THE EFFECT OF PLANT NUTRITION ON THE REPRODUCTIVE RATE AND SUSCEPTIBILITY TO MALATHION OF TWO STRAINS OF THE TWO-SPOTTED SPIDER MITE, TETRANYCHUS TELARIUS (L.)

by
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ABSTRACT

Title of Thesis: The Effect of Plant Nutrition on the Reproductive Rate and Susceptibility to Malathion of Two Strains of the Two-Spotted Spider Mite, Tetranychus telarius (L.).

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Studies were conducted to determine the effect of plant nutrition on the reproductive rate and susceptibility to malathion of two strains of the two-spotted spider mite. The two strains of mites used as test organisms are characterized by their widely different levels of susceptibility to phosphate acaricides. Lima bean plants were grown in quartz sand and supplied nutrient solutions containing varying levels of nitrogen, phosphorus and potassium. Total nitrogen and total water soluble carbohydrate in the host plant tissue were determined by standard methods. Correlation analysis with the number of mite progeny and results of leaf analyses were conducted. The effects of plant nutrition on susceptibility to malathion of the two mite strains were determined by comparing per cent mortality data of mites from plants supplied the various nutrient solutions. Dosage-mortality responses of the two mite strains were also determined for mites of both strains from plants supplied nutrient solutions producing the greatest response in susceptibility.

The reproductive rate of both strains increased as the supply and absorption of nitrogen increased. However, in studies with the resistant mite, a reduction in the number of progeny occurred on plants supplied the highest nitrogen level. The number of progeny of the malathion non-resistant mite were significantly correlated to increased nitrogen absorption.

Increased reproductive rate of both strains was correlated to the

carbohydrate present in the leaf tissue. When carbohydrate content in the leaf tissue was increased along with an increase in nitrogen supply and absorption the mite reproductive rate also increased. At still higher levels of nitrogen supply and absorption, carbohydrate content of leaf tissue decreased and the mite reproductive rate was depressed or failed to increase.

The malathion non-resistant mite appeared more responsive to plants deficient in nitrogen than the resistant mite. On plants supplied the low nitrogen nutrient solutions, non-resistant mites failed to subsist, while the resistant mites maintained relatively high populations.

The malathion non-resistant mite also produced more progeny on plants when phosphorus supply was increased. Populations of the resistant mite increased at higher levels of potassium.

Phosphorus and potassium supply alone and in combination with certain levels of nitrogen affected nitrogen absorption and the relative amounts of carbohydrate present in the leaf tissue.

Increasing the nitrogen supply to host plants resulted in increased susceptibility of the resistant mite to malathion. The non-resistant mite was more responsive to variations in phosphorus supply of host plants. A decrease in susceptibility followed an increase in phosphorus supply.

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INTRODUCTION

The phytophagous arthropod pest and its relationship to the host plant as a source of nutritional requirements is of first importance to the economic entomologist. The loss of efficiency or complete destruction of the host plant as a result of this relationship deprives man of food and fiber essential to his well-being. Wood (1953), stated, "Green plants alone, save for some negligible exceptions, manufacture the basic materials of life, the existence of animals and human beings depends on the basic products of these living green factories. Any serious breakdown in the process threatens life itself." It has been conservatively estimated that the cost of such loss due to insect ravages is in excess of 4 billion dollars in an average year (Haeussler 1952).

The effect of the growing condition of the plant on the biological processes of arthropods has long been a subject of interest to entomologists. Lees (1926) proposed that changes in plant tissue due to different cultural factors such as irrigation and manuring subsequently affect the attacking insect.

Inherent variation in the composition of plant tissue and growing knowledge of the selective preference of phytophagous species has stimulated this interest. Painter (1936, 1941, 1951) has written that different nutritive values of plants to insects is evidenced by the insect's ability to maintain a population on them. Nutritive substances from plants, used by the insect, are factors of great importance in insect biology. Recognition of differences in food value of plants may

furnish a tool for insect nutrition study and be an important factor in the development of plants resistant to insect attack. Painter further proposed that the interrelation of insect and plant is a product of the evolution of physiological reactions, with special emphasis on the food requirement which has accompanied a parallel evolution of morphological characters. Trager (1958) has stated the ecological role and economic importance of an insect are largely determined by what and how much it eats.

Lipke and Fraenkel (1956) in a recent review of insect nutrition noted the revival of interest in host preference of phytophagous species but reported that the amount of research conducted falls far short of the emphasis which the importance of the subject warrants.

It behooves the entomologist to study the relationship between the host plant and the arthropods which feed upon it to understand more fully the nutritional requirements of the arthropod as related to the growing conditions of the host.

The specific nutritional requirements of an insect or mite would be most efficiently studied by the use of definitively altered artificial diets. Generally, the entomologist is unable to employ such a technique because chemically defined diets and aseptic methods in most cases are lacking. One alternative method is to alter the composition of plant tissue by treatment of the plant, subsequently measuring the effect on biological processes of a test organism subsisting on the plant tissue.

The present study was conducted to determine the effect of host plant nutrition on two strains of the two-spotted spider mite. The experiments were conducted with two objectives:

1. To determine the effects of varying plant nutrition on reproductive capacity.
2. To determine the effects of varying plant nutrition on susceptibility to malathion.

REVIEW OF LITERATURE

Phytophagous insects and mites have been observed by a number of investigators to be affected by changes in the host plant induced through mineral element nutrition.

Relatively little is known about insect nutrition, but in general increased populations of arthropods following improved plant nutrition has been attributed to an increase of available nutrients. Friend (1958) and Thorsteinson (1960) recently reviewed the subject of the nutritional requirements and host preferences of phytophagous insects. Painter (1951) in an excellent text, "Insect Resistance in Crop Plants," has also thoroughly reviewed the literature concerning the subject. The value of studies of this type are recognized for their usefulness in the development of plants resistant to insect attack and the accumulation of information regarding the nutritional requirements of insects.

The results of reports by various investigators on the effect of plant mineral element nutrition on insect populations are summarized in Table 1. Generally, increased fertilization of plants has resulted in an increase of populations or reproductive rate of insects. However, considerable variation in reports has occurred. Several investigators have found no difference in insect reproductive rate due to variations in the mineral element supply to host plants. In other cases, increased supply of mineral elements has resulted in a marked depression of insect populations.

Table 1. A summary[1] of reported work on the effect of host plant mineral element supply and relation to insects.

Order	Mineral Element N	P	K	Ca	Mg	S	Fe	Zn	Cu	Reference
Homoptera										
Aphis gossypii (Glov.)	+									McGarr (1942, 1943)
	+		+							Isely (1946)
Aonidiella aurantii (Mask.)	-	O		+						Steyn (1951)
Brevicoryne brassicae (L.)	+									Evans (1938)
Chrysomphalus aonidum (L.)								+	+	Thompson (1939)
Lepidosaphes beckii (Newm.)						+				Osburn and Spencer (1938)
					+			+	+	Thompson (1939, 1941, 1942)
Macrosiphum pisi (Harris)	+	+	+	+	+					Barber and Tauber (1951)
	-									Barber and Tauber (1954)
	+									Maltais (1951), Maltais and Auclair (1957)
	O	O	O							Taylor et al (1952)
Macrosiphum solanifolii (Ashm.)	O	O	O		O	O	O			Taylor et al (1952)

Table 1. Continued

Order	Mineral Element N	P	K	Ca	Mg	S	Fe	Zn	Cu	Reference
Myzus persicae (Sulz.)	0	0	0	0	0					Barber and Tauber (1951)
	0	0	0							Volk *et al* (1952)
Phenacoccus aceris (Sign.)	≠									Schoene (1941)
Pseudoccus citri (Risso)									≠	Spear (1952)
Toxoptera graminum (Rond.)	-			-						Arant and Jones (1941)
	-	0	0							Daniels (1957)
	≠	≠	≠	≠	≠		≠			Haseman (1946)
Trialeurodes vaporariorum (Westw.)	-	≠			-		≠			Haseman (1946)
Hemiptera										
Blissus leucopterus (Say)	-									Dahms and Fenton (1940)
	≠(-)	≠(-)								Dahms (1947)
	-									Haseman (1946)
Coleoptera										
Calandra oryzae (L.)	≠	0	0							Eden (1953)
Leptinotarsa decemlineata (Say)	-									Arenz and Schroppel (1952)
	0									Grison (1957)

Table 1. (Continued)

Order	Mineral Element N	P	K	Ca	Mg	S	Fe	Zn	Cu	Reference
Phaedon cochleariae (F.)	↗	↗	↗				↗			Allen and Selman (1955)
Scolytus rugulosus (Ratz.)	↗		-	-						Jepson (1926a, 1926b)
Lepidoptera										
Alabama argillacea (Hbn.)								↗	↗	Creighton (1938)
Agrotis orthogonia Morr.	↗									Hocking (1953)
Pyrausta nubilalis (Hbn.)	↗	↗	↗							Taylor et al. (1952)
Heliothis zea (Boddie)	↗	-								Gausman and Wene (1954)
Thysanoptera										
Heliothrips haemorrhoidalis (Bouche)	-									Haseman (1946)
	-			-						Wittwer and Haseman (1945)
Orthoptera										
Melanoplus mexicanus (Sauss.)	↗									Smith and Northcott (1951)

1/ ↗, -, 0 indicate an increased supply of the tested mineral resulted in an increase, decrease, or no response, respectively.

In many cases results have been obtained on the basis of field fertilizer trials without supporting leaf analysis or certainty that increased absorption of inorganic elements or changes in the leaf tissue have occurred.

The effects of mineral element supply on plants are also reflected in the organic constituents of plant tissue. The subsequent effects of the quantity and quality of these organic materials available to feeding arthropods have not been extensively investigated. However, evidence is accumulating to demonstrate that the organic constituents of plant tissue are important factors in the interpretations of studies concerned with host plant-arthropod interrelations.

Davidson (1923) stated that favorable development and reproduction of aphids was associated with the nature of the cell sap. The pea aphid, Macrosiphum pisi (Harris), has been observed by several investigators to reproduce more rapidly on susceptible alfalfa plants (Blanchard and Dudley 1934, Seamans and McMillan 1935). Emery (1946) reported that temporary pea aphid immunity of alfalfa plants was correlated to the acid condition and scarcity or absence of sucrose in the plant.

Reproduction of the cabbage aphid, Brevicoryne brassicae (L.), was found positively correlated to the amount of nitrogen in the plant (Evans 1938). The production of winged forms, however, decreased with increased nitrogen content. Alate forms increased as soluble sugar and total carbohydrate decreased. With another insect, Pieris brassicae (L.), the same author reported that the rate of growth, length of larval period, pupal weight and the amount of food eaten were related to the chemical composition of the plant.

Auclair and Maltais (1950, 1957b) reported 15 amino acids from extracts of pea aphids; 11 amino acids were found in the host pea plant. Susceptible pea varieties had higher concentrations of amino acids than resistant varieties. Pea aphids feeding on plants supplied asparagine and glutamine increased in weight more than aphids feeding on plants not supplied the two amides and did as well on these plants as aphids on plants supplied all the amino acids known essential to insects (Maltais 1959). Maxwell and Harwood (1959) found increased fecundity of the pea aphid, on 2,4-D treated broad beans, was associated with an increase of certain amino acids in the plant tissue.

Beck (1956 a, b) found that the physical characteristics and sugar content of the plant were related to orientation and feeding of larvae of the corn earworm, Heliothis zea (Boddie). Larvae prolonged feeding and concentrated on agar discs containing the highest concentration of glucose, fructose or sucrose (Beck 1956 c).

Simulated cotton flower nectar solution fed to moths of the pink bollworm, Pectinophora gossypiella (Saund.), was reported to induce greater oviposition but had no effect on longevity of moths (Lukefahr and Griffen 1956, Clark and Lukefahr 1956).

Grison (1957) found fecundity of the Colorado potato beetle, Leptinotarsa decemlineata (Say), directly correlated to the amount of food eaten. However, fecundity decreased as the glucose content of leaf tissue increased. The fecundity index of females feeding on young leaves was twice the feeding index of females feeding on old leaves.

Differences in reproductive rate have been induced by feeding test insects different parts of the same host plant or different types of host plants. These reports in most cases have not been accompanied by leaf

analysis but indicate different host plants or even different parts of the same plant vary in their nutritional value to the insect. Hodge (1933) reported increased vigor, longevity and fertility of the differential grasshopper, Melanoplus differentialis (Thomas), on diets of wheat, barley and rye leaves. Irregular growth, development and susceptibility to pathogens occurred on diets of lettuce or oats.

Hill (1946) reported the type of food plant affected oviposition and length of adult life of the tuber flea beetle, Epitrix tuberus Gent.

Hocking (1953) found whole wheat seedlings superior to cut wheat leaves as food for the larvae of the pale western cutworm, Agrotis orthogonia Morr. This was attributed to greater nitrogen intake permitted by the higher water content of the whole wheat seedlings.

The cotton leafworm, Alabama argillacea (Hbn.), fed cotton and apple leaves produced fewer eggs. Subsequent feeding on cotton flowers resulted in an increase of vitality and egg production. The cotton stainer, Dysdercus suturellus (H.-S.) on a cotton leaf diet produced fewer eggs; but on bolls or seed, the insect resumed normal egg production (Creighton 1938).

The application of certain spray materials to host plants has also been observed by various investigators to produce more favorable conditions for certain arthropods.

Populations of the citrus mealybug, Pseudoccus citri (Risso), were observed to increase after sprays containing copper compounds (Spear 1922). Purple scale, Lepidosaphes beckii (L.), and Florida red scale, Chrysomphalus aonidium (L.), increased after lime or wettable sulfur applications (Osburn and Spencer 1938). A possible explanation of these results was reported by Thompson (1939). Copper and zinc compounds were found to inhibit fungi attacking scale insects.

Some evidence has been shown to implicate a relationship between the host plant and tolerance of insects to insecticides. Larvae of the southern armyworm, Prodenia eridania (Cram.), fed on polk weed, squash and sweet potato were found more resistant to lead arsenate than the larvae fed on collard (Swingle 1939). Potter and Gillham (1957) found aphids from clover more resistant to rotenone than aphids from broad bean. The aphids from clover were smaller and had a higher proportion of dry matter than aphids from broad bean. Adkisson (1958) reported two to three times more bollworm larvae in fertilized plots but control appeared more effective than in unfertilized plots.

Reports of experimental work with mites and relationship to host plant nutrition have been less frequent. Thompson (1939) reported that increased populations of the rust mite, Eriophyes oleivorus (Ashm.), occurred after copper sprays were applied to citrus trees. Populations of the citrus red mite, Paratetranychus citri (McG.) (= Metatetranychus citri (McG.)), were found to increase after sprays of zinc sulfate, copper sulfate and hydrated lime or zinc sulfate and soda ash (Holloway et al. 1942). Henderson and Holloway (1942) found that more eggs were deposited by mites, Metatetranychus citri (McG.), on young and medium age leaves as compared to old leaves. It was also reported that mite feeding injury influenced a reduction in egg production. Kuenen (1949, 1958) reported that egg production of Metatetranychus ulmi (Koch) was higher in well kept orchards. Increased population density of the same mite occurred after pruning and nitrogen fertilization of neglected orchards. Breukel and Post (1959) reported higher nitrogen content of leaves from trees in well kept orchards but no difference in calcium, magnesium or phosphorus content. Higher reproductive rate of M. ulmi occurred on leaves with the higher nitrogen content.

Garman and Kennedy (1949) reported increased populations of the two-spotted spider mite with increased plant fertilization. Rodriguez and Neiswander (1949) found higher mite populations in greenhouses where the same crops were grown twice in the same year. The high mite populations were correlated to the amount of soluble salt content of the soil.

Rodriguez (1951) reported that spider mite populations were positively correlated to absorption of phosphorus below .30 per cent, potassium and magnesium, but negatively correlated to nitrogen, phosphorus above .30 per cent and boron absorption in tomato plants. In a more recent study (1958), Rodriguez reported populations of T. telarius positively correlated to absorbed nitrogen in apple foliage, but negatively correlated to increased nitrogen absorption when phosphorus levels were increased. Mite populations were again reported positively correlated to phosphorus and potassium absorption. Seemingly contradictory results were explained on the basis of interrelations of ions and different ranges of absorption.

LeRoux (1954) reported increased fecundity of the two-spotted mite with increasing nitrogen, phosphorus and potassium supply to cucumber host plants grown in sand culture but no leaf analyses were made.

Hamstead and Gould (1957) followed the development of populations of the European red mite and two-spotted spider mite in apple orchards. They found increased populations of the two species correlated to the normal seasonal increase in nitrogen occurring in apple leaf tissue.

METHODS AND MATERIALS

The experiments herein discussed were conducted in a greenhouse at Beltsville, Maryland. Lima beans were grown from seed to the cotyledon stage in a sand propagating bench. The seedlings were potted individually in quartz sand in 1/2 gallon glazed clay crocks and watered with distilled water. The nutrient solutions were applied the first day after potting and twice a week thereafter for the duration of the test. Two-hundred and fifty ml. of nutrient solution of the appropriate concentration were applied at each feeding and the pots were leached with the same amount of distilled water on the days they received no nutrient solution.

Stock solutions of the following mineral salts were prepared: .5M ammonium sulfate, .5M calcium nitrate, M ammonium nitrate, .2M potassium dihydrogen phosphate, .1M potassium sulfate, .2M sodium acid phosphate, .5M calcium chloride, and M magnesium sulfate containing .0485M boric acid, .0011M zinc sulfate, .001M copper sulfate, .0359M ferrous sulfate, .0182M manganese chloride, and 3 ml. of sulfuric acid per liter. From these stock solutions the appropriate amounts were diluted and delivered to the experimental plants to provide the various nutritional levels. Nitrogen, and/or phosphorus and/or potassium concentrations were the experimental variables. The experiments discussed were conducted with 4 - 6 replications.

Two strains of the two-spotted spider mite, Tetranychus telarius (L.), were used as test organisms. One designated non-resistant and the second, resistant to phosphate acaricides. The non-resistant strain was isolated in 1949 from carnations in Waltham, Massachusetts; the phosphate resistant strain was isolated in 1951 from roses at Cranbury, New Jersey. Since the original isolations, the mites have been maintained at Beltsville, Md., in

the greenhouse in individual cheesecloth covered cages (Fig. 1). The colonies have never been exposed to insecticides or acaricides except for periodic dusting with DDT to eliminate predators. The two strains of mites were characterized as to their widely different tolerances to malathion by Taylor and Smith (1956).

Two methods were used to determine the effect of plant treatment on the reproductive rate of mites. The first, referred to as the "leaf disc" method proceeded as follows: Approximately 3 weeks after infesting the experimental plants with mites, a random sample of 5 leaf discs 9/16" in diameter was taken from each plant. The discs were mounted on 1/4" cork strips and the total number of living forms counted with the use of a stereoscopic microscope.

The second method of observing the effect of plant nutrient treatments on the reproductive rate of mites was accomplished by confining a known number of mites to individual leaves of the experimental plants. An adaptation of the cage described by MacGillivray and Anders (1957) was used for this purpose. The cage was made of .002" thickness cellulose nitrate cut in strips 3/4" wide and 2 3/4" long. The two extreme ends were fastened together with acetone. A Lady Ellen "Klippie" hair clip was inverted, the two bottom prongs bent to fit the cellulose nitrate cage and a common pin pushed through the bent prongs and the cage to hold them together. The cage could then be attached to a plant leaf with ease, as illustrated in Fig. 2.

Mites were transferred to the leaf with a camel hair brush through the open top of the cage, which was ringed with lanolin to prevent the mites from escaping. The total number of eggs, larvae and quiescent forms were counted in 7 days.

Fig. 1. Mite-colony cage for the culture and isolation of resistant and non-resistant spider mites.

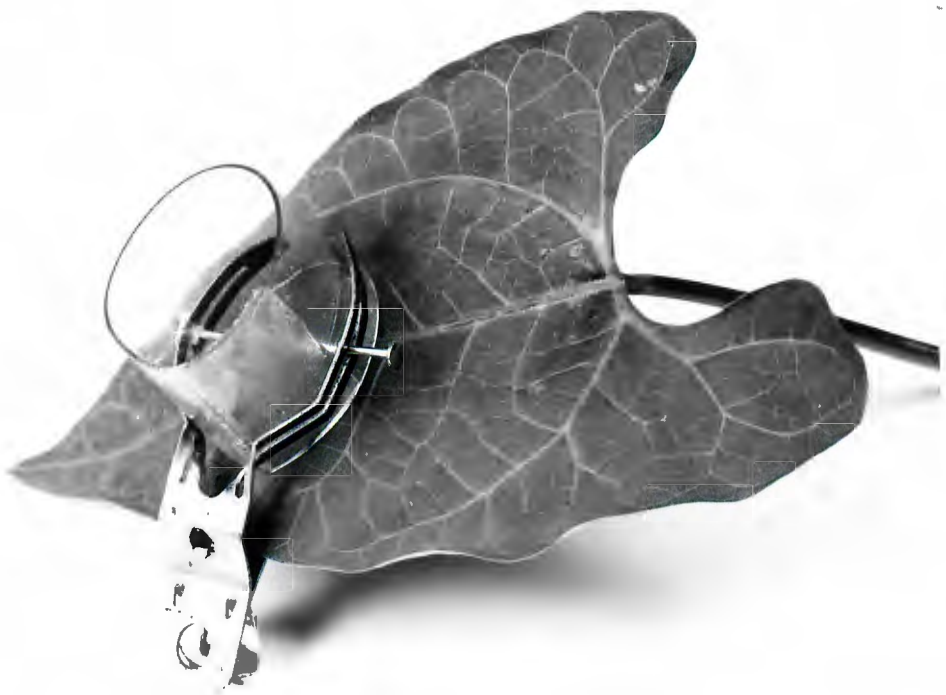

Fig. 2. "Klippie" cage used to confine mites to individual leaves of experimental plants.

In the studies with the "Klippie cage", leaf tissue was analyzed for total water soluble carbohydrate and total nitrogen. The total carbohydrate present in living leaf tissue was determined colorimetrically by an adaptation of the method described by Hewitt (1958). The method was adapted by Hewitt from similar methods described by Fales (1951) and Schlegal (1956). It is possible by this method to measure the carbohydrate content of plant material containing different amounts of chlorophyll by using a blank containing sulfuric acid and plant material for each determination. Murphy (1958) reported the method not as accurate as classical methods but the saving in time justifies its use.

The reagent consists of .2 gram of anthrone, 8 ml. of absolute alcohol and 100 ml. of concentrated chemically pure sulfuric acid.

Five leaf discs 9/16" in diameter were taken at random from each of the experimental plants. The discs were placed in a Waring Blendor and ground for 2 minutes with approximately 100 ml. of water. The extract was adjusted to 100 ml. upon removal from the blender and for each determination 1 ml. of this extract was pipetted into each of 3 standard test tubes. The first tube in each case was the "blank" to which 10 ml. of concentrated chemically pure sulfuric acid was added. To each of the other tubes the anthrones reagent was added. Color was developed in boiling water for 7 minutes after which the samples in the test tubes were immersed in cold water. Each sample was then transferred to matched test tubes and per cent transmittance read at 620 millimicrons in a Bausch and Lomb Spectronic 20. The determinations were then compared to a glucose standard treated in the same manner. The results are expressed as micrograms of glucose per 100 ml. of plant extract.

Nitrogen was determined by the methods of Lindner and Harley (1944) as adapted by the Horticulture Department of the University of Maryland.

To determine the effect of host nutrition on susceptibility, the following procedure was followed. After 19 - 21 days of growing in the experimental nutrient solutions, plant growth was visibly affected by mineral element supply. At this time, mite-infested leaves from the resistant colony were pinned to the primary leaves of the experimental plants. When the populations of mites on the individual experimental plants were of sufficient magnitude for testing, mites were transferred from the experimental plants to bean seedlings by the same method. In this way 90 - 120 adult female mites were transferred to the seedlings within a two-hour period. The seedlings, trimmed of all but the two primary leaves were set in 150 ml. bottles containing a complete nutrient solution (Hyponex)1/. The petiole of each leaf was banded with lanolin to keep mites from wandering off the plants, and the neck of each bottle was smeared with a sticky barrier (Deadline)2/ to prevent contamination from the benches.

The seedlings with mites were then dipped in appropriately diluted malathion solutions which gave 30 - 70 per cent kill of mites in the experiments discussed. The mites were dipped in 1000 ppm or 5 ppm of actual malathion for the resistant and non-resistant mite respectively. The number of living and dead adult female mites were counted in 24 hours.

1/ A commercially-prepared all-purpose plant food, manufactured by Hydroponic Chemical Company, Inc., Copley, Ohio.

2/ Insect barrier manufactured by the California Spray Corporation. The active ingredient is a mixture of Butylene polymers.

The dosage-mortality response of mites from plants supplied the nutrient solutions which gave the maximum and minimum response to malathion were determined for each strain and also for the respective parent colonies. The L.D. 50's were calculated by the method of Finney (1952).

The experimental data were statistically analyzed by the methods of Snedecor (1956) and Cochran and Cox (1959). The comparison and separation of means was accomplished by the method of Duncan (1955).

RESULTS OF EXPERIMENTS TO DETERMINE THE EFFECT OF PLANT NUTRITION ON THE REPRODUCTIVE RATE OF MITES

The leaf disc method and the Klippie cage method, as described, were used to determine the effect of plant nutrition on the reproductive rate of mites. Both methods were employed to obtain data for each strain in separate experiments.

The leaf disc method was used to determine the population of mites developing on plants supplied the nutrient solutions shown in Table 2.

The Klippie cage method was used to confine a known number of mites to an individual leaf on the experimental plants supplied the nutrient solutions shown in Table 3. Leaf analyses for total nitrogen and total water soluble carbohydrate were made. The test for partial correlation coefficients were performed in multiple correlation analyses of mite data, percent nitrogen and carbohydrate.

Studies with the Resistant Strain Using the Leaf Disc Method

As shown in Fig. 3, the mite populations on host plants supplied the intermediate or high level of nitrogen were more than double the populations on host plants supplied the low level of nitrogen. No significant increase occurred on plants supplied the highest nitrogen level as compared to the population on plants supplied the intermediate nitrogen level.

Studies with the Resistant Strain Using the Klippie Cage Method

Effect on mites. Increasing the nitrogen and potassium supply to host plants caused significant increases in the number of progeny produced by resistant mites. However, a reduction in the number of progeny was evident on plants supplied the highest level of nitrogen as compared to the number

Table 2. Concentrations of ions in nutrient solutions supplied bean plants in experiments to determine the effect of plant nutrition on the reproductive rate and susceptibility to malathion of spider mites.

Element	Level of Nutrient Low m.e./L. [1/]	Intermediate m.e./L	High m.e./L
(N) Nitrogen			
as NH_4	.5	2.5	5.
as NO_3	1.5	7.5	15.
(P) Phosphorus as PO_4	.2	2	4
(K) Potassium	.2	2	4
Calcium	7.5	7.5	15
Magnesium	2	2	2
	ppm	ppm	ppm
Boron	.50	.50	.50
Manganese	1.00	1.00	1.00
Zinc	.07	.07	.07
Copper	.06	.06	.06
Iron	2.00	2.00	2.00

1/ m.e./L. - milliequivalent per liter.

Table 3. Concentrations of ions in nutrient solutions supplied bean plants in experiments to determine the effect of plant nutrition on the reproductive rate of resistant and non-resistant mites and susceptibility to malathion of the non-resistant mite.

Nutrient Element	Level of Nutrient		
	Low m.e./L.[1/]	Intermediate m.e./L.	High m.e./L.
(N) Nitrogen			
as NH_4	1.	4	25
as NO_3	2.5	10	31
(P) Phosphorus			
as PO_4	.2	2	8
(K) Potassium	2	-	8
Calcium	10	10	10
Magnesium	2	2	2
	ppm	ppm	ppm
Boron	.5	.5	.5
Manganese	1.	1.	1.
Zinc	.07	.07	.07
Copper	.06	.06	.06
Iron	2.	2.	2.

1/ m.e./L. - milliequivalent per liter.

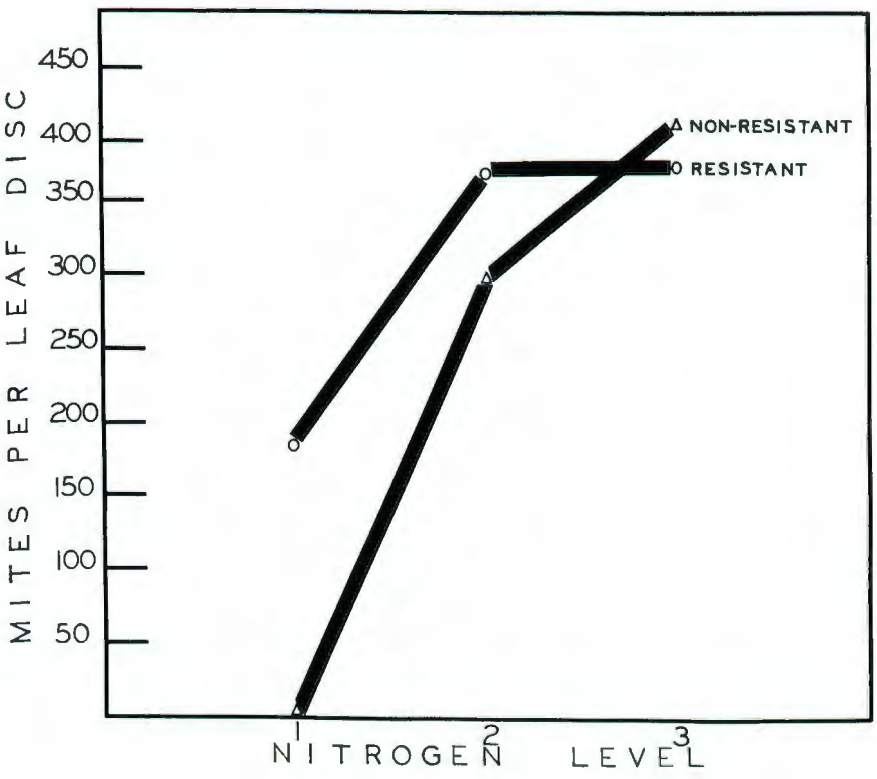

Fig. 3. Mean number of mites per 5-leaf disc sample of resistant and non-resistant mites from plants supplied low, intermediate and high levels of nitrogen. (Points shown are means of main effects of nitrogen with all combinations of phosphorus and potassium).

of progeny of the mites on plants supplied the intermediate level of nitrogen (Fig. 4 and Table 4). The number of mite progeny produced were significantly correlated ($r = .6273$) with the total carbohydrate content of the leaf tissue. The number of progeny produced increased with an increase in total carbohydrate and was depressed when total carbohydrate decreased at the highest level of nitrogen supply and absorption.

Leaf analyses. Nitrogen was absorbed in increasing amounts with increasing nitrogen supply. The total carbohydrate in leaf tissue was affected by the amount of nitrogen and phosphorus supplied the experimental plants. Carbohydrate increased with nitrogen supply, however a decrease in carbohydrate occurred in plants supplied the highest nitrogen level as compared to plants supplied the intermediate nitrogen level.

More carbohydrate was found in plants supplied low or intermediate phosphorus as compared to plants supplied high phosphorus (Table 4).

With low nitrogen, more carbohydrate was found in the leaf tissue of plants supplied low or intermediate phosphorus than in leaf tissue of plants supplied high phosphorus. With high nitrogen, more carbohydrate was observed in plants supplied the intermediate phosphorus level than in the leaf tissue of plants supplied low or high phosphorus. Plants supplied low nitrogen with low potassium had less carbohydrate than plants supplied low nitrogen with high potassium (Table 5).

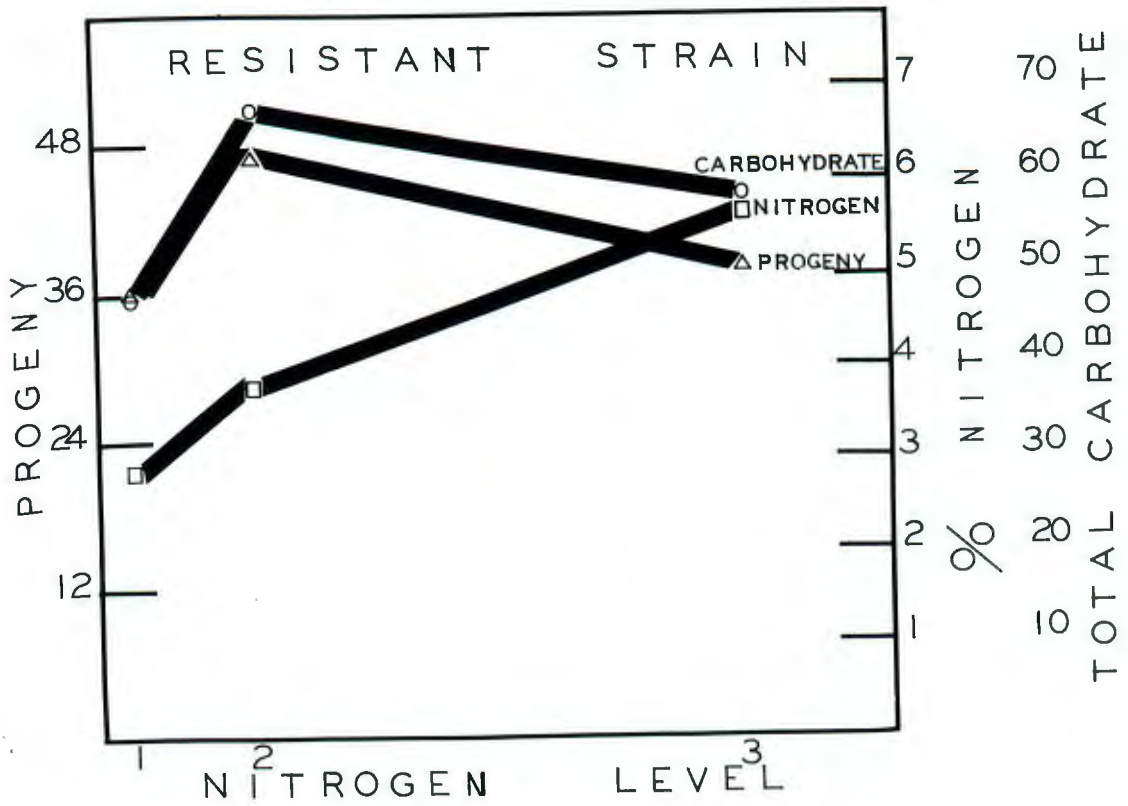

Fig. 4. Mean number of resistant progeny, total carbohydrate and per cent nitrogen of plants supplied low, intermediate and high levels of nitrogen. (Points shown are the means of the main effects of nitrogen, with all combinations of phosphorus and potassium.)

Table 4. Number of progeny of the resistant mite and analysis of plants supplied different levels of nitrogen, phosphorus and potassium.

Treatment	Progeny[1]	Per cent[1] Nitrogen	Micrograms[1] Carbohydrate
Nitrogen			
Low	35.6 a	2.91 a	47.9 a
Intermediate	46.8 b	3.83 b	68.2 b
High	38.3 a	5.74 c	58.9 c
Phosphorus			
Low	38.3 a	3.79 a	61.6 b
Intermediate	39.9 a	4.33 a	62.4 b
High	42.4 a	4.36 a	51.1 a
Potassium			
Low	37.4 a	4.19 a	57.9 a
High	43.1 b	4.13 a	58.8 a

1/ Mean of main effects of nitrogen, phosphorus and potassium factorially arranged treatments.

Means followed by a common letter are not significant at the 5% level.

Table 5. Total carbohydrate[1/] in plant tissue as affected by nitrogen with phosphorus and potassium interactions (resistant mite experiment).

	Nitrogen		
	Low	Intermediate	High
Phosphorus			
Low	55.8 b	76.2 d	52.8 b
Intermediate	48.6 b	72.1 cd	66.4 c
High	39.5 a	56.3 b	57.3 b
Potassium			
Low	43.8 a	71.2 cd	58.7 b
High	52.1 b	65.2 d	59.0 bc

1/ Means followed by a common letter are not significantly different at the 5% level.

Studies with the Non-resistant Strain Using the Leaf Disc Method

As shown in Fig. 3 and Table 6, the population of spider mites on plants supplied the intermediate level of nitrogen was nearly 60 times as great as the population of mites on plants supplied the low level of nitrogen. The population of mites on plants supplied the high level of nitrogen was approximately 80 times greater than the population of mites on plants supplied low levels of nitrogen.

The response to increased amounts of potassium supplied host plants was somewhat less obvious. However, a significant depression of the mite population occurred on plants supplied the high level of potassium as compared to the population of mites on plants supplied the low level of potassium.

Studies with the Non-resistant Strain Using the Klippie Cage Method

Effect on mites. The results of mite counts are shown in Fig. 5 and Table 7. The number of progeny increased with nitrogen and phosphorus supply. More progeny were produced on plants supplied the intermediate and high levels of nitrogen than on plants supplied the low level of nitrogen. No difference occurred between the number of progeny produced on plants supplied the highest level of nitrogen and the number of progeny produced on plants supplied the intermediate level of nitrogen. The number of progeny produced on plants supplied the intermediate and high levels of phosphorus were greater than the number of progeny produced by mites on plants supplied the low level of phosphorus. No difference in reproductive rate occurred between mites on plants supplied the intermediate or high level of phosphorus.

The number of progeny produced by mites was significantly correlated to absorbed nitrogen ($r = .4495$) and total carbohydrate ($r = .4614$) of the leaf tissue.

Table 6. Mean number of non-resistant mites[1/] per 5-leaf disc sample from plants supplied combinations of low, intermediate or high nitrogen, phosphorus and potassium.

Treatment	Progeny	Statistical Significance[2/]
Nitrogen		
Low	5	a
Intermediate	300	b
High	418	c
Phosphorus		
Low	228	NS
Intermediate	225	NS
High	270	NS
Potassium		
Low	289	a
Intermediate	243	a
High	191	b

1/ Mean of main effects of nitrogen, phosphorus, and potassium factorially arranged treatments.

2/ Means followed by a common letter are not significantly different at the 5% level.

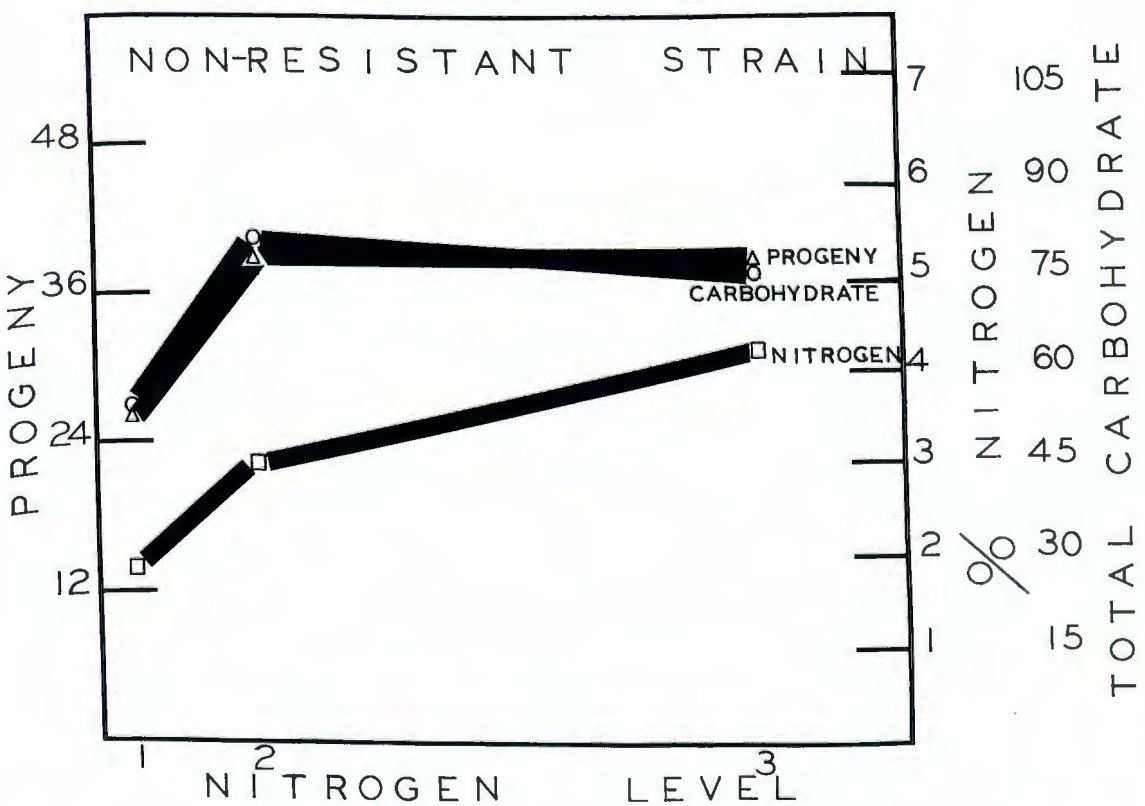

Fig. 5. Mean number of non-resistant progeny, total carbohydrate and per cent nitrogen of plants supplied low, intermediate and high levels of nitrogen. (Points shown are the means of the main effects of nitrogen in all combinations of phosphorus and potassium).

Table 7. Number of progeny of the non-resistant mite and analysis of plants supplied different levels of nitrogen, phosphorus and potassium.

Treatment	Progeny[1]	Per cent[1] Nitrogen	Micrograms[1] Carbohydrate
Nitrogen			
Low	26.8 a	1.97 a	53.6 a
Intermediate	38.9 b	3.01 b	81.3 b
High	39.1 b	4.17 c	77.0 b
Phosphorus			
Low	29.7 a	3.08 a	70.7 a
Intermediate	37.0 b	3.02 a	74.2 a
High	37.5 b	3.06 a	67.1 a
Potassium			
Low	36.3 a	3.28 a	74.6 a
High	33.2 a	2.83 b	79.5 a

1 Mean of main effects of nitrogen, phosphorus and potassium factorial treatment arrangement.

Means followed by a common letter are not significantly different at the 5% level.

Leaf analyses. The results are shown in Figure 5 and Table 7. The total nitrogen in leaf tissue was affected by nitrogen and potassium supply, and phosphorus supply with certain levels of nitrogen. Nitrogen absorption increased with nitrogen supply. A reduction in the amount of nitrogen absorbed occurred with the high potassium supply. High levels of phosphorus resulted in an increase of absorbed nitrogen with high levels of nitrogen supply. The high and intermediate phosphorus supply with the intermediate level of nitrogen resulted in a decrease of absorbed nitrogen (Table 8).

Total carbohydrate of plant tissue was affected by nitrogen supply and phosphorus or potassium supply with certain levels of nitrogen. Total carbohydrate was positively correlated to absorbed nitrogen ($r = .4966$). An increase of total carbohydrate occurred in plants supplied the intermediate and high levels of nitrogen as compared to the low levels of nitrogen (Table 7).

With low nitrogen, high phosphorus resulted in a reduction of carbohydrate. With high nitrogen, intermediate phosphorus levels resulted in an increase of carbohydrate. High potassium with intermediate nitrogen resulted in decreased carbohydrate (Table 9).

Table 8. Per cent dry weight of nitrogen[1/] as affected by phosphorus interaction with certain levels of nitrogen supply

	Nitrogen		
	Low	Intermediate	High
Phosphorus			
Low	1.96 ab	3.66 d	3.63 d
Intermediate	1.92 a	2.65 bc	4.50 e
High	2.03 ab	2.73 c	4.41 e

1/ Means followed by a common letter are not significantly different at the 5% level.

Table 9. Total carbohydrate 1/ affected by nitrogen, phosphorus and potassium interactions (non-resistant mite experiment).

	Nitrogen		
	Low	Intermediate	High
Phosphorus			
Low	59.4 bc	85.5 e	67.1 cd
Intermediate	53.7 ab	80.6 e	88.2 e
High	47.5 a	77.8 de	75.9 de
Potassium			
Low	52.0a	87.3 c	74.6 b
High	54.9 a	75.3 b	79.5 bc

1/ Means followed by a common letter are not significantly different at the 5% level.

RESULTS OF EXPERIMENTS TO DETERMINE THE EFFECT OF PLANT NUTRITION ON SUSCEPTIBILITY OF MITES TO MALATHION

Studies With The Resistant Strain

Two preliminary experiments were conducted. Low and intermediate levels each of nitrogen, phosphorus and potassium, in all combinations, were the experimental variables (Table 2).

Mites from bean plants supplied the intermediate level of nitrogen were easier to kill than mites from plants supplied the low level of nitrogen (Table 10). Approximately 11 per cent higher mortality was obtained when mites were cultured on plants supplied the intermediate level of nitrogen.

Mites from plants supplied low nitrogen and potassium were less susceptible to malathion than mites from plants supplied low nitrogen with high potassium or intermediate nitrogen with either level of potassium (Table 11).

A second experiment with the resistant mite was conducted, however, it was expanded to include plants supplied a third level each of nitrogen, phosphorus and potassium in all combinations. The third level in each case was double that of the intermediate level (Table 2).

Mites of the resistant strain from plants supplied the low level of nitrogen were less susceptible to malathion than mites from plants supplied either the intermediate or high level of nitrogen (Fig. 6).

The mites most susceptible to malathion were those cultured on plants supplied intermediate nitrogen, low phosphorus and high potassium. Mites least susceptible to malathion were those from plants supplied low nitrogen, intermediate phosphorus and potassium.

The malathion dosage-mortality response of mites from plants supplied

Table 10. Per cent mortality 1/ of resistant mites from plants supplied low or intermediate nitrogen.

Treatment	Experiment 1	Experiment 2
	% Mortality	% Mortality
Nitrogen		
Low	43.8 a	51.5 a
Intermediate	54.4 b	62.2 b

1/ Mean of main effects of nitrogen with phosphorus and potassium in all combinations.

Means followed by a common letter are not significantly different at the 5% level.

Table 11. Per cent mortality 1/ of resistant mites for the nitrogen and potassium interaction

	Nitrogen	
	Low	Intermediate
Potassium		
Low	36.1 a	58.6 b
High	51.4 b	50.2 b

1/ Means followed by a common letter are not significantly different at the 5% level.

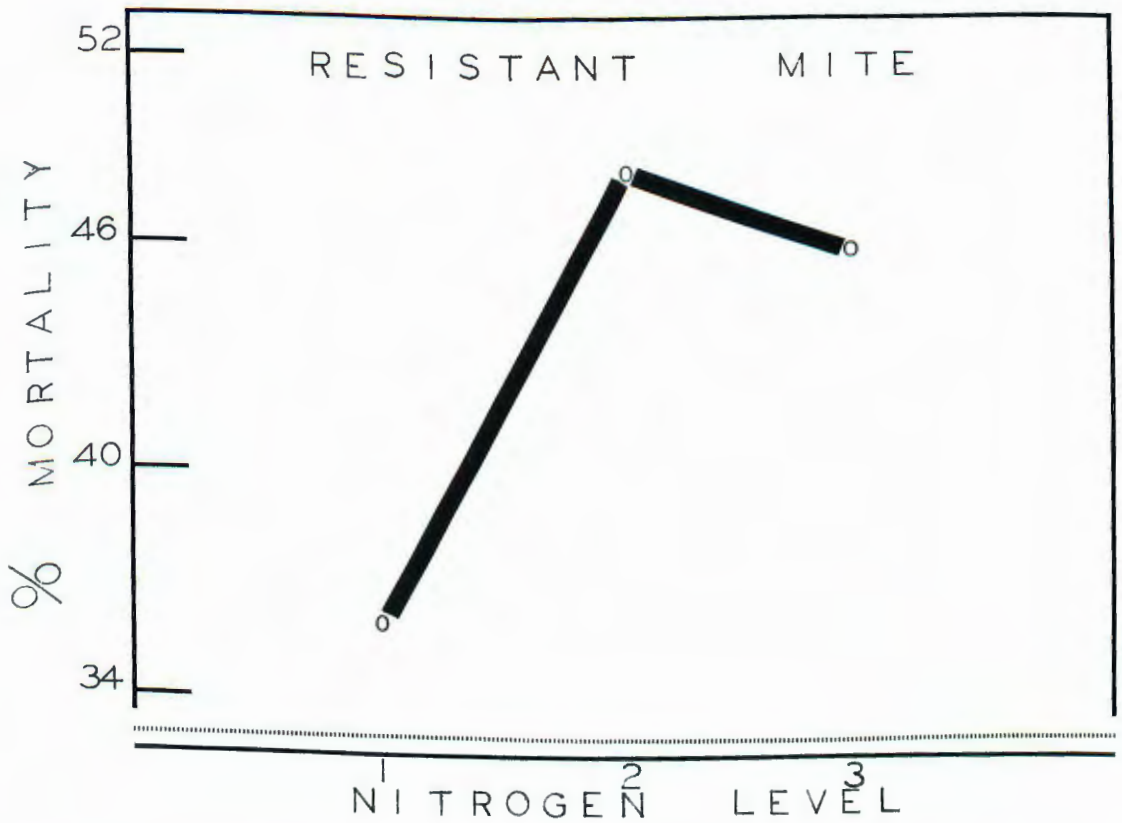

Fig. 6. Mortality of resistant spider mites on plants supplied low, intermediate and high levels of nitrogen. (Points shown are the means of the main effects of nitrogen in all combinations of phosphorus and potassium).

these nutrient solutions and the parent colony were determined. The LD 50's of the mites from the three sources are shown in Table 12.

Mites from plants supplied nutrient solutions were more susceptible to malathion than mites from the colony. Mites from plants supplied intermediate nitrogen, low phosphorus and high potassium were more susceptible to malathion than mites from plants supplied low nitrogen, intermediate phosphorus and potassium.

The median lethal dose of malathion to mites from the colony was approximately 2.2 times as great as the median lethal dose to mites cultured on plants supplied intermediate nitrogen, low phosphorus and high potassium and approximately 1.4 times as great to mites from plants supplied low nitrogen, intermediate phosphorus and potassium. The median lethal dose of malathion to mites from plants supplied low nitrogen, intermediate phosphorus and potassium was approximately 1.5 times as great as the median lethal dose to mites from plants supplied intermediate nitrogen, low phosphorus and high potassium.

Studies with the Non-Resistant Strain

The failure of the non-resistant strain to subsist on plants supplied the low nitrogen level has been discussed. The effects of treatments on susceptibility to malathion were not statistically significant. There was a tendency for increased mortality of mites from plants supplied intermediate phosphorus as compared to mites from plants supplied high phosphorus as compared to mites from plants supplied high phosphorus (See Appendix L and M).

To investigate further the effects of nitrogen, phosphorus and potassium on susceptibility to malathion of the non-resistant strain, it was necessary to increase the supply of plant nutrients. The experiment which follows was conducted in the same manner as previously

Table 12 Malathion lethal dose 50 of mites from the colony and plants supplied various nutrient treatments

Mite Source	LD 50 (ppm)
Non-resistant	
Colony	43
$N_I P_L K_L$	13
$N_I P_H K_L$	30
Resistant	
Colony	1015
$N_L P_I K_I$	718
$N_I P_L K_H$	474

described with the exception that the concentrations of nutrient ions supplied the experimental plants were those shown in Table 3.

As shown in Figure 7, mites from plants supplied the low level of phosphorus were more susceptible to malathion than mites from plants supplied intermediate or high phosphorus. Mites from plants supplied higher levels of nitrogen tended to be less susceptible to malathion while mites from plants supplied high potassium tended to be more susceptible to malathion.

The greatest response in susceptibility occurred when the phosphorus supply was varied with the intermediate level of nitrogen and low potassium.

Non-resistant mites were most susceptible to malathion on plants supplied intermediate nitrogen (196 ppm), low phosphorus (6.2 ppm) and low potassium (78 ppm). Mites of this strain were least susceptible to malathion on plants supplied intermediate nitrogen, high phosphorus (248 ppm) and low potassium.

The malathion dosage - mortality response of mites from plants supplied these nutrient solutions and the parent colony were determined. The LD 50's of the mites from the 3 sources are shown in Table 12.

Mites from plants supplied intermediate nitrogen (196 ppm), low potassium (78 ppm) and low (6.2 ppm) or high (248 ppm) phosphorus were more susceptible to malathion than mites from the parent colony. The median lethal dose of malathion to mites from the non-resistant colony was approximately 3.3 times as great as the median lethal dose of malathion to mites from plants supplied intermediate nitrogen, low phosphorus and potassium and 1.4 times as great as the median lethal dose

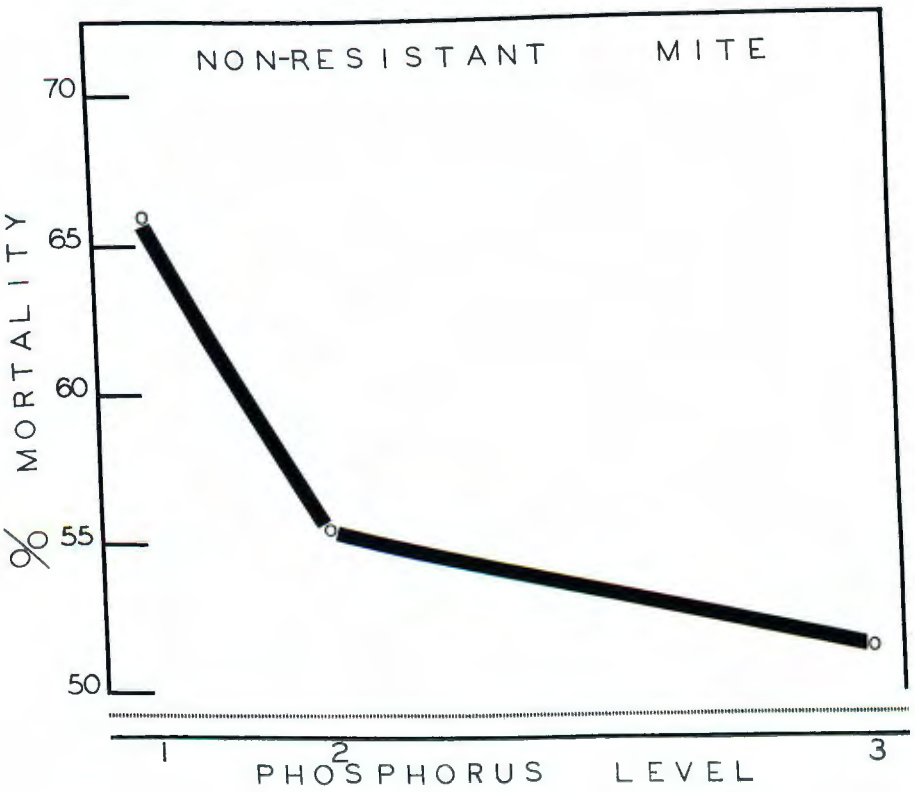

Fig. 7. Mortality of non-resistant mites from plants supplied low, intermediate and high phosphorus levels. (Points shown are means of phosphorus with all combinations of nitrogen and potassium.)

to mites from plants supplied intermediate nitrogen, high phosphorus and low potassium. The median lethal dose of malathion to mites from plants supplied intermediate nitrogen, high phosphorus and low potassium was approximately 2.3 times as great as the median lethal dose to mites from plants supplied intermediate nitrogen, low phosphorus and potassium.

DISCUSSION OF RESULTS

Two strains of two-spotted spider mite used as test organisms in the present study responded to changes in plant tissue induced through manipulation of inorganic mineral nutrient supply. The response was manifested in two ways, reproduction and susceptibility to malathion.

In general, both mite strains produced more progeny on plants with increased nitrogen supply and nitrogen absorption. The resistant mite produced more progeny as absorbed nitrogen increased to approximately 3.83% dry weight of the leaf tissue. On leaf tissue of approximately 5.54% nitrogen, there occurred a significant reduction in the number of progeny. In studies with the non-resistant mite, nitrogen absorption above 4.17% did not occur. In this case, no further increase in the number of progeny was observed at the highest level of nitrogen supply and absorption.

These findings agree in part with results reported by other investigators. Fritzsche (1957) reported increased reproduction of spider mites parallel with increases in the amount of leaf nitrogen. LeRoux (1954) reported increased fecundity of spider mites with increased nitrogen supply to cucumber host plants but no foliage analysis was made. Rodriguez (1951), using tomatoes as host plants with foliage ranging from 3.27% to 6.11% nitrogen, found that mite populations were negatively correlated to absorbed nitrogen. In a more recent study (1958), with apples as host plants, and foliage analyzing 2.35% to 3.14% nitrogen, he found mite populations positively correlated to the nitrogen content of leaf tissue.

These contradictory reports were explained on the basis of differences in ion absorption in the two host plants. Since mineral element supply affects the organic constituents of plant tissue, it may not be possible to explain results such as this solely on the basis of inorganic mineral element requirement of the insect or mite.

In the present study similar results were obtained under different circumstances in the same experiment. The failure to show an increase in reproductive rate or in some cases a depression of reproductive rate after certain levels of nitrogen in the leaf tissue are reached, may be a result of decreased total carbohydrate in the leaf tissue. This is shown in the present study. Sap from host plants is assumed to contain adequate supplies of free amino acids and amides for aphids. Secretions of honeydew contain considerable quantities of amino acids (Friend 1958). The supply of protein or amino acids in certain plant sap may also be adequate for mites. Additional amounts may be unnecessary, and some other factor such as carbohydrate becomes limiting. High nitrogen absorption in plants promotes rapid protein synthesis at the expense of carbohydrate utilization to account for the decrease in carbohydrate of plants in the present study.

The turgor pressure of the plant cell has been demonstrated to facilitate aphid feeding (Kennedy and Mittler 1953). Bondarenko (1949) found that increased application of fertilizer to greenhouse cucumbers resulted in increased osmotic concentration of the cell sap. This was associated with increased populations of Tetranychus urticae Koch [=telarius (L.)]. The changes in plant tissue induced by mineral element supply may provide more desirable nutrients and also facilitate mite feeding and the availability of these nutrients.

Other explanations may also account for increases in reproductive rate on the basis of availability of plant nutrients. Lutman (1934) reported on the effect of mineral element supply on cell size and structure of certain plant tissue. Deficiencies generally result in smaller cell size with obvious thickening of cell walls. Meyer and Anderson (1955) reported that when nitrogen is abundant relative to carbohydrate, plant cells are large, thin walled and rich in protoplasm. The relationship of these changes in cell morphology and physical resistance of the cell to penetration of mites and insects prior to feeding has not been investigated. Painter (1951) recognized the importance of this relationship in the development of plants resistant to insect attack.

A particularly striking feature of these experiments was the failure of non-resistant mites to subsist on plants low in nitrogen although resistant mites were able to subsist on such plants and produce relatively large populations.

Lehr and Smith (1957) have reported higher oviposition rate of the non-resistant mite as compared to the resistant mite. This higher oviposition rate may reflect a necessity for increased amounts of plant nutrients not required by the resistant mite.

Total leaf nitrogen is an expression of the amount of nitrogen present from various amino acids and protein constituents of the leaf tissue. In most insects proteins are essential for egg production but the housefly requires a source of sugar and water in addition to protein for the production of eggs (Wigglesworth 1950).

The phloem sap of the host plant has been shown to contribute the necessary nitrogen for aphid development. The total nitrogen

content of the honeydew of aphids has been found to be less than that of the phloem sap of the host plant. (Lipke and Fraenkel 1956). The results of the present study show that a source of carbohydrate and protein or amino acids in plant sap are beneficial to the production of eggs by spider mites.

Fecundity of both strains was correlated with the amount of carbohydrate present in the leaf tissue. Fritzsche (1957) reported increases of spider mites correlated with increased reducing sugar in the host plant. The need for carbohydrate in insects is non-specific; it generally serves as a convenient source of energy but is not required in some insects. The criteria for utilization of carbohydrate in insects generally appears to be whether it can be absorbed and metabolized or changed by digestive processes to a form which can be utilized or absorbed (Wigglesworth 1950, Trager 1953, Lipke and Fraenkel 1956, Friend 1958).

The voracious feeding by aphids has been explained on the basis of high protein requirement with the excretion of excess sugar as honeydew. In this case, protein requirement is assumed to be more important than carbohydrate. Evans (1938) supported this theory. More recently, Gray and Fraenkel (1954) reported that this may not always be the case. The honeydew of the citrus mealybug was found to be a digestive product and not merely an excess of carbohydrate and water.

The data of the present experiments show a close relationship between the amount of carbohydrate available and the increased number of progeny produced by mites. Carbohydrate obtained by mites while feeding may be an important factor in their metabolism.

Rodriguez (1953, 1954, 1958) has proposed the use of "detached leaf" culture in mite nutrition studies. By this method, leaves are

removed from the experimental plant, mites introduced to discs cut from the leaves and subsequent correlations of mite data to leaf analysis from comparable plant samples made. Drastic changes in carbohydrate content of detached leaf tissue may be an important factor to consider in this technique.

Increasing phosphorus supply resulted in an increase of the non-resistant strain. The resistant mites also reproduced at a more rapid rate on plants supplied the high phosphorus levels but the results were not statistically significant. With high levels of nitrogen, intermediate and high phosphorus levels influenced greater nitrogen absorption, which may account for the increase in the number of progeny. However, Rodriguez (1954) reported the utilization of large amounts of phosphorus in egg production by T. telarius.

Resistant mites produced more progeny on plants supplied high levels of potassium. The non-resistant mite produced fewer progeny on plants supplied high potassium, however, in studies with this strain, high potassium resulted in a marked depression of nitrogen absorption.

Resistant mites from plants supplied high nitrogen were more susceptible to malathion than mites from plants low in nitrogen. Non-resistant mites were most responsive to increased phosphorus supply but were less susceptible to malathion as phosphorus supply was increased. In either case mites from plants supplied the control nutrient solutions were more susceptible than mites of the respective parent colony. The effect of plant nutrition on susceptibility of mites and insects to insecticide application may help to explain frequently reported variation in effectiveness of insecticides. Related work concerning the effect of host plant nutrition on susceptibility of insects and mites to pesticides is lacking. However, some evidence is available that a

relationship exists.

Potter and Gillham (1957) found aphids more resistant to rotenone than aphids from broad bean. Boll weevil tolerance to toxaphene has been shown to increase 240 times late in the season as compared to early season susceptibility (Rainwater and Gaines 1951). Brazzel et al. (1957) in an attempt to explain this variation found the accumulation of fat in resistant and non-resistant boll weevils proceeded at the same rate. The authors concluded fat accumulation was not responsible for the resistance to chlorinated hydrocarbons by the boll weevil. Swingle (1939) found southern armyworm larvae more resistant to lead arsenate when they were fed on different host plants.

The results of the present study lend further support to the growing evidence of a relationship between the condition of the host plant and susceptibility to pesticides of the phytophagous-arthropod pest. This relationship may be an indirect one. The metabolism of the pest may be the contributing factor as a result of adverse nutritional needs. Hoskins and Gordon (1956) in a recent review recognized the heterogeneous nature of response to toxicants by insects. More than one condition or process is often involved. Tolerances to insecticides are determined by a great variety of factors. A developed strain through breeding individuals which have survived exposure to diverse stresses may have altered ability to withstand many kinds of stress. This is commonly called "vigor tolerance" which may augment or decrease normal tolerance to a toxicant. With spider mites, the condition of the host plant may induce such stress, accounting for the difference in tolerance to an acaracide.

The practical application of limiting mite and insect populations by manipulation of plant fertilizers has been discussed by Haseman (1950).

Practices of this type are limited, since economic feasibility and adverse effects to the growing condition of the plant must be considered of first importance. In most related work, as in the present study, depression of the arthropod population, parallel to economic control, is not attained without adverse effects on the growing condition of the plant.

CONCLUSIONS

Strains of the two-spotted spider mite produced more progeny when the inorganic nitrogen supply of lima bean host plants was increased. Populations of mites susceptible to malathion were more greatly depressed on plants low in nitrogen than were populations of resistant mites. Increased reproductive rate was correlated with absorbed nitrogen.

Populations of both mite strains increased with increases in total water-soluble carbohydrate.

Increased phosphorus supply resulted in increased progeny of the non-resistant strain. The resistant strain produced more progeny on plants supplied high potassium.

Phosphorus and potassium supply with certain combinations of nitrogen supply affected the soluble carbohydrate content of leaf tissue. High phosphorus levels with low or intermediate nitrogen resulted in decreased soluble carbohydrate content of the leaf tissue. Low nitrogen and potassium supply resulted in a decrease of total carbohydrate.

High potassium supply resulted in a marked depression of nitrogen absorption in one experiment. High phosphorus levels in one experiment resulted in increased nitrogen absorption.

Increased nitrogen supply affected susceptibility to malathion of the resistant strain. Susceptibility increased as nitrogen supply was increased.

Increased phosphorus supply affected susceptibility to malathion of the non-resistant strain. Susceptibility decreased as phosphorus supply was increased.

APPENDIX A

Resistant mites[1] per 5-leaf disc sample from plants supplied low, intermediate, and high levels of nitrogen, phosphorus and potassium in all combinations.

Treatment	Mites	Statistical Significance[2]
N_L		
P_LK_L	334	a b c
P_LK_L	409	a b c d
P_HK_L	252	a b
P_LK_I	451	b c d
P_IK_I	411	a b c d
P_HK_I	488	c d
P_LK_H	393	a b c d
P_LK_H	370	a b c d
P_HK_H	218	a
N_I		
P_LK_L	490	c d
P_IK_L	610	d e f g
P_HK_L	963	h i
P_LK_I	748	e f g h
P_IK_I	541	c d e
P_HK_I	734	e f g h
P_LK_H	787	f g h i
P_IK_H	971	h i
P_HK_H	829	g h i
N_H		
P_LK_L	918	h i
P_IK_L	538	c d e
P_HK_L	574	c d e f
P_LK_I	824	g h i
P_IK_I	918	h i
P_HK_I	547	c d e f
P_LK_H	784	f g h i
P_IK_H	995	i
P_HK_H	872	h i

1/ Mean of 4 replications.

2/ Means followed by a common letter are not significantly different at the 5% level.

APPENDIX B

Resistant mites[1] per 5-leaf disc sample from plants supplied combinations of low, intermediate, or high nitrogen, phosphorus and potassium.

Treatment	Progeny	Statistical Significance[2]
Nitrogen		
Low	185	a
Intermediate	371	b
High	372	b
Phosphorus		
Low	318	NS
Intermediate	320	NS
High	304	NS
Potassium		
Low	283	NS
Intermediate	314	NS
High	345	NS

1/ Mean of main effect of nitrogen, phosphorus and potassium factorially arranged treatments.

2/ Means followed by a common letter are not statistically significant at the 5% level.

APPENDIX C

Number of progeny of the resistant mite and analysis of plants supplied combinations of nitrogen, phosphorus and potassium.

Treatment	Progeny[1]		Per cent[1] Nitrogen		Micrograms[1] Carbohydrate	
N_L						
P_LK_L	34.9	abcd	2.49	a	49.5	abcd
P_IK_L	33.2	abc	2.63	a	45.2	abc
P_HK_L	27.4	a	3.28	abc	36.7	a
P_LK_H	39.6	abcde	2.90	ab	62.0	defgh
P_IK_H	40.3	abcde	2.88	ab	52,0	bcde
P_HK_H	38.5	abcde	3.32	abc	42.4	ab
N_I						
P_LK_L	36.6	abcd	3.83	abcd	79.7	i
P_IK_L	50.2	bcde	4.01	abcd	74.4	hi
P_HK_L	56.0	e	4.29	bcd	59.5	defg
P_LK_H	52.2	de	3.29	abc	72.8	hi
P_IK_H	39.6	abcde	3.75	abc	69.8	ghi
P_HK_H	45.9	abcde	3.82	abc	53.1	bcde
N_H						
P_LK_L	31.4	ab	5.40	ef	50.5	bcd
P_IK_L	33.8	abc	6.56	f	68.2	fghi
P_HK_L	33.0	abc	5.26	def	57.4	cdefg
P_LK_H	35.4	abcd	4.82	cde	55.2	bcdef
P_IK_H	42.8	abcde	6.17	ef	64.6	efgh
P_HK_H	53.6	e	6.23	ef	57.3	cdefg

1/ Mean of 4 replications.

2/ Means followed by a common letter are not significantly different at the 5% level.

APPENDIX D

Analysis of variance of deviations from regression of resistant mite progeny produced with per cent dry weight of nitrogen. (Resistant mite experiment)

Source	Degrees of Freedom	Sum of Squares	Mean Square	"F"
Mite Progeny to Nitrogen Absorbed	2	1614		
Linear Regression of Mite Progeny to Nitrogen Absorbed	1		2	
Deviation from Linear Regression	1		1612	11.76**

** Significant at 1% level.

APPENDIX E

Analysis of variance of leviation from linear regression of carbohydrate with nitrogen absorbed. (Resistant mite experiment)

Source	Degrees of Freedom	Sum of Squares	Mean Square	"F"
Carbohydrate to Nitrogen Absorbed	2	4928		
Linear Regression of Total Carbohydrate to Nitrogen Absorbed	1		668	
Deviation from Linear Regression	1		4261	62.62**

** Significant at 1% level.

APPENDIX F

Correlation coefficients(r) of mite progeny produced with per cent nitrogen, and total carbohydrate and total carbohydrate with per cent nitrogen

Source	Correlation Statistic (r) Resistant Strain	Nonresistant Strain
Progeny produced with % N	.0604	.4495**
Progeny produced with total CHO	.6273**	.4614**
Carbohydrate with %N	.1314	.4966**

** Significant at the 1% level.

APPENDIX G

Non-resistant mites[1] per 5-leaf disc sample from plants supplied low, intermediate or high nitrogen, phosphorus and potassium in all combinations

Treatment	Mites	Statistical Significance[2]
N_L		
P_LK_L	3	a
P_IK_L	0	a
P_HK_L	1	a
P_LK_I	1	a
P_IK_I	2	a
P_HK_I	11	a b
P_HK_I	9	a
P_IK_H	1	a
P_HK_H	23	a b c
N_I		
P_LK_L	320	a b c d
P_IK_L	393	a b c d
P_HK_L	509	d
P_LK_I	289	a b c d
P_IK_I	184	a b c d
P_HK_I	340	a b c d
P_LK_H	239	a b c d
P_IK_H	219	a b c d
P_HK_H	209	a b c d
N_H		
P_LK_L	492	b c d
P_IK_L	415	a b c d
P_HK_L	473	a b c d
P_LK_I	435	a b c d
P_IK_I	439	a b c d
P_HK_I	492	c d
P_LK_H	266	b c d
P_IK_H	377	a b c d
P_HK_H	379	a b c d

1/ Mean of 4 replications.

2/ Means followed by a common letter are not significantly different at the 5% level.

APPENDIX H

Number of progeny of the non-resistant mite and analysis of plants supplied combinations of nitrogen, phosphorus and potassium.

Treatment	Progeny[1]		Per cent[1] Nitrogen		Micrograms[1] Carbohydrate	
N_L						
P_LK_L	30.9	abcd	2.19	abc	56.5	efg
P_IK_L	25.0	ab	2.05	abc	53.3	fg
P_HK_L	32.3	abcde	2.38	abc	46.5	g
P_LK_H	19.1	a	2.19	ab	62.3	defg
P_IK_H	24.9	ab	1.78	ab	54.2	fg
P_HK_H	25.7	ab	1.68	a	48.5	g
N_I						
P_LK_L	26.8	ab	3.72	efg	89.7	ab
P_IK_L	53.9	f	3.04	cdef	87.3	abc
P_HK_L	45.9	bcde	2.67	abcd	85.0	abc
P_LK_H	34.5	bcde	3.60	def	81.5	abc
P_IK_H	35.6	bcde	2.27	abc	73.8	bcde
P_HK_H	36.4	bcde	2.80	bcde	70.7	cdef
N_H						
P_LK_L	29.9	abc	3.69	defg	55.8	fg
P_IK_L	43.8	cdef	5.04	h	94.8	a
P_HK_L	38.4	bcde	4.74	gh	73.2	bcde
P_LK_H	37.0	bcde	3.58	def	78.3	abcd
P_IK_H	39.1	bcde	3.96	fgh	81.5	abc
P_HK_H	46.3	ef	4.08	fgh	78.7	abcd

[1] Mean of 4 replications. Means followed by a common letter not significantly different, 5% level.

APPENDIX I

Per cent mortality[1/] of resistant mites from plants supplied low and intermediate levels each of nitrogen and/or phosphorus and/or potassium

Treatment	Experiment 1 Per cent Mortality	Experiment 2 Per cent Mortality
N_L		
P_LK_L	35.9 a	34.5 a
P_HK_L	36.4 a	54.5 b
P_LK_H	45.5 a b	59.2 b
P_LK_L	57.4 a b	57.9 b
N_I		
P_LK_L	59.3 a b	70.6 b
P_HK_L	57.9 b	55.0 b
P_LK_H	48.6 b	59.2 b
P_HK_H	51.9 b	64.1 b

1/ Mean of 4 replications. Means followed by a common letter are not significantly different at the 5% level.

APPENDIX J

Per cent mortality[1] of resistant mites from plants supplied low, intermediate and high levels of nitrogen, phosphorus and potassium in all combinations.

Treatment	Mortality	Statistical Significance[2]
N_L		
P_LK_L	35.7	a b c d
P_IK_L	33.0	a b
P_HK_L	31.2	a
P_LK_I	40.8	a b c d e
P_IK_I	30.7	a
P_HK_I	35.9	a b c d
P_LK_H	36.6	a b c d
P_IK_H	45.2	a b c d e f
P_HK_H	35.0	a b c
N_I		
P_LK_L	41.6	a b c d e f
P_IK_L	52.5	e f
P_HK_L	43.1	a b c d e f
P_LK_I	48.1	b c d e f
P_IK_I	52.8	e f
P_HK_I	43.9	a b c d e f
P_LK_H	56.4	f
P_IK_H	49.4	c d e f
P_HK_H	39.8	a b c d e
N_H		
P_LK_L	42.2	a b c d e f
P_IK_L	42.1	a b c d e f
P_HK_L	45.7	a b c d e f
P_LK_I	49.0	c d e f
P_IK_I	44.4	a b c d e f
P_HK_I	51.4	d e f
P_LK_H	48.7	b c d e f
P_IK_H	47.5	b c d e f
P_HK_H	40.3	a b c d e

1/ Mean of 6 replications

2/ Means followed by a common letter are not significantly different at 5% level

APPENDIX K

Malathion dosage-mortality data 1/ for mites of the resistant colony and mites from plants supplied nitrogen, phosphorus and potassium treatments.

Mite Source	Concentration (ppm) 5000	2500	1250	625	Mean
Colony	89.5 d	76.0 c	46.6 a	37.9 a	62.5
$N_L P_I K_I$	93.2 d	75.4 c	62.8 b	48.1 a	69.9
$N_I P_L K_H$	95.8 d	61.4 b	63.3 b	60.7 b	70.3

1/ Mean of 4 replications

Means with a common letter are not statistically significant at the 5% level.

APPENDIX L

Per cent mortality 1/ of non-resistant mites from plants supplied combinations of nitrogen, phosphorus and potassium

Phosphorus and Potassium	Nitrogen	
	Intermediate	High
P_LK_L	79.1	58.9
P_IK_L	63.5	57.5
P_HK_L	44.7	64.3
P_LK_I	55.0	60.9
P_IK_I	63.6	61.3
P_HK_I	61.7	54.7
P_LK_H	39.8	59.6
P_IK_H	67.6	60.4
P_HK_H	64.8	48.3

1/ Mean of 4 Replications

APPENDIX M

Per cent mortality 1/ of non-resistant mites from plants supplied intermediate and high levels of nitrogen, low, intermediate and high levels of phosphorus and potassium.

Phosphorus and Potassium	Nitrogen Intermediate	Nitrogen High	Mean
P_L	58	60	59
P_I	65	60	62
P_H	57	56	56
Mean	60	58	
K_L	62	60	61
K_I	60	59	60
K_H	57	56	57

1/ Mean of main effects of nitrogen, phosphorus and potassium factorially arranged treatments.

APPENDIX N

Per cent mortality[1] of non-resistant mites from plants supplied combinations of nitrogen, phosphorus and potassium.

Treatment	Mortality	Statistical Significance[2]
N_L		
$P_L K_L$	67.9	b c
$P_I K_L$	60.1	b c
$P_H K_L$	63.6	b c
$P_L K_H$	69.2	b c
$P_I K_H$	54.6	a b c
$P_H K_H$	60.7	b c
N_I		
$P_L K_L$	70.3	c
$P_I K_L$	43.6	a b
$P_H K_L$	30.5	a
$P_L K_H$	68.8	b c
$P_I K_H$	59.2	b c
$P_H K_H$	48.6	a b c
N_H		
$P_L K_L$	52.0	a b c
$P_I K_L$	55.3	b c
$P_H K_L$	48.0	a b c
$P_L K_H$	68.2	b c
$P_I K_H$	60.2	b c
$P_H K_H$	57.9	b c

1/ Mean of 4 replications.

2/ Means followed by a common letter are not statistically significant at the 5% level.

APPENDIX O

Per cent mortality of non-resistant mites from plants supplied nitrogen, phosphorus and potassium levels in all combinations

Treatment	%Mortality 1/	Statistical 2/ Significance
Nitrogen		
Low	63	NS
Intermediate	54	NS
High	57	NS
Phosphorus		
Low	66	a
Intermediate	56	b
High	52	b
Potassium		
Low	55	NS
High	61	NS

1/ Mean of main effects of nitrogen, phosphorus and potassium each, in all combinations.

2/ Means followed by a common letter are not significantly different at the 5% level.

APPENDIX P

Malathion dosage-mortality data 1/ for mites of the non-resistant colony and mites from plants supplied nitrogen, phosphorus and potassium treatments

Mite Source	Concentration (ppm) 50	33.3	22.2	14.8	9.9	6.2	Mean
Colony	69.7 i	36.2 ef	26.1 cde	16.9 abc	9.1 ab	6.3 a	27.3
$N_I P_L K_L$	57.3 ghi	56.0 ghi	61.9 hi	60.9 hi	54.2 ghi	23.3 bcde	52.4
$N_I P_H K_L$	69.7 i	51.8 gh	45.2 fg	31.9 def	18.3 abcd	19.3 abc	39.3

1/ Mean of 4 replications

Means with a common letter are not statistically significant at the 5% level.

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