDY SOIL
RESIDUE (ppm)
LATERITIC LOW LAND
LATERITIC UP LAND
7 30 60 90 120
15 45 75 105 135
INTERVALS AFTER TREATMENT (DAYS)
BLACK COTTON SOILS

Fig. 4

(10.69 to 13.7 ppm) followed by those of lateritic low land (9.24 to 12.05), lateritic upland (9.03 to 10.08) and black cotton (4.88 to 7.11) soils.

The dissipation of the residues in plants grown in sandy soil occurred abruptly at 75 DAT (from 10.34 ppm at 60 DAT to 3.86 ppm at 75 DAT) and reached non-detectable levels at 135 DAT. In all the observations from 75 DAT, the least residue content was seen in plants grown in sandy soil. From 75 DAT to 105 DAT the highest residue was observed in plants grown in lateritic low land soil (3.27 to 10.04 ppm) and it was followed by the plants raised in black cotton (2.52 to 5.09) and lateritic upland (1.23 to 4.69) soils.

Based on the LD_{50} values (vide para 4.1.4 and Table 2b) the period upto which the residues are likely to give significant kill of P. nigronervosa in the plants grown in sandy, lateritic low land, lateritic upland and black cotton soils may be presumed as 75, 105, 90 and 105 DAT respectively.

Phorate content: The data relating to the phorate content also showed the lowest level in plants grown in sandy soil at seven and 15 DAT. At seven DAT the highest residue was in plants grown in lateritic low land (0.84 ppm) and it was followed by that of the plants grown in

lateritic upland (0.55 ppm) and black cotton (0.49 ppm) soils. At 15 DAT the phorate content in plants grown in lateritic upland, lateritic low land and black cotton soils did not show significant variations (1.44 to 1.68 ppm). During the active absorption phase (30 to 60/75 DAT), the residue content of phorate was in the higher range in plants grown in sandy soil (3.22 to 6.53 ppm). It was followed by the residues in plants grown in lateritic low land (2.03 to 3.38), lateritic upland (2.10 to 3.21) and black cotton (0.56 to 1.34) soils. A drastic fall in phorate content was observed at 60 DAT in plants grown in sandy and lateritic upland soils and at 75 DAT in the plants grown in the other two types of soil. In plants of sandy soil residue reached non-detectable level at 120 DAT and in the plants grown in all other types of soil it became non-detectable in samples collected at 135 DAT only.

Phorate sulfoxide: It could be detected in all the treatments at seven DAT and the content showed a variation ranging from 1.12 to 1.47 ppm. But no definite trend was noted in the observations at seven and 15 DAT. During the active absorption phase (30 to 60 DAT), the content of phorate sulfoxide in plants grown in sandy (2.39 to 3.15 ppm), lateritic low land (2.16 to 3.92) and lateritic upland (1.10 to 3.77) soils did not show wide variations. But in the plants grown in black cotton soil the residues were relatively

lower (1.633 to 2.77 ppm only). The fall in the content of phorate sulfoxide in plants grown in sandy soil between 60 and 75 DAT (from 3.15 to 0.95) was very sharp and it was same in lateritic upland also (3.67 to 1.13). In the other two treatments, the dissipation of the residue was gradual from 60 to 120 DAT. In plants grown in sandy soil the residue reached the non-detectable level at 120 DAT, while in all other treatments the non-detectable level was reached only at 135 DAT. Phorate sulfoxide also was less in plants grown in sandy soil at the early stage (upto 15 DAT) and it was higher in plants grown in lateritic low land. In black cotton soil the plants did not show the residue at seven DAT but at 15 DAT it came up (0.56 ppm) near to that of the plants grown in lateritic upland soil (0.64 ppm).

Phorate sulfone: Its content remained high in plants grown in andy soil from 30 to 60 DAT and suddenly declined (from 2.30 to 0.95 ppm) and became non-detectable at 120 DAT. A similar abrupt dissipation was noted in plants grown in lateritic upland and lateritic low land soils also at 90 DAT and in both non-detectable level was reached at 135 DAT. In the plants grown in black cotton soil the residue content reached the peak at 60 DAT but the reduction in the content was gradual upto 120 DAT and it became non-detectable at 135 DAT.

Oxyphorate sulfoxide: The content was highest in plants grown in lateritic low land soil at seven and 15 DAT

and it was followed by the content in plants grown in lateritic upland. It was non-detectable in plants grown in sandy soil at seven and 15 DAT while in plants grown in black cotton soil the residue was non-detectable at seven DAT and slight (0.14 ppm) at 15 DAT. The levels of all residues showed a sharp decline at 60 DAT in plants grown in sandy, lateritic low land and lateritic upland soils. Plants in sandy soil lost the residue faster and the residue became non-detectable at 120 DAT. In the other treatments the decline in residue content from 60 to 135 DAT was gradual and the residue did not reach non-detectable level upto 135 DAT.

Oxyphorate sulfone: This metabolite was not detectable in any treatment at seven DAT. At 15 DAT it was present in plants grown in black cotton and sandy soils (0.09 and 0.12 ppm). The higher levels were seen in plants grown in lateritic low land (0.88 ppm) followed by the content in lateritic upland (0.37 ppm). The peak in oxyphorate sulfone content in plants grown in sandy soil was observed at 75 DAT and in the remaining treatments the peak was observed at 90 DAT. In plants grown in sandy and black cotton soils the residue reached non-detectable level at 135 DAT while in the lateritic low land and upland soils the plants showed traces of the residue (0.02 and 0.04 ppm) even at 135 DAT.

As seen clearly from Fig. 4, the absorption of phorate was high in plants grown in sandy soil upto 60 DAT but the levels of phorate suddenly declined and remained ineffective from 90 to 135 DAT. The absorption of phorate upto 60 DAT was more or less similar in plants grown in lateritic upland and lateritic low land soils. But the persistance of the metabolites was significantly higher in the latter treatment. The phorate contents in plants grown in black cotton soil were comparatively low. The residue levels of the metabolite reached the peak earlier but dissipated gradually. With reference to the content of the other metabolites in plants lateritic low land soil appeared to be more favourable for their absorption and retention. It was followed by lateritic upland and black cotton soil. The content was getting reduced at more rapid rate in plants grown in sandy soil.

4.4.1.2 Percentage of phorate and its metabolites in the total residue content in plants

The percentages of phorate and its metabolites in banana plants observed at different intervals after treatment are presented in Table 11. The results clearly showed that the phorate content was relatively higher upto 60 DAT in plants grown in sandy soil (31.5 to 60.11 per cent). In plants grown in lateritic low land and lateritic upland soils the ranges in percentages of phorate were almost the same during the period

e 11 Percentage distribution of phorate and its metabolites in banana plants, treated with the insecticide at 2.5g ai/plant at planting, as observed at different intervals after treatment.

cticide/ bolite	Percentage of phorate and metabolites (ppm) in leaf sheaths observed at different intervals after treatment (days)									
	7	15	30	45	60	75	90	105	120	135
				Sandy soil						
rate	60.11	39.01	49.06	47.44	31.15	7.86	7.48	27.11	-	-
rate sulfoxide	28.01	45.83	27.06	24.64	30.48	24.55	32.39	9.81	-	-
rate sulfone	11.88	9.37	13.37	13.27	22.27	24.55	32.93	23.58	-	-
horate sulfoxide	-	-	5.20	5.85	14.98	16.65	15.02	19.93	-	-
horate sulfone	-	5.84	5.30	8.79	1.13	26.52	12.17	20.22	100	
				Lateritic low land						
rate	54.98	30.09	23.58	28.05	17.80	24.93	7.97	4.01	6.19	-
rate sulfoxide	21.49	27.19	23.39	32.55	31.59	24.38	23.73	13.46	15.52	-
rate sulfone	14.88	12.30	13.11	15.00	13.09	15.69	21.26	34.22	20.53	-
horate sulfoxide	8.65	14.17	24.22	5.06	14.74	13.09	25.26	30.43	24.45	62.
horate sulfone	-	16.23	15.70	19.27	22.77	21.91	21.79	17.86	33.30	37.
				Lateritic upland						
rate	52.22	43.37	45.68	20.80	25.45	5.14	4.54	6.04	8.23	-
rate sulfoxide	32.86	24.82	15.67	37.42	39.05	23.99	16.96	19.00	17.74	-
rate sulfone	12.32	14.03	18.80	29.89	17.35	37.23	22.91	26.02	50.16	-
horate sulfoxide	2.20	6.61	12.54	51.97	11.32	14.29	24.95	38.99	9.84	50.
horate sulfone	-	11.17	7.31	6.43	6.83	19.36	30.62	10.03	14.03	50.
				Black cotton soil						
rate	80.03	51.08	18.88	17.35	9.39	9.22	2.66	4.05	4.80	-
rate sulfoxide	19.97	24.73	32.40	46.88	27.64	28.10	13.03	15.45	12.00	67.
rate sulfone	-	17.06	30.23	22.81	17.21	17.28	24.81	22.37	19.07	-
horate sulfoxide	-	4.34	10.77	5.57	20.68	23.77	29.40	31.59	33.73	32.
horate sulfone	-	2.82	8.35	7.19	7.62	21.16	30.11	26.54	30.40	-

Table 12 Contents of phorate and its metabolites in different soils treated with the insecticide @ 2.50 g ai/plant at planting, as observed at different intervals after application.

Insecticide/ Metabolite	Residue (ppm) in soil samples collected at different intervals after treatment (days)						Half life (days)
	0	7	15	45	90	120	
		Sandy soil					
Phorate	104.360	58.501	24.380	10.554	0.152	ND	
Phorate sulfoxide	14.150	12.219	20.174	9.261	0.602	ND	
Phorate sulphone	ND	ND	14.311	9.225	0.672	0.056	
Oxyphorate sulfoxide	ND	ND	5.488	3.784	0.986	0.427	
Oxyphorate sulphone	ND	ND	4.164	3.336	0.549	0.434	
Total	118.540	82.330	68.517	32.160	3.161	0.917	70.83
		Lateritic low land					
Phorate	91.980	53.501	28.414	9.860	0.817	0.338	
Phorate sulfoxide	14.540	18.300	9.215	11.419	1.545	0.632	
Phorate sulfone	ND	8.470	4.933	5.886	1.796	0.427	
Oxyphorate sulfoxide	ND	ND	ND	3.938	1.127	0.517	
Oxyphorate sulfone	ND	ND	ND	1.277	1.904	0.903	
Total	106.520	80.271	42.562	32.380	7.190	2.817	82.84
		Lateritic upland					
Phorate	90.260	58.06	20.253	5.482	0.541	0.071	
Phorate sulfoxide	14.578	16.180	9.161	9.481	1.479	0.156	
Phorate sulfone	ND	10.579	6.279	9.879	3.102	0.398	
Oxyphorate sulfoxide	ND	ND	4.819	1.261	2.415	0.462	
Oxyphorate sulfone	ND	ND	5.711	1.918	1.784	0.593	
Total	104.838	84.223	46.223	28.020	9.321	1.680	83.26
		Black cotton soil					
Phorate	92.804	55.180	13.168	3.234	0.356	0.291	
Phorate sulfoxide	9.521	10.860	15.642	6.978	1.258	0.420	
Phorate sulfone	ND	2.510	2.302	2.185	2.580	0.659	
Oxyphorate sulfoxide	ND	ND	1.742	2.718	1.060	0.541	
Oxyphorate sulfone	ND	ND	ND	1.768	1.069	0.332	
Total	102.325	68.550	32.254	16.883	6.325	2.243	73.90

ND = Not detectable

(17.80 to 54.98 and 25.45 to 52.22 respectively) while in black cotton soil the initial residue of 80.03 per cent fell to 51.08 and 18.89 per cent successively and then remained low. In the percentages of phorate sulfoxide and phorate sulfone wide variations were not seen in plants grown in different types of soil. The percentages of oxyphorate sulfoxide and oxyphorate sulfone were least in plants grown in sandy soil and they were slightly higher in plants grown in black cotton soil. The percentages of the metabolites in plants grown in lateritic low land were the highest and they were closely followed by the percentages in the plants raised in lateritic upland soils.

4.4.2.1 Peristence of phorate and its metabolites in different types of soil treated with the insecticide

The half-life (Table 12) of total phorate was highest (83.26 days) in lateritic upland soil and it was closely followed by the half-life in lateritic low land soil (82.84 days). The half-life was least in sandy soil (70.83 days) and in black cotton soil it was slightly higher (73.90 days).

Total phorate: On the day of the treatment the total phorate residue in sandy soil was 118.54 ppm while in the other types of soil the total residue ranged from 102.325 to 106.52 ppm only. At seven DAT the residue in black cotton soil got reduced to 68.6 ppm while in other types of soil the total r sidues remained at close levels (80.27 to 84.82 ppm). At

15 DAT also the highest residue (68.52 ppm) was observed in sandy soil and it was followed by the residue in lateritic upland (46.22), lateritic low land (42.56) and black cotton soil (32.25). At 45 DAT the total residue in black cotton soil was very low (16.88) compared to the residue in other types of soil (28.02 to 32.38 ppm). At 90 DAT the residue level in black cotton soil (6.32) came close to that of lateritic low land (7.197) and lateritic up land (9.32) soil, thus showing sharper fall in the latter two. The reduction in residue content of sandy soil was still higher and it reached the level of 3.16 ppm during the period. At 120 DAT also the insecticide persisted in all treatments and the residue levels ranged from 0.917 to 2.243 ppm.

Phorate: The content of phorate (parent compound) in sandy soil on the day of treatment (104.36 ppm) was higher than the contents in the remaining types of soil (90.26 to 92.80 ppm). At seven DAT the insecticide content in sandy soil (58.50 ppm) came close to that of lateritic upland (58.06) while in black cotton (55.18) and lateritic low land (53.5) the residues were lower. At 15 DAT the highest residue content was in lateritic low land (28.41) and it was followed by the residues in sandy, black cotton and lateritic upland soils. At 90 DAT the residues of the insecticide fell below 1 ppm. The sharp decline in the residue content of phorate

between 15 and 45 DAT is very clearly seen in Fig. 5.

Phorate sulfoxide: It was present in all the types of soil on the day of treatment and the content was little lower in black cotton soil (9.52 ppm) compared to the contents in other soil types (14. 18 to 14. 58). At seven DAT there was a reduction of this metabolite in sandy soil while in other soils the content showed an increase. At 15 DAT the content showed an increase in sandy and black cotton soils while in lateritic soils there was significant reduction in the content. At 45 DAT also there was an erratic trend in the content of phorate sulfoxide in soil. At 90 DAT the residue got reduced to very low levels in all soils (0.60 to 1.55 ppm). Small quantities were present in samples collected at 120 DAT (ND to 0.42 ppm) also.

Phorate sulfone: It was detected in sandy soil only at 15 DAT while in other soils it was detectable at seven DAT. At seven DAT the highest residue was found in lateritic upland (10.58 ppm) and it was closely followed by the residue in lateritic low land (8.47 ppm) soils. In black cotton soil the residue was low (2.51 ppm). Between 15 and 45 DAT there was a fall in the content of phorate sulfone in sandy soil while in other soils the content remained static or showed slight increase only (vide Fig. 5). Persistence in sandy soil at 90 and 120 DAT was low and the reductions were least in black

cotton soil. At 45 and 90 DAT the highest content of phorate sulfone was in lateritic upland soil.

Oxyphorate sulfoxide: The metabolite was present in sandy (5.49 ppm), lateritic upland (4.82 ppm) and black cotton soil (1.74 ppm) at 15 DAT. In lateritic low land the residue was first detected at 45 DAT only. At 90 DAT 2.42 ppm of the metabolite was found in lateritic upland soil while in other types the content ranged from 0.99 to 1.13 ppm only. At 120 DAT residue was seen in all soil types and it ranged from 0.43 to 0.54 ppm.

Oxyphorate sulfone: This metabolite became detectable in samples of sandy (4.16 ppm) and lateritic upland (5.71) soils at 15 DAT. In sandy soil alone it was high at 45 DAT (3.34 ppm) while in other soil types it ranged from 1.28 to 1.92 ppm only. At 90 DAT the content of the metabolite ranged from 0.55 to 1.90 ppm and at 120 DAT the range was between 0.33 and 0.90 ppm only.

The low persistence of oxyphorate sulfoxide and oxyphorate sulfone in different soils is clearly seen in Fig. 5.

4.4.2.2 Percentage of phorate and metabolites in the total residue content of the insecticide in different types of soil

Percentages of the constituents in the total phorate observed in the treated soils at different intervals after

Fig 5 Persistence and metabolism of phorate applied in different types of soil in which banana plants were grown.

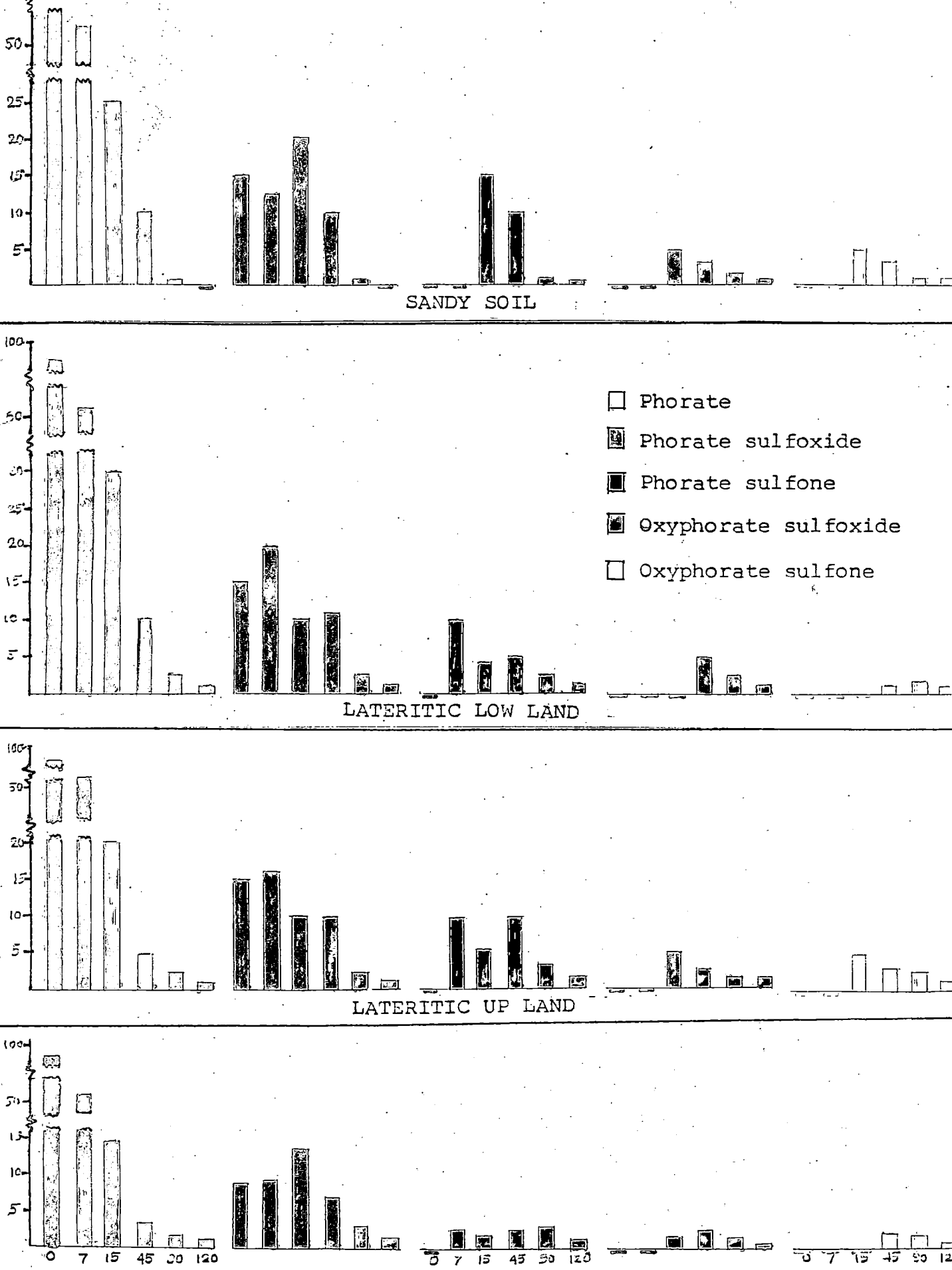

FIG- 5

INTERVALS AFTER TREATMENT (DAYS)
BLACK COTTON SOILS

treatment are shown in Table 13.

Phorate: On the day of the treatment, the percentages of the parent compound ranged from 86.09 to 91.70 only in different soils. The highest reduction in percentage at 15 DAT was seen in sandy soil (35.58 per cent). It was followed by black cotton (40.83 per cent), lateritic upland (43.82 per cent) and lateritic low land (66.76 per cent) soils. At 45 DAT, the percentage in sandy soil dropped to 32.82 from 35.58 per cent, while the fall in the percentages of phorate in other treatment were wider; the percentages dropped from 66.65 to 30.45 in lateritic low land, from 43.82 to 19.56 in lateritic upland and 40.83 to 19.16 in black cotton soils. The percentage of the parent compound was least in black cotton soil at 45 DAT. At 90 and 120 DAT, the percentages in lateritic low land remained the same (11.36 and 11.99 respectively) while the percentages in the remaining soil types ranged from 4.81 to 0 level (in sandy) and 5.80 to 4.20 (lateritic upland) respectively. Black cotton soil showed an increase (12.77 per cent) at 120 DAT.

Phorate sulfoxide: From 0 to 15 DAT, the percentage of phorate sulfoxide showed the highest increase in black cotton soil (8.30 to 48.49) and it was followed by the percentage increase in sandy soil (11.96 to 29.44). The increase

Table 13 Percentage distribution of phorate and its metabolites in different soils, treated with the insecticide @ 2.5g ai/plant at planting, as observed at different intervals after application.

Insecticide/ Metabolite	Percentage in soil samples collected at different intervals after treatment (days)					
	0	7	15	45	90	120
			Sandy soil			
Phorate	88.04	71.16	35.58	32.82	4.81	ND
Phorate sulfoxide	11.96	14.84	29.44	28.80	19.04	ND
Phorate sulfone	ND	9.94	20.89	19.36	21.26	6.11
Oxyphorate sulfoxide	ND	ND	8.01	11.77	31.20	46.56
Oxyphorate sulfone	ND	ND	6.08	10.37	17.37	47.33
			Lateritic low land			
Phorate	86.35	66.65	66.76	30.45	11.36	11.99
Phorate sulfoxide	13.65	22.80	21.65	35.26	21.49	22.44
Phorate sulfone	ND	10.55	11.59	18.18	24.98	15.16
Oxyphorate sulfoxide	ND	ND	ND	12.16	15.67	32.55
Oxyphorate sulfone	ND	ND	ND	3.94	26.48	32.06
			Lateritic upland			
Phorate	86.09	68.45	43.82	19.56	5.80	4.20
Phorate sulfoxide	13.91	19.08	19.82	33.84	15.87	9.23
Phorate sulfone	ND	12.47	13.58	35.26	33.28	23.55
Oxyphorate sulfoxide	ND	ND	18.42	4.50	25.94	27.34
Oxyphorate sulfone	ND	ND	12.36	6.85	19.14	35.09
			Black cotton soil			
Phorate	91.70	80.50	40.83	19.16	5.63	12.97
Phorate sulfoxide	8.30	15.84	48.49	41.33	19.89	18.72
Phorate sulfone	ND	3.66	7.14	12.94	40.79	29.38
Oxyphorate sulfoxide	ND	ND	5.40	16.10	16.76	24.12
Oxyphorate sulfone	ND	ND	ND	10.47	16.90	14.80

ND : Not detectable.

in the lateritic low land and lateritic upland were almost same (13.65 to 21.65 and 13.91 to 19.82 per cent respectively). In the lateritic low land and the lateritic upland and the percentages of the metabolite showed an increase from 15 to 45 DAT while in sandy and black cotton soils it declined to some extent. At 90 and 120 DAT, the reduction in percentages of the metabolite were more conspicious in sandy and lateritic upland soils than in lateritic low land and black cotton soils.

Phorate sulfone: At 15 DAT, the percentage of this metabolite was at its peak (20.89) in sandy soil and it was followed by the percentages in lateritic lupland (13.58), lateritic low land (11.59) and black cotton (7.14) soils. The change in percentages between 15 and 45 DAT was least in sandy soil (20.89 to 19.36). In the remaining treatments increasing trend was observed in the percentages of phorate sulfone. At 90 and 120 DAT the highest percentage of the metabolite was noted in black cotton soil and it was followed in the descending order in lateritic low land and sandy soils.

Oxyphorate sulfoxide: It was first detected in all the soils (except lateritic low land) at 15 DAT. The highest percentage at that stage was noted in the lateritic upland (18.42) and it was followed by the percentages of the metabolite in sandy and black cotton soils. But at 45 DAT, it was least in lateritic upland (4.5 per cent) while in the reamining soil types the variations were not high (11.77 to 16.10 per cent).

In subsequent observations there was an increase in the percentage of the metabolite. This increase was highest in sandy soil followed by increase in lateritic low land, lateritic upland and black cotton soils.

Oxyphorate sulfone: The percentages of oxyphorate sulfone in sandy and lateritic upland soils at 15 DAT were 6.08 and 12.36 respectively. In lateritic low land and black cotton soils the residues of the metabolite were non-detectable at 15 DAT. The percentages showed an increasing trend upto 120 DAT and the maximum level was in sandy soil (47.33) and it was followed by lateritic upland (35.09), lateritic low land (32.06) and black cotton (14.80) soils.

4.4.3 Correlations between the contents of phorate and its four metabolites in soil and in banana plants grown in treated soils, as observed at different intervals after treatment and in different soil types

The correlation coefficients between the contents of phorate and its metabolites present in plants and those in soil at 15, 45, 90 and 120 days after treatment were worked out and the data are presented in Table 14. (Appendices 11 to 14).

Residues of phorate in plants growing in treated sandy soils were significantly influenced by the concentration of the insecticide in soil at 15 and 45 DAT; the correlation coefficients were significant and positive (0.9724 and 0.9192). At 90 DAT

Table 14 Correlation between the content of phorate and its metabolites in banana plants and in the soil, observed at different intervals after treatment

Insecticide/ Metabolite	Correlation coefficients relating to observations made at different intervals after treatment (days)							
	15	45	90	120	15	45	90	120
	Sandy Soil				Lateritic low land soil			
Phorate	0.9724*	0.9192*	0.8449	-	0.9661*	0.9702*	0.8911	0.4535
Phorate sulfoxide	0.8726	0.9169*	0.9791*	-	0.9537*	0.8960	0.9579*	-0.2373
Phorate sulfone	0.7041	0.4842	0.9724*	-	0.4870	0.9871*	0.8422	0.9080*
Oxyphorate sulfoxide	-	0.9885*	0.7166	-	-	0.7808	0.8834	0.7919
Oxyphorate sulfone	0.9241*	0.9727*	0.9667*	0.5333	-	0.1571	0.9033*	0.9903*
	Lateritic upland soil				Black cotton soil			
Phorate	0.9709*	0.6241	0.8909	0.9850*	0.7436	0.7008	0.6601	0.6818
Phorate sulfoxide	0.9748*	0.7729	0.9713*	0.9547*	-0.1858	-0.7769	-0.5083	-0.4665
Phorate sulfone	0.2652	-0.4183	-0.6910	0.9075*	-0.4665	-0.5614	-0.3474	-0.2967
Oxyphorate sulfoxide	-0.1090	0.4569	0.5003	0.7188	0.3566	-0.0711	0.2329	-0.0823
Oxyphorate sulfone	0.8043	-0.2353	-0.7684	0.4854	-	0.6756	0.5114	0.3855

* Significant at 5 per cent level

the association was positive but not significant (0.8449). In lateritic low land, the relationship was positive and significant at 15 and 45 DAT (0.9661 and 0.9702) while it was positive but not significant at 90 and 120 DAT. Similar significant associations were seen in lateritic upland soil at 15 and 120 DAT (0.9709 and 0.9850) while the coefficients were positive but not significant at 45 and 90 DAT. In black cotton soils the correlations were not significant though they were high and positive at all the periods of observation.

Phorate sulfoxide contents in plants were significantly and positively influenced by concentration of the toxicant in soil at 45 and 90 DAT in sandy soil. In lateritic low land similar correlations were observed at 15, 45 and 90 DAT (0.9537, 0.8960 and 0.9579 respectively) while a weak and negative correlation was seen at 120 DAT. The relationship was significant and positive at 15, 90 and 120 DAT in lateritic upland soils also. Correlations between the content of the metabolite in soil and plant were negative with reference to black cotton soil, in all observations.

The correlation coefficients between varying contents of phorate sulfone in soil and plant were positive and significant at 90 DAT relating to sandy soil (0.9724) while they were positive but not significant at 15 and 45 DAT. The coefficients were positive in all the stages of observation

in lateritic low land; the values at 45 and 120 DAT showed statistical significance. The coefficient in lateritic upland was positive and significant at 120 DAT only while the values were negative at 45 and 90 DAT. The concentrations of the metabolite in soil and plant were negatively correlated in the four observations in black cotton soil. But they were not statistically significant.

Oxyphorate sulfoxide concentrations, in sandy soil and in plants grown in it showed significant and positive correlation (0.9885) at 45 DAT. In lateritic low land the correlations were positive but not significant in the three observations (0.7808, 0.8834 and 0.7919 respectively). Correlations were positive but not significant in lateritic upland soil at 45, 90 and 120 DAT while the coefficient at 15 DAT was negative and weak (-0.1090). In black cotton soil, the coefficients were positive but low at 15 and 90 DAT (0.3566 and 0.2329) and negative but low (-0.0711 and -0.0823) at 45 and 120 DAT.

Oxyphorate sulfone concentrations in plant were significantly influenced by the concentration in soil at 15, 45 and 90 DAT in sandy soils, the coefficients being 0.9241, 0.9727 and 0.9667 respectively. In lateritic low land the relations were significant at 90 and 120 DAT (0.9033 and 0.9903). The influences were positive but not significant at 15 and 120 DAT (0.8043 and 0.4854) in lateritic upland

while they were negative but not significant at 45 and 90 DAT (-0.2353 and -0.7684). In black cotton soil the coefficients were positive but not significant (0.6756, 0.5114 and 0.3855 respectively) at 45, 90 and 120 DAT.

4.4.4 The effect of phorate granules applied around the base of banana plants grown in different types of soil, on the soil microflora as observed at the time of harvest

The effect of insecticide, applied @ 2.5g ai/plant in different soils, on bacteria, fungi and actinomycetes (expressed as the number of colonies per gram soil) were analysed statistically and the results are presented in Table 15.

4.4.4.1 Effect on soil bacteria

The application of phorate at planting did not significantly influence the population of bacteria at harvest of the crop in any of the soils. In sandy soil the mean number of colonies was slightly higher in treated plots (23.04) than in the untreated plots (21.82). In lateritic low land and lateritic upland also the mean number of colonies per g soil were slightly higher in phorate treated plots (29.05 and 27.12) than in control plots (28.40 and 26.84 respectively). The populations in treated black cotton soil were slightly lower in treated plots (35.80) than those noticed in untreated plots (37.02), though the differences were not statistically significant.

Table 15 Population of bacteria, furgi and actinomycetes in different soils, treated with phorate @ 2.5g ai/plant, at planting, as observed at harvest (330 DAP)

Treatments		Mean number per g soil		
Soils	Insecti-cide	Bacteria ($\times 10^6$)	Fungi ($\times 10^4$)	Actinomycetes ($\times 10^6$)
Sandy	Phorate	23.04	28.52	24.02
	Control	21.82	31.30	22.60
Lateritic low land	Phorate	29.05	34.04	29.06
	Control	28.40	38.46	28.10
Lateritic upland	Phorate	27.12	29.45	29.82
	Control	26.84	31.40	28.30
Black cotton	Phorate	35.80	24.26	36.40
	Control	37.02	27.19	32.18
F test		NS	NS	NS

NS : Treatment effects not significant

4.4.4.2 Effect on soil fungi

The application of phorate did not significantly influence the populations of soil fungi. The populations (number of colonies per g soil) in treated sandy, lateritic low land and lateritic upland (28.52, 34.04 and 29.45 respectively) were slightly lower than those in the control plots (31.30, 38.46 and 31.40 respectively). In black cotton soil the populations in control (27.19) and treated plots (24.26) were slightly lower than those observed in other types of soil.

4.4.4.3 Effect on actinomycetes

The actinomycete population was not seen significantly affected by the application of phorate in any of the soils included in the experiment. The populations were slightly higher in treated plots than in control plots. The mean number per g soil ($x\ 10^6$) in treated sandy, lateritic low land, latefitic upland and black cotton soils were 24.02, 29.06, 29.82 and 36.40 respectively while those in untreated plots were 22.60, 28.10, 28.30 and 32.18 respectively.

DISCUSSION

DISCUSSION

Bunchytop, the most serious disease of banana in Kerala, is being tackled by controlling its vector Pentalonia nigronervosa Coq., using phorate granules as a phophylatic treatment. The recommendations followed at present envisage three applications of the insecticide first at planting @ 2.5g ai/plant and then at 75 days after planting (DAP) and at 165 DAP @ 1.25g ai/plant, if applied in the leaf axil and @ 2.5g ai/plant if applied in the soil (Kerala Agricultural University, 1986). The effect of such repeated applications of the insecticide on the absorption of the toxicant by the plant, the metabolism of the insecticide and consequent persistence and the terminal residues in banana bunches have not been studied so far. The existing recommendations are based on some field experiments (Nair et al., 1973) in which none of the basic aspects had been investigated. The present investigations have been taken up with a view to gathering detailed data on all basic problems related to the above extensively adopted control measures.

5.1 Uptake and persistence of phorate in banana plants when treated with different doses of the insecticide at different growth stages of the crop

5.1.1 Uptake and persistence

The results of the field experiment presented in para 4.1.1 showed that the stage of the crop at the time of treatment influenced the uptake and persistence of the insecticide remarkably. When applied at the time of planting the phorate content in the plants at 15 DAT were low at both the levels of the toxicant. In the observation at 30 DAT a steep rise in residues of phorate in plants treated at planting was observed and in subsequent observations, plants in the above treatment showed high levels of residues. The initial low level of the pesticide in the plant might have been caused by the condition of the plant at the time of treatment. At planting the roots and outer layers of the suckers are removed (parring) as a regular practice to eliminate the life stages of plant parasitic nematodes and other soil pests which may be surviving in the planting material. The poor initial absorption can hence be attributed to the lack of roots at the time of treatment. The observation indicated the desirability of delaying the first treatment for two to three weeks to avoid wastage of the pesticide in soil through degradation. Results in para 4.4.2 and Table 12 showed that there was fast reduction of the residues in soil soon after treatment (7 and 15 DAT). This finding may be relevant to all transplanted crops which are to be protected from pests at early stages using granular insecticides.

The increase in the phorate content in the plant upto 60, 45 and 30 DAT when treated at planting, at 75 and at 165 DAP, respectively and the subsequent drop indicated that the absorption of the insecticide from the soil continued till then and subsequently the dissipation of the insecticide alone occurred within the plant. In treatments done at 0, 75 and 165 DAP, the peak of insecticide residues were noted at 60, 45 and 30 DAT and the pesticide content remained sufficiently high to cause adequate mortality upto 75, 60 and 45 days after treatment. If the application of the pesticide is delayed by three weeks from the time of planting as indicated above, the efficacy of the first application will be prolonged beyond 75 days and the efficacy of the second treatment may not extend upto 165 DAP. The results thus indicated that the existing recommendation to apply the insecticide at 0, 75 and 165 DAP do not agree with the persistence and bioefficacy of the insecticide. There is no previous work on the absorption and persistence at phorate in banana.

The results presented in para 4.1.1 and 4.1.2 showed that the enhancement in the residue

content in the plant and the mortality of the insect caused by the increase in the dosage of the insecticide from 1.25 to 2.5g ai/plant was least in treatments done at planting and was showing an increasing trend in treatments done at 75 and 165 DAP. The difference in the PT indices in the treatments with the two doses of the insecticide done at 0, 75 and 165 DAP were 460, 682 and 2373, respectively (vide Table 2). The results clearly indicated the lack of response to a higher dose of the pesticide at the early stages of the crop growth. It may be possible to enhance the persistent toxicity of the pesticide significantly in the third treatment done at 165 DAP by using the higher dosage 2.5g ai/plant. However, residues of the insecticide were detected in mature unripe fruits when the insecticide was applied @ 2.5g ai/plant at 150 and 180 DAP and in mature ripe fruits when applied at 180 DAP (vide Table 7). Hence the use of phorate @ 2.5g ai/plant for the third treatment may not be desirable in robusta variety of banana. Thus a reduced dose of 1.25g ai/plant was seen to be as effective as the higher dose of 2.5g ai/plant used at present for treatments at planting and at 150 DAP. At 180 DAP 2.5g ai/plant was more effective but the

treatment was leaving residues above tolerance limit in fruits and hence found undesirable. Hence the necessity for a revision of the recommended dosage of 2.5g ai/plant was strongly indicated in the results. Results from other field experiments conducted at the College of Agriculture, Vellayani showed that the dosage of 2.5g ai/plant now adopted can be reduced to 1.5g ai/plant without significant reduction in the efficacy of treatment in checking the vector population and for controlling the disease (Reghunath, 1989).

The results presented in para 4.1.1 and 4.1.2 further showed that the insecticide content in plants applied at the root zone was significantly higher than the content observed in plants treated at the leaf axil in all the observations made after the treatment. The results established the need for a change in the present recommendation to use phorate @ 1.25g ai/plant at leaf axil in lieu of 2.5g ai/plant in the soil for treatments done at 75 and 165 DAP. Further, filling of leaf axil with insecticide granule is not an easy practice, especially, at later stages when the plant has grown up. Application of granules in leaf axils

have been reported effective for the control of pests in crops like sorghum, sugarcane, etc. especially in early stages when the crop remain short. It is also known that one of the major routes for insecticide dissipation is through volatalization. When applied in leaf axil of tall plants like banana exposure to sun and wind will be more and the consequent loss of the insecticide will be higher than when the toxicant is applied in soil where the granules are raked into the lower layers. Thus the application of phorate at root zone is bound to be more effective than the treatment done at leaf axil.

The content of total phorate in plants (leaf sheath) observed at different intervals after treatment showed that the toxicant rises up to the levels of 9.8, 4.8 and 2.4 ppm, when applied at 0, 75 and 165 DAP respectively with a basal dose of 1.25g ai/plant. The respective levels for 2.5g dosage were 9.9, 6.0 and 5.7 ppm. The absorption and translocation of phorate in banana is being studied for the first time. The peak of phorate content reported in other crops were highly varying; in rice 2.16 ppm at 3 DAT (Narayanaswamy et al.,1975); 4.60 at 60 DAT (Garg and Sethi, 1982 b); in cotton 9.5 and 9.5 ppm at 30 and 60 DAT (Gulab Singh et al., 1984); in mustard 2.50 ppm at 30 DAT (Jain et al., 1974 b); 2.20 ppm at 20 DAT (Agnihotri et al.,1975);

in oats 7 ppm, in barley 10 ppm and in wheat 20 ppm at 22 DAT (Lilly et al., 1958); in peas 30 ppm at 8 DAT (Getzin and Chapman 1960) and in lemon 95 ppm at 4 DAT (Metcalf et al., 1957) were observed.

The persistence of phorate in banana is in broad agreement with the reports on other crops. The content in leaf sheath after the periods of 90, 90 and 60 days in treatments done at 0, 75 and 165 DAP were 2.3, 1.1 and 2.4 ppm, respectively. The residues reported were 0.12 to 0.50 ppm at harvest (180 DAT) in carrots (Lichtenstein et al., 1973); 1.75 and 1.56 ppm at 40 and 90 DAT in potato (Kathpal et al.,1983); 1.44 ppm in mustard flowers at 90 DAT (Agnihotri et al.,1975); 0.96, 1.45 and 2.4 ppm in flowers, pods and flag leaf, respectively, at 90 DAT in mustard (Jain et al.,1974 b); in rice 0.24 and 0.39 ppm in grain and straw, at 95 DAT (Prasad and Mani 1979); 0.28 ppm in straw at 90 DAT (Garg and Sethi 1982 a) and 5.9 and 2.8 ppm at 60 and 90 DAT in cotton plants (Gulab Singh et al., 1984). The prolonged availability of insecticide in plants may be attributed to the prolonged availability of the insecticide in treated soils as seen in Table 11 and 12. In lateritic upland soils, in which plants in the first experiment were grown, around 10 per cent of the applied dosage persisted at 90 DAT, when the insecticide was applied @ 2.50g/plant at planting.

5.1.2 Bioefficacy of phorate content of treated banana plants to P. nigronervosa

The results on bioefficacy of the insecticide content in leaf sheath against the test insect (vide para 4.1.2) showed that 100 per cent mortality occurred only to four out of the 56 observations in the experiment, even when the insects were confined on the feeding site in cages. The mortalities ranged from 28 to 100 per cent during the first 60 days after different treatments (vide Table 2). Obviously, the application of phorate @ 1.25 or 2.5g ai/plant at 0, 75 and 165 DAP will not ward off the vector completely under field conditions. But the treatments have been proved effective in checking the bunchy top disease of banana. These results indicated that 100 per cent control of a vector is not a must for protecting crops from the incidence of virus diseases.

5.1.3 Dose-effect relationship observed when P. nigronervosa was exposed to treated plants containing varying levels of phorate content

The results presented in para 4.1.3 showed that the mortalities of P. nigronervosa on banana plants treated with phorate granules were positively ocrrelated with the total insecticide content in the leaf sheath and the correlations were highly significant. The results obtained

from path coefficient analysis of the data (vide para 4.1.7) also showed that 98 per cent of the mortality observed in the test organism could be attributed to the content of phorate and its metabolites in plant tissue. The residuals observed in the analysis of the data were below two per cent in different treatments (Table 5). The age of the crop and other environmental factors were not affecting the dose-effect relationship between phorate and P. nigronervosa.

The application of graded doses of a systemic insecticide will not ensure corresponding ranges of insecticide content in plants grown in the treated soils. Absorption of the toxicant from the soil and its persistence will depend on various extraneous factors. The results in Table 1 also showed that the residue content in plant did not show a proportionate increase when the dose of the insecticide applied in soil was increased from 1.25 to 2.5g ai/plant. In this context an attempt was made to establish a dose-effect relationship from the data obtained from the experiment as described in para 4.1.4. This new analysis of the data revealed many interesting facts.

The LD_{50} of phorate ranged from 1.624 to 2.711 ppm upto 60 DAT (period of active absorption of toxicant) and 3.147 to 3.614 between 75 and 90 DAT (period of dissipation

of residues in plant). The higher dose requirement towards the later stages after treatment may be attributed to the metabolism of the insecticide in plant tissues leading to the formation of less toxic components in the total insecticide content observed in the leaf sheath.

The data presented in para 4.1.4 further showed that the age of the plant was not altering the dose-effect relationship of the toxicant. This indicated that the feeding rate of the insect and consequent intake of the toxicant from plants of different ages were not varying significantly.

Another interesting information which emanated from the dose-mortality studies was that the residue contents in plants, at the active period of absorption (45 and 60 DAT) were far above that required for the effective kill of the pest (shown by LD_{50},LD_{90} estimates). When applied at the time of planting, the residue at 45 and 60 DAT were 7.5 and 9.8 ppm and 9.2 and 9.9 ppm respectively for the doses of 1.25 and 2.5g ai/plant and the mortalities observed in all the treatments were near 100 per cent. LD_{90} levels of the toxicant, estimated from the data, were below 5.5 ppm even for the period of 65 to 90 DAT. Excess residue of the insecticide which accumulated in the plant would obviously get metabolised and lost without serving its full purpose of controlling the pest. Such high accumulation of phorate

residues have been reported earlier in other crops too. (Dobson et al., 1960 in alfalfa; Getzin and Chapman, 1960 in peas; Jain et al., 1974b in mustard and Gang and Sethi, 1982b in rice). It may be possible to minimise such losses of insecticide by reducing the dosages of insecticide per treatment and by increasing the frequency of application.

5.1.4 Metabolism of phorate in banana

The methods for the estimation of phorate and its metabolites in plants had been standardized by Blinn, (1963). He recommended TLC separation followed by quantification with infrared spectrophotometry. This technique was modified facilitating the estimation of the residue with spectrophotometer since infrared spectrophotometer is a rare facility in the residue laboratories in India. The colour of palladium chloride used as a visualizing agent on the chromatogram, as per the procedure of Blinn, interfered with the colour developed by paranitro benzyl pyridine and cyclohexyl amine in the final sample when the transmittance was estimated with a spectrophotometer. Such interference was not observed in infrared spectrophotometry. The difficulty was circumvented by following the procedure described in para 3.3.4.5.3. The modified procedure was found to be simple and it was reliable as evidenced by the high recovery percentages of the residues (vide Appendix 1).

The metabolites identified in treated banana plants were the four oxidative products, phorate sulfoxide, phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone. A transient spot was also seen on chromatogram at a place corresponding to the reported Rf of oxyphorate. But the identification of the metabolite and its quantification were not possible due to the lack of reference standard.

As described in para 4.1.5, all the four metabolites appeared in all the treatments (except the treatment done at 0 DAP) at 15 DAT. In the treatments done at 0 and 75 DAP, the content of phorate, phorate sulfoxide and phorate sulfone showed an increasing trend upto 60 and 45 DAT respectively. Phorate and phorate sulfone showed a sudden decline in content at 75 and 60 DAT respectively, while the reduction of phorate sulfoxide during the period was less drastic. The trend seen in treatments done at 165 DAP also was similar but the fall in quantities of the metabolites was not as drastic as in the other treatments. The overall trends seen in the content of oxyphorate sulfoxide and oxyphorate sulfone also were the same. The contents of these metabolites were increasing upto the peak periods in the total residue content and then declined. The delay in the appearance of the metabolites in treatments done at the time of planting may be attributed more to the poor

absorption of the toxicant due to lack of absorbing roots than to the lower metabolic rate in the plant. Less conspicious reduction in the content of metabolites between the periods of peak and decline indicated a slightly lower metabolism in plants treated at 165 DAP. The persistence of the metabolites also failed to show wide variations. All of them reached non-detectable levels between 90 and 105 DAT.

The concurrent increase and fall in the total residues and of the metabolites in the plant suggest that either the parent compound metabolised in the plant was being continuously replaced by absorption from the soil or the quantities of metabolites available in the plant might be contributed directly from the soil also. In the first experiment the levels of the parent compound and metabolites in the soil were not studied. Results from a later experiment (vide para 4.4.2.1) showed that phorate and all the four metabolites were present in the soil from 15 DAT (in lateritic upland soil) when applied at the time of planting and that they appeared in plants also in detectable levels during the period (vide para 4.4.1.1). During the period of increase in the residue content (phorate and metabolites) of the plant there was a corresponding decline in the residue levels in the soil. This indicated that the content in the soil was contributing to the content in the plants. However, the

content of phorate and the metabolites in the soil and plants did not show statistically significant ocrrelations (vide Table 14). The results indicated that the residue content in the plant was a combination of the materials formed by the direct metabolism of the parent compound within the plant tissues and of the components which were being continously absorbed from the soil.

The metabolism of phorate in the plant and soil and the absorption of the toxicant and the metabolites from the soil by the plant as well as their retention were not significantly affected by the variations in the dose of phorate applied in the soil. In plants treated at 165 DAP the rate of metabolism was slightly lower. The quantities of metabolites were less in plants treated at the leaf axis than when treated at the root zone.

The metabolism of phorate in banana has not been studied so far. The metabolism of this compound as reviewed in para 2.2 showed very wide variations in different crops.

Bowman and Casida, (1957) reported the presence of all the five oxidative metabolities, phorate sulfoxide, phorate sulfone, oxyphorate, oxyphorate sulfoxide and oxyphorate sulfone in vegetables. Saunders and Getzin, (1973) found all of them in the bark and needles of scots pine at five months after treatment. In brassica plants all the

metabolities except oxyphorate were detected at 15 DAT by Krishnaiah and Kalra, (1978). Leuk and Bowman, (1970), similarly, found all the metabolites except oxyphorate in corn plants 14 days after treatment. They also reported the same composition of metabolites in treated bermuda grass at 21 days after treatment.

Bowman and Casida, (1958) reported that while at 1 DAT phorate sulfoxide and phorate sulfone constituted 76.2 per cent of the metabolites, their proportion fell to 64.0 per cent at 12 DAT with the appearance of oxyphorate sulfoxide and oxyphorate sulfone which constituted 8.5 per cent of the total residue at that time.

Phorate sulfoxide and phorate sulfone were the only metabolites in sugar beets at 8, 16 and 24 DAT (Reynolds et al., 1960), in carrots at harvest (Suett 1971 and 1974), in sorghum plants (Khajuria et al., 1973), in mung beans and soybeans (Talekar et al., 1977a) and in radishes (Chapman and Harris, 1980).

Menzer and Ditman, (1968) on the other hand reported the presence of phorate sulfone and oxyphorate sulfone only in treated spinach plants at harvest. Kathpal et al., (1983) could detect phorate sulfoxide only in potato tubers at 70 and 80 DAT.

5.1.5 Percentage distribution of phorate and its metabolites in banana treated at different intervals after planting

The estimation of the percentages of different components of the total phorate residue in the plant at different intervals after treatment was done with a view to understanding their interdependence, if any. The results presented in para 4.1.5 and 4.1.6 showed that while the content of phorate and phorate sulfoxide showed an increasing trend, the percentages of the two compounds in the total residues showed a reciprocal relation thus indicating that the phorate absorbed into the plant was at least partially the precursor of the other metabolites. Contentwise, oxyphorate sulfoxide and oxyphorate sulfone showed an initial increasing trend followed by a decreasing trend in many of the treatments. Assessment of their percentages in the total residue showed clearly that the metabolites were gradually increasing in proportion from 15 to 105 DAT, indicating the continuous oxidation of the parent compound within the plant.

Bull, (1972) identified two major pathways in the oxidative metabolism of phorate in plants, viz., oxidation of thioether moiety leading to the formation of phorate sulfoxide and phorate sulfone and desulfurations of phorate producing a transient oxyphorate which subsequently get

oxidized to oxyphorate sulfoxide and oxyphorate sulfone. The conversion of sulfide to sulfoxide was rapid while its further oxidation to sulfone was very slow. With a view to understand the relative dominence of these two metabolic pathways, the data in Table 4 was regrouped and are presented in Table 16. The results showed that both the metabolic routes were prevalent in the plant within 15 DAT. In the earlier phase the sufoxidation of the thioether moiety was having an upper hand while in the declining phase of the total residues, the percentage of oxyphorate sulfoxide and oxyphorate sulfone showed an increasing trend. The mean percentages presented in the Table 16 showed that the increase in the dose of phorate applied to the soil and the age of the plant at the time of treatment did not noticeably affect the metabolic pathways.

5.1.6 Correlation between the insecticide residues and the mortality of the test insect and path coefficient analysis of the data.

The data presented in para 4.1.7 clearly showed that the observed mortality was very strongly associated with the residue content in the plant. The content of the parent compound in the tissues showed the highest direct effect on the mortality in four out of eight treatments in the experiment (vide Table 5), while phorate sulfoxide,

ble 16 Percentages of metabolites of phorate in treated plants formed through different pathways, observed at different intervals after treatment

Treatments			Insecticide/ Metabolite content	Percentage oin plant samples collected at different intervals after treatment (days)							
lte of pplica- ion	Dose g ai/ plant	Time of appli- cation DAP		15	30	45	60	75	90	105	Mean
pot one	1.25	0	Phorate	57.5	43.0	59.8	30.9	20.2	12.9	0	37.4
			Phorate sulfoxide+ Phorate sulfone	42.5	49.8	51.6	36.8	37.9	21.5	0	40.0
			Oxyphorate sulfoxide+ Oxyphorate sulfone	0	7.2	8.6	32.3	41.9	83.6	100	58.5
pot one	1.25	75	Phorate	41.4	42.6	21.6	25.9	17.3	0	0	24.8
			Phorate sulfoxide+ Phorate sulfone	35.8	34.5	33.0	45.6	63.0	32.4	0	40.4
			Oxyphorate sulfoxide+ Oxyphorate sulfone	22.8	22.9	45.4	28.9	19.7	67.6	100	43.9
pot one	1.25	165	Phorate	38.4	38.2	22.6	7.9	8.3	0	0	23.2
			Phorate sulfoxide+ Phorate sulfone	45.6	48.9	54.3	63.1	41.9	0	0	50.8
			Oxyphorate sulfoxide+ Oxyphorate sulfone	16.0	12.8	23.0	28.9	49.8	100	0	36.8
pot one	2.50	0	Phorate	60.9	33.9	32.2	30.6	29.3	9.1	0	37.6
			Phorate sulfoxide+ Phorate sulfone	31.8	40.9	30.7	19.2	34.4	41.1	100	42.6
			Oxyphorate sulfoxide+ Oxyphorate sulfone	7.2	25.1	37.1	49.3	36.9	60.9	0	36.1
pot one	2.50	75	Phorate	40.5	27.0	21.9	30.4	9.7	0	0	25.9
			Phorate sulfoxide+ Phorate sulfone	35.2	40.9	38.4	45.1	57.4	55.7	0	45.5
			Oxyphorate sulfoxide+ Oxyphorate sulfone	24.3	32.2	39.6	24.9	33.0	44.3	100	42.6
pot one	2.5	165	Phorate	33.9	26.3	32.8	26.8	28.5	0	0	29.7
			Phorate sulfoxide+ Phorate sulfone	43.9	41.9	32.1	30.4	48.4	56.0	57.0	44.9
			Oxyphorate sulfoxide+ Oxyphorate sulfone	22.1	31.9	35.1	35.7	23.1	44.0	43.0	33.6
eaf xil	1.25	75	Phorate	12.9	46.0	20.4	23.9	17.7	13.0	0	22.3
		8	Phorate sulfoxide+ Phorate sulfone	68.1	38.5	36.2	45.7	57.4	11.7	0	42.9
			Oxyphorate sulfoxide+ Oxyphorate sulfone	19.0	11.2	45.1	15.4	25.0	75.3	0	31.8
eaf xil	1.25	165	Phorate	30.1	25.8	29.1	46.2	0	0	0	32.8
			Phorate sulfoxide+ Phorate sulfone	38.0	49.1	39.6	50.6	100	0	0	55.4
			Oxyphorate sulfoxide+ Oxyphorate sulfone	21.6	25.1	31.1	3.3	0	0	0	20.3

oxyphorate sulfoxide and oxyphorate sulfone showed the maximum direct effect on mortality in 2, 1 and 1 treatments respectively. When applied at higher doses, the parent compound showed higher direct effect. Phorate and phorate sulfoxide appeared to show a comparatively higher effect on the test insect and phorate sulfone appeared to be the least effective. Phorate and phorate sulfoxide showed a positive and significant association with the mortality in seven and six out of the eight treatments repsectively.

In all the treatments except in the leaf axil filling done at 165 DAP, the parent compound showed a direct positive effect on the mortality while the direct effect of the other constituents of the residue showed a positive effect in some treatments and negative effect in others. The overall results of the data thus indicated that the phorate and phorate sulfoxide contents in the plants had a more dominent effect on the test organisms than the other metabolites. Path coefficient analysis has been tried for the first time in analysing the relative importance of the phorate precursor and its metabolites in causing toxicity to the test insect.

The relative toxicities of phorate and its metabolites as reported by earlier workers (para 2.3.2) do not show a general agreement. While the parent compound was reported to be more toxic to insects by Lichtenstein (1966),

Getzin and Shanks, (1970), Schulz et al., (1973) Walter-Echols and Lichtenstein, (1977) and Ho and Galley (1982); phorate sulfoxide and phorate sulfone were found more toxic by Harris and Bowman, (1981), and oxyphorate and oxyphorate sulfone were seen more toxic by Bowman and Casida, (1958). The variations manifested in the direct and indirect effects of phorate and its metabolites on the mortality of the test insect in different treatments was obviously caused by the changes in the percentages of the components in the plant tissue partly contributed by the highly reversible nature of the oxidative metabolism of the toxicant within the plant.

5.2.1 Absorption and persistence of phorate in banana plants treated at different growth stages of the crop

The results presented in para 4.2.1 (Table 6) showed that the initial absorption of the toxicant in treatments done upto 150 DAP were on par as indicated by the mortality of P. nigronervosa. The mortality at 24 DAT did not show significant variations in treatments done upto 150 DAP. The increasing mortality recorded in each of the consecutive observations in a treatment is caused by the cumulative effect of residues persisting in the plant and the quantum of the toxicant that was being continously absorbed from the soil. Since the treatments done upto 150 DAP did not significantly differ in causing the mortality of test

insect at 24 DAT, it may have to be presumed that the plants did not show significant variation in the absorption of the insecticide upto 174 DAP.

The relation between the residues at 31 to 90 DAT in treatments done at 0 to 150 DAP (as evidenced by the mortality of the test insect) and the age of the plant was reciprocal. Since the period of observation relating to these treatments (upto 150 DAP) fall within the period in which the rate of absorption was not found significantly varying (upto 174 DAP), the low mortality observed in these treatments might be attributed to the higher metabolic degradation of the toxicant.

When treated at 2.5g ai/plant, effective kill of the insect (above 50 per cent) was obtained in treatments done at 0, 30, 60, 90, 120 and 150 DAP, upto 60, 60, 60, 45, 31 and 31 days after treatment, respectively. Persistent toxicities were higher and were on par in younger plants (upto 60 DAP). Obviously, the interval between treatments may have to be shortened after 60 DAP to ensure adequate bioefficacy.

In plants treated at 180, and 210 DAP, the absorption and persistent toxicity of the insecticide were very low. The results indicated the need for assessing the bioefficacy of the third application of the insecticide

at 165 DAP now being followed for controlling the vector. The highest mortality observed in the treatments done at 150, 180 and 210 DAP, from 3 to 90 DAT were 62.5, 38.35 and 35.8 per cent, respectively. This appears to be low for the control of an insect vector aiming to prevent the spread of a virus disease. The persistent toxicities of phorate with reference to the varying growth stages of any crop have not been reported so far. Obviously, the effect of skipping or preponing the third treatment may have to be studied through field trials for recommending a reliable methodology for the control of the vector population on robusta variety of banana.

5.2.2 Terminal residues of phorate in the fruits when the plants were treated at different intervals after planting

Results presented in para 4.2.2 indicated that for ensuring the total phorate residues within tolerance limits (0.1 ppm) in raw fruits, the insecticide treatment had to be limited upto 150 DAP (vide Table 7) and for the mature ripe fruits, the limit could be extended upto 180 DAP. Earlier reports on phorate residues in banana fruits are not available in literature.

5.3 Effect of rainy and summer season on the absorption and persistence of phorate

Results presented in para 4.3.1 showed that the insecticide contents in the leaf sheath of plants grown and

treated in summer months were significantly higher than those of the corresponding treatments in rainy season, when observed at 60, 75 and 90 DAT. At 105 and 120 DAT also the residues were higher in plants treated in summer. The effect of season was not manifested in the earlier period of the experiment (15 to 45 DAT).

The toxicity of the residues to P. nigronervosa, observed at different intervals after treatment (vide para 4.3.2), revealed that the effect was more in summer months rather than in rainy season in all observations except at 15 and 30 DAT. The presence of higher residues of phorate in plants treated and grown in summer months is in general agreement with the observation of VanMiddlem and Baranowski, (1962) who reported that highest concentration of phorate in tomato plants usually coincided with preceeding periods of relatively high temperature and rainfall. The relatively lower persistence in the rainy season could be due to leaching of the insecticide to lower layers. Agnihotri et al., (1975) found that phorate persisted longer (60 days) in brassica plants and in soils under unirrigated condition than under irrigated condition (45 days). They also reported that unirrigated plants contained 10.7 per cent more phorate than those grown under irrigated condition.

It is well known that the oxidation products of phorate are highly polar and more water soluble than phorate and

thus they may get lost through leaching from the soil (Getzin and Chapman, 1970, Schulz et al., 1973 and Lichtenstein et al., 1974). Obviously, the total phorate content in the plant is likely to be lower in rainy season than in the summer months due to lesser availability of the metabolites in the soil.

5.4.1 Absorption, metabolism and persistence of phorate in banana grown in different types of soils in Kerala

The results presented in para 4.4.1 showed that the plants when treated at planting contained less of total insecticide residues when grown in sandy soil and the highest when grown in lateritic low land; the content in lateritic upland and black cotton soils coming in between. These differences can probably be due to the earlier rooting and consequent earlier absorption of the insecticide in plants grown in lateritic low land. In sandy soil the rooting may be delayed due to low organic matter content in the soil.

During the active phase of absorption (30 to 60 DAT), the highest residue content was observed in plants grown in sandy soil and it was followed by lateritic low land and lateritic upland soils. The least absorption during the period was found in the black cotton soil. The high organic content of the black cotton soil may render the toxicant less

available to the plant due to greater adsorption (Appleman and Sears, 1946, Foster et al., 1946, Getzin and Chapman, 1960 and Lindley, 1963). During the declining phase of absorption (beyond 60 DAT), a sudden drop in residue content was observed in sandy soil while the declining trend, though high, was comparatively lower in lateritic upland and it was rather gradual in lateritic low land soil. In plants grown in black cotton soil, at 60 DAT, there was still an increase in the residue content and the decline noted after 75 DAT also was very gradual.

The total residue content remained sufficiently high to give good protection of the crop from the vector (sufficient to give above 50 per cent mortality based on LD_{50} values vide para 4.1.4), upto 75 DAT in plants grown in sandy and 90 DAT in those grown in lateritic upland soils. In low land soil the persistence was adequate upto 105 DAT. Inspite of low absorption of the insecticide in plants grown in black cotton soil, the residue persisted at effective levels upto 105 DAT. It was due to the longer persistence of the insecticide in these soils. The results indicated that the recommendation to give the second application of the insecticide at 90 DAT will hold good for all types of soils covered in the study.

The content of phorate (parent compound) and the four metabolites in different periods after treatment showed

an overall trend similar to that of the total phorate. The phorate and metabolites remained higher in the earlier phase (upto 60 DAT) in plants grown in sandy soil and it was followed by the contents in plants grown in lateritic upland and lateritic low land soils. The residue in plants grown in black cotton soil was the least. The fall in the content of metabolites was higher in plants grown in sandy soil followed by that in plants grown in lateritic upland and lateritic low land soils. The residues of components reached the peak earlier in black cotton soil but the dissipation was more gradual. The results indicated that variations in the residue contents of metabolites depended on the phorate availability in the plants rather than on the variation in the rate of metabolism inside the plants grown in different types of soil.

5.4.2 Percentages of phorate and metabolites in total residue content in plants observed at different intervals after treatment

The results presented in para 4.4.1.2 showed that the different types of soil were not significantly and consistently altering the percentages of different components of the total phorate residue in banana plants when observed at different intervals after treatment. The data summerised in Table 17 also showed that the plants grown in lateritic

Table 17 Percentages of metabolites of phorate formed through different path ways in plants, treated with the insecticide @ 2.5g ai/plant at planting, as observed at different intervals after treatment.

nsecticide/ etabolite	Percentage of phorate and metabolites in leaf sheaths observed at different intervals after treatment (days)										
	7	15	30	45	60	75	90	105	120	135	Mean
					Sandy soil						
horate	60.1	39.0	49.1	47.4	31.2	7.0	7.5	27.1	-	-	33.6
horate sulfoxide+ horate sulfone	39.9	55.2	40.4	37.9	37.9	52.7	49.1	65.3	33.4	-	46.8
xyphorate sulfoxide+ xyphorate sulfone	-	5.8	10.5	14.6	16.1	43.2	27.2	40.1	100	-	28.6
					Lateritic low land						
horate	55.0	30.1	23.6	28.1	17.8	24.9	8.0	4.1	6.2	-	21.9
horate sulfoxide+ horate sulfone	36.3	39.5	36.5	47.6	44.6	40.1	44.9	47.7	36.0	-	38.2
xyphorate sulfoxide+ xyphorate sulfone	8.7	30.4	39.9	24.3	37.5	35.0	47.1	48.3	67.8	100	43.4
					Lateritic upland						
horate	52.2	43.4	45.7	20.9	25.5	5.1	4.5	6.1	8.2	-	22.6
horate sulfoxide+ horate sulfone	45.2	38.8	34.5	67.3	56.4	61.2	39.9	45.0	67.9	-	50.7
xyphorate sulfoxide+ xyphorate sulfone	2.2	17.8	19.8	58.4	18.1	33.6	55.6	49.0	23.8	100	37.8
					Black cotton soil						
horate	80.0	51.1	18.9	17.4	9.4	9.2	2.7	4.1	4.8	-	20.9
horate sulfoxide+ horate sulfone	19.9	41.8	62.6	69.7	44.8	35.4	37.8	37.8	31.8	67.8	48.7
xyphorate sulfoxide+ xyphorate sulfone	-	7.1	19.1	12.7	28.3	44.8	59.5	58.1	64.1	32.2	36.2

low land manifested the sulfoxidation route of metabolism in less prominent manner than the desulfuration route, while the reverse trend was seen in plants grown in lateritic upland and black cotton soils. The desulfuration pathway was least in plants grown in sandy soil. Investigations in this line are lacking in literature. Lack of a reciprocal relationship between phorate precursor and metabolites indicated the continued absorption of the metabolites of phorate from the soil upto 45/60 days after treatment. Saunders and Getzin (1973) observed that higher concentration of phorate sulfoxide and phorate sulfone in scotspine seedlings, five months after application, was due to the continous absorption of those metabolites from the soil and from the metabolism of absorbed phorate within the plant tissues.

5.4.3 Persistence of phorate and its metabolites in different types of soil treated with insecticides

The results presented in para 4.4.2.1 showed that the persistence of phorate as shown by the half-life values was higher in lateritic upland soil and it was followed by the persistence in lateritic low land, black cotton and sandy soils.

The total residues obtained from different types of soil on the date of treatment showed variations and these can be attributed to the variations in the recovery percentages of the pesticide in different types of soil (vide Appendix 1).

This could probably be due to binding of a part of the applied phorate to the soil fractions. Several workers have reported the phenomenon of binding of phorate in soil. Getzin and Chapman, (1960) found that 14-25 per cent of the applied radio active phorate was bound in sandy soil. The rate of binding was higher in muck soils having high organic matter content. Bull, (1972) reported the conjugations with glycosides to be the process by which organophosphates get bound in the soil. Lichtenstein et al., (1974) found that the binding ranged from 1.81 per cent in quartz sand to 4.3 per cent in sandy soil.

At 15 DAT the highest content of the residue was observed in sandy soil, though the mean persistence was least in this soil type. As observed in para 4.4.1.1 the absorption of the insecticide by the plants grown in sandy soil in the early phase (due to poor root system) could have remained low and that contributed to a higher retention of the residue in the soil. Between the 15th and 45th DAT the residue content in the sandy soil dropped to the level of 50 per cent (68.5 to 32.2 ppm) whereas the fall in residue during the period was relatively lower in lateritic upland and lateritic low land soils. Thus the depletion of the insecticide residue may be linked with the corresponding high levels of the insecticide uptake in banana plants grown in the soil during the period. This relationship

also indicated that the rise in residue content in the plants grown in sandy soil was linked more with the continued absorption from the soil than with the variation in metabolic degradation within the plant. The soil depletion of the insecticide can be due to its movement to lower layers because of less organic matter and clay contents of the soil. But a similar drop in the residue was obtained in black cotton soil during 15 to 45 DAT though there was no proportionate increase in the residue content of the plant. In this case, due to higher clay and organic matter contents in the soil, a simultaneous degradation or binding of the residues also might have contributed to the dissipation (Getzin and Chapman, 1960 and Bull, 1972). Between 45 and 90 DAT there was a drastic fall in the residue of pesticide in all the types of soil and this drop also was more in sandy soil than in other types. During this phase the residue content in plants also showed a dropping tendency. Probably in the plants and in soil, the degradative metabolism commenses during this phase. The commencement of the degradative metabolism could not be assessed from the present investigation since the hydrolytic metabolites in the samples were not estimated.

Percentage of metabolites of phorate formed through different pathways as described in para 4.4.2.2 and summerized in Table 18 showed that the types of soil influenced the

Table 18. Percentages of metabolites of phorate formed through different pathways in different soils treated with insecticide @ 2.5g ai/plant at planting, as observed at different intervals after application.

Insecticide/ Metabolite	Percentage of phorate and metabolites in soil samples observed at different intervals after treatment (days)						
	0	7	15	45	90	120	Mean
			Sandy soil				
Phorate	88.04	71.16	35.58	32.82	4.81	--	46.48
Phorate sulfoxide + phorate sulfone	11.96	24.78	50.33	48.16	40.30	6.11	30.27
Oxyphorate sulfoxide + Oxyphorate sulfone	-	-	14.09	22.14	48.57	93.89	44.67
			Lateritic low land				
Phorate	86.35	66.65	66.76	30.45	11.36	11.99	45.59
Phorate sulfoxide + phorate sulfone	13.65	32.35	33.24	53.44	46.47	37.60	36.13
Oxyphorate sulfoxide + Oxyphorate sulfone	-	-	-	16.10	42.15	54.61	37.62
			Laterite upland				
Phorate	86.09	68.45	43.82	19.56	5.80	4.20	39.98
Phorate sulfoxide + Phorate sulfone	13.91	31.55	33.40	69.10	49.15	32.78	38.32
Oxyphorate sulfoxide + Oxyphorate sulfone	-	-	40.78	11.35	45.08	62.43	39.91
			Black cotton soil				
Phorate	91.7	83.50	40.83	19.16	5.63	12.97	42.29
Phorate sulfoxide + Phorate sulfone	8.3	19.50	55.60	54.27	60.68	48.10	41.07
Oxyphorate sulfoxide * Oxyphorate sulfone	-	-	5.40	26.57	33.66	38.92	26.14

content of the parent compound in the soil significantly. Contentwise the residue at 15 DAT was maximum in lateritic low land and it was followed by sandy, lateritic upland and black cotton soils (28.41, 24.38, 20.25 and 13.17 ppm) but with reference to the percentage of this component in the total phorate content, the differences were wider; the percentages being 66.76, 35.58, 43.82 and 40.83 respectively. This indicated a faster metabolism in sandy soil, lowest metabolism in lateritic low land and a similar variation in lateritic upland and black cotton soils. Similarly phorate sulfoxide and oxyphorate sulfoxide appeared in the samples collected at 15 DAT in sandy and lateritic upland soil whereas in lateritic low land and black cotton soils, they could be detected at 45 DAT only. Upto 45 DAT (the period of active absorption), the products in desulfurative metabolism were very low in percentage though at 90 and 120 DAT their percentage increased. This was more due to the hydrolytic breakdown of phorate, phorate sulfoxide and phorate sulfone rather than due to higher levels of formation of oxyphorate sulfoxide and oxyphorate sulfone. Quantitatively all the metabolites were very low in the soil at 90 and 120 DAT.

The correlations between the contents of phorate and its metabolites in soil and plants (vide para 4.4.3) revealed that there was a strong and significant association between

them in many observations. Figure 6 also showed that during the active phase of absorption of the insecticide the content in the soil was getting depleted concurrent with the increase in the content of the residues in the plants. The results showed that the constituents of the total phorate found in the plant tissue are, at least partly, contributed from the metabolites formed in the soil. This association was less conspicious in black cotton soil. Though the metabolites are more polar than the parent compound (Getzin and Shanks, 1970) they may be remaining bound to the organic matter content. These observations also indicated that the presence of systemic insecticide and its metabolites in the soils will be greatly influenced by the capacity of plants, grown in them, to absorb the toxicant. Hence the persistence of systemic insecticides in ecosystem may have to be expressed in relation with its flora.

The persistence of phorate in banana fields, has been studied for the first time. The half-life of the insecticide agreed with the findings of Visalakshy, (1977), Chapman and Harris, (1980) who reported that the persistence in sandy soils was low as compared to soils with high organic matter and clay contents. The high variations in the half-life of phorate in various soils by Getzin and Rosefield, (1966)

Fig. 6. Residues of total phorate (ppm) in plants grown in treated soils and the corresponding residues in soils, observed at different intervals (days) after treatment @ 2.50g ai/plant at planting.

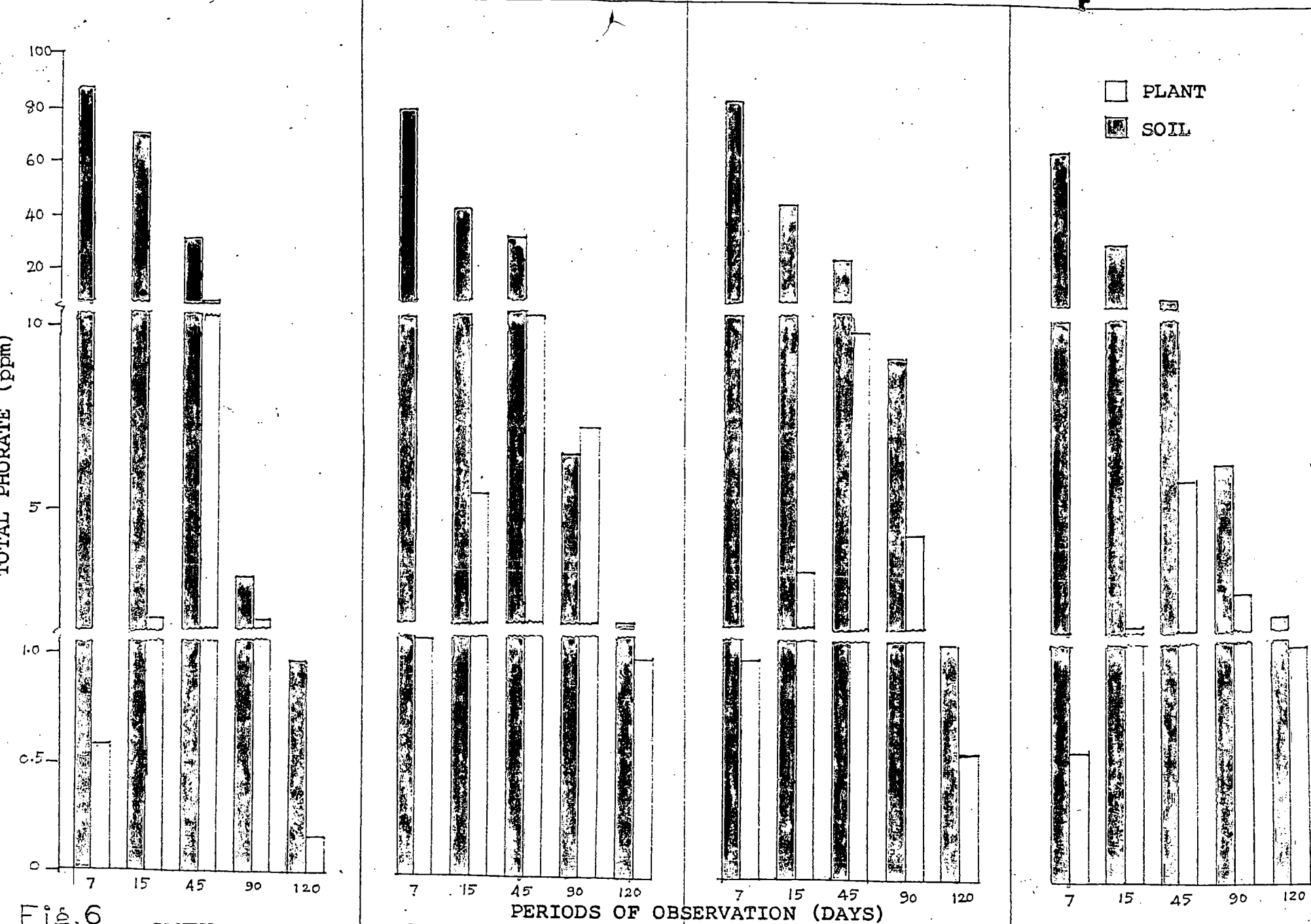
PLANT
SOIL
TOTAL PHORATE (ppm)
100
90
60
40
20
10
5
1.0
0.5
0
7
15
45
90
120
PERIODS OF OBSERVATION (DAYS)

Fig.6

was not seen among sandy, lateritic low land and lateritic upland soils included in the study. Black cotton soil alone showed significant variation.

5.5 The effect of phorate granules, applied around the base of plant at planting, on the soil microflora in different soil types, as observed at the time of harvest.

The results presented in para 4.4.4 indicated that the application of phorate at planting did not have any influence on the population of soil bacteria, fungi and actinomycetes when observed at the harvest of the crop. The finding is in agreement with a number of earlier reports that the initial alterations caused by the pesticide get corrected over a period of time (Cyanamid International, 1970, Chelliah, 1972, Satpathy, 1974 and Varshney and Rana, 1987).

SUMMARY AND CONCLUSIONS

S U M M A R Y

A series of field and laboratory studies were carried out for assessing the basic problems related with the current recommendations for controlling the bunchytop disease of banana by checking the population of the vector of the disease, Pentalonia nigronervosa Coq.

The results of the first field experiment and the chemical assay of the insecticide content, at different intervals after treatment, gave detailed information on many important aspects related to the recommendations.

1. The condition of the plant at the time of treatment significantly influenced the uptake of the insecticide from the soil. When applied at the time of planting the phorate content in plants, even after 15 DAT (days after treatment), was low. This may be attributed to the lack of adequate number of absorbing roots at that time. Later experiments showed that there was a significant depletion of the insecticide in the soil during the first and second weeks after treatment. The results thus strongly indicated the need to shift the first application of the insecticide to a later period (2-3 weeks after planting).

2. The residue levels of phorate in the plants and bioefficacy data revealed that the application of phorate at 0, 75 and 165 days after planting remained effective for 75, 60 and 45 DAT respectively. The age of the plant at the time of treatment significantly influenced the absorption of the insecticide and its persistence in the crop. These findings indicated the need to revise the present recommendation to treat the plants at planting and then at 75 and 165 DAP.

3. The total content of phorate in banana observed at different intervals after treatment with the doses of 1.25 and 2.50g ai/plant showed that in early stages of the crop growth the enhancement of the dose did not enhance the residue content or the bioefficacy. Thus reduction in the dose of 2.50g ai/plant in the current recommendation was strongly indicated. It may be desirable to retain the higher doses in last treatment since the higher dose gave higher response at that stage. But in short duration varieties like robusta it may lead to residue problem in raw fruits.

4. The residue levels in plant at different intervals after treatment and the corresponding bioefficacies revealed that the absorption and the retention of the insecticide was significantly lower when the granules were applied in leaf axil than when applied in soil. Hence the current recommendation to use 1.25g ai/plant in leaf axil in lieu of 2.50g ai/plant at base for the second and third treatments is illogical and needs correction.

5. The results of bioassay studies carried out throughout the experiment revealed that the mortalities of the vector, even when confined at feeding sites in cages, varied from 28 to 100 per cent and the frequency of occurrence of 100 per cent kill in various treatments was limited. Still the treatment had been established as an effective method for controlling bunchytop disease. The results indicated that 100 per cent control of a vector is not a must for checking the spread of virus diseases of plants.

The data on contents of the toxicant obtained from the chemical assay of the residues in plants and mortality of the test insect obtained from the bioassay studies were seen strongly associated when statistically analysed. Path coefficient analysis of the data also established this association and about 98 per cent of the mortality of the insect could be attributed to the content of insecticide and its metabolites in the plants. Based on these observations the dose-effect relationship was studied through probit analysis of the data. Such analysis have not been done by earlier workers. This study has led to the following conclusions.

1. The LD_{50} of total phorate in the leaf sheath ranged from 1.2 to 2.7 ppm during the period of active absorption of the toxicant (upto 60 DAT) while it increased

to 3.15 to 3.6 ppm at later periods (after 60 DAT). It indicated that the residues at later occasions contained some less toxic components.

2. The age of the plant did not influence the quantity of the pesticide content required, in the leaf sheath, for causing the mortality of P. nigronervosa feeding at the site.

3. The residue content of the plant in many of the observations made at different periods after treatment exceeded even the LD_{90} levels. This indicated that the quantity of the pesticide often exceeded the optimum quantity in plants. Such high dose might lead to wastage of the insecticide due to metabolic degradation in the plant and in soil.

The identification and estimation of the metabolites of phorate was done for the first time in banana. A simple TLC technique followed by colorimetry using a spectrophotometer was standardized for the purpose, modifying the methods of Blinn (1963).

Four metabolites, phorate sulfoxide, phorate sulfone, oxyphorate sulfoxide and oxyphorate sulfone could be detected and they were estimated at different intervals after treatment. A transient spot presumed to be of oxyphorate also could be identified in some samples which

could not be quantitatively estimated for want of reference material. The studies revealed that:

1. All metabolites were present in the leaf sheath at 15 DAT, when the assay of the residues was first done, except in treatments done at planting. The difference might be attributed to the lack of absorbing roots rather than to the lower metabolism.

2. The parent compound and the metabolites showed an increasing trend till the total residue content in the plant reached the peak and then declined. The rate of fall in content was a little lower in older plants indicating slightly slower metabolic rate in them.

3. The decline of phorate sulfoxide was a little slower than that of phorate and phorate sulfone and the content of oxyphorate sulfoxide and oxyphorate sulfone persisted slightly longer.

4. The data obtained from the first experiment and those from one of the later experiments clearly indicated that the residues of metabolites in banana plants were partly formed by the metabolism of the absorbed phorate in the plants and partly by direct absorption from the soil.

5. The varying doses of phorate applied to the soil did not significantly affect the trends of metabolism of phorate in banana plants.

6. Rate of metabolism as indicated by the content of metabolites was slower in older plants (165 DAP) and also when the granules were applied in leaf axils.

7. Assessment of percentage of phorate and its metabolites in the total residue in plants showed that the percentage of phorate and phorate sulfoxide were inversely related. The percentage of oxyphorate sulfone showed an increasing trend from 15 to 90 DAT.

8. A regrouping of the data under the different metabolic pathways revealed that sulfoxidations of thioether moiety and desulfuration commenced within the plant soon after the absorption of the toxicant. In general, the former had an upper hand in earlier phase while the latter was dominating in the later phase.

The correlation between the content of the parent compound/metabolites and the mortality of the test insect showed that the association was statistically significant for phorate and phorate sulfoxide than for the other metabolites. The path coefficient analysis also showed that phorate and phorate sulfoxide had a more dominent direct positive effect on the mortality of the insect than the remaining metabolites constituting the residue content. This may be the effect of the higher content of the former metabolite in the total residues (vide Table 4), observed at different intervals after treatment and/or due to

its higher toxicity. The inconsistency in the effects of the parent compound and metabolites on the mortality of the insect observed in different treatments indicated the reversibility of the oxidative reactions of the insecticide in the plant tissue also.

The persistent toxicity of phorate applied @ 2.50g ai/plant at different intervals after planting was assessed following standard bioassay methods using P. nigronervosa as test insect. The objective was to study the effect of age of the plant at the time of treatment on the absorption and persistence of phorate in treated plants. The results revealed:

1. The absorption of the pesticide was not varying in plants treated from 0 to 150 days after planting. When treated at 180 and 210 DAP the absorption was very low.

2. The persistence of the insecticide in plants treated at 0-150 DAP did not vary to cause significant variations in the mortality of the test insect upto 24 DAT. In subsequent observations bioefficacy and the age of the plant showed an inverse relation.

3. In plants treated upto 60 DAP and at 90, 120 and 150 DAP adequate mortalities (above 50 per cent) were observed upto 60, 45, 31 and 31 days after treatment, respectively. Hence intervals between successive treatments

at later stages of the crop may have to be shortened for ensuring the required bioefficacy against the vector.

4. The toxicity of phorate in plants treated at 180 and 210 DAP failed to control the vector effectively at any occasion after the treatment. The efficacy of the third treatment at 165 DAP, now being followed, may have to be rechecked under field conditions especially when a short duration variety like robusta is involved.

For ensuring the terminal residues of insecticides in raw and ripe fruits below tolerance limit the application of phorate @ 2.5g ai/plant had to be limited upto 150 DAP.

The absorption, persistence and bioefficacy of phorate applied at 1.25 and 2.50g ai/plant as influenced by the seasons was investigated. The results indicated that:

1. The absorption of the insecticide was significantly higher in plants grown in summer season than in the rainy season at 60, 75 and 90 DAT. The difference was not significant at the other periods of observation.

2. Application of higher dose of insecticide resulted in significantly higher residue contents in plant parts at 45, 60 and 75 DAT in rainy season and at 30, 60 and 75 DAT in summer season.

3. The insecticidal effect (P) persisted for 90 days in rainy season while it persisted for 105 days in the summer season in both the doses.

4. The average toxicity (T) was higher in summer season than in the rainy season at both the doses.

5. The overall bioefficacy of the treatments based on persistant toxicity (PT) index was found to be higher in summer months in both the doses than in the rainy season.

The metabolism and persistence of phorate in different types of soil of Kerala and in the banana plants grown in them were investigated. The study led to the following findings.

1. The total residue content in the plants grown in different types of soil showed that the initial absorption (at 7 and 15 DAT) was the highest in plants grown in lateritic low land and it was least in sandy soils. The plants grown in lateritic upland and black cotton soils came in between. This is attributed to the earlier rooting of the plants grown in lateritic low land followed by those grown in lateritic upland, black cotton and sandy soils.

2. The absorption during 30 to 60 DAT was higher in plants grown in sandy soils and it was followed by the plants grown in lateritic low land, lateritic upland and black cotton soils.

3. The residues persisted at effective levels upto 75 DAT in plants grown in sandy and 90 DAT in lateritic upland soils while in lateritic low land and black cotton soils the persistance was upto 105 DAT.

4. The results indicated that there was no need for varying the schedule of treatments against the vector for plants grown in different types of soils in Kerala.

5. The residues of phorate precusor and metabolites in banana plants observed at different intervals after treatment showed a trend similar to that of the total residue in plants grown in different types of soil. This indicated that the variations were caused more by the variation in absorption of the insecticide than by the differences in the rates of metabolism within the plant.

6. The estimation of the percentage of different components of the total residue formed by the different metabolic routes showed that in plants grown in sandy soils the sulfoxidation of thioether moiety was predominant while desulfuration pathway was more predominant in plants grown in other types of soil.

The long term effect of the application of phorate granules (applied at planting) on the population of fungi, bacteria and actinomycetes in different types of soil was assessed at the time of harvest of the crop. It was found that the population of the microflora was not significantly affected in any of the four types of soil.

REFERENCES

REFERENCES

Agnihotri, V.P., H.K.Jain, S.Y.Pandey, R.S.Dewan, A.N. Saxena and K.M.Peswani. 1975. Influence of soil moisture on the dissipation of phorate and disulfoton in soil and in mustard crop. (Brassica campestris L.) Indian J. Ent. 37 (1) : 68-71.

Ahmed, M.K. and J.E.Casida. 1958.Metabolism of some organophosphorous insecticides by microorganisms. J. Econ. Entomol. 51 (1) : 59-63.

Ahmed, N., D.D. Walgenbach and G.R.Sutter. 1979. Comparative disappearance of fonofos, phorate and terbufos soil residues under similar South Dakota field conditions. Bull. Environ. Toxicol. 23 : 423-429.

Allen, D.N. 1953. Experiments in soil microbiology. Burgess Publishing Co., Minneapolis, Minnesota, USA. 127 p.

Anonymous. 1973. Progress Report of the Project on the control of bunchy top disease of banana, College of Agriculture, Vellayani.

Appleman, M.C. and M.C.Sears. 1946. Effect of DDT upon nodulation in legumes. J. Amer. Soc. Agron. 38 : 545-550.

Bacon, O.G. 1960. Systemic insecticide applied to cut seed pieces and to soil at planting time to control potato insects. J. Econ. Entomol. 53 (5) : 835-839.

Barlow, F. and A.B.Hadaway. 1959. Studies on the acqueous suspensions of insecticides. VII. Influence of relative humidity on the sorption of insecticides by soils. Bull. Entomol. Res. 49 : 333-354.

Bhatia, S.K., W.R.Young, K.G. Phadke and A.N.Srivastava. 1973. Control of corn leaf aphid on barley in India. J. Econ. Entomol. 66 (2) ; 463-467.

Blinn, R.C. 1963. Thin layer chromatographic isolation and infrared or colorimetric identification of Thimet residues. J. Assoc. Off. Anal. Chem. 46 (6) : 6952-. 6960

Bowman, J.S. and J.E.Casida. 1957. Metabolism of systemic insecticide 0,0 - diethyl S - ethylthio methyl phosphorodithioate (Thimet) in plants. J. Agric. Food Chem. 5 (1) : 192-197.

Bowman, J.S. and J.E.Casida. 1958. Further studies on the metabolism of Thimet by plants, insects and mammals. J. Econ. Entomol. 51 (6) : 838-843.

Bull, D.L. 1972. Metabolism of organophosphate insecticides. Residue Rev. 43 : 1-22.

Burt, P.E., R. Bardner and P. Ethridge. 1965. Influence of volatility and water solubility of systemic insecticides on their movement through soil and absorption by plant roots. Ann. Appl. Biol. 56: 411-418.

Chapman, R.A. and C.R.Harris. 1980. Insecticidal activity and persistence of terbufos, terbufos sulfoxide and terbufos sulfone in soil. J. Econ. Entomol. 73 (4) : 536-543.

Chapman, R.A., C.M.Tu, C.R.Harris and C.R.Harris. 1982. Biochemical and chemical transformations of phorate, phorate sulfoxide and phorate sulfone in natural and sterile mineral and organic soils. J. Econ. Entomol. 75 (1) : 112-117.

Chellaiah, S. (1972). Effect of pesticides on soil microorganisms, biological activities and availability of major plant nutrients in soil and their influence on growth, nodulation and yield of Co-1 Blackgram (Phaseolus mungo), M.Sc. thesis, Tamil Nadu Agricultural University, Coimbatore.

Chendrayan, K. and N.N.Prasad. 1976. Effect of soil application of phorate and disulfoton on Rhizobium - groundnut (Arachis hypogaea L.) symbiosis. Madras Agric. J. 63 : 528-530.

Chiou, C.T., L.J.Peters and V.H.Freed. 1979. A physical concept of soil-water equilibria for non ionic organic compounds. Science 206 : 831-832.

Chisholm, D. and H.B.Specht. 1967. Effect of application rates of disulfoton and phorate and of irrigation on aphid control and residues in canning peas. Canadian J. Pl. Sci. 47 : 175-178.

Cyanamid International. 1970. Comprehensive Technical Mannual - Thimet. American Cyanamid Company, New York. 43 p.

Das, L. 1986. Effect of application of plant protection chemicals on the survival of Rhizoctonia solani Kühn. Ph.D. thesis, Kerala Agricultural University, Vellanikkara.

Dobson, R.C., G.O. Thorneberry and T.E. Billing.1960. Residues in established alfalfa treated with granulated phorate and their effect on cattle fed with the hay. J. Econ. Entomol. 53 (2) : 306-310.

Edwards, C.A. 1966. Insecticide residues in soils. Residue Rev. 13 : 83-132.

Finney, D.J. 1962. Probit analysis. 2nd ed. Cambridge University Press, London 318 p.

Foster, A.C., V.R.Boswell, R.D.Chisholm, R.H.Carter, G.L.Gilpin, R.B.Pepper, W.S.Anderson. and M.Geiger. 1946. Influence of soil characteristics on the phytotoxicity of some insecticides. USDA Tech. Bull. 36 : 1149.

Galley, D.J. and L.A. Foerster. 1976. Distribution and loss of phorate in the foliage of broad bean plants following root uptake of ^{14}C-labelled phorate. Pestic. Sci. 7 : 301-306.

Garg, A.K. and G.R.Sethi. 1982 a. Persistence of some granular systemic insecticides in paddy. Indian J. Ent. 44 (1) : 83-88.

Garg, A.K. and G.R. Sethi. 1982 b. Distribution of phorate, disulfoton, dimethoate and chlorpyriphos in paddy. Indian J. Ent. 44 (2) : 194-197.

Gerolt, P. 1961. World Health Org. Bull. 24 : 577 In. Organic Chemicals in the Soil Environment Ed. Goring, C.A.I. and J.W.Hamaner. Marcel Dekkar Inc., New York.

Getzin, L.W. 1958. The effect of soils upon the efficacy of systemic insecticides with special reference to Thimet. Dissertation Abstr. 19 : 625.

Getzin, L.W. and R.K. Chapman. 1960. The fate of phorate in soils. J. Econ. Entomol. 53 (1) : 47-51.

Getzin, L.W. and I.Rosefield. 1966. Persistence of diazinon and zinophos in soils. J. Econ. Entomol. 59 : 512-516.

Getzin, L.W. and C.H.Shanks Jr. 1970. Persistence, degradation and bioactivity of phorate and its oxidative analogues in soil. J. Econ. Entomol. 63 (1) : 52-58.

Gulab Singh, Zile Singh and T.S. Kathpal. 1984. Method of application affecting phorate persistence in soil and its translocation into cotton plants. Indian J. Ent. 46 (2) : 183-186.

Gupta, A., C.R.Prasad, M.Rai and K.Yadav. 1985. Organophosphorous (phorate) and organochlorine (gamma BHC) insecticides affecting yield of sugarcane and biotic factors in calcarious soil. Indian Sugar. 35 (1) : 15-18.

Harris, C.R. 1961. Factors affecting the volatalization of insecticides from soils. Dissertation Abstr. 22 : 375.

Harris, C.R. 1969. Laboratory studies on the persistence of biological activity of some insecticides in soils. J. Econ. Entomol. 62 (6) : 1437-1441.

Harris, C.R. and B.T. Bowman. 1981. The relationship of insecticide solubility in water to toxicity in soil. J. Econ. Entomol. 74 (2) : 210-212.

Harris, C.R. and R.A.Chapman. 1980. Insecticidal activity and persistence of phorate, phorate sulfoxide and phorate sulfone in soils. Canadian Entomologist 112 (7): 641-653.

Ho, S.H. and D.J.Galley. 1982.Relative toxicity of phorate and some of its metabolites to Aphis fabae Scop. Pestic. Sci. 13 (2) : 183-188.

Jain, H.K., S.Y.Pandey, N.P.Agnihotri and R.S.Dewan. 1974 a. Rapid estimation of organophosphorous insecticides. Indian J. Entomol. 36 (2) :145-149.

Jain, H.K., S.Y.Pandey, N.P.Agnihotri, R.S.Dewan, A.N.Saxena and K.M.Peswani. 1974b. Dissipation of phorate and disulfoton in rape seed crop (Brassica campestris) Indian J. Plant Prot. 1 (2) : 37-42.

Jain, H.K., S.Y.Pandey, N.P.Agnihotri and K.P.Srivastava. 1980. Residues of insecticides on rice crop. Indian J. Ent. 42 (4) : 675-679.

Jefferson, R.N., F.S.Morishita, S.T.Besemer and W.A.Humphrey. 1964. Control of thrips in carnations with systemic insecticides. J. Econ. Entomol. 57 : 357-360.

Kandaswamy, D., T.Marimuthu, K.Rajukkannu, R.Raguraj, G.Obliswamy, K.K.Krishnamurthy and T.R.Subramaniam. 1975. A study on the relationship between the dissipation of insecticides and rhizosphere microflora of paddy. Madras agric. J. 62 (4) : 203-207.

Kathpal, T.S., Gulab Singh, P.R.Yadav, R.K.Kashyap and A.V.Verma. 1983. Persistence of phorate in soil and its translocation into potato tubers. Pesticides 17 (12) : 39-43.

Kearney, P.C., E.A.Woolson, J.R.Pilmer and A.R.Isensee. 1969. Decontamination of pesticides in soils. Residue Rev. 29 : 137-149.

Kerala Agricultural University. 1986. Package of Practices Recommendations. 1986. Directorate of Extension, Mannuthy, 680 651, Trichur, Kerala, India. 239 p.

Khajuria, G.N., H.K.Jain. and R.S.Dewan. 1973. Residue following the treatment of sorghum with phorate and dimethoate for control of insect pest complex of the crop. Proceedings of First All India Symposium on Progress and Problems in Pesticide Residue Analysis held at Ludhiana Nov. 1977. 87-92 pp.

Kolkaila,A.M. and A.A.Soliman. 1954. A study of the banana aphid, Pentalonia nigronervosa Coq. Bull. Soc. Fouad Entomol. 38 : 231-250.

Krishniah, N.V. and R.L.Kalra. 1978. Persistence of phorate in soil and its uptake and metabolism in mustard crop. UAS Tech. Bull. Series 32 : 367-374.

Kuster, E. and S.T.William. 1964. Selection of media for isolation of Streptomyces. Nature 202 : 928-929.

Leuk, D.B. and M.C.Bowman. 1970. Residues of phorate and five of its metabolites, their persistence on forage corn and grass. J. Econ. Entomol. 63 (6) ; 1838-1842.

Lichtenstein, E.P. 1966. Persistence and degradation of pesticides in the environment. Sci. Aspects Pest Contr. Nat. Acad. Sci. Publ. 1402 : 221-229.

Lichtenstien, E.P., T.W.Fuhremann and K.R. Schulz. 1974. Translocation and metabolism of (14c) phorate as affected by percolating water in a model soil - plant ecosystem. J. Agric. Food Chem. 22 (6) : 991-996.

Lichtenstein, E.P., T.W.Fuhremann, K.R. Schulz and T.T.Liang. 1973. Effect of field application methods on the persistence and metabolism of phorate in soil and its translocation into crops. J. Econ. Entomol. 66 (4) : 863-866.

Lichenstein, E.P., G .R.Myrdal and K.R.Schulz. 1965. Absorption of insecticidal residues from contaminated soils into five carrot varieties. J. Agric. Food Chem. 13 : 126-131.

Lilly, J.H., I.Madamba, K.J.Fret, J.A.Bowman, W.H.Orgell and P.A.Dahm. 1958. Thimet residues in small grains grown in treated soil. J. Econ. Entomol. 51 (5) : 623-625.

Lindley, C.D. 1963. The use of phorate granules on potato and carrots. Agric. Vet. Chem. 4 (6) : 166-170.

Magee, C.J.P. 1927. Investigation on the bunchy top disease of bananas. Bull. Coun. Sci. Industr. Res. Aust. 30 : 64-68.

Martin, J.P. 1950. Use of acid, rosebengal and streptomycin in the plate method for estimating soil fungi. Soil Sci. 69 : 215-233.

Menn, J.J. and J.B.McBlain. 1974. New aspects of organophosphorous pesticides. IV New aspects of metabolism of phosphonate insecticides. Residue Rev. 53 : 35-51.

Menzer, R.E. and L.P.Ditman. 1968. Residues in spinach grown in disulfoton and phorate treated soil. J. Econ. Entomol. 61 :225-229.

Menzer, R.E., E.L.Fontanilla and L.P.Ditman. 1970. Degradation of disulfoton and phorate in soil, influenced by environmental factors and soil type. Bull. Environ. Contam. Toxicol. 5 : 1-5.

Metcalf, R.L. T.R.Fukuto and R.B.March. 1957. Plant metabolism of Dithio-systox and Thimet. J. Econ. Entomol. 50 (3) : 338-345.

Mithyantha, M.S. and N.G.Perur. 1974. Persistence of phorate in Karnataka soils. Symp. Indian Soc. Agric. Chemists Abst. 3.

Murthy, V.K., J.E.Edward and K.P.Singh. 1976. Effect of Thimet on the soil and rhizosphere microflora of okra. 17th Annual Conference of Association of Microbiologists of India Manipal, Karnataka 4p.

Nair, M.R. G.K., P.C. Jose, P. Reghunath and N.Gangadharan Nair. 1973. Effect of some insecticide granules on the control of the banana aphid, Pentalonia nigronervosa Coq. Agric. Res. J. Kerala 11 (2) : 101-12.

Narayanaswamy, P., M. Balasubramanian and P.Baskaran. 1975. Studies on the persistence of granular phorate (Thimet 10G) insecticide applied to rice plant. Rice Ent. Newsl. 2 : 38-40.

Naseema Beevi, S. 1987. Persistence and metabolism of phorate in rice plants and in different soil types of Kerala and its effect on non target organisms. Ph.D. thesis, Kerala Agricultural University, Vellanikkara.

Ostogic, N., N.Strovic and M.Zigic. 1972. Mobilmost nekih organofosfornih insectcida i lindana u raznim zipovima Zemljista. (Mobility of some organophosphorous insecticides and lindane in different soil types). Zastita Bilja 23 : 285-291.

Pandian, R.M. 1975. Uptake and persistence of phorate as influenced by soil plant relationship. M.Sc. (Ag.) Dessertation, Annamalai University.

Pandian, R.M. and M.Balasubramanian.1978. Effect of phorate on the rhizosphere microflora of paddy in four soil types. IL RISO 27 (3) : 211-216.

Parker, B.L. and J.E. Dewey, 1965. Decline of phorate and dimethoate residues in treated soils based on toxicity to D. melanogaster. J. Econ. Entomol. 58 (1) : 106-111.

Patterson, R.S. 1962. Use of phorate and Disyston for potato insect control and a study of factors which influence phorate absorption by plants and loss in the soil. Dissertation Abstr. 23 : 1471.

Pillai, K.S..1981. Use of insecticides as granules for protecting paddy crop against pests. Ph.D. thesis, Kerala Agricultural University, Vallanikkara.

Pradhan, S. 1967. Strategy of integrated pest control. Indian J. Ent. 29 (1) : 105-122.

Pramer, D. and E.L.Schmidt. 1965. Experimental soil microbiology. Burgess Publishing Co., Minneapolis, Minnesota, USA. 197 p.

Prasad, N.N. and A.Mani. 1979. Effect of organic amendments on the persistence of phorate in soil and in rice plants. Ind. J. Plant Prot. 7 (1) : 33-38.

Rajukkannu, K. and K.K.Krishnamurthy. 1979. Uptake and persistence of phorate and carbofuran in IR-20 rice. IL RISO 28 : 197-199.

Rajukkannu, K., R.Raguraj, K.K.Krishnamurthy and T.R.Subramaniam. 1977. Persistence of phorate and carbofuran in flooded soils. Pesticides 11 (1) : 14-15.

Rajukkannu, K., K.Saivaraj, K.A.Ali. T.R.Subramaniam and K.K.Krishnamurthy. 1976. Residues of granular and foliar insecticides applied to rice. Madras agric. J. 65 (5-7) : 369-371.

Rangaswami, G. 1972. Diseases of crop plants in India. 2nd ed. Prentice - Hall of India, New Delhi.

Rao. B.N., P.P.Rao and N.K.Reddy, 1986. Residues of phorate 10G and carbofuran 3G in rice. Proc. Sym. Pest. Resid. and Env. Pollu. 37-44 pp.

Read, D.C. 1969. Persistence of some newer insecticides in mineral soils measured by bioassay. J. Econ. Entomol. 62(6) : 1338-1342.

Reghunath, P. 1989. Personal communication.

Regupathy, A., K.S.Subramanian and T.G.Naganathan. 1983. Evaluation of certain aphicides in the containment of banana bunchy top disease. Pesticides 17 (7) : 35-36.

Reynolds, H.T., T.R. Fukuto and G.D. Paterson. 1960. Effect of topical applications of granulated systemic insecticides and of conventional applications of other insecticides on control of insects and spider mites on sugarbeet plants. J. Econ. Entomol. 53 : 725-729.

Reynolds, H.T. and R.L. Metcalf. 1962. Effect of water solubility and soil moisture on plant uptake of granulated systemic insecticides. J. Econ. Entomol. 55 : 2-5.

Ridgeway, R.L., D.A. Lindquist and D.I. Bull. 1965. Effect of method of application on uptake of disyston by cotton plants. J. Econ. Entomol. 58 : 349-352.

Satpathy, J.M. 1974. Effect of soil treatment with granular insecticides on soil microorganisms. Indian J. Ent. 36 : 139-141.

Saunders, J.L. and L.W. Getzin. 1973. Distribution of phorate and oxidation analogues in Scots pine. J. Econ. Entomol. 66 (2) : 530-534.

Schulz, K.R., E.P. Lichtenstein, T.W.Fuhremann and T.T.Liang. 1973. Movement and metabolism of phorate under field conditions after granular band applications. J. Econ. Entomol. 66 (4) : 873-875.

Singh, K.and K.C.Gulati. 1972. A study on the effect of Disyston and Thimet on soil microorganisms, ammonification and nitrification in soil. Pesticides 6 : 24-29.

Sharma, S.K., V.K.R.Shinde and M.K.Puri. 1980. Efficacy of granular insecticides against the white grub Lachnosterna (Holotrichia) consanguinea Blanch under different soil moisture levels. J. Entomological Res. 4 (2) : 229-230.

Srinivas, P.R., K.S.R.K.Murthy and B.H.K.Rao. 1985. Dissipation and accumulation of phorate in soils and ground nut crop grown on rainfed and irrigated lands. Indian J. Agric. Sci. 55 (9) : 596-600.

Stover, R.H. 1972. Banana, Plantain and Abaca Diseases. Longman, London. 316 p.

Suett, D.L. 1971. Persistence and degradation of chlorfenvinphos, diazinon, fonofos and phorate in soil and their uptake by carrots. Pestic. Sci. 2 : 105-112.

Suett, D.L. 1974. Uptake of chlorfenvinphos and phorate from soil by carrots as influenced by mode of application and cultivation. Pestic. Sci. 5 : 67-71.

Suett, D.L. 1975. Persistence and degradation of chlorfen vinphos, chlormephos, disulfoton, phorate and pirimiphos ethyl following spring and late summer application. Pestic. Sci. 6 : 385-393.

Suett, D.L. and C.E. Padbury. 1980. Uptake of phorate by lettuce. Pestic. Sci. 11 (3) : 351-360.

Suett, D.L. and C.E.Whitefield. 1983. Insecticide residues in spring grown, quick maturing carrots in relation to control of first generation carrot fly larvae. Mededelingen Van de Faculteit Landbouwwetenschappen Rijksuniversiteit Gent 48 (4) : 913-922.

Talekar, N.S., E.M. Lee and L.T. Sun. 1977 a. Absorption and translocation of soil and foliar applied ^{14}C-Carbofuran and ^{14}C-phorate in soybean and mungbean seeds. J. Econ. Entomol. 70 (6) : 685-688.

Talekar, N.S., L.J. Sun, E.M. Lee and J.S. Chen. 1977 b. Persistence of some insecticides in subtropical soil. J. Agric. Food Chem. 25 : 348-352.

Tewari, H.K., R.S.Sindu and D.S.Chakal. 1972. Effect of insecticides on microbial flora of groundnut field. 13th Annual conference of Association of Microbiologists of India. 21 p.

Thompson, A.R. 1973. Persistence of biological activity of seven insecticides in soil assayed with Folsomina candida. J. Econ. Entomol. 66 (4) : 855-857.

Tu, C.M. and J.R.W. Miles. 1975. Interactions between insecticides and soil microbes. Residue Rev. 64 : 17-37.

Van Middlem, C.H. and R.M.Baranowski. 1962. Phorate residues in tomato fruit and foliage. J. Econ. Entomol. 55 : 603-608.

Varshney, U. and S.S.Rana, 1987. Studies on the effect of phorate, Disyston and carbofuran on soil microflora of tarai soil. Pesticides XXI (4) : 39-41.

Verma, S. 1979. Effect of temperature on the dissipation of phorate in soil. Pesticides 13 (7) : 141-142.

Visalakshi, A. 1977. Dissipation of phorate residues in soil and cowpea plant in relation to pea aphid control and soil microbe population. Ph.D. thesis, Kerala Agricultural University, Vellanikkara.

Visalakshy, A., S. Naseema Beevi, T.Premkumar and M.R.G.K.Nair 1981. Residual effect of soil application of pesticide granules on rhizosphere microflora of black pepper (Piper nigrum). Third International Symbposium on Plant Pathology. Dec. 14-18. pp.222.

Visalakshi,A., K.Santhakumari, T.Nalinakumari and N.Mohan Das. 1979. Residues of some systemic insecticides used for rice pest control in rice grain and straw. Entomon 4 (4) : 383-384.

Waller, J.B. and P.A. Dahm. 1973. Phorate loss from Iowa soils as affected by time, temperature and soil sterilization. Proceedings of North Central Branch of the Entomological Society of America 28 : 171.

Walter-Echols, G. and E.P. Lichtenstein. 1977. Microbial reduction of phorate sulfoxide to phorate in a soil-lake mud-water microcosm. J. Econ. Entomol. 70 (4) : 505-509.

Wang, C.Y. 1980. Movement and persistence of OP insecticide phorate in soils. J. Agric. Assoc. China 110 : 38-49.

Wardlaw, C.W. 1961. Banana diseases including Plantain and Abaca Diseases. Longman, London. 648 p.

Wardlaw, C.W. 1972. Banana diseases including plantains and Abaca. Longman, London. 878 p.

Way, M.J. and N.E.A. Scopes. 1968. Studies on the persistence and effects on soil fauna of some systemic insecticides. Ann. appl. Biol. 62 : 199-214.

Yaron.E., A.N.R.Swoboda and G.W. Thomas. 1967. Aldrin adsorption by soils and clays. J. Agric. Food Chem. 15 : 671-675.

APPENDICES

APPENDIX - 1

Percentage recovery of phorate and metabolites from plant, fruit and soil samples

Samples treated with	Leaf sheath	Fruits unripe	Fruits ripe	Soil Samples			
				Sandy	Clay loam	Laterific upland	Black cotton
Phorate	95.4	92.3	90.5	95.8	90.4	92.0	88.2
Phorate sulfoxide	91.6	-	-	88.3	82.0	82.4	78.2
Phorate sulfone	83.3	-	-	89.1	80.6	81.2	78.0
Oxyphorate sulfoxide	80.4	-	-	92.2	82.2	85.8	77.1
Oxyphorate sulfone	82.4	-	-	91.2	80.0	85.0	74.4

APPENDIX - 2

Summary of Analysis of Variance tables of the uptake, translocation and persistence of phorate applied at different doses at the root zone and leaf axils of banana at different intervals after planting (vide Table - 1)

Source	df	Mean squares at different intervals (days) after application					
		15	30	45	60	75	90
Replications	5	0.421*	0.907*	1.612	3.669*	1.0264	0.185
Treatments	7	4.571**	25.834**	52.140**	105.416**	39.229**	8.765**
Root Zone							
A (Doses)	1	5.452**	83.284**	45.147**	4.926**	2.856	7.173
B (Time)	2	1.700**	1.093**	61.552**	201.526**	67.049**	6.378**
A X B	2	1.187**	0.091	5.257**	2.758**	0.425	2.167**
Leaf Axils							
Between times (75 vs 165)	1	0.094	0.004	14.480**	4.498**	2.805	0.299
Between Methods	1	11.571**	43.520**	67.455**	109.088**	55.538**	19.262*
Error	35	0.080	0.103	0.010	0.469	0.887	0.0589

APPENDIX - 3

Summary of Analysis of Variance tables of the bio-efficacy of phorate applied at different doses at the root zone and leaf axils of banana at different intervals after planting, to P. nigronervosa (vide table - 2)

Source	df	Mean squares at different intervals (days) after application					
		15	30	45	60	75	90
Replications	5	489.65**	441.35**	274.28**	38.48*	748.12**	699.93**
Treatments	7	1174.69**	1111.09	2494.45**	5295.15**	4724.56**	1196.96**
Root zone							
A (Doses)	1	1252.22**	1932.53**	2718.67**	319.28**	391.04**	421.16*
B (Times)	2	878.14**	490.12**	1749.92**	8990.56**	7507.89**	1018.51**
A X B	2	101.33	145.88*	936.31**	156.22**	319.69**	225.24
Leaf axils							
Between Times (75 vs 165)	1	5.32	71.70	142.34**	54.86*	426.36**	360.59*
Between Methods	1	2656.99**	2279.24**	4238.77**	7808.06**	7150.24**	2715.47**
Error	35	39.48	25.40	52.07	7.87	48.39	78.88

APPENDIX - 4

Summary of Analysis of Variance tables of the absorption and translocation of phorate (@ 2.5 g ai/plant applied at the root zone) in banana treated at different growth stages of the crop. (Mean corrected mortalities of aphid - angular transformation)

Source	df	Mean squares at different intervals after treatment (days)			
		3	10	17	24
Replications	7	70.032	67.792*	103.886*	121.016
Treatments (Growth stages)	7	1911.666**	1927.597**	1273.634**	478.801**
Error	49	53.974	28.733	42.241	71.580

Source	df	Mean squares at different intervals after treatment (days)			
		31	45	60	90
Replications	7	420.109**	218.837**	209.862*	327.230**
Treatments (Growth stages)	7	2447.520**	4709.395**	4057.807**	796.211**
Error	49	85.018	51.310	85.442	83.992

APPENDIX - 5

Summary of Analysis of Variance tables of uptake, translocation and persistence of phorate applied at the root zone of banana in the rainy and summer seasons (Residues of phorate (ppm) at different intervals)

Source	df	Mean squares at different intervals (days) after application							
		15	30	45	60	75	90	105	120
Replications	7	0.541	1.633	6.569	2.704	1.154	0.601	0.068	0.064
A (Seasons)	1	0.001	0.034	0.000	40.163**	52.849**	7.198**	0.226	0.086
B (Doses)	1	0.112	19.636**	13.266**	90.511**	47.317**	10.352**	0.000	0.095
A X B	1	0.127	1.576	0.698	1.968	6.134	4.898	0.253	0.146
Error	21	0.267	2.069	1.484	1.247	1.725	0.511	0.161	0.139

APPENDIX - 6

Summary of Analysis of Variance tables of bio-efficacy of phorate applied at the root zone of banana in the rainy and summer seasons to P. nigronervosa at different intervals. (Mean corrected mortalities of aphid - angular transformation)

Source	df	Mean squares at different intervals (days)						
		15	30	45	60	75	90	105
Replications	7	9.13	14.91	137.54*	26.42	14.70	110.89	23.18
A (Seasons)	1	1.59	0.07	461.14**	4875.75**	856.64**	684.22**	367.81**
B (Doses)	1	105.09*	1058.58**	1551.50**	2000.89**	2020.26**	245.03*	90.28
A X B	1	268.93**	485.70**	31.06	409.72**	615.64**	314.94**	90.28
Error	21	13.80	18.10	44.28	17.55	9.65	36.90	3.61

APPENDIX - 7

Summary of Analysis of Variance tables of the persistence and metabolism of phorate in banana plants grown in Sandy Soils.

Source	df	Mean squares of phorate and metabolites				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxypherate sulfoxide	Oxyphorate sulfone
Replications	4	1.239	0.810	0.166	0.561	0.563
Periods	9	29.415**	9.463**	3.428**	1.246**	0.951**
Error	36	0.437	1.229	0.280	0.334	0.299

APPENDIX - 8

Summary of Analysis of Variance tables of the persistence and metabolism of phorate in banana grown in Clay loam soil.

Source	df	Mean squares of phorate and metabolites				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
Replications	4	0.121	0.657	0.327	1.628	0.041
Periods	9	6.849**	10.067**	2.319**	3.168**	4.787*
Error	36	0.420	0.450	0.141	0.626	0.579

APPENDIX - 9

Summary of Analysis of Variance tables of the persistence and metabolism of phorate in banana plants grown in lateritic upland.

Source	df	Mean squares of phorate and metabolites				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
Replications	4	0.393	0.287	0.356	0.172	0.322
Periods	9	6.890**	9.665**	4.562**	0.891*	0.953*
Error	36	0.141	0.433	0.365	0.247	0.211

APPENDIX - 10

Summary of Analysis of Variance tables of the persistence and metabolism of phorate in banana plants grown in black cotton soils.

Source	df	Mean squares of phorate and metabolites				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
Replications	4	0.444	0.056	1.405	0.395	2.152
Periods	9	1.715*	4.686**	2.053*	1.060	0.723
Error	36	0.315	0.275	0.576	0.530	0.389

APPENDIX - 11

Summary of Analysis of Variance tables of correlations of concentrations of phorate and metabolites in plant and soil at 15, 45, 90 and 120 days after application in Sandy soils.

Source	df	Mean squares at different intervals				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
		At 15 days after application				
Due to regression	1	0.651*	2.221	0.135	-	0.240*
Deviation from regression	3	0.013	0.232	0.046	-	0.014
		At 45 days after application				
Due to regression	1	6.078*	9.035*	0.136	3.025*	6.558*
Deviation from regression	3	0.372	0.571	0.148	0.024	0.124
		At 90 days after application				
Due to regression	1	0.238	3.146*	1.637*	0.326	0.623*
Deviation from regression	3	0.032	0.045	0.031	0.103	0.015
		At 120 days after application				
Due to regression	1	-	-	-	-	0.010
Deviation from regression	3	-	-	-	-	0.008

APPENDIX - 12

Summary of Analysis of Variance tables of Correlations of concentration of phorate and metabolites in plant and soil at 15, 45, 90 and 120 days after application in clay loam soils.

Source	df	Mean squares at different intervals				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
		At 15 days after application				
Due to regression	1	0.301*	0.844*	0.168	-	-
Deviation from regression	3	0.007	0.028	0.180	-	-
		At 45 days after application				
Due to regression	1	8.997*	4.489*	0.719*	0.053	0.180
Deviation from regression	3	0.187	0.367	0.006	0.011	2.367
		At 90 days after application				
Due to regression	1	0.741*	3.483*	0.765	6.123	2.421*
Deviation from regression	3	0.064	0.104	0.105	0.575	0.182
		At 120 days after application				
Due to regression	1	0.016	0.011	0.298*	0.161	0.556*
Deviation from regression	3	0.021	0.061	0.021	0.032	0.004

APPENDIX 13

Summary of Analysis of Variance tables of Correlations of concentration of phorate and metabolites in plant and soil at 15, 45, 90 and 120 days after application in lateritic upland soils.

Source	df	Mean squares at different intervals				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
		At 15 days after application				
Due to regression	1	0.551*	1.703*	0.114	0.001	0.930
Deviation from regression	3	0.011	0.030	0.502	0.103	0.169
		At 45 days after application				
Due to regression	1	0.788	0.994	0.238	0.330	0.092
Deviation from regression	3	0.412	0.223	0.373	0.417	0.521
		At 90 days after application				
Due to regression	1	0.201*	0.360*	0.893	0.555	0.319
Deviation from regression	3	0.017	0.007	0.326	0.554	0.074
		At 120 days after application				
Due to regression	1	0.019*	0.118*	0.221*	0.038	0.035
Deviation from regression	3	0.001	0.004	0.016	0.012	0.038

APPENDIX - 14

Summary of Analysis of Variance tables of Correlations of concentration of phorate and metabolites in plant and soil at 15, 45, 90 and 120 days after application in black cotton soil.

Source	df	Mean squares at different intervals				
		Phorate	Phorate sulfoxide	Phorate sulfone	Oxyphorate sulfoxide	Oxyphorate sulfone
		At 15 days after application				
Due to regression	1	2.120	0.053	0.169	0.052	-
Deviation from regression	3	0.571	0.495	0.203	0.119	-
		At 45 days after application				
Due to regression	1	1.632	1.141	2.445	0.002	0.619
Deviation from regression	3	0.564	0.250	1.771	0.127	0.246
		At 90 days after application				
Due to regression	1	0.065	0.072	0.410	0.085	1.970
Deviation from regression	3	0.028	0.069	0.996	0.492	1.854
		At 120 days after application				
Due to regression	1	0.049	0.160	0.144	0.031	0.337
Deviation from regression	3	0.019	0.162	0.497	1.519	0.644

Appendix - 15

Weather data during the period of the experiment (1985) for assessing the effect of seasons on the persistence of phorate in banana plants (vide Tables 8 and 9)

Date/Month	Period after treatment (days)	Temperature (Average) Max. (°c)	Min. (°c)	Rainfall (Total) (mm)	Relative humidity (Average) Morning %	Evening %
		Summer Season				
Feb 5 - Feb 20	0 - 15	34.1	22.3	0	87	46
Feb 21 - Mar 7	16 - 30	35.9	23.3	0	46	62
Mar 8 - Mar 22	31 - 45	36.8	24.2	0	78	34
Mar 23 - Apr 6	46 - 60	35.6	25.4	2.0	84	56
Apr 7 - Apr 21	61 - 75	35.8	24.8	17.3	83	54
Apr 22 - May 6	76 - 90	36.2	26.3	0	81	51
May 7 - May 21	91 - 105	33.6	24.8	125.6	88	63
May 22 - Jun 5	106 - 120	29.1	25.0	280.5	94	83
Jun 6 - Jun 20	121 - 135	29.0	22.9	350.9	92	82
		Rainy Season				
Jul 22 - Aug 6	0 - 15	28.7	22.5	210.7	93	78
Aug 7 - Aug 21	16 - 30	28.6	23.1	214.5	93	81
Aug 21 - Sept 5	31 - 45	29.6	23.6	31.5	94	75
Sept 6 - Sept 20	46 - 60	29.6	22.7	48.2	93	72
Sept 21 - Oct 5	61 - 75	31.3	23.2	16.5	91	66
Oct 6 - Oct 20	76 - 90	30.6	22.6	167.3	92	71
Oct 20 - Nov 4	91 - 105	31.5	22.2	209.8	85	63
Nov 5 - Nov 19	106 - 120	31.3	23.2	11.7	84	65
Nov 20 - Dec 4	121 - 135	32.7	22.4	2.7	86	68

EFFECT OF PHORATE APPLIED FOR THE CONTROL OF BUNCHY TOP VECTOR OF BANANA, *Pentalonia nigronervosa* Coq. ON THE PLANT AND IN THE SOIL ENVIRONMENT

BY

D. SITARAMA RAO

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement

for the degree

DOCTOR OF PHILOSOPHY

Kerala Agricultural University

Faculty of Agriculture

DIVISION OF AGRICULTURAL ENTOMOLOGY

COLLEGE OF AGRICULTURE

VELLAYANI — TRIVANDRUM

1989

A B S T R A C T

A series of experiments were carried out for ascertaining the basic problems related to the current recommendations for managing bunchytop disease of banana through the application of phorate.

The absorption, translocation and metabolism of phorate applied in the soil was influenced more by the condition and age of the plant than by the dose of the insecticide.

Since the application of 2.50g ai/plant did not result in corresponding increase in the residue content or the bioefficacy in the early phases of crop growth, when compared to the 1.25 dose, the latter can be used without significant loss in efficacy.

A definite dose-effect relationship existed between the phorate content of plant and the mortality of P. nigronervosa confined at feeding sites.

The median lethal doses of the insecticide content of the plant tissue were higher during declining phase of absorption as compared to those obtained during the active absorption phase. The result indicated the lesser toxicity of some components in the total residue during the later phase of the crop.

Application of phorate granules in leaf axils was less effective than the treatment done in the soil and hence the current recommendation to use less quantity of insecticide when applied in the leaf axils has to be altered.

A simple technique for the seperation, identification and quantification of phorate and its metabolites was developed.

Phorate and phorate sulfoxide contents of the total residue showed inverse relationship with each other while the other metabolites did not exhibit a clear relationship among them.

Phorate and phorate sulfoxide exhibited more positive direct influences on the mortality of the vector than the other metabolites.

The absorption and toxicity of the insecticide content in plants did not vary significantly upto 174 DAP, when applied @ 2.50g ai/plant at different intervals after planting. Absorption was very low when the insecticide was applied at 180 and 210 DAP.

For ensuring residues within tolerance limits (0.10 ppm) in raw fruits, the insecticide treatment has to be limited to 150 DAP and for ripe fruits the limit can be extended upto 180 DAP.

The absorption and persistence of phorate and metabolites was significantly higher in plants grown in summer season than in those grown in rainy season.

The absorption of insecticide was high in sandy soils and it was lowest in black cotton soils during the active absorption phase.

The insecticide persisted at effective levels for 75 days in sandy, 90 days in lateritic upland and 105 days in black cotton soil.

Sulfoxidation of the thioether moiety was the dominent metabolic pathway in sandy soil while desulfuration pathway was predominent in the other three soils.

Application of phorate at planting, @ 2.50g ai/plant, did not adversely affect the soil microflora as observed at the time of harvest of the crop.