SOME ASPECTS OF THE ECOLOGY OF THE CITRUS RED MITE, PANONYCHUS CITRI (McGREGOR), IN THE EASTERN CAPE PROVINCE.

by

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PREFACE.

This dissertation has been bound in two parts to facilitate reference to the Figures while the text is being read. The Tables and Plates have been bound in with the text as near as possible to the pages on which reference is first made to them.

TABLE OF CONTENTS.

		Page
1.	INTRODUCTION.	1
2.	THE SYSTEMATIC POSITION OF THE CITRUS RED MITE, PANONYCHUS CITRI (McGREGOR).	4
3.	THE DISTRIBUTION OF THE CITRUS RED MITE IN SOUTH AFRICA.	5
4.	THE ECONOMIC IMPORTANCE OF THE CITRUS RED MITE.	11
5.	LOCALITY, WEATHER AND CITRICULTURAL PRACTICES IN THE SUNDAYS RIVER VALLEY.	17
	a. Locality.	17
	b. Weather.	18
	1. Temperature.	18
	2. Relative humidity.	19
	3. Rainfall.	20
	c. Citricultural Practices.	23
	1. Organisation and Production.	23
	2. Entomological Practices.	24
	3. Weed Control.	25
	4. Fertilisation.	25
6.	THE LIFE CYCLE OF THE CITRUS RED MITE.	25
7.	SAMPLING TECHNIQUE.	35
	a. Choice of Sampling Method.	35
	b. The Accuracy of Sampling Techniques.	37
	c. The Determination of Leaf Sample Size.	42
	d. The Distribution of P.citri and the Predaceous mite, A.addoensis on a Citrus tree.	42
	e. The Sampling Method.	51
	f. The Sampling Error.	54
8.	THE DISTRIBUTION OF THE CITRUS RED MITE, P.CITRI, IN THE SUNDAYS RIVER VALLEY, AND ITS SEASONAL ABUNDANCE IN A CITRUS ORCHARD UNDER NATURAL CONTROL.	58
	a. The Distribution of P.citri in the Sundays River Valley.	58
	b. The Seasonal Abundance of the Citrus Red Mite under Natural Control in an Orchard in the Sundays River Valley.	60
	1. Experimental Design.	60
	2. The Seasonal Abundance of P.citri.	61
9.	EXPERIMENTAL STUDIES ON THE INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON THE DEVELOPMENT AND LIFE HISTORY OF THE CITRUS RED MITE.	66
	a. The Choice of a Substrate.	66
	b. The Effect of Different Substrates on the Life Cycle of the Citrus Red Mite.	69

		Page
	c. The Development of Unfertilised Eggs of *P.citri*.	73
	d. The Effect of Simulated Summer, Autumn and Winter conditions of Temperature and Relative Humidity on the Development of the Citrus Red Mite.	74
	e. The Effect of Constant Temperature and Relative Humidity on the Development of the Citrus Red Mite.	83
	f. The Variation in the Temperature of the Microclimate Surrounding the Leaf, and the Effect of High Temperature on the Seasonal Abundance of the Citrus Red Mite.	92
10.	OTHER FACTORS THAT MAY AFFECT THE SEASONAL ABUNDANCE AND POPULATION DENSITY OF THE CITRUS RED MITE.	109
11.	THE INFLUENCE OF THE PREDACEOUS MITE, *AMBLYSEIUS (TYPHLODROMALUS) ADDOENSIS* VAN DER MERWE AND RYKE, ON THE POPULATION DENSITY OF THE CITRUS RED MITE.	115
	a. The Feeding Habits of *A.addoensis*.	118
	b. The Efficiency of *A.addoensis* as a Predator of *P.citri*.	131
	c. The Influence of *A.addoensis* on the Population Density of *P.citri*.	135
12.	THE AFFECT OF RED SCALE INSECTICIDAL SPRAYS ON THE POPULATION DENSITY OF THE CITRUS RED MITE.	142
	a. The Experimental Design.	143
	b. The Unsprayed Control Treatment at "Ruimte".	145
	c. The Effect of Parathion on the Population Density of *P.citri*.	150
	d. The Effect of the Insecticides Trithion, Rogor and Gusathion on the Population Density of the Citrus Red Mite.	158
13.	DISCUSSION.	168
14.	SUMMARY.	181
15.	ACKNOWLEDGEMENTS.	186
16.	REFERENCES.	187
17.	APPENDIX 1.	199
18.	APPENDIX 2.	206

1.

INTRODUCTION.

The citrus red mite, Panonychus citri (McGregor), is a relatively new pest to South African citriculture, the first recorded injury to citrus trees was from Rustenberg, Transvaal in 1950 (Smith 1953).

In the U.S.A. the biology of this mite has been studied by Quayle (1938), Prendergast (1938), English and Turnipseed (1941), DeBach (1947), DeBach et al. (1950), Ebeling (1959) and Jeppson et al. (1957, 1961). However, in South Africa little information is available concerning the ecology of the citrus red mite. The majority of the literature pertaining to P.citri in the Republic, (Smith (1953), Mentz (1954), Stofberg (1959), Schwartz (1965) and Brodrick (1965)), is of a descriptive nature, and mainly concerned with the chemical control of the mite. The only biological investigation on the development of P.citri, and the effect of insecticides and insect predators on its biology, under South African conditions, was made by van Rooyen (1966) at Zebediela, Transvaal.

In the control of citrus pests, such as the citrus red mite, the need for a better understanding of their ecology has been well emphasised by DeBach (1951) and Griffiths (1951). DeBach (1951) in particular, stressed the danger of the continued reliance on insecticidal treatment as the only method of pest control, and has pointed out that persistent chemical applications may only serve to intensify the pest problem. He has suggested that a closer study of the environment of the pest species could provide a solution to the problems now encountered as a result of insecticidal control measures.

The scarcity of information on the influence of the environment of P.citri on its seasonal abundance in South Africa, led to this ecological study of the citrus red mite in the Sundays River Valley, a citrus producing area of the Eastern Cape Province (Figure 1). Four ecological factors, thought to be instrumental in determining the seasonal abundance and population density of P.citri, were selected for study. These factors were temperature, relative humidity, the predaceous mite, Amblyseius (Typhlodromalus) addoensis van der Merwe and Ryke 1964, and insecticidal treatments for the control of the California red scale, Aonidiella aurantii (Maskell).

In the study of P.citri under laboratory conditions, a number of preliminary experiments were conducted to determine the effect of substrate type on the development of the citrus red mite, and the production of males from unfertilised eggs.

The effect of temperature, relative humidity and A.addoensis on the population density of P.citri were investigated in laboratory experiments and an untreated orchard at "Imiti", Addo (Figure 2), and the results of these investigations were used to explain the seasonal abundance of the citrus red mite in the Sundays River Valley.

Only a single predator, A.addoensis was investigated in this study. It was considered that while the role of entomophagous insects on the population density of P.citri had been studied in some detail, both in South Africa and California, little had been done on the effect of predaceous mites. A.addoensis was commonly found on citrus trees in the Sundays River Valley, and as such I considered that this offered an ideal opportunity to study the effect of a predaceous mite on citrus red mite population density.

With the appearence of P.citri as a pest of citrus in South Africa in 1950, and the introduction of insecticides such as Parathion in the same year, there has been some speculation among citrus entomologists as to the effect of insecticidal sprays on citrus red mite and predator populations. In order to clarify this situation, the effect of several different red scale sprays, on field populations of P.citri and A.addoensis, was investigated in two chemical trials on the farms "Ruimte" and "Littlecote" in the Sunland area (Figure 2).

This study of P.citri which was carried out between March 1965 and March 1968, consisted therefore, of field trials and laboratory experiments on four ecological components in the environment of this mite pest, and their influence on its seasonal abundance and population density in the Eastern Cape.

2.

<u>THE SYSTEMATIC POSITION OF THE CITRUS RED MITE, PANONYCHUS CITRI (McGREGOR).</u>

Penthalodes mytilaspidis - Riley 1885

Tetranychus mytilaspidis - Ewing (nec Banks 1900) 1912

Tetranychus (Paratetranychus) citri - McGregor 1916

Paratetranychus citri - McGregor 1919

Panonychus mori - Yokoyama 1929

Metatetranychus citri (McG) - Pritchard and Baker 1955

Panonychus citri (McG) - Ehara 1956

In 1885 Riley (vide Quayle 1938) described a mite from oranges in Florida under the name *Penthalodes mytilaspidis*. Banks in 1900 (vide Quayle 1938) placed this species in the genus *Tetranychus*, and until 1916 it was known as *Tetranychus mytilaspidis*. McGregor (1916), on examining the classification to *T.mytilaspidis* concluded that Banks was not correct in assuming the citrus red mite to be identical with that described by Riley. Thus the citrus red mite was undescribed. McGregor consequently renamed the citrus red mite *Tetranychus (Paratetranychus) citri*. Later, McGregor (1919) placed the citrus red mite in the genus *Paratetranychus*.

Between the years 1916 and 1928, various workers considered *Paratetranychus citri* to be a synonym for the European red mite, *Paratetranychus pilosus* (Can. & Franz)(Boyce 1936) until McGregor and Newcomer (1928) showed these two mites to be two distinct species.

In a comprehensive revision of the Tetranychidae by Pritchard and Baker (1955), Paratetranychus citri was placed in the genus Metatetranychus.

Ehara (1956) recorded a number of Tetranychid mites infesting mulberry trees in Japan. One of the species was referred to in the literature as Panonychus mori (Kishida), but as Kishida had published no description of this mite, credit for the generic name was given to Yokoyama (1929, vide Ehara 1956). On examination of Yokoyama's syntypes by Ehara (1956) it was found that P.mori was a synonym of Metatetranychus citri (McG), Metatetranychus was therefore congeneric with Panonychus. Thus the correct and present taxonomic name for the citrus red mite is Panonychus citri (McGregor).

3.

THE DISTRIBUTION OF THE CITRUS RED MITE IN SOUTH AFRICA.

A map showing the world-wide distribution of the citrus red mite, P.citri, has been compiled by the Commonwealth Institute of Entomology (1964). From the information published in this map, P.citri has been found in citrus producing areas of Europe, Asia, Russia, Africa, Australasia, North-, South- and Central America, the West Indies and on many Pacific Islands.

The distribution of the citrus red mite in South Africa is shown in the following list of citrus growing areas in the Republic where P.citri is at present found. The year in which the mite was first observed in pest proportions is given in brackets.

TRANSVAAL : Western Transvaal - Rustenberg (1950)

Northern Transvaal - Zebediela (1950)

Letaba Estates(1952)

Eastern Transvaal - Nelspruit - Crocodile Valley (1953)

Nelspruit - Sub-tropical Research Institute (1953)

White River (1953)

Plastron (1953)

Carino (1953)

Curlewis (1953)

Mataffin (1953)

NATAL : Muden Estates (1951)

Nkwalini (1960)

CAPE PROVINCE: Eastern Cape - Gamtoos River Valley (1961)

Sundays River Valley (1961)

Western Cape - Citrusdal (1965).

The citrus red mite appears to be indigenous to the Orient, where it was confined to the coastal and sub-coastal areas (Ebeling 1959). This mite species was recorded from California in 1890, and at that time was reported to have been introduced from Florida (Quayle 1938).

The first specimens of P.citri found in the Republic of South Africa were collected by Mr. I.B. Kok at Zebediela in 1942 (Matthee 1966). At that time this mite was considered a rarity in citrus orchards, and of no economic importance to South African citriculture. In June 1950 red mite damage to citrus trees was first observed in an orchard at Rustenberg (Smith 1953), and in September of the same year, injury to citrus at Zebediela was reported. Within a few years of these findings, P.citri was reported to be present throughout the citrus areas of the Transvaal and Natal (Ryke and Meyer 1958).

In 1961, the first report of the citrus red mite in the Eastern Cape Province was received from the Gamtoos River Valley (Bredell 1967), and in the same year Meyer (1961) recorded the mite in the nearby Sundays River Valley (See Figure 1). Finally, in 1965 P.citri was found in several orchards in the citrus areas around Citrusdal, Western Cape Province (Whitnall 1967).

At present, one of the few citrus producing areas of the Eastern Cape from which the citrus red mite has not been reported is the Koonap-Kat River area (See Figure 1). This fact was confirmed in a citrus red mite survey of this region in June 1966.

Eight orchards were chosen in the Koonap-Kat River area, and from each orchard ten citrus trees, representative of the orchard, were selected haphazardly. From each tree, 20 mature leaves from the southern aspect were collected into plastic bags and stored in a chilled, insulated container until the samples could be microscopically examined, about 48 hours after collection.

No P.citri were found in any of the leaf samples collected, nor was there any evidence of past red mite infestations in the orchards surveyed.

Several trees which are related to Citrus occur in the indigenous bush of the Eastern Cape. These trees of the family Rutaceae, include Calodendrum capense, Fagara capaensis and Clausena anisata. A microscopic examination of the leaves of C.capense and *C.anisata*, collected from the indigenous bush surrounding a citrus farm outside Grahamstown, failed to show the presence of the citrus red mite.

The absence of *P.citri* in the Koonap-Kat River area, and on the two indigenous tree species related to *Citrus* in the Grahamstown area, raises the question as to whether the citrus red mite is indigenous to South Africa or an introduced pest species. In an attempt to answer this question, questionnaires were sent to Technical Officers in all the major citrus producing areas of the Republic with regard to the nature of the red mite outbreak in their particular area, and the occurrence of *P.citri* in the surrounding natural bush. In all cases it was reported that the red mite had not been observed on the local vegetation. All correspondents expressed the opinion that the citrus red mite was an introduced species, and that the use of organo-phosphate insecticides, such as Parathion, for the control of California red scale, had enhanced its pest status. However, in all but three cases, no suggestion was advanced to explain how the introduction could have taken place.

In the Sundays River Valley, the first report of *P.citri* was from the Government Research Station at Addo in May 1961 (Meyer 1961), where young citrus trees, obtained from Nelspruit, Transvaal, were found to be infested with the mite.

In the Gamtoos River Valley, the discovery of *P.citri* was coincident with the planting of young trees brought from the Nelspruit area (Bredell 1967).

Joubert (1967) suggested that the introd ction of the citrus red mite at Citrusdal, Western Cape, was probably caused by the use of contaminated second-hand citrus pockets purchased from areas in which the red mite was already present.

Dr. T.J. Naude, Chief of the Division of Entomology in 1924 was of the opinion that P.citri, although not indigenous, had been in the Republic for over 50 years. When taking a visitor from the U.S.A. on a tour of South African citrus producing areas soon after 1924, the American indicated to Dr. Naude several cases of mite damage to citrus trees, but the identity of the mite was not verified (Coates 1967).

From the survey of the Koonap-Kat River area, the absence of mites from leaves of two indigenous trees related to Citrus and from the opinions of people closely associated with the control of citrus pests throughout the Republic, three main points emerge concerning the possible origin of P.citri in South Africa:-

(a) It is unlikely that the citrus red mite is an indigenous species, and was probably introduced into South Africa at the turn of the century. Dr. Naude regarded it as unlikely that P.citri was imported after the passing of the Revised Plant Import Regulations in 1904, because of the provision for the fumigation of all imported citrus stock with high concentrations of HCN gas. He was of the opinion that the citrus red mite had been introduced into South Africa in the days when the Cape was a port of call for ships travelling to and from India.

(b) The spread of P.citri to nearly all citrus producing areas of South Africa appeared to be mainly due to the contamination of plant material moved from one district to another. However, the reason for the absence of the citrus red mite in the Koonap-Kat River area is unknown.

(c) The use of organo-phosphate insecticides on a vast scale for the control of insect pests of citrus, in particular the California red scale, and the limited use of chlorinated hydrocarbons such as DDT, for the control of bollworm, Heliothis armigera (Hübn.), have materially increased the pest potential of P.citri.

The citrus red mite, although an important pest of Citrus, is not specified to these plants, and has several alternative hosts. In the U.S.A., P.citri has been found to attack various species of broadleaved evergreen trees and shrubs (Prendergast 1938).

In Japan, Ehara (1956) reported collecting citrus red mite from mulberry trees.

The citrus red mite in South Africa has been collected from Cedrela toona (Meliaceae) and Hawthorn at Rustenberg, and Glycine javanica (Leguminosae) in Swaziland (Meyer 1966). I have also reared this mite over several generations on seedlings of three indigenous trees related to Citrus, namely Calodendrum capense, Fagara capensis and Clausena anisata.

Of the different varieties of Citrus grown in the Eastern Cape Province and attacked by P.citri, observations over several years indicate that the Navel and Valencia orange are most frequently attacked, while grapefruit and lemons are seldom injured.

4.

THE ECONOMIC IMPORTANCE OF THE CITRUS RED MITE.

The citrus red mite feeds on the fruit, leaves and green bark of citrus trees, but damage is most evident on the leaves and green fruit.

Kuenen (1949) and Blair (1951) both investigated the injury caused to apple leaves by the fruit tree red spider mite, Panonychus (=Metatetranychus) ulmi Koch. They found that in feeding on the lower surface of the leaf, the mite forced its stylets through the epidermis, through the spongy mesophyll and into a cell of the palisade tissue. Only the cell actually penetrated by the stylets was damaged. The feeding of the mite was found to result in the disappearence of the chloroplasts from the cell and depletion of the starch.

P.citri, in contrast to P.ulmi, feeds mainly on the upper surface of the citrus leaf. From a description of the feeding habits of the citrus red mite by Woodworth (1902, vide Prendergast 1938), a slit is made in the leaf surface into which the stylets are inserted. The leaf contents are then sucked up through a tube-like cavity between the palpi. The injury caused to a citrus leaf by P.citri is shown in Plates A and B.

From Plates A and B, the greatest amount of damage to a citrus leaf appears to be the withdrawal of the cell contents from the palisade tissue. The removal of the cell contents by the citrus red mite results in a silvery 'stippled' appearence of the leaves (Plate C), twigs and fruit, which is possibly

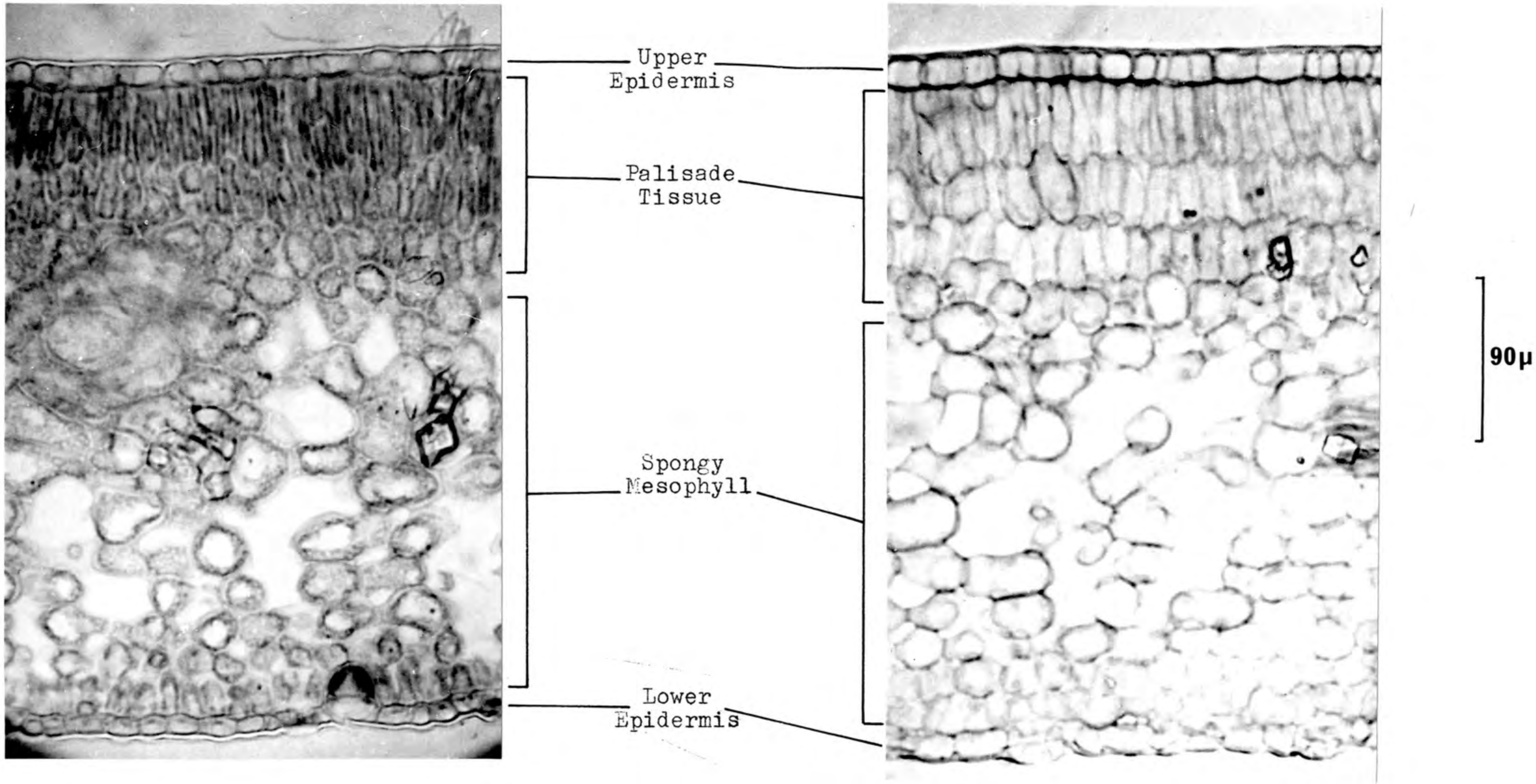

Plate A. A transverse section through a normal undamaged Washington Navel citrus leaf.

Plate B. A transverse section through a Washington Navel citrus leaf damaged by *P.citri*.

Plate C. The progressive leaf damage to the leaves of a Washington Navel citrus tree caused by the citrus red mite.

Plate D. The defoliation of a Washington Navel citrus tree and the resulting bare twigs with the leaf petioles attached to the twigs, caused by an infestation of citrus red mite.

due to the replacement of the cell contents with air. Severe infestations of P.citri may cause leaf drop resulting in bare twigs with the leaf petioles still attached to the twigs (Plate D).

The bare twigs generally die back as a result of leaf drop (Plates E and F).

Fruit which is damaged by the red mite while still green, will ripen and colour up normally. However, if the mite attack occurs after the fruit is mature, the markings are of a more permanent nature. Heavy infestations of citrus red mite before maturity may also cause considerable fruit fall.

Wedding, Riehl and Jeppson (1958) have measured the effect of P.citri damage on the various physiological processes of citrus plants. It was found that mite-damaged leaves had a significantly lower rate of photosynthesis than undamaged leaves. Further, the damaged leaves produced carbohydrates at a lower than normal leaves. The feeding of P.citri was found initially to produce a marked stimulation of transpiration, which reached a maximum on the second day after the mites were applied to the leaves. However, the rate of transpiration quickly declined until at the end of a week there was an appreciable inhibition of transpiration on the injured leaves. These severe alterations in transpiration are suggested by these authors as a possible cause of the leaf drop and twig die-back seen on P.citri infested trees.

Apart from the injury caused to citrus trees exposed to high populations of citrus red mite, little work has been done to evaluate the economic importance of P.citri damage. Smith (1953), Stofberg

Plate E. Defoliation and twig die-back of a Washington Navel citrus tree caused by the citrus red mite.

Plate F. Twig die-back on a Washington Navel citrus tree caused by the citrus red mite.

(1959) and Brodrick (1965) report that injury caused to citrus trees by P.citri might result in a light to poor crop in the following season, but this assumption has never been proved.

It has been shown by Ebeling (1950) that a citrus mite infestation affects the citrus trees making it more susceptible in injury from oil sprays. Ebeling (1959) states that economic losses are caused by the weakening of the fruit stem so that mature fruit falls more readily than if it were not infested, and in addition, red mite infestations can cause a reduction in fruit size.

Work by Roussel et al. (1951), Chapman et al. (1952), Unterstenhofer (1954) and van de Vrie (1956) has shown that spider mites on apples and cotton materially affect the crop yield. I conducted no investigation on the effect of P.citri on crop yield of infested citrus trees because this deviated from the main theme of this study, however, an attempt was made to determine the effect of a build-up of a large population density of citrus red mite on the defoliation of young citrus trees.

Three two year-old Washington Navel citrus trees budded on rough lemon root stock, and grown in the laboratory, were selected, and the leaves, twigs and stems of all three trees were cleaned manually with water and cotton wool. The leaves, twigs and stems were then examined with a handlens to ensure that they were free of P.citri. Twenty adult female P.citri were placed on the leaves of two of the three trees, the third tree, which was not infested served as the control. All three trees were kept in the laboratory and watered and fertilised regularly. At 14 day intervals, 20 leaves from each tree were chosen haphazardly, examined with a handlens, and the number of adult female red mites on the 20 leaves counted. Wind action was simulated by lightly shaking the trunk of each tree, and every fortnight a note was made of the number of leaves that had fallen from each of the three trees. No leaves were removed from the trees by hand.

A record was kept of the daily temperatures and relative humidity in the laboratory during the course of the experiment. Temperature was recorded by means of a maximum-minimum thermometer, and the relative humidity on an "Edney" paper hygrometer. The temperature and humidity readings were taken daily at 08.00 hours.

The results of this experiment are given in Table 1.

From the information in Table 1, it can be established that P.citri was absent from the control tree during the entire period of the experiment. There was a certain amount of leaf fall recorded from this tree between the 6th June to 17th July 1967, but this was considered to be natural leaf-fall.

On trees 2 and 3, which were infested with the red mite, the population density gradually increased between the 6th June and 25th September 1967, and was accompanied by a leaf drop of increasing severity. The mite population on Tree 2 appeared to increase faster, and to a greater density than on Tree 3, but the reason for this is not known. It was interesting to note that during the 14 days from the 1st to the 14th August, although there was an increase in the

TABLE 1.

The effect of P.citri on the defoliation of 2 year old Washington Navel citrus trees, grown in the laboratory, during the period 6th June 1967 to 25th August 1967.

	Tree 1 (Control)		Tree 2		Tree 3		Mean Temperature (°C)		Mean Relative Humidity
	Leaves Fallen	Female P.citri.	Leaves Fallen	Female P.citri	Leaves Fallen	Females P.citri	Max.	Min.	
6.6.67	0	0	0	0*	0	0*	-	-	-
6-19.6.67	10	0	10	11	5	7	-	-	-
20- 3.7.67	4	0	5	12	6	9	18	16	70
4-17.7.67	5	0	47	21	13	12	17	15	69
18-31.7.67	0	0	64	264	18	67	18	15	68
1-14.8.67	0	0	0	324	0	226	18	15	66
15-28.8.67	0	0	30	783	3	411	21	15	68
29-11.9.67	0	1	176	1144	412	894	22	17	69
12-25.9.67	0	0	143	-	132	-	22	18	69
	559**		10**		4**				
TOTAL	578		485		593				

* 20 adult female P.citri placed on the leaves.

** Total number of leaves remaining on the tree on 25.9.67

number of red mite on both infested trees, no leaf drop was recorded. The reason for this was unclear, but during this period it was observed that flush growth was produced by all three trees. It is suggested that some physiological factor, related to the production of the new growth, might have been responsible for the absence of leaf drop.

During the 112 days, 6th June to 25th September 1967, the two infested trees Tree 2 and 3, lost 98% and 99% of their leaves respectively. The control, however, lost only 3% of the total number of leaves on the tree. A visual impression of the effect of P.citri on the three test trees may be obtained from the photographs given in Plates G and H.

The red mite infestation and accompanying leaf damage was readily visible to the casual observer by the 31st July on Tree 2, and by the 14th August on Tree 3, between 56 and 70 days after P.citri was first applied.

While this investigation indicated the effect of the citrus red mite on young trees, it is my experience that in the Sundays River Valley, the more mature trees are less susceptable to large densities of red mite, and do not appear to be affected to any noticable degree by the defoliation resulting from high densities of P.citri. It must be emphasised, however, that despite the apparent resistance of older trees to the effects of P.citri, there is still no information to indicate the effect of red mite populations on crop yield. I consider, therefore, that until we know more about the exact economic importance of the citrus red mite, this species must be considered as a pest of young and old trees in the Sundays River Valley.

Plate G. The three Washington Navel experimental trees on the 6th June 1967, at the beginning of the investigation on the effect of citrus red mite populations on citrus tree defoliation. Tree 1 was the uninfested control tree and Trees 2 and 3 were each infested with 20 adult female *P.citri.*

Plate H. The three Washington Navel experimental trees on the 25th September 1967, at the end of the investigation on the effect of citrus red mite populations on citrus tree defoliation. Tree 1 was the uninfested control tree.

5.

LOCALITY, WEATHER AND CITRICULTURAL PRACTICES IN THE SUNDAYS RIVER VALLEY.

At the outset, it is necessary to describe, in brief, the climate and citriculture of the Sundays River Valley in which the majority of the research work was performed.

a. Locality.

The Sundays River Valley is the lower portion of the Sundays River, and extends from Korhaans Drift, where the river cuts through the Zuurberg range, down to about eight miles east of Barkly Bridge station (Figure 2).

The Valley, which is approximately 36 miles long and from ¼ to 4 miles wide, is situated 38 miles north of Port Elizabeth. The Valley lies at an altitude of between 20 and 300 feet above sea level, and comprises an area of 36,000 acres of irrigable land.

Geologically, the Sundays River Valley lies in the Uitenhage series (Van der Merwe 1926/27, Steyn 1946). The Uitenhage series was formed during the Cretaceous period and is subdivided into the following three beds:-

1. Sundays River Beds - bluish clay or shale and sandy limestone with marine fossils.

2. Variegated Marls and Wood Beds - soft yellow sandstone, shales and limestone with a few marine shells and numerous fossil plants.

3. Enon Conglomerate - sandstone, marls and conglomerates.

The Sundays River has cut its way through these beds, removed all the silty material and left behind waterworn rubble, stones and boulders. This waterworn rubble together with river stone rests on the Uitenhage series. On this rubble layer the river subsequently deposited sandy or silty material of loessic origin, and colluvial material from the Uitenhage series.

This fertile alluvial soil, makes possible the cultivation of high quality citrus fruit.

b. Weather.

The prevailing winds experienced in the Sundays River Valley are the cool south-easterly and the hot, dry north-westerly winds. The north-westerly wind in early Spring may cause extensive defoliation and fruit-fall as a result of its desiccating action. Further, the injury to citrus trees caused by citrus red mite infestations may be accentuated by this dry wind to such an extent that leaf-drop, twig die-back and fruit-fall may occur.

1. Temperature. The mean minimum and maximum temperatures registered at the Government Research Station, Addo, from January 1965 to December 1967, are presented in Table 2. These temperature records were obtained from a thermograph in a Stevenson screen at a height of four feet above the soil surface. The mean monthly and mean annual temperatures for this period are also shown in Table 2.

Table 2.

The mean monthly minimum (Min.) and maximum (Max.) temperatures, and the mean monthly (Mn.) and mean annual (Ma.) temperatures, in degrees Centigrade, at the Government Research Station, Addo, for the period January 1965 to December 1967.

	1965			1966			1967		
Month	Min.	Max.	Mn.	Min.	Max.	Mn.	Min.	Max.	Mn.
Jan.	16.5	28.9	22.7	17.2	28.7	23.0	16.7	29.7	23.3
Feb.	15.5	29.9	22.7	14.7	27.1	20.9	18.4	29.0	23.7
Mar.	14.5	27.9	21.2	16.4	30.1	23.3	15.8	28.6	22.2
Apr.	13.1	25.5	19.3	10.3	25.7	18.0	12.9	24.5	18.7
May	7.9	23.0	15.5	8.4	23.5	16.0	8.9	24.4	16.7
Jun.	4.2	20.4	12.3	5.8	23.5	14.7	6.3	20.7	13.5
Jul.	7.3	21.4	14.4	5.4	21.8	13.6	4.3	20.8	12.6
Aug.	7.5	22.8	15.2	8.1	21.1	14.6	5.6	24.3	15.0
Sept.	9.8	25.5	17.7	8.9	23.7	16.3	7.9	23.9	15.9
Oct.	10.9	24.5	17.2	10.9	25.1	18.0	11.2	25.8	18.5
Nov.	12.7	23.3	18.0	13.1	25.9	18.5	13.0	27.2	20.1
Dec.	11.6	27.2	19.4	16.3	28.1	22.2	14.2	28.4	21.3
		Ma. =18.0			Ma.= 18.3			Ma.= 18.5	

From Table 2 it is evident that in the Sundays River Valley, the summers are hot and the winters cool. Excessively high and low temperatures are not uncommon, and although frost may be experienced, frost damage to citrus trees is very infrequent.

2. Humidity. The average percentage relative humidity at 08.00 hours and 14.00 hours recorded at the Government Research Station, Addo, from January 1965 to December 1967, is given in Table 3. Relative humidity records were obtained from a wet and dry bulb thermometer in a Stevenson screen at a height of four feet above soil level.

Table 3.

The mean monthly relative humidity, recorded at 08.00 hours and 14.00 hours, at the Government Research Station, Addo, for the period January 1965 to December 1967.

	1965		1966		1967	
Month	08.00	14.00	08.00	14.00	08.00	14.00
Jan.	74	47	77	51	68	47
Feb.	76	44	74	52	81	51
Mar.	79	41	81	46	85	52
Apr.	83	49	89	47	85	57
May.	79	40	90	45	88	52
Jun.	90	41	86	43	90	52
Jul.	88	53	77	28	86	43
Aug.	89	49	91	45	88	43
Sept.	79	44	83	42	85	52
Oct.	77	49	70	42	75	48
Nov.	76	55	68	43	77	52
Dec.	64	42	70	44	69	49
Average	80	46	80	44	81	50

The percentage relative humidity, recorded at 08.00 hours was generally uniform throughout the year, but low relative humidities do occur during the months of November to January (Summer). However, this is not surprising because as relative humidity is related to temperature, the lowest relative humidities would be expected to occur during periods of highest temperature. The humidites recorded at 14.00 hours were on the whole, uniformly low. In all months, however, there was a marked difference between the relative humidity recorded at 08.00 hours and 14.00 hours.

3. Rainfall. Table 4 shows the total monthly and annual rainfall recorded at the Government Research Station, Addo, for the period January 1960 to December 1967.

Table 4.

The total monthly and annual rainfall, in inches recorded at the Government Research Station, Addo, for the period January 1960 to December 1967.

Month	1960	1961	1962	1963	1964	1965	1966	1967
Jan.	0.78	1.61	0.66	2.87	0.93	0.35	2.01	0.41
Feb.	0.21	1.92	1.48	1.14	1.39	0.39	0.39	0.41
Mar.	1.19	2.45	3.49	3.76	0.74	1.96	1.06	1.54
Apr.	1.64	0.48	2.55	3.25	1.76	1.44	0.88	2.15
May	0.69	1.97	0.35	1.35	0.01	2.33	0.63	6.07
Jun.	0.57	0.15	0.17	0.31	4.96	1.56	0.13	0.41
Jul.	0.54	0.52	0.12	1.08	0.19	2.50	0.32	1.08
Aug.	0.58	1.13	1.92	0.65	1.37	0.19	1.36	0.25
Sept.	1.27	0.08	0.28	0.05	3.36	1.36	0.83	0.98
Oct.	1.50	0.94	2.35	0.70	0.99	2.63	0.13	0.73
Nov.	1.02	0.91	1.14	1.28	0.59	4.68	1.99	1.07
Dec.	0.35	0.33	0.30	1.33	1.07	0.30	0.71	0.21
Total	10.34	12.49	14.81	17.77	17.36	19.69	10.44	15.31

Average annual rainfall (1934 - 1959) = 15.06 inches
Average annual rainfall (1960 - 1967) = 14.78 inches
Average annual rainfall (1934 - 1967) = 14.92 inches

In the Sundays River Valley heavy falls of rain may occur during any month of the year, and if the year is broadly divided into the six warm summer months, October to March, and six cool winter months, April to September, it is found that approximately equal amounts of rain fall during these two periods. Between 1960 and 1967 a total of 57.82 inches of rain fell between April and September, while 60.39 inches fell during the period October to February.

From the temperature and rainfall data presented in Tables 2 and 4, the climate of the Sundays River Valley could be classified as that of an arid (steppe) region or a BSha climate. This climatic classification, devised by Koppen (1918, 1931 and 1936, vide Schulze 1947) defines a BSha-type climate as a hot climate where the rainfall is more or less evenly distributed throughout the year, where the mean annual temperature exceeds 18°C (64.4°F) and the mean temperature of the warmest month is greater than 22°C (71.6°F). This climate-type of the Sundays River Valley, based on the information in Tables 2 and 4 is in agreement with the classification assigned to this area by Schulze (1947).

The production of citrus in the Sundays River Valley under these climatic conditions would be impossible if the annual rainfall were not supplemented. The annual rainfall is supplemented with irrigation water supplied to the Valley from Lake Mentz, a large reservoir on the Sundays River, by means of a series of irrigation canals.

In the Sundays River Valley approximately 32 inches of water are required per year to mature a normal crop under conditions of reasonably clean cultivation (Mathews 1944). Theron (1937) estimated that of the average annual rainfall of 15 inches, 8.5 inches was "effective rainfall" and reached the root zone of the citrus tree. From this estimation Theron calculated that the irrigation requirements of a citrus tree in the Sundays River Valley would be about 24 inches of water per year.

The preparation of the orchards for irrigation purposes consists of erecting a system of earth banks, which are designed to form "basins" between the trees. Irrigation water is lead into the basins from furrows situated between the rows of trees. This system, which is known as the basin method of irrigation, is the method most extensively used in the Sundays River Valley.

c. Citricultural Practices.

1. Organisation and Production. In South Africa the citrus industry is organised on a co-operative basis, and the majority of fruit produced is handled by the co-operatives who collectively constitute the South African Co-operative Citrus Exchange Limited. These co-operatives usually grade and pack their respective members fruit, and in accordance with the directions from the Citrus Board, despatch it to the coast for export.

In the Sundays River Valley most citrus farmers belong to the local citrus co-operative. Commercial plantings total approximately one million trees which consists of Navels, mid-season Valencia's, Valencia's, Grapefruit and Lemons. In general, the trees are planted in rows 20 feet apart, and rough lemon root stock is used exclusively because it is hardy and resistant to disease. Table 5 shows the number of citrus trees owned by farmers in the Valley according to a tree census of 1966, and the amount of fruit produced in 1967 (Fourie 1968).

Table 5.

The total number of citrus trees owned by farmers belonging to the Sundays River Citrus Co-operative in 1966, and the fruit yield for the 1967 season.

Variety of Citrus	Export (Half Cases)	Local (Pockets)	Total Number of Trees
Navels	1,200,626	555,244	446,528
Mid-season's	154,181	93,826	63,090
Valencia's	1,008,942	622,959	351,691
Grapefruit	549,905	384,658	202,365
Lemons	91,062	64,005	37,423
Total	3,004,716	1,720,692	1,101,097

Citrus is an evergreen tree which produces two major flushes of new growth annually, in the Spring (August-October), and late Summer (February). A number of minor flushes may occur of which the most important of these occur between April and May.

The normal fruiting habit of the orange tree is to produce a crop from the blossom that appears in the Spring. The crop produced from this Spring flush is called the in-season crop. This in-season crop ripens at different times of the year depending on the variety of citrus, in the case of Navels the crop is harvested from April to June, whereas the Valencia orange is picked from July to September.

2. Entomological Practices. In the Eastern Cape the insecticidal treatment of citrus trees centres around the control of the California red scale, A.aurantii. Usually only one spray treatment is applied per season, but the presence of other insect and mite pests may necessitate the application of additional control measures. A comprehensive pest control treatment may therefore consist of the following insecticidal sprays.

a. 0.075% Parathion + 0.2% Spray oil during October to December against the California red scale, (Aonidiella aurantii (Mask.)), the citrus thrips, (Scirtothrips aurantii (Faure)), and the citrus aphid, (Toxoptera citricidus (Kirk.)).

b. 0.6% Spray oil from January onwards, for the control of the soft brown scale, (Coccus hesperidum (L.)).

c. 0.053% Kelthane from September to November, and March to May against the citrus red mite, P.citri. A similar treatment may be applied for the control of the two-spotted spider mite, (Tetranychus telarius (L.)), from December onwards.

d. 6 - 12 oz. Thiodan 5% dust per tree during September to October, for the control of boll-worm, (Heliothis armigera (Hübn.)).

3. Weed Control. Weed competition for nutrients and moisture has a deleterious effect on citrus trees, therefore it is essential for the farmer to keep his orchard free from weeds throughout the year. Three main methods of weed control are practiced in the Sundays River Valley, mechanical cultivation, chemical control and hand-hoeing, but of these, mechanical cultivation is most generally employed.

4. Fertilisation. The alluvial soils of the Sundays River Valley are, in the main, very fertile, and even with the cultivation of citrus over many years nitrogen is the only nutrient element that requires regular supplementation. When required, trace elements such as zinc, copper, magnesium and molybdenum are applied, usually in the form of a folio-spray.

6.

THE LIFE CYCLE OF THE CITRUS RED MITE.

The eggs of *P.citri* are distinct from the eggs of other mites found on citrus trees because it has a vertical stalk from the tip of which ten to twelve guy-fibrils radiate to the surface on which the egg is attached. The bright red eggs of the citrus red mite are spherical in shape, and are laid on the leaves, fruit and twigs of the citrus tree. On the citrus leaf the majority of eggs are laid on the upper surface close to the mid-vein.

Ebeling (1959) described the life cycle of P.citri, and his description agrees with my observations. The activity of the larva about to emerge, causes the egg to split along its equatorial axis, the upper portion of the eggshell being pushed back. After the larva has emerged, the upper half of the egg springs back into place and the egg resumes its normal shape but for the absence of the embryo, which is indicated by a translucent appearance of the egg.

The first instar is called the "larva", and as in all the Acarina, with the exception of the Eriophyids, possesses only three pairs of legs. At the end of the larval instar, the larva moults to the "protonymphal" stage, and acquires its fourth pair of legs.

The protonymph moults to the "deutonymph" stage which in turn gives riso to the adult males and females.

The metamorphosis of the nymphal stages occurs during periods of inactivity, at which time the mite anchors itself to the substrate and assumes a characteristic pose. The legs are held close to the body and a new cuticle is laid down before the exuvia is cast. During this period the young protonymph is called a "protochrysalis", the deutonymph a "deutochrysalis", and the adult a "teliochrysalis". It is not known whether during these 'chrysalis' stages there is any increase in somatic cell number. No mitotic cells have been found in any stage beyond that of the larva (Schrader 1923, vide Boudreaux 1963) and the suggestion is that all the somatic cells are formed in the larval instar. Any increase in size of the mites is as a result of cell size increase (Boudreaux 1963).

The adult female is distinctly red in colour and oval in shape. Large white setae arise from prominent tubercles on the back and sides of the mite. These distinctive characters together with the stalk and fibrils of the egg make identification of this species a relatively simple matter (Meyer 1964).

A mite commonly found in the Sundays River Valley on orchards windbreaks of Grevillea robusta (Proteaceae), is the mite, Oligonychus coffeae (Nietner). This mite, which I have observed on citrus trees in the Valley, could easily be confused with P.citri, especially at low magnifications. However, the lack of guy-fibrils from the dorsal egg stalk, and the absence of tubercles on the dorsal surface of the adults distinguish it from the citrus red mite.

The female red mite is fertilised immediately after moulting from the teliochrysalis stage, and egg laying starts shortly afterwards. Rodriguez (1954) has shown that the uptake of radioactive phosphorus from plants by laying females of Tetranychus telarius (L.) is high, and is correlated with the process of egg laying. Much of the ingested phosphorus became deposited in the eggs, which indicated that an intensification of feeding occurs during oviposition. Observations made by Boudreaux (1958), on the culture of several species of Tetranychus in the laboratory, confirmed this high rate of feeding during the oviposition period originally observed by Rodriguez

(1954). I have noted that little damage is caused to the substrate by the immature stages of P.citri, but that after the emergence of the mature females, extensive injury is soon apparent. In contrast, when only males are produced in cultures from virgin P.citri females, little damage was caused to the substrate.

The male of the citrus red mite is smaller than the female, and the abdomen narrows posteriorly. Males are usually found in association with the female teliochrysalis, which the males detect by contact (Boudreaux 1963). The male remains alongside the teliochrysalis until the exuvia is cast off. Boudreaux (1963) states that the shedding of the exuvia is often aided by the male pulling it off from the posterior end of the female, but I have not noticed this in P.citri.

On the mating behaviour of the citrus red mite, I have observed the male to crawl, head first, under the posterior end of the newly emerged female and arch the end of its abdomen upwards to achieve copulation. During the act of copulation the female red mite is held with the two pairs of forelimbs of the male.

The sizes of the various stages occurring in the life cycle of P.citri are given in Table 6, and and are compared with similar measurements quoted by van Rooyen (1966) and Ebeling (1959).

Table 6.

A comparison of the egg diameter and body lengths, in millimeters, of the stages occurring in the life cycle of P.citri, as measured by the author, van Rooyen (1966) and Ebeling (1959). The figure in brackets indicates the total number of stages measured.

	Author		Van Rooyen (1966)		Ebeling (1959)
	Range	Mean	Range	Mean	Range or Mean
Egg	0.10-0.18 (100)	0.13	0.14-0.17 (100)	0.15	Mean 0.13
Larva	0.12-0.20 (100)	0.16	0.14-0.17 (50)	0.15	Mean 0.20
Protonymph	0.18-0.23 (100)	0.22	0.20-0.30 (50)	0.23	Range 0.20-0.25
Deutonymph	0.25-0.30 (100)	0.27	0.18-0.38 (100)	0.30	Range 0.25-0.30
Female	0.32-0.40 (100)	0.36	0.37-0.46 (50)	0.41	Range 0.32-0.37
Male	0.25-0.33 (100)	0.28	0.20-0.42 (50)	0.29	-

From the information in Table 6, the measurements of the egg and active stages of P.citri as measured by the author, van Rooyen (1966) and Ebeling (1959) agree closely, especially if any possible size variation in the sample, that might be caused by such factors as diet and genetics, is taken into account.

It is well established that the male tetranychids undergo the usual sequence of instars during development, as do the females, but Shinakji (1959) has found that in the citrus red mite some males may omit the deutonymphal instar.

Since 1897 (Perkins, vide Boudreaux 1963), arrhenotoky has been known to occur among tetranychid mites, and since then it has been noted by Schrader

(1923, vide Boudreaux 1963) and Rodriguez (1954). In *P.citri*, virgin females produce eggs which hatch into males only. Mated females, however, produce offspring of both sexes. It is assumed, from circumstantial evidence, that the chromosome number of the males is haploid, (Schrader 1923, vide Boudreaux 1963), while genetic experiments on the transmission of resistance between different strains of two-spotted spider mites, by Taylor and Smith (1956), tend to confirm this assumption.

Davis (1961), and other workers have referred to the sex ratio of tetranychid mites as if it were 1:1, but in observing *P.citri* in the laboratory and in the field, it is apparent that this sex ratio does not exist. Boudreaux (1963) states that it is just as normal for a virgin female to produce only males, as it is for an occasional mated female to produce no males at all. He suggests that the sex ratio produced by any female is dependent upon the amount of spermatozoa introduced during the mating act, which in turn depends on the length of time spent in copula, and the sperm supply of the male. Boudreaux found that when males were allowed to mate with up to eleven females in quick succession, the first mated females always produced a preponderence of females, while the last matings produced mostly males. Boudreaux (1963) suggested that in crosses between *Tetranychus telarius* and *T.lobosus*, the mating act resulted in the establishment of some unknown factor which prevented further effective insemination of the females. It is difficult, however, to understand what form this "unknown factor" might take. Helle (1967) has shown that in the two-spotted spider mite, Tetranychus urticae (Koch), fertilisation of the oocytes occurs at a very early stage of egg development, and suggests that fertilisation takes place in the ovary and not in the oviduct. Using genetic markers, Helle has demonstrated that in most cases the first mating is effective, while later matings are usually ineffective. However, he suggests that in such cases where later matings are successful, the sperm supply from the first matings was insufficient to fertilise all eggs.

The adults and immature stages of P.citri are small, ranging from 0.10 mm to 0.40 mm in length, and as a résult it is highly unlikely that these forms could distribute themselves over any appreciable distance by locomotion, as suggested by Ewing (1914) and McGregor and McDonough (1917) An indication that threads of silk were used as "parachutes" to move from one area to another, arose from the observation by Ebeling (1934) that individuals of P.citri lowered themselves on such threads from their host plant. This behaviour has been confirmed in my own work, where citrus red mites were found to lower themselves on threads from one leaf to another on several heavily infested young citrus trees grown in the laboratory. Actual observations that such dispersal takes place in P.citri was reported by Fleschner et al. (1956). These authors, together with Gilliat (1935) and Marle (1951), have shown that a number of tetranychid mites, including the citrus red mite, may disperse against prevailing daytime wind. This was explained by the observation that the spinning of the "Parachute" threads usually took place during a gentle breeze at dusk, which generally blew in an opposite direction to the prevailing wind. It is suggested by Fleschner et al. (1956), that the dispersal of the citrus red mite in this way is probably associated with the depletion of the food supply of the host plant.

The fact that wind is the main agent of dispersal, particularly from tree to tree within an orchard, was also found in the Sundays River Valley. One foot Polythene squares, were coated with an adhesive "Ostico", and placed on each side of a rectangular block of nine citrus trees, which were an average height of twelve feet, and heavily infested with P.citri. On each side of the block of nine trees, the sides of which corresponded to one of the four cardinal points of the compass, adhesive squares were situated at three feet, five feet and seven feet above ground level, and approximately three feet from the tree, with the adhesive coating directed inwards towards the trees. The adhesive squares were removed and microscopically examined twice during the period 6th September to 16th September 1966, and the number of P.citri caught at each height level recorded. After the removal of the adhesive squares, they were immediately replaced with freshly coated ones. The number of immature and female citrus red mites caught on these adhesive squares during September 1966 are given in Table 7.

Table 7.

The number of immature stages (I), and female stages (F) of P.citri caught on adhesive polythene squares placed at different height levels around a block of nine heavily infested citrus trees, from the 6th to the 16th September 1966.

Period	Level	North		South		East		West		Total	
		I	F	I	F	I	F	I	F	I	F
6th-10th Sept.	7 ft.	1	0	2	0	2	0	21	1	26	1
	5 ft.	2	0	2	0	0	0	19	1	23	1
	3 ft.	2	0	2	0	0	0	22	0	26	0
11th-16th Sept.	7 ft.	2	0	2	0	2	0	6	2	12	2
	5 ft.	0	2	1	0	0	1	6	0	7	3
	3 ft.	4	0	4	0	1	0	2	0	11	0

From the information in Table 7, the majority of red mites were caught by the adhesive squares on the western side of the block, which was related to the prevailing wind. Records of wind direction and wind velocity for the period 6th to 16th September 1966, given in Table 8, were obtained from the Government Station, Addo, which was situated about one mile from the orchard in which this experiment was carried out.

Table 8.

The wind direction and duration, in hours, and the wind velocity, in meters per hour, for the period 6th to 16th September 1966 as obtained from the Government Research Station, Addo.

Wind Direction and Duration.

	Date	East	North East	North	North west	West	South West	South	South East	Calm	Wind Velocity
	6	–	9	4	–	4	–	3	–	4	3750
	7	–	–	–	–	–	5	10	–	9	5542
	8	–	–	–	–	–	–	13	9	2	5417
	9	–	15	–	–	–	–	8	–	1	5500
	10	–	–	6	–	–	14	–	4	–	7708
SEPTEMBER	11	–	–	2	1	–	–	4	9	8	5583
	12	–	–	6	–	–	–	8	2	8	3458
	13	–	–	7	–	–	10	–	–	7	6625
	14	2	–	2	–	–	9	1	1	9	6250
	15	–	–	8	–	11	–	–	–	5	4917
	16	–	–	3	–	6	7	4	–	4	5583
	Total	2	24	38	1	21	45	51	25	57	

From Table 8, it is evident that the prevailing wind during the period 6th to 16th September 1966 blew from a South to South-westerly direction. If P.citri was dispersed by the prevailing wind, the greatest numbers of citrus red mite caught on the adhesive squares would be expected to occur on the East of the tree block. This was not the case (Table 7), the majority of P.citri caught were recorded from the adhesive trap to the West. These data indicated that the distribution of the citrus red mite in the Sundays River Valley was largely against the direction of the prevailing wind, as suggested by Fleschner et al.(1956) in the U.S.A.

From Table 7, there appeared to be no difference in the number of P.citri caught at the different height levels, but it was interesting to note that the majority of mites trapped on the adhesive squares were the immature forms.

It is also possible that insects and birds may also act as an incidental means of dispersal, as was suggested for Eriophyid mites by Batchelor (1952).

7.

SAMPLING TECHNIQUE.

a. Choice of Sampling Method.

The most simple method of estimating mite populations is to count all the mites on a sample of leaves with the aid of a low power microscope. However, this method becomes tedious and impractical when large mite populations are encountered. Various techniques, reported in the literature, have been suggested for speeding up the process of estimation without losing the accuracy of the microscope method.

Several direct methods for assessing mite populations have been devised. Hoskins, Boyce and Lamiman (1938) marked five selected areas on a leaf by means of a circular rubber stamp, and counted the number of mites in each area. Baten and Hutson (1943) used a similar method, but instead of marking the leaf off into areas, they inserted the leaf between two halves of a folded piece of cardboard, each half of the cardboard having an opening of one inch square. The mites were then counted in these areas with the aid of a hand-lens. Both these methods are applicable to low populations of readily visible mites, but are impracticable for large populations unless the mites are immobilised.

Apart from the above direct methods of estimating mite density, there are several indirect methods. One method is that devised by Venables and Dennys (1941), and commonly known as the "paper impression" method. Briefly this technique consists of placing leaves between the halves of a folded sheet of absorbent paper, and passing it through the rollers of a wringer. The mites and eggs are crushed, and leave identifiable stains on the paper.

Jones and Prendergast (1937) suggested the removal of mites from leaves in the following manner. The leaves and fruit area were stored in 5% formalin and later transfered to a 0.25% solution of hot potassium hydroxide to remove the eggs. The plant material was then removed and the solution made up to a specific volume. The mites and eggs were maintained in a uniform suspension by agitation, an aliquot drawn off, and the mites counted with the aid of a low power microscope. The disadvantage of this method is that, besides being slow when large populations are encountered, it is also complex, and as a standard technique has little to recommend it over the purely visual method of counting under a microscope.

A third indirect method is that developed by Summers and Baker (1952), and improved by Boudreaux (1953). It consists of beating twigs and foliage over a collecting rack. This method is unsatisfactory for estimating mite density on trees in orchards because of the possibility of causing damage to the trees.

A method developed by Henderson and McBurnie (1943) utilises the mite brushing machine. In brief, the apparatus consists of an electric motor which powers two contra-rotating brushes between which the leaf is inserted and withdrawn. An adhesive-coated disc is situated below the brushes on which the mites brushed off the leaf are collected.

Of all the methods described, apart from the visual microscope method of counting mites, only the paper impression and mite brushing machine were thought to be the most suitable, because they were simple, practical and rapid. As a result, the efficiency of these two methods were compared against the visual method, as techniques for assessing the density of P.citri populations.

b. The Accuracy of Sampling Techniques.

Initially, the paper impression and microscope methods were examined to compare the accuracy of these two techniques on citrus trees with high and low populations of P.citri. Two Washington Navel citrus trees with the required mite densities were selected, and from each tree two lots of 120 leaves were gathered from all aspects and heights of each tree. One of the two samples from the low population density tree, and the other from the high population density tree were examined under a microscope. The remaining samples were processed in the orchard by the paper imprint method, and the mite squashes were examined under a low power microscope in the laboratory. The results of this investigation are given in Table 9.

Table 9.

The results in estimating the accuracy of the paper impression method and the microscope method on two Washington Navel citrus trees having a high and low population density of P.citri.

High Population Density Tree.

Microscope Method			Paper Impression Method.	
Eggs	4063	5111	Eggs and Immature Stages	4944
Immature Stages	1048			
Females	482	610	Females and Males	639
Males	128			
Total	5721			5583

(Chi-squared=1.68; df=1)

Low Population Density Tree.

Microscope Method			Paper Impression Method.	
Eggs	107	114	Eggs and Immature Stages	105
Immature Stages	7			
Females	3	3	Females and Males	3
Males	0			
Total	117			108

(Chi-squared=0.10; df=1)

An analysis of the information in Table 9 by means of the 2 x 2 Contingency Test indicated that the microscope method of estimating P.citri was not significantly different from the paper impression technique at the 5% level of significence.

A further experiment was performed to test the microscope, paper impression and mite brushing machine method of assessing citrus red mite populations on a number of citrus trees in an orchard. Then trees were selected at random from an orchard, and from the southern aspect of each tree, sixty mature leaves were picked in the following manner. From one leaf-bearing twig, taken indiscriminately, three successive leaves were collected. One leaf was examined microscopically the second processed by the paper impression method, and the third leaf brushed with the mite brushing machine. This was repeated 20 times for each of the ten trees. The results of this experiment are given in Table 10.

Table 10.

The results obtained by estimating the citrus red mite population density on ten trees, selected at random, using the microscopic, paper impression and mite brushing machine techniques. (20 leaves per sample).

Tree No.	Microscope Method				Paper Impression Method		Brush Machine			
	E	I	F	M	E + I	M + F	E	I	F	M
1	435	139	23	10	523	42	164	146	20	6
2	63	7	0	0	40	0	10	3	0	0
3	94	15	2	0	66	3	16	10	0	0
4	233	42	3	1	227	8	38	34	3	1
5	84	17	2	0	61	4	32	12	3	0
6	67	19	3	0	50	2	17	15	2	1
7	32	10	0	0	21	0	15	8	0	0
8	204	79	12	2	239	12	53	74	12	1
9	32	3	0	0	17	0	14	5	0	0
10	28	8	1	0	28	1	11	8	0	0
Total	1272	339	46	13	1272	72	370	315	40	9

E = Eggs of <u>P.citri</u>. F = Females of <u>P.citri</u>.
I = Immature stages of <u>P.citri</u>. M = Males of <u>P.citri</u>.

An analysis of the information in Table 10, by means of the Wilcoxon matched-pairs signed rank test, indicated that the numbers of males and females recorded by each method were not significantly different at the 5% level. However, the total number of eggs and immature stages were significantly different.

The discrepancy in the number of eggs and immature stages recorded by the brush machine and microscope techniques was found to be due to the inability of the brush machine to remove all these stages of P.citri adhering to the leaf surface. In some cases examination showed that the brush machine removed less than half the total number of eggs present.

A microscopic examination of the leaves processed with the paper impression method showed that only few eggs and immature stages of P.citri were not crushed and recorded as stains on the absorbent paper. Thus, the reason for the significant difference between the number of eggs and immature stages of the citrus red mite recorded by the microscope and paper impression method remained unexplained. It was therefore decided to examine the accuracy of the paper impression method in greater detail.

The accuracy of the paper impression method in estimating mite populations was established by first placing a known number of adult and egg stages of P.citri on citrus leaves, counting them under a low power microscope and then crushing them by the imprint method. The numbers of adults and eggs used in this determination were, on the average, comparable to the density of these stages of P.citri found on a single leaf in the field. The results of this experiment are given in Table 11.

Table 11.

An estimation of the accuracy of the paper impression method, using adult and egg states of P.citri.

ADULTS		EGGS	
Actual number of adult P.citri on leaf surface (Counted under microscope.	Number of P.citri adults recorded by the paper impression method.	Actual number of P.citri eggs on leaf surface (Counted under microscope).	Number of P.citri eggs recorded by the paper impression method.
1	1	9	9
4	3	50	48
5	5	20	18
3	3	30	27
2	2	6	6
6	5	55	51
7	7	36	36
8	7	16	13
9	8	27	24
10	9	13	10
6	6	9	8
Total 61	56	271	250

From Table 11, there is a difference of 8% between the total number of P.citri initially counted under the microscope and the number later recorded by the paper impression method. These results indicate that the variation in the numbers of individuals observed in Tables 9 and 10, between the paper impression method and the microscope method, was not due to the failure of these two techniques to record the number of red mite on a leaf, but rather to the variation of P.citri between individual leaves. Further, identifiable stains left on the paper by P.citri crushed in the field, were distinct from those of other fauna found to occur on citrus leaves, and were identical to the stains produced when different stages of the citrus red mite were squashed in the laboratory.

In the light of the results of this comparison of methods, the paper impression technique was used in survey work only when the total number of citrus red mite in all stages was required. In the ecological investigations, however, where the number of different life stages of *P.citri* were required, the microscope method of estimation was used.

c. The Determination of Leaf Sample Size.

It is obvious that to obtain a figure for the total number of all stages of *P.citri* on a citrus tree is virtually impossible. Thus, the sampling method must be a reliable estimate of the population. This requirement poses two sampling problems, the choice of a suitable sample size, and the manner of collection of the sample.

Sample sizes used in investigations by other authors have varied considerably. Jones and Prendergast (1937) suggested the collection of 50 leaves, Baten and Hutson (1943) 300 leaves, DeBach *et al*. (1950) 25 leaves, Jeppson *et al*. (1957) 32 leaves, while Muir (1965a) chose eight leaves per tree in one report, and only six leaves per tree in another report (Muir 1965b). After due consideration of this information, it was decided that a leaf sample of 20 leaves per tree would be used. A leaf sample of this size was found to be practical, convenient to examine, easily collected and sufficiently large for a statistical analysis of the results.

d. The Distribution of *P.citri* and the Predaceous mite, *A.addoensis*, on a Citrus Tree.

A most important question in regard to the manner of collection of the leaf sample, is whether or not the mite population is randomly distributed in a citrus tree. If a mite population is randomly distributed, then sampling may be performed at any site on the tree. If, however, the mite population is not distributed at random, the sampling method must be designed to account for this non-randomness. In order to answer this question with respect to the sampling of citrus leaves for P.citri and A.addoensis population density estimations, a Washington Navel citrus tree, infested with citrus red mite, was selected for study.

The tree chosen had a circumference of 35 feet and was 13 feet high. The tree was partitioned into seven segments, each segment being five feet in width at the periphery. Each segment was divided into three heights, below four feet from the ground, between four and eight feet, and above eight feet. These heights were designated Level A, Level B and Level C respectively. In addition, the leaves in each segment were divided into those on the outside of the tree, and leaves occurring on the inside of the tree. The details are illustrated in Figure 3.

From each area on the tree, as defined by level, segment and inside or outside, a leaf sample of 20 leaves was collected and examined under the microscope. The results of this examination, which was performed during August 1965, are given in Tables 12a and 12b.

The information in Tables 12a and 12b was analysed on an IBM 16/20 computor, by means of the square root transformation (See Appendix 1). No analyses were performed on P.citri males on the inside or outside leaves, nor on the number of A.addoensis on the outside leaves, because of the large number of zero values in

TABLE 12a.

The distribution of the mite, Panonychus citri, on a Navel orange tree during August 1965.

1. Outside leaves.

Level	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7	Total
A	E-364 I-38 F-16 W-2	E-423 I-26 F-12 M-1	E-873 I-115 F-25 M-3 W-1	E-1687 I-432 F-127 M-43 W-3	E-1134 I-335 F-84 M-23 W-3	E-276 I-78 F-21 M-1 W-2	E-154 I-34 F-7 W-1	E-4911 I-1058 F-292 M-71 W-12
B	E-174 I-13 F-8 W-1	E-237 I-27 F-5 M-1	E-1540 I-244 F-60 W-2	E-1288 I-172 F-80 M-5 W-4	E-1244 I-202 F-58 M-16 W-5	E-368 I-56 F-19 M-4 W-3	E-156 I-23 F-3	E-5007 I-737 F-233 M-26 W-15
C	E-224 I-34 F-10	E-369 I-40 F-8 W-2	E-1313 I-149 F-40 M-1 W-8	E-1010 I-230 F-47 M-2 W-3	E-1606 I-202 F-144 M-5 W-4	E-414 I-98 F-14 W-1	E-126 I-21 F-4	E-5062 I-774 F-267 M-8 W-18
Total	E-762 I-85 F-34 W-3	E-1029 I-93 F-25 M-2 W-2	E-3726 I-508 F-125 M-4 W-11	E-3985 I-834 F-254 M-50 W-10	E-3984 I-739 F-286 M-44 W-12	E-1058 I-232 F-54 M-5 W-6	E-436 I-78 F-14 W-1	E-14980 I-2569 F-792 M-105 W-45

KEY.

E = Eggs of P.citri.

F = Females of P.citri.

W = Predaceous mite, A.addoensis.

I = Immature Stages of P.citri.

M = Males of P.citri.

TABLE 12b.

The distribution of the mite, Panonychus citri, on a Navel orange tree during August 1965.

11. Inside leaves.

Level	Segment 1		Segment 2		Segment 3		Segment 4		Segment 5		Segment 6		Segment 7		Total	
A	E-158 F-8 W-7	I-20 M-1	E-23 F-2 W-12	I-5	E-71 F-6 W-14	I-12 M-1	E-40 F-7 W-6	I-10	E-107 F-8 W-15	I-41 M-1	E-50 F-3 W-13	I-11 M-2	E-42 F-4 W-8	I-10 M-1	E-491 F-38 W-75	I-109 M-6
B	E-155 F-8 W-27	I-11	E-130 F-5 W-12	I-11	E-166 F-11 W-18	I-18 M-1	E-263 F-13 W-14	I-46 M-2	E-119 F-11 W-20	I-28 M-1	E-57 F-5 W-27	I-12	E-69 F-5 W-12	I-3	E-959 F-58 W-130	I-129 M-4
C	E-383 F-12 W-10	I-31	E-153 F-5 W-12	I-24	E-279 F-8 W-11	I-16 M-1	E-204 F-5 W-18	I-16	E-296 F-8 W-22	I-39 M-1	E-107 F-9 W-8	I-21 M-1	E-161 F-6 W-9	I-13	E-1583 F-53 W-90	I-160 M-3
Total	E-696 F-28 W-44	I-62 M-1	E-306 F-12 W-36	I-40	E-516 F-25 W-43	I-46 M-3	E-507 F-25 W-38	I-72 M-2	E-522 F-27 W-57	I-108 M-3	E-214 F-17 W-48	I-44 M-3	E-272 F-15 W-29	I-26 M-1	E-3033 F-149 W-295	I-398 M-13
													Grand Total (Inside and Outside)		E-18013 F-941 W-340	I-2967 M-118

KEY.

E = Eggs of P.citri.

I = Immature stages of P.citri.

F = Females of P.citri.

M = Males of P.citri.

W = Predaceous mite, A.addoensis.

the data.

The majority of P.citri occurred on the outermost leaves of the citrus tree, and the analysis showed that the number of eggs, immature and female stages were highest on the southern aspect of the tree, Segments 3, 4 and 5. Although the variations between height levels within the same segment was large, on an average there was a fairly uniform distribution of red mite from the lower to the upper parts of the tree.

On the inside leaves of the tree, the segment effect was significant at p=0.05. Segment 1 (North), had a significantly higher number of P.citri eggs than the adjacent Segments 2 and 7, while Segments 3, 4 and 5 (South), were again high compared with adjacent Segments 2 and 6. The number of eggs increased markedly from the lower to the higher parts of the tree. There was no significant difference between the number of immature stages on each of the inside segments, even though fairly large differences between segments did occur.

Segment 1 had more female red mites on the inside leaves than the adjoining Segments 2 and 7, but there was no significant difference in the number of females between height levels.

There was no significant difference in the density of the predaceous mite, A.addoensis, between each of the inside segments, where the majority of these predaceous mites were found, but there was some concentration at height Level B.

The distribution of P.citri and A.addoensis on this same tree was re-examined in January 1967, and the results are given in Tables 13a and 13b.

TABLE 13a.

The distribution of the mite, Panonychus citri on a Navel orange tree during January, 1967.

1. Outside leaves.

Level	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7	Total
A	E-1 W-1	E-3		E-4 I-1	E-10 I-1	E-4 I-3 F-2 W-2	E-6	E-28 I-5 F-2 W-3
B	I-1 W-1	E-2 I-1	E-6 I-3	E-17 I-1	E-1 F-1	E-3 I-1 F-1	E-6	E-35 I-7 F-2 W-1
C	E-3			E-3	E-1 I-1	E-2		E-9 I-1
Total	E-4 I-1 W-2	E-5 I-1	E-6 I-3	E-24 I-2	E-12 I-2 F-1	E-9 I-4 F-3 W-2	E-12	E-72 I-13 F-4 W-4

KEY.

E= Ess of P.citri.

I = Immature stages of P.citri.

F = Females of P.citri.

M = Males of P.citri.

W = Predaceous mite, A.addoensis.

TABLE 13b.

The distribution of the mite, Panonychus citri, on a Navel orange tree during January, 1967.

II. Inside leaves.

Level	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7	Total
A		E-1	W-1	W-5	E-1 W-1		W-3	E-2 W-10
B		W-1	W-1	I-2	E-3 I-1 W-1	W-1	E-3 F-1	E-6 I-3 F-1 W-4
C		E-1		E-5		E-1 W-3	E-1 I-1 W-1	E-8 I-1 W-4
Total		E-2 W-2	W-2	E-5 I-2 W-5	E-4 I-1 W-2	E-1 W-4	E-4 I-1 F-1 W-4	E-16 I-4 F-1 W-18
							Grand Total (Inside and Outside).	E-88 I-17 E-5 W-22

KEY.

E = Eggs of P.citri.

F = Females of P.citri

W = Predaceous mite, A.addoensis.

I = Immature stages of P.citri.

M = Males of P.citri.

By observation, the results of this re-examination indicated that the major proportion of the citrus red mite population was again found on the outermost leaves of the southern aspect, and the majority of A.addoensis on the leaves inside the tree.

As a result of the above analyses, the distribution of P.citri in relation to leaf area, on the southern aspect of the tree, was examined more closely, during August 1965. The southern aspect was subdivided into five segments, and each segment was divided into four height levels, at three feet intervals. The lowest level was designated Level A, and the highest Level D. Only the outermost leaves were examined, and from the areas defined by segment and height level, samples of 20 leaves were picked and examined microscopically.

The leaf area of the leaves in each sample was calculated in the following manner. After the number of P.citri had been counted on each leaf, the outline of the leaf was drawn on paper, and the area of the outline measured with a planimeter. The area given by the planimeter was then multiplied by two, for the upper and lower leaf surfaces, to give the total leaf area. This procedure was repeated for all 20 leaves in the sample, and the total leaf area was taken as the sum of the 20 individual leaf areas.

Counts of all stages of the citrus red mite, and the surface of the 20 leaves from which they were collected, are presented in Table 14.

TABLE 14.

The distribution of *Panonychus citri* in relation to the leaf area, (expressed in square centimeters) on the southern aspect of a Navel orange tree during August 1965.

Southern Aspect.

Level	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Total
A	E-580 I-52 F-5 M-1 *790	E-366 I-18 F-1 *923	E-264 I-13 F-1 *801	E-480 I-60 F-4 M-2 *877	E-676 I-59 F-3 M-1 *765	E-2366 I-202 F-14 M-4 *4156
B	E-1108 I-171 F-17 M-1 *806	E-861 I-144 F-17 M-4 *867	E-1137 I-157 F-22 *906	E-926 I-183 F-23 M-8 *830	E-553 I-40 F-4 M-3 *833	E-4585 I-695 F-83 M-16 *4242
C	E-1355 I-231 F-41 M-3 *885	E-1150 I-125 F-25 M-5 *845	E-669 I-101 F-24 M-9 *804	E-757 I-107 F-38 M-3 *985	E-588 I-62 F-18 M-1 *811	E-4519 I-626 F-146 M-21 *4330
D	E-1123 I-113 F-29 M-4 *982	E-2047 I-203 F-59 M-8 *1065	E-958 I-95 F-27 M-1 *912	E-1075 I-120 F-49 M-1 *791	E-926 I-75 F-44 M-2 *922	E-6129 I-606 F-208 M-16 *4672
Total	E-4166 I-567 F-92 M-9 *3463	E-4424 I-490 F-102 M-17 *3700	E-3028 I-366 F-74 M-10 *3423	E-3238 I-470 F-114 M-14 *3483	E-2743 I-236 F-69 M-7 *3331	E-17599 I-2129 F-451 M-57 *17400

KEY.

E = Eggs of *P.citri*. I = Immature stages of *P.citri*. F = Females of *P.citri*. M = Males of *P.citri*.

* = The total leaf surface area expressed in square centimeters.

An analysis was performed on the number of eggs and immature stages of P.citri, and the total leaf area, given in Table 14 (See Appendix 2). The data on the males and females of the citrus red mite were not analysed because of the large number of zero values.

The analysis indicated that the eggs and immature stages of the citrus mite were not distributed at random throughout the southern aspect, the main difference occurring between height levels. Level D had a significantly lower number of P.citri than the other height levels.

The correlation of leaf area with the number of eggs and immature stages was significant, but rather low. This indicated that the variates were related but that the relationship varied from leaf to leaf, and from sample to sample.

e. The Sampling Method.

Based on the above analysis, the sampling method which was used to estimate the relative density of P.citri and the predaceous mite, A.addoensis, on a citrus tree was as follows. A leaf sample of 20 mature citrus leaves was collected haphazardly into a container, at any height between ground level and eight feet, and from the southern aspect of the tree. The container was closed with a lid, returned to the laboratory and stored in a refrigerator at 5°C until the leaves were examined under a microscope. It was found that on keeping the leaf samples at 5°C, little or no reproduction took place during the 48 hours required to examine all the samples collected. Thus, the number of citrus red mite and A.addoensis stages counted on the leaf samples in the laboratory was approximately the same as that occurring on the leaves at the time the sample was collected. Storing of the leaves for up to 48 hours at this temperature had no apparent adverse effect on the mites.

At no time were leaves collected from the field while they were wet, for example after a heavy dew or rainfall. It was considered that picking leaves in this condition might be responsible for the loss of some immature stages, by them being washed off the leaves while being collected.

No old or young flush growth leaves were included in the leaf samples. The reason for this was that according to Henderson and Holloway (1942), the number of eggs produced by P.citri on young immature leaves is significantly greater than on the more mature leaves. Thus, by excluding old and immature leaves from the sample, the possible effect of leaf age on the population density of the citrus red mite was reduced to a minimum. The exclusion of flush growth leaves from the samples may have introduced a bias into the sampling method, especially as some authors, Jeppson et al. (1957), maintain that red mite population increases on orange trees is associated with the leaf flush periods. I considered, however, that despite the absence of young leaves in the sample, the periods of mite increase would be adequately reflected by the rise in the numbers of red mite on the mature leaves. By excluding young leaves from the sample it is possible that the maximum number of P.citri recorded during the flush periods might be an underestimate of the actual red mite population density.

All leaf sampling of citrus trees in the field was performed in the manner described above, unless otherwise stated.

During the time this leaf sampling method was employed, repeated field observations indicated that the greatest number of citrus red mite was not always found on the southern aspect of a citrus tree. As a result of this observation, it was decided to provide a further check on the distribution of P.citri. Six Washington Navel citrus trees, which constituted the six experimental trees in the natural control orchard on the farm "Imiti", Addo (See Figure 2), were chosen. From each of these six trees a sample of 20 leaves was picked from the northern and southern aspects, and all stages of P.citri on the leaves counted. This process was performed at weekly intervals, from January to September 1967.

The mean number of citrus red mite occurring on the northern and southern aspects of all six experimental trees at "Imiti", from January to September 1967, is given in Figure 4.

At "Imiti", the greatest number of red mite was found to occur on the northern aspect of all six trees sampled. From these data it would appear that contrary to previous information on the distribution of red mite on a citrus tree, the largest densities at "Imiti" were on the northern aspect. This result did not, however, invalidate the observations on the population fluctuations of red mite made by sampling the southern aspect but what was important was to establish whether the populations on both aspects of the tree fluctuated in a similar manner. The correlation co-efficient between the mean population variation on the northern and southern aspects was high, (r=0.82). This information indicated that despite a difference in population density, the seasonal variations of the citrus red mite populations on the northern and southern aspects was very similar. It was decided, therefore, to continue sampling from the southern side of the tree, although the figures obtained for the relative numbers of red mite was probably an underestimate. Further, any conclusions drawn from P.citri populations on the southern aspect would apply equally well to the mite population on the northern aspect.

f. Sampling Error.

The reliability of sampling twenty mature citrus leaves from the southern aspect of a citrus tree was evaluated by sampling two citrus trees with different population densities of P.citri. Of the two trees selected, one tree had an average number of 999 red mites of all stages per 20 leaves sampled, while the other tree had a lower population, an average of 90 mites of all stages per 20 leaves. Twenty leaf samples were picked from the southern aspect of each tree, and the standard error and the 95% confidence limits of the mean was calculated for each tree. The results of this analysis are given in Tables 15a and 15b.

From the calculation of the 95% confidence limits of the information in Tables 15a and 15b, the accuracy of the sampling method varied from between ± 10% (999 ± 97.5) and ± 13% (90 ± 11.3), depending on the population density. Thus a difference between samples of greater than 20% to 26% was significant, at the 95% level, when this method of sampling was used.

The above leaf sampling method was used to estimate not only the number of P.citri, but also the number of A.addoensis on the citrus tree. Thus the sampling error with respect to the predaceous mite was calculated.

Table 15a.

The information obtained from a citrus tree with an average number of 999 mites per twenty leaves, for the calculation of the sampling error of the leaf sampling technique employed for estimating the relative number of P.citri on a citrus tree.

Sample No.	Eggs	Immature Stages	Females	Males	Total
1	784	105	17	6	912
2	772	95	22	0	889
3	652	88	16	0	756
4	722	97	19	2	840
5	1372	128	27	1	1528
6	860	85	16	1	962
7	801	83	25	5	914
8	966	115	16	1	1098
9	1150	136	28	3	1317
10	676	60	14	2	752
11	902	86	23	2	1013
12	765	109	22	1	897
13	794	106	19	4	923
14	884	128	28	1	1041
15	1283	139	19	2	1443
16	865	98	20	1	984
17	678	77	11	1	767
18	1095	122	20	5	1242
19	730	79	17	2	828
20	776	70	25	0	871
Total	17527	2006	404	40	19977
				Mean	999

Standard error of mean = 999 ± 49.7

95% Confidence limits of mean = 999 ± 97.5

Table 15b.

The information obtained from a citrus tree with an average number of 90 mites per twenty leaves, for the calculation of the sampling error of the leaf sampling method employed for estimating the relative number of P.citri on a citrus tree.

Sample No.	Eggs	Immature Stages	Females	Males	Total
1	47	2	1	0	50
2	45	3	0	0	48
3	88	12	1	0	101
4	92	5	4	0	101
5	55	4	3	1	63
6	83	10	4	0	97
7	111	12	4	0	127
8	131	13	6	0	150
9	100	12	4	0	116
10	75	9	2	0	86
11	74	6	44	0	84
12	87	7	3	0	97
13	67	8	0	0	75
14	61	10	3	0	74
15	107	8	3	1	119
16	82	11	2	0	95
17	63	4	1	0	68
18	61	10	6	0	77
19	91	11	3	0	105
20	68	5	2	0	75
Total	1588	162	56	2	1808
				Mean	90

Standard error of mean = 90 $\pm$ 5.8

95% Confidence limits of mean = 90 $\pm$ 11.3

Two unsprayed Washington Navel citrus trees were chosen at random from the orchard at "Imiti", and from each tree ten leaf samples were picked from the southern aspect of each tree. The number of A.addoensis in each sample was counted with the aid of a microscope and the standard error and 95% confidence limits of the mean calculated for each tree. Because of the large number of zero values in the data, the actual counts were weighted to facilitate analysis.

An actual count of zero was therefore designated one, and a factor of one was added to all the other counts. The results of this analysis are given in Table 16.

Table 16.

The sampling error of the leaf sampling technique used for estimating the relative number of A.addoensis on a citrus tree, obtained from two Washington Navel citrus trees, chosen at random.

	Tree 1.		Tree 2.	
Sample No.	Actual Count	Weighted Count	Actual Count	Weighted Count
1	2	3	0	1
2	1	2	1	2
3	3	4	1	2
4	0	1	2	3
5	0	1	0	1
6	0	1	0	1
7	1	2	1	2
8	2	3	0	1
9	0	1	0	1
10	0	1	2	3
Total	9	19	7	17
Standard error of mean.	1.9 ± 0.3		1.7 ± 0.3	
95% Confidence limits of mean.	1.9 ± 0.7		1.7 ± 0.5	

From the calculation of the 95% confidence limits of the data in Table 16, the accuracy of the sampling method in estimating the number of A.addoensis varied between 30% (1.7 ± 0.5) and 35% (1.9 ± 0.7). Thus a difference between leaf samples in the number of predaceous mites greater than 60% to 70% was significant at the 95% level. This large sampling error in the number of A.addoensis could be explained by the fact that according to the distribution of this predaceous mite on a tree, Tables 12a and 12b, 86% (295) of these mites occur on the interior leaves, while the sampling method was based on the collection of the cutermost leaves on which only 14% (45) of the total number of predaceous mites were found. In sampling the edge of the distribution, therefore, relatively large variations in the predator population between consecutive samples could be expected.

In spite of the uneven distribution of the predator mite on the tree, the sampling method was not altered. It was considered important to record the number of predaceous mites on the outside leaves since it was this number of A.addoensis which were probably feeding on the citrus red mite on the date of sampling. (See page 135). In addition, I considered that to collect two leaf samples on a weekly basis, one for estimating the number of red mite and another for estimating the number of A.addoensis, would soon result in the complete defoliation of the tree sampled.

8.

THE DISTRIBUTION OF THE CITRUS RED MITE, P.CITRI, IN THE SUNDAYS RIVER VALLEY, AND ITS SEASONAL ABUNDANCE IN A CITRUS ORCHARD UNDER NATURAL CONTROL.

a. The Distribution of P.citri in the Sundays River Valley.

The first report of the citrus red mite in the Sundays River Valley was from the Government Research Station at Addo in May 1961 (Meyer 1961), where young trees imported from Nelspruit were found to be infested with the mite. Until 1965, however, it was not clear how widespread the red mite had become in the four years following its introduction into the Valley. As a start to the study of the ecology of P.citri in the Sundays River Valley several surveys were conducted in the Valley to determine the distribution of this pest species.

A total of three surveys were conducted, in March, April and June 1965. In each survey the method of assessing the red mite population was that of Venables and Dennys (1941), and commonly known as the "paper impression" technique (See page 36). Ten citrus trees, representative of the trees throughout the selected orchard were chosen indiscriminately, and from each tree ten leaves were picked from different aspects and heights around the tree. The ten leaves from each tree were pressed between two pieces of absorbent paper in the field, and the characteristic and identifiable stains left on the paper by the eggs, immature and adult stages of P.citri were counted with a low power microscope.

Twelve orchards, or sampling stations were selected throughout the Valley (See Figure 2). Orchards 4 and 5 had received no insecticidal applications since 1963, while the remaining ten orchards were regularly treated with insecticides for the control of citrus pests. However, at the beginning of 1965 no orchard had been sprayed, but between successive red mite surveys, stations 7, 8 and 10 were treated because of the high densities of citrus red mite which had developed.

The results of the three P.citri surveys of the Sundays River Valley during March, April and July 1965, are shown in Figure 5.

The results show that by 1965 P.citri was present in orchards throughout the Valley. In the three surveys, the highest population densities of the citrus mite were found in those orchards towards the south-eastern end of the Valley (Figure 2), but this was not always the case. Subsequent field observations indicated that large infestations of P.citri may also occur in orchards in the Kirkwood area, at the north-western end of the Valley.

b. The Seasonal Abundance of the Citrus Red Mite, P.citri, Under Natural Control in an Orchard in the Sundays River Valley.

In this study, the term "natural control" was taken to mean:-

> "the maintainence of a more or less fluctuating population density of an organism within certain definable upper and lower limits over a period of time, by the actions of abiotic and/or biotic environmental factors." (DeBach 1964).

1. Experimental Design. DeBach (1951) has pointed out that an orchard cannot be considered to be under natural control unless it has remained chemically untreated for up to four year. Thus, in the Sundays River Valley an orchard on the farm "Imiti", Addo, consisting of 156 Washington Navel citrus trees, planted in 1955, was chosen as the site for this investigation (See Figure 2). Since 1961, the orchard had received no insecticidal or acaricidal treatment, and the owner stated that although citrus red mite was present in the orchard, it had never developed into pest proportions. This statement together with the absence of

chemical control, was taken as an indication that between January 1961 and February 1966, when the investigation began, a state of natural control of P.citri had probably been established in this orchard.

The estimation of the number of P.citri and the predaceous mite, A.addoensis, on the trees in the orchard was done by means of leaf samples collected at weekly intervals and examined by the microscope method. Temperature and relative humidity records were obtained from a thermohygrograph inside a Stevenson screen, which was erected in the centre of the orchard.

Initially, 15 Washington Navel citrus trees for observation were selected at random from the orchard, and the distribution of these trees within the orchard is given in Figure 6.

2. The Seasonal Abundance of P.citri.

During the course of this investigation, it was noticed that the variation of the population density of citrus red mite, over a period of time, was similar on each of the 15 trees selected at random. Because of this it was decided to decrease the number of trees in the experiment from 15 to six, and to include in the six trees chosen two sets of three trees, each with a comparatively high and low population density of citrus red mite.

A comparison of the overall seasonal variation of the total number of P.citri obtained by sampling either 15 or six trees was made, and the results of this comparison are given in Figure 7.

From an analysis of the data in Figure 7, a high correlation (r=0.94), was found between the seasonal fluctuation of P.citri on 15 trees and on six experimental trees. From this it is concluded that although a small number of trees were used in this investigation, there would be little difference between the seasonal variation observed from six trees compared with that observed from a larger group of 15 trees.

Although each of the six trees examined at "Imiti" provided an essentially similar picture of seasonal fluctuation of P.citri, the density of red mite in leaf samples of 20 leaves varied widely between trees. An exactly similar variation in P.citri density between replicate trees was also found on the six untreated control trees in the two insecticidal trials at "Littlecote" and "Ruimte". In Figure 8 the variation in population density of the citrus red mite on four of the six experimental trees studied at "Imiti" from March 1966 to October 1967, is shown.

While this between tree variation does not affect the overall findings of the periods of seasonal abundance of P.citri, it is essential to examine the feasibility of expressing the density of the citrus red mite on replicate trees in some meaningful manner, for example as the mean number of mites per leaf, and the error surrounding such an estimate. Such a manipulation of the density data would greatly simplify the subsequent discussion of the possible causes behind the seasonal changes in red mite population density and provide a valid comparison between different sections of this study.

In considering replicate trees which show such marked differences in population density of P.citri, the question arises as to whether the variation between trees approximates to a normal distribution or not, without at this stage examining the cause of this between tree variation. Using the total number of mites on 20 leaves per tree, and with only six trees, this question is difficult to answer. However, by examining the number of mites per leaf in a 20 leaf sample from each of the six trees, a greater amount of information becomes available for analysis.

When the frequency with which all stages of P.citri occur on the 120 leaves was plotted, it was found that the resulting distribution approximated to a binomial with a small value of "p". This suggests that the mean number of mites, based on 20 leaf samples from individual trees, would approximate to a normal distribution, and it therefore becomes possible to describe the overall variation between the mean number of red mite per leaf based on 120 leaves (the sum of 20 leaf samples from six replicate trees), by a pooled standard error. The estimation of this error now allows us to determine whether the seasonal changes in P.citri density are significant.

In figure 9, the population changes of P.citri on the six experimental trees at "Imiti", from March 1966 to October 1967, are expressed in this way and we can now indicate what are the possible causes for the seasonal variation of this mite.

Figure 9 shows that the peak population densities of P.citri were attained during the months of March and June and August and September, while relatively low densities were recorded during July and from October to February. Of the two peak densities of citrus red mite, however, the March to June peak comprised the largest number of P.citri both in 1966 and 1967. The probable reason for the August to September peak being lower than that from March to June, will be discussed later.

In investigations on the seasonal variation of P.citri in untreated citrus orchards in the U.S.A., it has been generally found that the maximum numbers of citrus red mite occur in Spring and Autumn. Boyce (1936) stated that peak infestations of this mite in the coastal and sub-coastal areas of California normally occurred from April to June (Spring), and frequently from October to December (Autumn). He found, however, that large populations could develop during exceptionally warm winters or cool summers. Prendergast (1938) recorded the highest numbers of P.citri from February to May, and again from August to September. DeBach *et al.* (1950), in a study of the efficacy of the natural enemies of the citrus red mite in several untreated orchards in southern California, recorded two population maxima, one in May-June and another in October-November, while in a more recent study of the population fluctuations of the red mite in four untreated lemon orchards in California, Jeppson *et al.* (1957) found that the maximum numbers of this mite occurred from June to November.

In comparing the seasonal abundance of P.citri in the untreated orange orchard at "Imiti" with the above observations from California, it was concluded that in general, the peak numbers of citrus red mite occur during the same seasons of the year in these two different areas.

In the Republic of South Africa, Smith (1953), Stofberg (1959), Brodrick (1965) and Schwartz (1965) have reported that the maximum number of citrus red mite occur during Spring and Autumn. However, van Rooyen (1966) recorded the greatest number of P.citri at Zebediela, Transvaal, from November to January (Summer). This observation is interesting because of its variation from my findings and from the observations of the authors quoted above. The results of van Rooyen (1966) will be examined in more detail later.

From a comparison of the peaks of P.citri population density and the variation in the number of hours per week temperature was greater than or equal to 18°C and relative humidity less than or equal to 30% (Figure 9), maximum populations of red mite were coincident with those periods of the year when temperatures and relative humidity were moderate. On the other hand, periods when temperatures over 18°C and relative humidities less than 30% were frequently recorded corresponded with low numbers of P.citri. This apparent relationship between the citrus red mite populations and temperature and relative humidity was investigated in more detail in the laboratory, and the results are given below.

9.

EXPERIMENTAL STUDIES ON THE INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON THE DEVELOPMENT AND LIFE HISTORY OF THE CITRUS RED MITE.

a. The Choice of a Substrate.

In experiments designed to study the development of an animal such as the citrus red mite, the selection and arrangement of a substrate on which to culture and observe the mites should meet certain requirements.

1. The substrate should be acceptable to the experimental animal as a source of food.

2. The substrate should remain in as fresh a condition for as long a period as possible.

3. The arrangement of the substrate should be such that it is easily examined with a microscope.

4. The arrangement of the substrate should be designed so that no mites are lost from unnatural causes.

5. The substrate must be readily available throughout the year.

There are a number of methods recorded in the literature for the culture of phytophagous mites, but all fail to completely satisfy the above mentioned requirements. However, several methods which held some promise were examined.

The culture of _P.citri_ on rough lemon seedlings was unsatisfactory because individuals were lost by either crawling or by dropping off the plant, and microscopic examination of the seedlings was difficult. Valencia seedlings were not tried as a substitute for lemon seedlings as they were unobtainable, but presumably they would have had the same disadvantage.

An attempt was made to breed P.citri on leaf discs using the technique devised by Callan (1947) for the culture of Thysanoptera. In brief this technique consists of floating a circular leaf disc, cut from a fresh leaf, on water. The water surface serves to keep the disc fresh and at the same time acts as an effective barrier to the animal. This method proved satisfactory in that the mites readily feed on the citrus leaf tissue, but numbers of red mite were lost by being trapped in the water on which the leaf floated. In addition, after a period of about two weeks the condition of the citrus leaf discs began to deteriorate and necessitated the transfer of the mites onto fresh discs.

From the results of the above attempts to rear the red mite, it was decided to try citrus fruits as a substrate. At the time these experiments were started, only two types of fruit were available, the Valencia orange and the lemon. The fruits were prepared in the following manner. The calyx end of the fruit was coated with wax, and the fruit attached by the lower end to a wax platform inside an open container. The container was filled with water until only the upper uncoated portion of the fruit was left exposed. A thin layer of Castor oil was then added to the surface of the water to eliminate evaporation. A diagram of this rearing unit is given in Figure 10.

In these rearing units, all stages of P.citri could be introduced onto the upper uncoated surface of the fruit. This arrangement proved very satisfactory for the breeding of red mite and satisfied nearly all the aforementioned requirements. However, it was found that the use of this technique could result in a loss of up to 13% of the total number of active stages in a 24 hour period, by their being trapped in the oil layer, but it must be emphasised that this high artificial loss seldom occurred in laboratory experiments. When citrus mites were lost in the oil layer, the loss was generally between 3% and 5% of the total number of active stages. It was assumed that this loss occurred in a random manner, for each mite had an equal chance of coming into contact with the oil.

In the laboratory experiments, no differentiation was made between the protochrysalis and protonymph, nor between deutochrysalis and deutonymph, or the teliochrysalis and adult. The duration of time occupied by the chrysalis stage was included in the time spent in the respective instar.

The citrus fruit most favoured for these life cycle studies was the lemon, as this fruit was available throughout the year. In the field however, P.citri seldom occurred in lemon orchards, although the citrus red mite can be most successfully reared on lemon fruit in the laboratory. Thus in order to be able to use the lemon for life cycle studies and then to equate the results obtained with those observed on orange trees in the field, a comparison between the life cycle of P.citri on the lemon substrate and its life cycle on hosts on which it occurs naturally in the field, was essential. A series of life cycle studies were therefore performed in the laboratory on lemon and valencia fruits and on Washington Navel leaf discs.

b. The Effect of Different Substrates on the Life Cycle of the Citrus Red Mite.

A comparison of the life cycles of P.citri on different substrates was conducted in the laboratory. The temperature and relative humidity records were obtained from a maximum-minimum thermometer and a wet and dry bulb thermometer situated in the middle of the laboratory. The light intensity was lower in the laboratory in comparison with the most exposed parts of the citrus tree.

In the laboratory the relative humidities were calculated daily at 08.00 hours and 14.00 hours, and the maximum and minimum temperatures read every 24 hours. The average weekly maximum and minimum temperatures and relative humidities recorded in the laboratory over the duration of the comparative experiments are given in Table 17.

Table 17.

The mean weekly maximum and minimum temperatures and relative humidities recorded in the laboratory.

	Mean Weekly Temp. (°C)		Mean Weekly R.H.	
Date	Maximum	Minimum	08.00 hrs.	14.00 hrs.
20-27. 9.66	23.6	18.5	72	62
28- 4.10.66	22.9	19.7	67	60
5-12.10.66	24.0	20.0	61	56
13-19.10.66	22.4	19.0	64	56
20-26.10.66	23.6	19,8	55	53
27- 2.11.66	24.8	22.6	64	-
3- 9.11.66	23.9	22.0	63	56
10-16.11.66	26.0	22.5	63	51
Mean	23.9	20.5	64	56

Several mature males and females of P.citri were placed on the upper uncoated surface of either a lemon or Valencia orange fruit, or the surface of a floating leaf disc. These adult stages were permitted to lay eggs ad lib. After sufficient eggs had been laid, the adult stages were removed and the development from egg to adult was recorded daily. On each substrate the development of P.citri was recorded through one generation. All eggs laid by the first generation females were counted and removed at the end of each 24 hour period. This was done so that the eggs laid during one 24 hour period were not confused with those produced in the subsequent 24 hours.

The results of these life cycle studies on the lemon, Valencia and Washington Navel leaf disc substrates are given in Figures 11, 12 and 13.

A comparison of Figures 11, 12 and 13, taking into account the differing numbers of eggs at the start of the experiments, indicate that the time spent by the different stages of P.citri in each instar, when reared on the three different substrates, was very similar. Under the laboratory conditions described, the eggs hatched between seven to nine days after oviposition. In all cases the percentage viability of the eggs was high, approximately 98%.

The period spent in the larval instar was two days on all three substrates, in the protonymphal instar two days and one to three days in the deutonymphal instar. With the exception of the citrus red mites reared on leaf discs, Figure 13, the males of P.citri appeared several days prior to the emergence of the females. It is suggested that this early appearance of the males allows them adequate time to seek out the female teliochrysalis and position themselves for fertilisation when the adult female emerges. So that the male can emerge before the female, the rate of development in the deutonymphal stage is probably faster than that of the female, or alternatively the deutonymphal instar may be excluded from the male life cycle. The information in Figure 13 suggested that the males spend as little as 48 hours in the deutonymphal instar, while the data in Figures 11 and 12 indicated, as reported by Shinakji (1959), that the males may omit the deutonymphal instar.

On all three substrates the females of P.citri spend two or three days in the deutonymphal instar, and egg production begins one to two days after emergence from the teliochrysalis. Under the laboratory conditions of temperature and relative humidity, egg production rose rapidly to a maximum seven to eight days after the appearance of the females, after which the egg production gradually declined. On the fruit substrates, Figures 11 and 12, the egg production curves were very similar, but on the Navel leaf discs, Figure 13, the number of eggs produced by the first generation females was low, when compared with the number of females present. This low egg production on the leaf discs could be attributed mainly to the deterioration of the leaf discs at this stage in the experiment. It is suggested that this deterioration was largely caused by the withdrawal of nutrients and cell sap from the discs by the adult forms.

Under these laboratory conditions the average time, from egg to egg, on all substrates, was 17 days.

On the fruit substrates the average life-span of P.citri males was 22 days, as compared with 13 days on the leaf discs. In the case of the female stages on the fruit hosts, the average length of female life was 27 days compared to an average of 19 days on the leaf discs. The average generation time on the lemon and Valencia fruits and Navel leaf disc substrates was found to be 42 days, 44 days and 34 days respectively.

A summary of the data from the above laboratory experiments on the life cycle of P.citri on lemon and Valencia fruits and Washington Navel leaf discs are given in Table 18.

Table 18.

A summary of the information obtained from laboratory experiments on the life cycle of P.citri on lemon and Valencia fruits and on Washington Navel leaf discs.

	SUBSTRATE.		
	Lemon	Valencia	Washington Navel Leaf Discs.
% viability of eggs	96%	100%	99%
Mean length of larval life	2 days	2 days	2 days
Mean length of pro-tonmphal life	2 days	2 days	2 days
Mean length of deu-tonymphal life	2 days	2 days	3 days
Mean length of female life	26 days	28 days	19 days
Mean length of male life	23 days	21 days	13 days
Period from egg to egg	17 days	17 days	17 days
Generation time	42 days	44 days	34 days

From the information in Table 18, it may be seen that the time occupied by P.citri in the immature instars on all three substrates was the same. In the case of the leaf discs, however, there was a marked reduction in the length of time spent by the mite in the male and female stages, when compared with the corresponding periods on the fruit hosts. This effect might have been overcome by transfering the mites onto fresh leaf discs, but this was not done mainly because of the possibility of increasing the unnatural mortality by losing mites in the process of transfer.

In the light of the above findings, it was decided to reject the technique of rearing P.citri on leaf discs as a method for investigating the development and life cycle of the red mite in the laboratory.

There was little difference between the life cycle of the red mite on either the lemon or Valencia fruit substrates, and as the lemon fruit was readily available throughout the year, it was used exclusively.

c. The Development of Unfertilised Eggs of P.citri.

It has been stated by many authors, including Ebeling (1959), Boudreaux (1963) and van Rooyen (1966), that the unfertilised virgin females of the citrus red mite lay eggs which produce males only. This statement was verified by an experiment in which the environment room was programmed to the following conditions of temperature and relative humidity:-

	Temperature	R.H.	Light
Day Conditions	23°C	60%	12 hours
Night Conditions	8°C	94%	12 hours

Several female teliochrysalids were placed on a lemon fruit and allowed to moult and lay eggs. After a number of eggs had been laid, the females were removed and the development of the eggs was followed, observations being made at regular 24 hour intervals. The experiment was terminated when all immature stages had reached the adult stage. This experiment was replicated twice, and the results are given in Figure 14.

From Figure 14, all immature stages that emerged from the unfertilised eggs gave rise to males alone, and all the males passed through the deutonymphal instar. This result, in which the males included the deutonymphal instar in their development, was unlike that obtained in the experiments conducted to evaluate the suitability of different substrates, where on the fruit substrates the males were observed to omit this stage from development. The reason for these variable results is not known.

d. The Effect of Simulated Summer, Autumn and Winter Conditions of Temperature and Relative Humidity on the Development of the Citrus Red Mite.

Based on the information gained from the study of the seasonal abundance of *P.citri* on the six observation trees at "Imiti" (Figure 9), it was concluded that there was a relationship between temperature, relative humidity and the development of the citrus red mite in the field. In an investigation of the effect of these two abiotic ecological factors on the citrus red mite, it was decided that the first step should be to investigate what effect summer, autumn and winter conditions of temperature and relative humidity had on the development of *P.citri*.

In the field, an organism such as the citrus red mite is normally exposed to considerable variations in temperature and humidity, and if reared in the laboratory under constant conditions, development is often inhibited (Odum 1961). Under such conditions, the development of the organism cannot be compared directly with that observed in the field. Parker (1929) demonstrated that the eggs and nymphs of the grasshopper, Melanoplus atlanis Riley, developed faster under a variable temperature regime than at constant temperature. Additional observations by Hamilton (1950) and Clarke (1967) have shown that adult female locusts deposit more eggs per egg pod, and the growth rates of the fourth instar and adult locusts were higher under fluctuating temperature, than when the temperature was kept constant.

With this information regarding the effect of fluctuating temperatures on the life cycle of several different species of insects, it was decided to investigate the development of P.citri using an environment room which could be programmed for different climatic conditions.

From a study of the field climatic records, taken during the period that observations were carried out at "Imiti", a day representative of summer, autumn and winter was selected, and the environment room programmed to produce a climate that was, on an average, equivalent in thermal and humidity units to that recorded in the field during summer, autumn and winter.

To ensure that the information selected from the field data did reflect the temperature conditions of these three seasons, a check was made in which the temperatures were expressed in thermal units of 18°C hours. It was found that this conversion gave 112 18°C hours per week, 49 18°C hours per week and 28 18°C hours per week for summer, autumn and winter respectively. These values were similar to those observed in the field over a weekly period at "Imiti" for the three respective seasons of the year (Figure 9).

In simulating these climatic conditions, cognisance was also taken of daylength. The simulated summer day was taken as being 12 hours in duration, while autumn and winter daylengths were reduced to 10 hours each. The temperature and relative humidity values, based on the recorded field information, on which the environment room was programmed to produce the three seasonal conditions of temperature and humidity is presented in Table 19.

Table 19.

The temperature, in degrees Centigrade, and the relative humidity, based on recorded field data, which was produced in the environment room to duplicate summer, autumn and winter temperatures and relative humidities.

	Day			Night		
	Temperature (°C)	R.H. (%)	Time (Hours)	Temperature (°C)	R.H. (%)	Time (Hours)
Summer	25±0.5	50±5.	12	17±0.5	70±5	12
Autumn	17±0.5	60±5	10	12±0.5	90±5	14
Winter	14±0.5	60±5	10	10±0.5	90±5	14

The temperature and relative humidity variations recorded in the field for the selected summer, autumn and winter days, and the temperature and relative humidity produced in the environment room, are given in Figures 15a-15c.

The experimental procedure employed in this investigation was as follows. Several males and females of P.citri, collected from the field, were placed on the upper uncoated surface of a green lemon and allowed to acclimate in the environment room to the simulated temperature and humidity for an empirically chosen period of 24 hours. All eggs laid during this period were removed from the fruit surface and were excluded from the experiment. After acclimation, the adults were permitted to lay eggs until approximately 20 eggs had been laid on the fruit. The adults were then removed, and the development of the eggs and subsequent immature and adult stages were observed. All eggs laid by the first generation females were counted, and removed from the fruit at the end of each 24 hour period. Observations were maintained until all first generation females and males had died. This procedure was replicated three times for each regime.

The effect of simulated summer, autumn and winter conditions of temperature and humidity on P.citri in the environment room, expressed as the mean development time of the mite on the three fruit replicates, is given in Figures 16, 17 and 18.

In the summer regime, Figure 16, the mean generation time was 31 days, of which the eggs took seven days to hatch. The viability of the eggs was high, 93% of all eggs hatched. There was a marked overlapping between the development periods of the different immature stages, for example, on the 14th day after oviposition, all immature stages were found on the fruit. The time taken from the larval to the protonymphal instar was three days, from the protonymphal to the deutonymphal instar a further three days.

Males of P. citri were observed on the fruit 15 days after oviposition, and the females a day later. The appearance of the males prior to the females was in agreement with the observation made during the experiments conducted to evaluate the fruit and leaf substrates. All males passed through the deutonymphal stage of development. In all cases, the life-span of the males, ten days, was shorter than that of the females which lived for an average of 16 days. The production of the eggs by the first generation females began one to two days after the emergence of the females.

In the autumn regime (Figure 17), the mean generation time was 50 days, 19 days longer than that of summer. The eggs took 16 days to hatch, and the viability of the eggs was high, 97% of the total number of eggs observed on the three replicates hatched. The period from larva to protonymph was three days, but from protonymph to deutonymph took five days, two days longer than under summer conditions. Again the males appeared before the females, and all included the deutonymphal instar in their development. Females were present on the 29th day after oviposition, and egg production began five days later. On all three replicates the females lived for 22 days, six days longer than in summer, and the males an average of 23 days, 13 days longer than summer.

Under simulated winter conditions the mean generation time of the citrus red mite was extended to 70 days (Figure 18). The eggs, all of which were viable, took 23 days to hatch, six days longer than under autumn conditions. The period between larval and protonymphal instars was six days, three days longer than in autumn, and between protonymphal and deutonymphal instar seven days, two days longer than autumn. The males, all of which passed through the deutonymphal instar, appeared a day before the females. The females were present on the 44th day after oviposition, and egg production began four days later. From the three replicates, the average life span of the males was 21 days, and that of the females 27 days.

A summary of the data on the influence of simulated summer, autumn and winter conditions of temperature and humidity on the development and life cycle of P.citri is given in Table 20.

Table 20.

The influence of simulated summer, autumn and winter conditions of temperature and relative humidity on the development and life cycle of P.citri. Time is expressed in days.

	Summer	Autumn	Winter
% viability of the total number of eggs observed on the three replicates.	93%	97%	100%
Incubation time of eggs	7	16	23
Mean length of larval life	3	3	6
Mean length of protonymphal life	3	5	7
Mean length of male deutonymphal life	1	3	6
Mean length of female deutonymphal life	2	4	7
Mean length of male life	10	23	21
Mean length of female life	16	22	27
Mean period from egg to egg	16	32	47
Mean period from appearance of first generation female to egg production.	1	5	4
Mean length of egg production by first generation females	16	18	24
Mean generation time	31	50	70

The number of eggs produced per female per day, on each of the three replicate lemons, under the three simulated seasonal conditions of temperature and humidity, is given in Table 21.

Table 21.

The number of eggs produced per female *P.citri* per day, on each of the three replicate lemon fruit, under simulated summer, autumn and winter conditions of temperature and relative humidity.

	Summer			Autumn			Winter		
	Replicate			Replicate			Replicate		
Days	1	2	3	1	2	3	1	2	3
1	0.4	0.3	1.0	0.2	0.5	0.3	0.1	0.2	0.1
2	2.1	0.8	1.5	0.3	0.3	0.6	0.5	0.7	0.5
3	2.9	1.5	1.1	0.8	0.8	0.7	1.1	0.9	1.3
4	2.9	1.8	3.3	1.1	1.5	1.6	1.4	1.6	1.5
5	3.3	2.3	3.3	1.8	1.8	1.5	1.4	1.7	1.5
6	2.6	4.1	3.1	2.0	2.3	2.4	1.8	1.5	1.5
7	3.0	2.6	2.6	2.0	2.1	2.6	2.2	2.1	1.8
8	3.4	2.3	2.0	2.9	2.4	2.3	2.0	1.9	2.0
9	2.2	2.9	3.5	2.8	2.4	2.3	2.2	1.8	2.0
10	1.8	1.3	1.5	3.0	2.4	2.2	1.8	1.5	1.3
11	1.4	1.3	0.6	2.6	2.4	2.3	1.8	1.5	1.5
12	0.6	1.0	1.0	1.4	1.8	1.4	1.4	1.2	1.4
13		1.3		1.0	1.3	0.8	1.4	1.3	1.5
14		1.3		1.3	1.0	1.8	1.6	1.3	1.5
15		0.6		1.0	1.0	0.8	1.3	1.3	1.7
16				1.0	1.0	1.0	1.5	1.4	1.1
17							0.9	0.7	0.8
18							0.7	0.9	0.5
19							0.8	1.0	1.0
20							0.3	0.6	0.5
21							0.9	0.7	
22							1.0	0.5	
23							0.8		
23							1.0		
Total	26.6	25.4	24.5	25.2	25.0	24.6	29.9	26.3	25.0
Mean		25.5			24.9			27.1	
S.E. of mean		±0.6			±0.2			±1.5	
2 x S.E.		±1.2			±0.4			±3.0	

From Table 21, two times the standard error of the mean number of eggs laid per female P.citri under simulated climatic conditions of summer, autumn and winter, indicated that there was no appreciable difference in the number of eggs produced per female. Thus despite the fact that the life spans of the females were different in duration, the total number of eggs laid per female was the same.

Based on the results of the above environmental room studies, an estimation was made of the number of generations of the citrus red mite which may occur in a year. In this estimation, the results of which are shown in Figure 19, the start of the first generation was considered as occurring on the 1st February.

From Figure 19, it was concluded that approximately 13 P.citri generations a year may occur in the Sundays River Valley. This figure is in close agreement with that of Quayle (1938) for the citrus red mite in California, and is the same as that determined for P.citri at Zebediela by van Rooyen (1966).

The data presented in Tables 20 and 21 have shown that the seasonal variation of both temperature and humidity, duplicated in the environment room, did influence the development of P.citri. A comparison of this information with similar information from California indicated that the development of the citrus red mite during the periods of maximum density is similar to that in the Sundays River Valley. Quayle (1938) states that during the warmer season, May to October inclusive, the period of hatching to maturity was about three weeks, and this could be extended to five weeks of longer in Winter. He does mention, however, that the most important single factor responsible for the difference in the generation times was the extra time taken for the eggs to hatch, a fact which I have already demonstrated. Quayle (1938) goes on to state that the entire cycle from the hatching of the egg to the death of the adult occupied from 35 to 40 days, divided in the following manner: eggs - 10 days; larva - 3 days; protonymph - 3 days; deutonymph - 3 days; adult - 18 days. These times are comparable with those of autumn shown in Table 20.

In a study of the effect of temperature and season on the citrus red mite in Alabama, U.S.A., English and Turnipseed (1941) found that several stages in the life history of this mite could be mathematically related to the average temperature calculated from thermograph records. These experiments were conducted in a screened insectary, and the results obtained on the incubation period of the egg and the development of the adult stages were similar to those shown in Table 20. In one respect, however, my findings differed from those of English and Turnipseed (1941). These workers found that the number of eggs deposited per female varied with the season, the greatest number of eggs per female being deposited during the season of highest population density. I found however, that the number of eggs laid per female, under the three duplicated seasonal conditions were not significantly different.

From the environment room studies, it was difficult to detect a response of P.citri to relative humidity, as temperature and relative humidity were examined in combination. Further, all three simulated conditions had approximately the same humidity.

From Figure 9, however, there does appear to be a relationship between humidity and red mite numbers, especially in winter, where low numbers of citrus red mite coincided with low humidity and temperature. A factorial experiment was therefore designed to investigate the influence of relative humidity, temperature and their possible interaction on a population of P.citri.

e. The Effect of Constant Temperature and Relative Humidity on the Development of the Citrus Red Mite.

In this investigation on the effect of temperature and relative humidity on the development of P.citri, constant temperature and relative humidity conditions were used. In the field, fluctuating temperature and humidity make it difficult to determine just what effect each of these factors is having on a red mite population. However, by keeping the two factors constant, in an environment room, their individual actions on the life cycle of the citrus red mite might be determined.

The range of temperature and relative humidity selected for study were those which were most frequently recorded in the field. Three values of humidity were chosen, namely 30%, 60% and 90%, and three temperatures 17°C, 22°C and 27°C.

Each constant temperature was maintained in the environment room, which was itself kept at a constant humidity of 60%. The relative humidities 30% and 90% were produced from solutions made by mixing a known quantity of sulphuric acid with water, according to the method described by Solomon (1951).

For each temperature and humidity, three breeding units, similar to that shown in Figure 10, were used. In the case of 30% and 90% humidities, the units were enclosed in two separate desiccators with the respective sulphuric acid solution. Inside each desiccator was placed a calibrated "Edney" paper hygrometer, and the solutions were changed when the recorded humidity deviated by more than ± 5% from the desired value. A record of temperature inside each desiccator was measured with a thermometer set permanantly in the lid of the desiccator. The temperature and 60% relative humidity produced in the environment room was recorded on a thermohygrograph. During the course of the experiment, the temperatures did not vary by more than ±0.5°C, and the humidity was kept constant to within ±5%.

The effect of temperature and relative humidity on the development of P.citri was conducted in the following manner. In the environment room, set at one of the three temperatures, the development of the mite was studied with respect of the three different humidities. A number of adult male and female P.citri were placed on the upper uncoated surface of the lemon rearing units, and allowed to acclimate for 24 hours. All eggs produced during this period were removed from the experiment. The females were then allowed to lay approximately 20 eggs, and the development of these eggs and the subsequent immature stages were observed until the death of the first generation adults. Observations were carried out with the aid of a low power microscope every 24 hours. The lemon rearing units in each of the two desiccators were removed, counts made of the number of stages present, and then immediately replaced in the desiccator. At no stage during this examination were the fruit substrates outside the desiccator for longer than five minutes. All eggs laid by the first generation females were counted and removed after each 24 hour observation period.

The results of this experiment are given in Table 22.

Table 22.

The effect of constant temperature and near constant relative humidity on the development and life cycle, expressed in days, of the citrus red mite reared on lemon fruit.

RELATIVE HUMIDITY		Temperature 17°C	22°C	27°C
90%	a)	11, 11, 11	7, 7, 7	5, 5, 5
	b)	5, 5, 5	3, 3, 3	3, 3, -
	c)	5, 5, 5	3, 3, 3	3, 3, -
	d)	6, 5, 7	2, 2, 2	2, 1, -
	e)	18, 13, 11	11, 14, 12	11, 9, -
	f)	16, 15, 13	14, 13, 15	10, 12, -
	g)	30.4, 33.5, 33.2	35.0, 28.8, 33.6	31.3, 41.4, -
60%	a)	11, 11, 11	7, 7, 7	5, 5, 5
	b)	5, 5, 5	3, 3, 3	3, 3, 3
	c)	5, 5, 5	3, 3, 3	3, 3, 3
	d)	5, 5, 5	2, 2, 2	1, 1, 1
	e)	8, 6, 15	10, 14, 10	12, 11, 5
	f)	16, 19, 19	14, 15, 11	11, 11, 8
	g)	44.1, 46.6, 36.1	40.5, 72.9, 49.6	61.1, 54.0, 38.7
30%	a)	11, 11, 11	8, 8, 7	5, 5, 5
	b)	5, 5, 5	3, 3, 4	3, 3, 3
	c)	5, 5, 5	3, 3, 4	3, 3, 3
	d)	6, 7, 6	2, 3, -	2, 2, 1
	e)	11, 13, 10	7, 7, -	10, 10, 4
	f)	14, 19, 20	12, 8, -	8, 11, 10
	g)	21.7, 34.2, 26.8	23.9, 13.5, -	20.3, 37.0, 39.6

a) Incubation time of eggs.
b) Duration of larval life.
c) Duration of protonymphal life.
d) Duration of deutonymphal life.
e) Duration of male life.
f) Duration of female life.
g) Total number of eggs laid per female.

In Table 22, no observations were made on the third fruit replicate at 27°C and 90% relative humidity after the hatching of the eggs, and on the third fruit replicate at 22°C and 30% relative humidity after the protonymphal instar, as both these rearing units were accidentally destroyed during the course of the experiment.

To determine whether there was a significant difference in the effect of temperature and humidity on the development and life cycle of <u>P.citri</u>, and whether there was an interaction between these two abiotic factors, the information in Table 22 was analysed by means of an analysis of variance. The results of this analysis are given in Table 23.

<u>Table 23</u>.

The significance of temperature and relative humidity, and their possible interaction, on the development and life cycle of <u>P.citri</u>, expressed as the value of "F", from an analysis of variance on the data presented in Table 22.

	Value of "F"		
	Temperature	Humidity	Interaction
Incubation of eggs	207.0**	0.3	0.5
Duration of larval life	277.5**	0.0	1.3
Duration of protonymphal life	277.5**	0.0	1.3
Duration of deutonymphal life	159.3**	7.0**	0.0
Duration of male life	1.2	4.6**	2.9
Duration of female life	24.6**	0.6	2.5
Total number of eggs laid per female	1.0	13.6**	0.9

** denotes a significant difference at the 5% level.

From the results of the experiment shown in Tables 22 and 23, temperature is the major factor controlling the development of the citrus red mite. An increase in temperature significantly reduced the incubation period of the egg and the duration of the larval, protonymphal and deutonymphal instars. Humidity appeared to play little part in the development of the eggs and immature instars, with the exception of the deutonymphal instar, where a significant value of "F" indicated that humidity was a factor in deutonymphal development.

Prendergast (1938) in a similar investigation found that the time required for the eggs of the citrus red mite to hatch was not influenced by humidities between 20% and 80%, but that temperature was the main factor regulating incubation. Using the larvae of P.citri, Prendergast (1938) found that relative humidities of 95%, 40%, 20% and 5% at temperatures from 15.6°C (60°F) to 37.8°C (100°F) were fatal to larval development, and that only those larvae at a constant humidity of between 60% and 80% were able to reach maturity. This result is completely different from my findings. I found that all larvae reared between 17°C and 27°C, at humidities of 30%, 60% and 90% attained the adult stage.

The duration of adult male life was unaffected by temperatures between 17°C and 27°C, but there was a significant relationship to humidity. This would suggest that the males are probably more tolerant to temperature variations over this range than are any other stage. This result appears to be similar to that of English and Turnipseed (1941), who found that the influence of temperature on the adult life span was not as marked as on development. The length of the male life in particular, appears to be very variable. English and Turnipseed (1941) showed that in an insectary the seasonal life span of the male citrus red mite varied from an average of 34.0 days in January to a minimum of 10.2 days in June, with an overall average of 30.4 days, yet one male which emerged in November lived for over 94 days.

The life span of the female red mite was significantly affected by temperature, but humidities between 30% and 90% had no marked effect on the length of life. In an investigation of constant temperature and humidity on the length of life of the female citrus red mite, Prendergast (1938) concluded that there was no significant difference in the female life span maintained in humidities of from 20% to 60%, but that increasing the temperatures from 15.6°C to 37.8°C resulted in the shortening of the length of female survival.

A most interesting result from this experiment on the influence of constant temperature and relative humidity on the development of P.citri was that no marked difference was found between the number of eggs laid per female, at the three temperatures examined. The relationship between egg production and humidity, however, was highly significant. This result could explain why no significant difference in egg production was detected in the investigation on the influence of the three simulated seasonal conditions of temperature and humidity on the citrus red mite in the environment room. In this latter experiment, although the temperature ranges for each season were different, the three seasonal ranges of humidity were very similar (Figure 15a - 15c). It could therefore be expected, from the results of the constant temperature and humidity experiment, that no difference in egg production would be found.

Boudreaux (1958) also found that relative humidity affected the egg laying capacity of spider mites. In an experiment in which six different species of spider mites were exposed to humidities of between 0% and 35% and 95% and 100% at uncontrolled laboratory temperatures between 24°C and 35°C, he found that the rate of egg production was lower at constant high relative humidity than at constant low relative humidity. In comparing these results with my findings for P.citri at constant temperature and humidity, in which the oviposition rate was shown to be significantly related to humidity, I found that the greatest number of eggs laid per female occurred at 60% relative humidity, and that the rate of egg production declined at humidities of 30% and 90%. However, apart from the different species of mites used as test animals, the great difference between the low relative humidities used in each experiment make the comparison of results very difficult.

From the results of his experiment, Boudreaux (1958) suggested that the effect of high humidity in reducing the rate of oviposition was caused by a decrease in the feeding rate of the mites. This decrease in the feeding rate was caused by the prevention of moisture loss from the body which results in a decrease in physiological activity. In a wet atmosphere, therefore, the utilisation of the food is slow, and hence its conversion into eggs occurs at a much slower rate than under dry conditions.

In the Sundays River Valley, the range of humidity throughout the year is generally uniform (Table 3), and as a result the egg production per female probably does not vary significantly from season to season. English and Turnipseed (1941), on the other hand, found a marked seasonal difference in the average number of eggs laid per female P.citri in Alabama, U.S.A. However, this result could be explained by the seasonal variation of relative humidity being more marked in this area than in the Sundays River Valley.

From the data in Tables 22 and 23, the most favourable humidity for oviposition was found to be 60% relative humidity. Humidities higher or lower than this value resulted in decreased egg production, while the effects of temperature were most marked on the incubation of the egg and the development of the immature stages. From this result it appears that these two abiotic factors influence the citrus red mite at different levels of the life cycle, humidity being the main factor controlling the rate of oviposition, and temperature eclosion and survival.

At no stage during the development or life cycle of P.citri, under these constant conditions, was there a significant interaction between temperature and humidity. This information indicated that temperature and humidity act independently on the red mite population. It must be stressed, however, that prolonged periods of constant temperature and humidity are seldom encountered in the field. Thus while this factorial experiment indicated the effect of constant temperature and relative humidity on the life cycle of P.citri in the laboratory, the effect of these two abiotic factors on a population of red mite in the field is probably very complex. In the laboratory it was found that humidities between 30% and 90%, and temperatures between 17°C and 27°C were not fatal to the development of the citrus red mite, but markedly altered the generation time and the rate of oviposition. In the light of these results it may be asked why the red mite population density does not reach its greatest level in the field in summer, instead of autumn and spring (Figure 9).

In a study of the effect of temperature and season on P.citri in the U.S.A., English and Turnipseed (1941) suggested that the reason for the increase in the number of red mite during the cooler seasons of the year was due to the rapid rate of development in hot weather being offset by the longer life in cool weather. In addition they found that the population potential for cool weather was increased by a rise in the rate of oviposition.

I found that under simulated summer and winter conditions, the development from egg to adult was 14-15 days, and 42-43 days respectively. In summer, therefore, development is approximately three times as fast as in winter. The adult female life span, however, is nearly twice as long in winter than in summer (Table 20). These results are in agreement with those of English and Turnipseed (1941). My findings differed from those of these workers in that the number of eggs laid per female under the three simulated seasonal conditions were not significantly different.

Thus, as the generation time in summer was 31 days, twice as fast as that in winter, 70 days, the total number of eggs produced per female in one generation in winter would be equivalent to half the number of eggs produced per female over the same period in summer. Thus, the maximum population of red mite in the Sundays River Valley would be expected to occur in summer.

A factor that might explain the seasonal abundance of the citrus red mite in the Sundays River Valley is the frequency of extreme temperatures which occur in the field during the respective seasons. It has been shown by Prendegast (1938) and estimated by English and Turnipseed (1941) that temperatures between 30°C and 38°C were lethal to the citrus red mite. Jeppson et al. (1957, 1961) also observed a relationship between temperatures of 38°C, relative humidities of below 20% and a decline in the citrus red mite population in the field. Accordingly, an investigation was carried out in the environment room to determine the effect of high temperature, temperatures greater than 35°C, on the immature and adult stages of P. citri.

f. The Variation in the Temperature of the Microclimate Surrounding the Leaf, and the Effect of High Temperatures on the Seasonal Abundance of the Citrus Red Mite.

Before the effect of high temperature on the seasonal abundance of the citrus red mite is discussed, the results of an examination of the variation in the temperature of the leaf microclimate are given.

In the previous experiments, the development and population density of the citrus red mite in the field has been studied in relation to the gross environmental temperature and relative humidity, as recorded by a thermohygrograph inside a Stevenson screen. However, these temperatures and humidities are not strictly those experienced by P.citri situated on the leaves of a citrus tree, for the red mite lives in a microclimate which surrounds the leaf. An investigation was therefore conducted to determine the difference in temperatures between those recorded in a Stevenson screen, and the microclimate 3 millimeters above the leaf surface.

The relative humidity of the leaf microclimate was not determined as no suitable method for field use was available. It has been pointed out by Thomas (1949), however, that the humidity of the leaf microclimate is related to a number of factors of which ambient temperature, relative humidity and wind velocity are among the most important.

For the purpose of measuring the temperature of the leaf microclimate in the field, a resistance thermometer was constructed using a thermistor probe. The circuit of the resistance thermometer is shown in Figure 20.

Three thermistor probes were used to compare the temperature recorded inside a Stevenson screen (ambient temperature), with the microclimate temperature of two leaves, one leaf on the southern aspect, and the other on the northern aspect of a mature Washington Navel citrus tree. Each thermistor was covered with aluminium foil, as shown in Figure 21. This foil prevented the direct rays of the sun affecting the temperature readings of those thermistors used on the leaves, while the thermistor used in the Stevenson screen was covered with foil to provide an exactly comparable unit for ambient temperature measurement.

Holes were made at the top of the aluminium foil cylinder to factilitate the circulation of air. Readings were taken at half-hourly intervals over a total period of 12 hours, from 06.00 hours to 18.00 hours, and on three occasions, in winter (2nd June 1966), spring (24th September 1966) and summer (19th January 1967). The results of these three temperature determinations are given in Figures 22a - 22c.

During the 2nd June 1966, the experimental orchard was covered with mist and dew from 06.00 hours to 10.00 hours. The mist lifted at 10.30 hours and by 12.30 hours the dew, which was most apparent on the shaded southern aspect, had evaporated. After the mist had lifted, the sky was clear until the temperature readings were terminated at 18.00 hours.

On the 24th September 1966, no mist or dew was observed on the experimental tree, and the cloud cover was always under 25%. The 19th January 1967 was a cool summer day, and the sky was overcast with an estimated cloud cover of 75% from 06.00 hours to 18.00 hours.

From Figures 22a - 22c, the temperature recorded from the leaf microclimate on the northern aspect was higher than ambient temperature, or the temperature on the southern aspect. Ambient temperature was generally higher than that recorded from just above the leaf surface on the southern aspect.

The greatest difference between the leaf temperatures on the northern and southern aspects occurred during winter (Figure 22a). It is suggested that the reason for these low temperatures on the southern aspect was probably due to the presence of dew on the leaf during the early morning, and the continual shade caused by the apparent movement of the sun northwards. In winter, the movement of the sun northwards results in the southern aspect being completely shaded throughout the day, while only the northern aspect receives the direct rays of the sun. In summer, however, with the apparent movement of the sun southwards, both southern and northern aspects receive the suns rays. Thus, in summer the leaf microclimate temperatures on the two aspects were not markedly different from ambient temperature (Figure 22c).

Fry (1947), working on the fish Gisella nigricans, found that the preferred temperature varied directly with the temperature at which the fish had been living, up to a certain point. Beyond this point, the preferred temperature became independent of the temperature to which the fish had been acclimatised. Fry designated this upper limit, above which the preferred temperature cannot be raised by further increasing the temperature at which the fish had been living, the "final preferendum". From the information presented on the temperature differences on the microclimate on the northern and southern aspects of a citrus tree, it would appear that there is a temperature gradient between these two aspects. From Figures 22a and 22b, it is suggested that during spring, autumn and winter the temperature preferendum of P.citri occurs on the northern aspect of the tree, thus the largest number of mites are found on this aspect. With the advent of summer, both northern and southern aspects are now exposed to the direct rays of the sun, the final preferendum is exceeded, and temperatures greater than the upper lethal limit may occur on both aspects. It is proposed that this destruction of the temperature preferendum, and the occurrence of unfavourably high temperatures contribute to the decline in red mite numbers on both aspects of a tree during summer.

The reason why the infrequent occurrence of unfavourably high ambient temperatures in autumn and winter do not appear to have the same effect on the population density of the citrus red mite as similar temperatures in summer, is because the temperature on the southern aspect of a citrus tree during these two seasons is several degrees lower than either ambient temperature or the microclimate temperature on the northern aspect. This point is well shown in Figure 22b, where on the 24th September 1966 a maximum ambient temperature of 36°C occurred and temperatures of greater than 38°C were recorded on the leaf microclimate on the northern aspect, but the temperature of the leaf microclimate on the southern aspect never rose higher than 33°C. Thus, this high ambient temperature probably had little effect on the P.citri population on the southern aspect of the tree.

From this microclimate study, the similarity between the temperature of the leaf microclimate on the northern and southern aspects of a tree with ambient temperature in summer, indicated that duplicating ambient temperature in the laboratory to evaluate the effect of high summer temperature on P.citri, was a good approximation to the temperature experienced by a population of red mite in the field during this season.

A hot-dry period during early summer, in which temperatures rose above 35°C, and which corresponded with the occurrence of low populations of P.citri, was selected and reproduced in the environment room. The period chosen for duplication was between the 18th and 23rd October 1966, and the variations of temperature and relative humidity over this period, obtained from the thermohygrograph situated in the orchard at "Imiti", are shown in Figure 23a.

From Figure 23a, temperatures of greater than 35°C were recorded at "Imiti" on the 19th and 23rd October, while over the whole six day period temperature ranged from 10°C to 39°C. The relative humidities recorded from the 18th to 23rd October varied from 20% to 93% relative humidity. In the environment room an attempt was made to simulate these temperature and humidity fluctuations, and the result is shown in Figure 23b.

It was found that although the high temperatures could be reproduced satisfactorily, the capacity of the environment room was unable to adequately reproduce the variations of humidity recorded in the field. It has already been shown that humidities between 30% and 90% had little effect on the survival of the immature and adult stages of the red mite, but the failure of the environment room to accurately reproduce humidities of 20% meant that the effect of low humidities of this order on the survival of P.citri, could not be investigated.

A number of immature and adult stages of the citrus red mite were collected from the field during February 1968, and placed on four lemon rearing units. Two of these units were kept in the laboratory and constituted the control trial. The two remaining units were placed in the environment room and exposed to the simulated temperature and humidity conditions shown in Figure 23b.

In the laboratory during the course of this experiment, the average maximum temperature was 24°C, the average minimum temperature 21°C and the average relative humidity, measured at 08.00 hours, was 65%. A count was made of the number of immature and adult red mite stages on each of the four lemon fruits with a low power microscope every 24 hours, and a note was kept of the number of stages that were dead. Before the start of the experiment the red mites were allowed to acclimate for 24 hours under laboratory conditions. After the acclimation period, the two test rearing units were transferred into the environment room. At the conclusion of the experiment the two test units were replaced in the laboratory, and the mites were considered to have survived the simulated temperatures, if after 48 hours in the laboratory no mortality of the remaining instars was observed.

The results of this experiment are shown in Table 24.

Table 24.

The effect of a simulated period of high summer temperature, 18th to 23rd October 1966 (Figure 23b), on the survival of the immature and adult stages of the citrus red mite.

Control

Time	Replicate 1			Replicate 2		
Acclimation period	F=10	M=2	I=14	F=10	M=2	I=16
18th October	F=10	M=2	I=14	F=10	M=2	I=16
19th October	F=11	M=3	I=12	F=10	M=4	I=12
20th October	F=11	M=3	I=12	F=13	M=4	I= 9
21st October	F=11	M=4	I=11	F=13	M=4	I= 9
22nd October	F=14	M=4	I= 8	F=15	M=5	I= 6
23rd October	F=14	M=4	I= 8	F=15	M=5	I= 6
After 48 hours	F=15	M=4	I= 7	F=16	M=6	I= 4

Test

Time	Replicate 1			Replicate 2		
Acclimation period	F=11	M=2	I=14	F=13	M=2	I=14
18th October	F=11	M=2	I=14	F=13	M=2	I=14
19th October	F= 8	M=0	I=12	F= 8	M=0	I=11
20th October	F= 8	M=3	I= 9	F= 7	M=2	I= 9
21st October	F= 9	M=3	I= 8	F= 9	M=3	I= 6
22nd October	F=10	M=5	I= 5	F= 9	M=3	I= 6
23rd October	F= 9	M=0	I=-4	F= 7	M=0	I= 6
After 48 hours	F= 9	M=1	I= 3	F= 7	M=0	I= 6

F = Adult female *P.citri*.
M = Adult male *P.citri*.
I = Immature stages of *P.citri*, (including larvae, protonymphs and deutonymphs).

From Table 24, the total number of immature and adult stages of the red mite were reduced by 50% on exposure to the simulated high summer temperature and relative humidity variations between the 18th and 23rd October. While the two days during which temperatures rose above 35°C resulted in the death of a number of immature and adult female stages, the greatest effect of these high temperatures was to completely eliminate the male stage.

No separate observations were conducted on the egg stage, but it was found that the eggs laid by the females on the test replicates were unaffected by the simulated temperatures. An examination of the test fruit after they had been removed from the environment room showed that a number of larval forms were present. Confusion of these newly hatched larvae with those surviving the simulated conditions was avoided by counting the total number of larvae present on the fruit and subtracting the number of empty egg cases.

In the field, the destruction of the male stage would lead to a reduction in the population density of P.citri. If the males are removed from the population by high temperatures, the eggs produced by the unfertilised females would give rise to males only. Thus, if temperatures in excess of 35°C were to occur with sufficient frequency, the male component of the population would be continually removed, and the population density would decline. If this process were continued over a prolonged period, the citrus red mite population would eventually be eliminated, but from field observations this was never the case. The citrus red mite population at "Imiti" did fluctuate between high and low densities, but the mite was never absent from the trees (Figure 9). A reason why the mite population was not eliminated is probably because the egg, immature and female stages appear to be more tolerant to these high temperatures than the male. During intervening periods of high temperature, therefore, the egg and immature stages could give rise to males, which in turn would ensure that the females deposited fertilised eggs. This process can be seen from Table 24, where on the test fruit, between the 19th and 23rd October, the immature stages gave rise to a number of adult males. This reappearence of the male stage after a period of high temperature would ensure the fertilisation of the female, and hence the maintainence of the population.

From December 1967 to January 1968, during an unusually cool summer, a marked increase in the population density of P.citri was observed in several untreated orchards in the Sundays River Valley. At the beginning of February 1968, however, following a 30 hour period in which the temperature reached 42°C and the relative humidity 13%, the density of the citrus red mite was drastically reduced. This led to the hypothesis that apart from the effect of temperatures between 35°C and 39°C, temperatures of greater than 40°C probably exceeded the upper lethal limit of the immature and adult stages of P.citri. Accordingly, this short period of very high temperature was simulated in the environment room, and its effect on the survival of the immature and adult stages of the citrus red mite studied.

The high temperatures and low humidities which were recorded in the field on the 5th February 1968 is shown in Figure 24a, and the temperature and humidity duplicated in the environment room in Figure 24b.

It was again found that the duplicated temperature conditions in the environment room were comparable with those recorded in the field, but a corresponding variation of relative humidity was not achieved. Thus while the relative humidity in the environment room did rise to 40%, the full effect of the humidity component on the red mite instars could not be examined.

As in the previous investigation, four lemon rearing units were used, on the surfaces of which a number of immature and adult stages of P.citri, collected from the field, were placed. Two of the rearing units were kept in the laboratory as the control, and the remaining two were placed in the environment room and exposed to the simulated conditions. The citrus red mite on all four units were allowed 24 hours to acclimate to laboratory conditions, after which the two test units were transferred to the environment room. A record was kept of the number of deaths that occurred during the experiment, and the four rearing units were examined after 24 hours under a low power microscope. At the conclusion of the period of exposure in the environment room, the two test units were transfered into the laboratory, and all P.citri alive on the fruit after 48 hours were considered to have survived exposure to the high temperature.

The results of this investigation are given in Table 25.

Table 25.

The effect of a 30 hour period, between 5th-6th February 1968, during which a maximum temperature of 42°C was recorded, on the survival of the immature and adult stages of the citrus red mite.

Control

	Replicate 1			Replicate 2		
Acclimation period	F= 9	M=2	I=4	F=7	M=1	I=6
5th February	F=-9	M=2	I=4	F=7	M=2	I=5
After 48 hours	F= 9	M=3	I=3	F=9	M=2	I=3

Test

	Replicate 1			Replicate 2		
Acclimation period	F=15	M=4	I=11	F=16	M=3	I=6
5th February	F= 1	M=0	I= 0	F= 0	M=0	I=3
After 48 hours	F= 1	M=0	I= 0	F= 1	M=2	I=0

F = Adult female P.citri.
M = Adult male P.citri.
I = Immature stages of P.citri (including larvae, protonymphs and deutonymphs).

From Table 25, only one female and three immature stages of the red mite survived exposure to 42°C, and all the surviving immature stages were in the teliochrysalid stage. After 48 hours under laboratory conditions, the female was still alive, and the immature stages had given rise to one female and two adult males. No mortality was observed in the two control replicates during the course of the experiment.

From the results of the three experiments on the effect of temperature and humidity on the survival and development of P.citri, the following explanation could be drawn as to why maximum numbers of the citrus red mite do not occur in the field during summer.

In any natural population, variations in density are related to the interaction between the birth rate and death rate, and all components of the environment act either directly or indirectly on these two parameters of the population, altering the balance between them. Thus, if the environment of a species over a period of time favours the birth rate, while the death rate is minimal, the population density of the species will increase. This relationship is the basis on which Birch (1948) developed the concept of "r", or the intrinsic rate of natural increase. There are, however, several disadvantages in applying this concept to populations of P.citri, where the intervals between generations are short, and successive generations overlap.

Birch (1948) stated that:-

> "the parameter 'r' refers to a population with a stable age distribution. In any other sort of population the rate of increase varies with time until the stable age distribution is assumed."

Thus, in the case of the citrus red mite, "r" cannot be determined until the growth of the population, under defined conditions, has been studied for a considerable period. In addition, it is doubtful whether a stable age distribution is ever attained in an animal such as P.citri, where the effect of extreme temperature and humidity influence the development and reproductive rate of the mite so markedly. Therefore, no intelligable significance can be attached to the parameter "r" after its value has been determined.

The formula used for the calculation of "r" considers that the growth of the population is constantly proportional to the size of the population. However, this is not true except for large populations over long periods of time, and as such it cannot be taken as a basis for the examination of experimental data.

In the results of the experiments reported above, two components of the environment of P.citri were studied, namely temperature, and to a lesser extent relative humidity which is dependent on temperature, and it has been shown that the rate of reproduction, development and the survival capacity are related to these two factors. The rate of development and reproduction was found to be directly related to temperature from 10°C to 27°C and humidities between 30% and 90%, while temperatures above 35°C resulted in an increase in mortality. Thus, the occurrence and variation of temperature and relative humidity in the field, by influencing the birth rate and death rate, can affect the population density of P.citri by creating periods which are either favourable or unfavourable for an increase in numbers. To test this hypothesis, it was decided to determine whether the results obtained from the environment and laboratory experiments could explain the seasonal abundance of P.citri recorded in the field. To this end a graph was constructed of the mean population variation of P.citri per leaf on the six trees at "Imiti", from March 1966 to October 1967, and the number of days per week temperatures of less than or equal to 5°C, greater than or equal to 35°C, and greater than or equal to 40°C and relative humidities of less than or equal to 25% occurred. This graph is given in Figure 25.

I have included low temperatures of less than or equal to 5°C in Figure 25 for I consider that temperatures of this order could influence the abundance of the citrus red mite by reducing the rate of development, a point which has been demonstrated in the study of simulated winter conditions on the development of the citrus red mite (Table 20). In addition, Woglum (1937, vide Ebeling 1959) has stated that while the coldest weather recorded in southern California did not produce a marked mortality of P.citri, it greatly reduced the activity of the species.

From Figure 25, the periods March 1966 and October 1966 to February 1967, during which temperatures of greater than or equal to 35°C and greater than or equal to 40°C were most frequently recorded, were coincident with low field populations of P.citri. Similarly, the periods of low temperature, less than or equal to 5°C, during June to July 1966 and June to September 1967 also corresponded with low numbers of red mite. In contrast, the maximum numbers of citrus red mite was observed during those periods when these temperatures were least frequent, autumn and spring.

The isolated occurrence of low humidities from March 1966 to March 1967 was not coincident with the variation in citrus red mite population density over this period. However, during July to October 1967, which was a period of drought in the Sundays River Valley, relative humidites of less than or equal to 25% were frequently recorded, and together with a wide variation in temperature, created an unfavourable period for red mite increase. Thus, the population density of the citrus red mite did not increase during this normally favourable time of the year.

As mentioned previously, the seasonal abundance of the citrus red mite at Zebediela, reported by van Rooyen (1966), differed from my findings on P.citri in the Sundays River Valley. In the light of this difference, therefore, I examined the work of van Rooyen in more detail. Climatic records were obtained from Mr. van Rooyen, which covered his period of study, and a graph was made of the extremes of temperature and relative humidity recorded at Zebediela from August 1962 to July 1963. The seasonal variation of P.citri at Zebediela, according to van Rooyen (1966), was then superimposed on this graph. The counts of P.citri are given as the mean number of P.citri per leaf divided by five. In this way a graph similar to that given in Figure 25 was constructed. This graph of the variation in the density of the citrus red mite, and the occurrence of extreme temperature and relative humidity at Zebediela, from August 1962 to July 1963, is given in Figure 26.

Zebediela, a citrus producing area in the northern Transvaal lies at an altitude of approximately 3,500 feet above sea level, and is situated in a summer rainfall area. From Figure 26, the number of days per week the temperature was less than or equal to 5°C, or greater than or equal to 35°C was far smaller at Zebediela than in the Sundays River Valley (Figure 25), and at no time during van Rooyens' investigation did the temperature rise above 40°C. This moderate temperature regime was not matched by relative humidity. At Zebediela relative humidities of less than or equal to 25% were frequently recorded, particularly between August and October 1962 and

February and May 1963. Cool but very dry winters are characteristic of the South African highveld. The following explanation, based upon the results of the factorial experiment reported in Tables 22 and 23, is therefore suggested to account for the occurrence of the peak populations of P.citri in summer at Zebediela, This factorial experiment clearly showed that a relative humidity of 30% significantly influenced the rate of oviposition of P.citri,and was independent of temperature. It follows then that the periods August to October 1962 and February to May 1963, when relative humidity was less than 25%, would be unfavourable for red mite increase. This was indeed the case as Figure 26 shows. The less frequent occurrence of low humidity between November 1962 and January 1963 was as a result of high rainfall, and during this period an increase in the population density of the citrus red mite look place. The reduction in the population numbers during January 1963 was shown by van Rooyen to be related to the action of insect predators. No further increase in red mite density occurred from February to July 1963 because of the low humidity during this period.

From the above analysis, the occurrence of high temperature and low relative humidity could alone explain the difference in the times at which peak populations densities of P.citri are found at Zebediela and the Sundays River Valley. In the following chapter other factors are examined which could reinforce the effect of these two abiotic factors on the seasonal abundance of P.citri, and offer an explanation of the variation in mite population density between trees. It has not been possible to examine all factors in detail but they are mentioned for the sake of completeness and to allow one to assess the limits of this study.

10.

OTHER FACTORS THAT MAY AFFECT THE SEASONAL ABUNDANCE AND POPULATION DENSITY OF THE CITRUS RED MITE.

Apart from temperature and relative humidity, other factors have been suggested by various authors as a possible cause for the fluctuations in citrus red mite population density.

The age of the leaf and the amount of damage caused by the feeding activity of P.citri has been proposed by Henderson and Holloway (1942) as a factor influencing citrus red mite populations. These workers found that there was an increase in the mortality of the red mite and a reduction in egg production associated with feeding injury. Henderson and Holloway (1942) also found that the number of eggs produced on young and medium aged leaves were significantly greater than on old leaves, but that feeding injury influenced egg production to a much greater extent on flush-growth leaves than on older leaves.

Fleschner (1952) proposed that there was a capacity for the host plant of resist attack by the citrus red mite. He suggested that this "host plant resistance" was caused by the biochemical constituents in the plant, or by mechanical means such as the thickness or physical condition of the cuticle or epidermis.

From the experimental evidence of Henderson and Holloway (1942), and the correlation of the major growth cycles of Navel orange trees with the population peaks of P.citri, Jeppson et al. (1961) suggested that the seasonal growth cycles of the orange tree may be largely responsible for the increase in population density of citrus red mite. In contrast, on lemon trees, which have no definite growth period, but which tend to produce new leaves during most of the year, Jeppson et al. (1957) and Jeppson (1963) state that on these trees it is the effect of weather rather than growth cycles that influence red mite population density.

While I would agree, from the evidence presented by Henderson and Holloway (1942), that the growth cycle may be a factor responsible for the development of large populations of P.citri, I am not entirely convinced from the information given by Jeppson et al. (1957, 1961), that the growth cycles in oranges are more important than climate. Jeppson et al., maintain that weather is the major factor determining P.citri density on lemons, but not on orange trees. However, if weather can influence the population density of the mite on one variety of Citrus, it can surely influence the density on another. In fact in the two orange orchards investigated by Jeppson et al. (1961), a relationship was found between temperature, the rate of evaporation and the development of red mite populations. The fact that orange trees exhibit definite periods of flush-growth, could be an additional factor affecting the density of P.citri on these trees, but to advocate that the growth cycle is more important than the influence of climate is possibly a little premature. I would propose that an answer to this problem would be a comparison of the population fluctuations of the citrus red mite on both orange and lemon trees in the same area, over the same period of time, with detailed records of the variation in temperature and humidity, and the occurrence of the growth cycles. Until this or a similar type of investigation can be carried out, it cannot be considered with any certainty, that the growth cycles of the orange tree have a greater affect on the population density of the citrus red mite, than climatic conditions.

I did not investigate the effect of leaf age and leaf injury, host plant resistance or the influence of the seasonal growth cycles on the population density or seasonal abundance of the citrus red mite, as this deviated from the main theme of this study. However, an investigation of these factors in South Africa might lead to a better understanding of the seasonal variation in the population density of the citrus red mite.

Hamstead and Gould (1957), Henneberry (1962), Henneberry and Shriver (1964) and Cannon and Connell (1965) have demonstrated that there is a direct relationship between the population density of mites and the nitrogen content of the host plant. In order to test this possibility, a leaf sample comprising 100 leaves was picked from each of the six experimental trees at "Imiti", in the manner prescribed by Stanton (1966). It was intended that these leaf samples be analysed for nitrogen, potassium and phosphorus content, but the samples were lost in transit from the Sundays River Valley to the analytical laboratory. A fresh sample of leaves was not collected, for immediately after the initial samples were taken the fruit crop from the six experimental trees was harvested, and as Stanton (1966) points out, it is difficult to select leaves of the same age from non-fruit bearing twig terminals. Leaf samples were taken, however, from two treatments in the red scale insecticidal trial at "Littlecote" (See Figure 2). The trees in this trial were mid-season Valencia's, Bailage variety, and from each of the six replicate trees within the unsprayed control treatment, and the six trees within the treatment which comprised a red scale spray of 0.05% Parathion + 0.025% Gusathion + 0.2% Spray oil, 100 leaves were collected at the 21st June 1967, in accordance with the recommendations presented by Stanton (1966). These leaf samples were analysed for nitrogen, potassium and phosphorus.

The variation in the total number of P.citri, on four of the six trees within the two red scale treatments sampled at "Littlecote", is presented in Figures 27 and 28.

During 1967, in the unsprayed control treatment (Figure 27), a marked increase in numbers of red mite were recorded from replicate trees 2 and 5, while the remaining two experimental trees showed little or no increase in mite density. On four of the six trials trees within the treatment which received a

Parathion-Gusathion spray in 1964, 1965 and 1966 (Figure 28), the greatest numbers of P.citri observed in 1967 were found on tree 6, while three 2 showed a slight rise in P.citri density from May to June. No increase in red mite density was recorded from replicate 3 and 5.

The percentage content of nitrogen, potassium and phosphorus in the leaf samples collected from each of the six trees within the two above treatments is given in Table 26.

Table 26.

The nitrogen, potassium and phosphorus in the leaf samples, expressed as the percentage of dry leaf tissue, from each of the six experimental trees within the unsprayed control treatment, and the six trees sprayed with 0.05% Parathion + 0.025% Gusathion + 0.2% Spray oil in October 1964, 1965 and 1966, in the red scale insecticidal trial on the farm "Littlecote",Sunland.

Unsprayed Control Treatment

	% Nitrogen	% Potassium	% Phosphorus
Tree 1	2.25	0.63	0.10
Tree 2	2.48	0.72	0.10
Tree 3	2.53	0.63	0.10
Tree 4	2.36	0.80	0.10
Tree 5	2.52	0.72	0.10
Tree 6	2.27	0.67	0.11

0.05% Parathion + 0.025% Gusathion + 0.2% Spray oil in October 1964, 1965 and 1966.

	% Nitrogen	% Potassium	% Phosphorus
Tree 1	2.50	0.83	0.11
Tree 2	2.50	0.72	0.10
Tree 3	2.25	0.80	0.10
Tree 4	2.14	0.80	0.12
Tree 5	2.52	0.60	0.11
Tree 6	2.25	0.87	0.11

The optimum ranges for nitrogen, potassium and phosphorus in leaf samples from mid-season Valencia's in the Sundays River Valley are taken as 2.10% - 2.50%, 0.90% - 1.50% and 0.11% - 0.14% of dry leaf tissue respectively (Moore, 1967). In comparing the results of the leaf analyses given in Table 26 with these ranges, all leaf samples showed a satisfactory nitrogen content. The percentage content of potassium was low in all trees, while the phosphorus content was low in the majority of cases. The reason for the low potassium and phosphorus levels in the twelve experimental trees was not known, but it is suggested that it was probably due to the fertilisation practices of the farmer concerned.

By observation, no apparent relationship was found between the red mite population density on the trees in both treatments and the level of phosphorus in the leaf samples. An analysis, using Students-t test, was made on the nitrogen level in the leaf samples taken from those trees on which large numbers of P.citri were recorded in 1967, and from those trees showed little or no red mite build-up. This analysis indicated that there was no significant difference, at the 5% level, in the nitrogen content of the leaves between these two groups of trees, ($t=0.471$; $df=10$), but that there was a significant difference between the potassium content of the leaves and the occurrence or absence of high red mite numbers on the trees, ($t=3.462$; $df=10$), However, it must be pointed out that these findings were based on the results of a single leaf analysis, and do not suggest anything other than the outcome of a preliminary experiment. This study of the ecology of the citrus red mite was not concerned with the possible relation between the nutritional status of the citrus tree and citrus red mite population density, consequently this line of investigation was not pursued any further, although its importance is appreciated.

Another factor that could be responsible for the variation in the population density of P.citri on individual replicate trees is the number of the predaceous mite, A.addoensis, on each tree. In the following chapter the biotic factor of predation by A.addoensis is examined in so far as it may offer an explanation of the variation in P.citri population density between trees, and also reinforce the effect of temperature and relative humidity on the seasonal abundance of the citrus red mite.

11.

THE INFLUENCE OF THE PREDACEOUS MITE, AMBLYSEIUS (TYPHLODROMALUS) ADDOENSIS van der Merwe and Ryke, ON THE POPULATION DENSITY OF THE CITRUS RED MITE.

The work of Quayle (1938), Debach et al.(1950), Fleschner and Ricker (1953a, 1953b) and Ebeling (1959) has shown that many species of predatory insects and mites attack the citrus red mite in the U.S.A., while in South Africa, van Rooyen (1966) has listed 14 different insect and mite species which feed on P.citri at Zebediela, Transvaal.

In the Sundays River Valley, I have observed several species of insects belonging to the families

Coniopterygidae, Chrysopidae and Coccinellidae, as well as a number of predaceous mite species associated with large populations of P.citri in infested orchards. A list of these insects and mites is given below

Order: Neuroptera

Family : Coniopterygidae

Conwentzia capensis Tjed.

Family : Chrysopidae

Chrysopa (Suarius) squamosa Tjed.

Order: Coleoptera

Family : Coccinellidae

Adalia flavomaculata (Deg.)

Chilomenes lunata (Fabr.)

Chilomenes propinqua (Muls.)

Exochomus flavipes (Thun.)

Lotis sp.

Pharoscymnus sp.

Scymnus sp.

Stethorus sp.

Order: Acarina

Family : Phytoseiidae

Amblyseius (Typhlodromalus) addoensis van der Merwe and Ryke.

Family : Cunaxidae

Cunaxa sp.

Cunaxoides sp.

Family : Tydeidae

Paralorryia sp.

Family : Erythraeidae

Balaustium sp.

Apart from insect and mite predators, other organisms have also been reported to cause mortality amongst P.citri populations in the field. A fungus, Entomophthora sp., was found by Fischer (1951) to destroy up to 95% of a citrus red mite population in Florida, U.S.A., while a type of dysentery, of which the causal agent has not yet been determined, was described by Muma (1955).

A virus disease of P.citri, suspected of being caused by a noninclusion virus (Smith *et al*., 1959), was discovered in 1958 by Munger *et al*. (1959). The virus was reported to occur naturally in the citrus producing areas of California by Gilmore and Munger (1963) and Tashiro and Beavers (1966). The presence of the disease was determined by either collecting mites from infected areas and culturing them in the laboratory until the disease symptoms appeared (Gilmore and Munger 1963), or by the presence of birefringent crystals in infested mites (Smith and Cressman, 1962). However, no investigation on the occurrence of this virus in P.citri populations in South Africa has yet been undertaken.

From a survey of the literature on the effect of predation on the citrus red mite, I concluded that the majority of the work is confined to the influence of insect predators on P.citri populations, while little has been done on the effect of predaceous mites. Further, in South Africa van Rooyen (1966) has shown that there is a relationship between citrus red mite density and the abundance of certain insect predators. In the light of the above, therefore, it was considered desirable that some work should be undertaken to evaluate the influence of predaceous mites on citrus red mite populations.

Of the five predaceous mite species found on citrus in the Sundays River Valley, A.addoensis was the most abundant, and the numbers of this species observed on the leaves of citrus trees heavily infested with P.citri suggested that it could be an important predator of the citrus red mite. The remaining four species of predaceous mite were not frequently found, and for this reason are probably not important predators of P.citri. A.addoensis was therefore selected for study, and the investigation of the relationship between this predaceous mite and P.citri on citrus in the Sundays River Valley was studied.

a. The Feeding Habits of A.addoensis.

The investigation of the influence of A.addoensis on the population density of P.citri was commenced by determining the preference of the predator for the various stages of the host. A number of eggs, immature stages, males and females of the red mite were isolated on lemon fruits together with several adult A.addoensis, and observations on the number of each stage eaten by the predaceous mite were made every 24 hours with the aid of a low power microscope. At the end of every 24 hour period, the number of stages of P.citri, eaten by the predator, were replaced. These experiments were conducted under the laboratory conditions of temperature and relative humidity shown in Table 17. The results of this investigation are given in Tables 27a-27d.

Table 27a.

The number of eggs of P.citri, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 192 hours' duration.

Trial 1.

Time (Hrs.)	Eggs at start	Eggs at finish	Eggs eaten	No. A.addoensis
0- 24	18	18	0	2
24- 48	18	18	0	2
48- 72	18	18	0	1
72- 96	18	18	0	2
96-120	18	18	0	2
120-144	18	18	0	1
144-168	18	18	0	1
168-192	18	18	0	1
Total	144	144 (100%)	0	12

Trial 2.

Time (Hrs)	Eggs at start	Eggs at finish	Eggs eaten	No. A.addoensis
0- 24	13	13	0	2
24- 48	13	13	0	2
48- 72	13	13	0	2
72- 96	13	13	0	2
96-120	13	13	0	1
120-144	13	13	0	1
144-168	13	13	0	3
168-192	13	13	0	2
Total	104	104 (100%)	0	15

Table 27b.

The number of immature stages of P.citri, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 216 hours duration.

Trial 1

Time (Hrs.)	Immatures at start	Immatures at finish	Immatures eaten	No. A.addoensis
0- 24	10	4	6	3
24- 48	10	1	9	3
48- 72	10	0	10	3
72- 96	10	1	9	3
96-120	10	0	10	3
120-144	10	0	10	3
144-168	20	0	20	3
168-192	20	0	20	3
192-216	20	3	17	3
Total	120	9 (7%)	111 (93%)	27

Trial 2

Time (Hrs.)	Immatures at start	Immatures at finish	Immatures eaten	No. A.addoensis
0- 24	10	6	4	3
24- 48	10	3	7	2
48- 72	10	2	8	2
72- 96	10	5	5	2
96-120	10	7	3	2
120-144	10	0	10	3
144-168	10	1	9	5
168-192	20	3	17	5
192-216	20	0	20	4
Total	110	27 (25%)	83 (75%)	28

Control Trial - No A.addoensis.

Time (Hrs.)	Immatures at start	Immatures at finish	Immatures dead	No. A.addoensis
0- 24	10	10	0	0
24- 48	10	10	0	0
48- 72	10	10	0	0
72- 96	10	10	0	0
96-120	10	10	0	0
120-144	10	9	1	0
144-168	10	10	0	0
168-192	10	10	0	0
192-216	10	10	0	0
Total	90	89 (99%)	1 (1%)	0

Table 27c.

The number of males of P.citri, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 168 hours' duration.

Trial 1

Time (Hrs.)	Males at start	Males at finish	Males eaten	No. A.addoensis
0- 24	10	1	9	3
24- 48	10	0	10	3
48- 72	10	0	10	3
72- 96	10	0	10	3
96-120	10	0	10	2
120-144	10	0	10	1
144-168	10	3	7	1
Total	70	4 (6%)	66 (94%)	16

Trial 2

Time (Hrs.)	Males at start	Males at finish	Males eaten	No. A.addoensis
0- 24	10	0	10	4
24- 48	10	0	10	4
48- 72	10	0	10	4
72- 96	10	0	10	2
96-120	10	0	10	2
120-144	10	1	9	2
144-168	10	0	10	2
Total	70	1 (1%)	69 (99%)	20

Control trial - No A.addoensis

Time (Hrs.)	Males at start	Males at finish	Males dead	No. A.addoensis
0- 24	10	10	0	0
24- 48	10	10	0	0
48- 72	10	9	1	0
72- 96	10	10	0	0
96-120	10	9	1	0
120-144	10	9	1	0
144-168	10	9	1	0
Total	70	66 (94%)	4 (6%)	0

Table 27d.

The number of females of P.citri, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 168 hours' duration.

Trial 1

Time (Hrs.)	Females at start	Females at finish	Females eaten	No. A.addoensis
0- 24	10	5	5	4
24- 48	10	5	5	4
48- 72	10	9	1	4
72- 96	10	7	3	4
96-120	10	9	1	4
120-144	10	9	1	4
144-168	10	10	0	1
Total	70	54 (77%)	16 (23%)	25

Trial 2

Time (Hrs.)	Females at start	Females at finish	Females eaten	No. A.addoensis
0- 24	10	9	1	1
24- 48	10	10	0	1
48- 72	10	9	1	2
72- 96	10	9	1	2
96-120	10	10	0	2
120-144	10	9	1	2
144-168	10	10	0	1
Total	70	66 (94%)	4 (6%)	11

Control trial - No A.addoensis

Time (Hrs.)	Females at start	Females at finish	Females dead	No. A.addoensis
0- 24	10	10	0	0
24- 48	10	10	0	0
48- 72	10	10	0	0
72- 96	10	10	0	0
96-120	10	10	0	0
120-144	10	10	0	0
144-168	10	8	2	0
Total	70	68 (97%)	2 (3%)	0

In the two feeding trials, each covering a total period of 192 hours, in which the eggs of P.citri were offered as food, Table 27a, the predaceous mite was not observed to eat any of the red mite eggs. Observations carried out during the duration of the experiment suggested that the presence of the guy-fibrils, which radiate from the dorsal vertical stalk of the egg, prevented the predator from getting close enough to the egg to apply its mouthparts. Subsequent observations, in which the eggs of P.citri with the guy-fibrils removed were presented to a number of adult A.addoensis, indicated that even in the absence of the fibrils the eggs were not attacked by the predator.

The immature and male stages of the citrus red mite were readily attacked by A.addoensis, Tables 27b and 27c. Observations showed that most of the smaller immature stages, viz. the larvae, and protonymphs, offered little resistance to the attacks of the predator. These immature stages were generally slow moving and of a size easily handled by the larger predator. In the case of the males and deutonymphs, resistance to the attacks of the predator were displayed by a continual struggle of the mite to break free from the predators grasp. The predator, however, in cases such as this showed an interesting behaviour which reduced the effectiveness of the struggling mite. As soon as contact was made with the citrus mite, the struggling mite was raised in the air by the predator holding the mite with its forelegs and standing upright on the remaining three pairs of legs. In this position, the legs of the captured red mite were usually unable to touch or grip the substrate. The predator then fed on the mite until all movement ceased, after which time the red mite was replaced on the substrate and feeding continued.

The females of P.citri were attacked by A.addoensis, Table 27d, but not to the same extent as were the immature and male stages. It is suggested that as the females were of a size comparable to that of the predator, they were more difficult to handle. On several occasions females were seen to escape from the attacks of the predaceous mite. A further possibility is that the females which were successfully captured provided a larger meal for the predator than any of the other stage, thus fewer individuals would need to be caught to satisfy the appetite of the predator.

In general, therefore it was concluded that the stages of the citrus red mite most preyed upon by adult A.addoensis are the immature and adult forms, while eggs are ignored completely. These results might explain why large numbers of eggs were recorded on the leaf samples taken from the field, while in comparison the immature and adults of P.citri were low in number.

From the results of the feeding trials there also appeared to be a relationship between the number of A.addoensis on the fruit substrate and the number of stages of P.citri eaten. This density component of predation was most evident in Table 27d, where a total number of 25 A.addoensis resulted in 23% of the females being eaten, while only 6% of the females were destroyed by 11 predaceous mites. However, the reason why the effect of predator density was not apparent on the immature and male stages is not clear.

The failure of A.addoensis to eat the eggs of P.citri lead to a comparison between the eggs of the citrus red mite and those of the red spider mite, Tetranychus telarius (L.). The eggs of T.telarius, unlike those of the citrus red mite, do not possess guy-fibrils or a dorsal vertical stalk and are generally laid free in the webbing produced by the adult mites on the undersurface of leaves. The investigation of the feeding habits of A.addoensis with respect to the different stages of T.telarius were performed in a manner similar to that described for P.citri and also under the same laboratory conditions of temperature and relative humidity (Table 17). The results of this investigation are given in Tables 28a - 28d.

From Tables 28a - 28d, the predaceous mite was found to attack all stages of T.telarius, including the egg stage. Of all the red spider stages, however, the female stage was the least attacked by A.addoensis (Table 28d), and it is suggested that this was probably for the same reasons as those advanced previously in the case of P.citri females.

Why the eggs of the citrus red mite should escape the attention of the predator, while the eggs of T.telarius were readily eaten, is not clearly understood. As mentioned previously, there is a great difference in the structure of the two types of egg, and observations suggest that the tentlike arrangements of the guy-fibrils of P.citri eggs act as a protective barrier against the predator. The failure of this predator to devour red mite eggs from which the guy-fibrils had been removed would suggest that there is an additional protective device, the nature of which is unknown.

Table 28a.

The number of eggs of T.telarius, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 216 hours' duration.

Trial 1

Time (Hrs.)	Eggs at start	Eggs at finish	Eggs eaten	No. A.addoensis
0- 24	20	6	14	2
24- 48	20	0	20	2
48- 72	20	0	20	2
72- 96	20	0	20	2
96-120	40	1	39	2
120-144	40	2	38	2
144-168	40	6	34	2
168-192	40	10	30	2
192-216	40	10	30	2
Total	280	35 (12%)	245 (88%)	18

Trial 2

Time (Hrs.)	Eggs at start	Eggs at finish	Eggs eaten	No. A.addoensis
0- 24	20	0	20	3
24- 48	20	0	20	3
48- 72	20	0	20	3
72- 96	20	16	4	2
96-120	20	5	15	1
120-144	40	20	20	1
144-168	40	15	25	2
168-192	40	20	20	2
192-216	40	12	28	2
Total	260	88 (34%)	172 (66%)	19

Table 28b.

The number of immature stages of T.telarius, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 216 hours' duration.

Trial 1

Time (Hrs.)	Immatures at start	Immatures at finish	Immatures eaten	No. A.addoensis
0- 24	10	1	9	4
24- 48	20	0	20	4
48- 72	20	3	17	4
72- 96	20	2	18	3
96-120	20	5	15	3
120-144	20	2	18	4
144-168	20	0	20	4
168-192	20	2	18	4
192-216	20	0	20	4
Total	170	15 (9%)	155 (91%)	34

Trial 2

Time (Hrs.)	Immatures at start	Immatures at finish	Immatures eaten	No. A.addoensis
0- 24	10	2	8	4
24- 48	10	2	8	3
48- 72	10	1	9	3
72- 96	10	4	6	2
96-120	10	5	5	1
120-144	20	2	18	3
144-168	20	1	19	3
168-192	20	2	18	3
192-216	20	2	18	3
Total	130	21 (16%)	109 (84%)	25

Control Trial - No A.addoensis

Time (Hrs.)	Immatures at start	Immatures at finish	Immatures dead	No. A.addoensis
0- 24	10	10	0	0
24- 48	10	10	0	0
48- 72	10	10	0	0
72- 96	10	10	0	0
96-120	10	9	1	0
120-144	10	9	1	0
144-168	10	10	0	0
168-192	10	8	2	0
192-216	10	7	3	0
Total	90	83 (92%)	7 (8%)	0

Table 28c.

The number of males of T.telarius, on lemon fruits, eaten by the predaceous mite, A.addoensis, in two trials each of 216 hours' duration.

Trial 1

Time (Hrs.)	Males at start	Males at finish	Males eaten	No. A.addoensis
0- 24	10	1	9	3
24- 48	10	2	8	3
48- 72	10	0	10	3
72- 96	10	1	9	3
96-120	10	0	10	2
120-144	10	0	10	4
144-168	10	0	10	4
168-192	10	0	10	3
192-216	10	0	10	3
Total	90	4 (4%)	86 (96%)	28

Trial 2

Time (Hrs.)	Males at start	Males at finish	Males eaten	No. A.addoensis
0- 24	10	0	10	3
24- 48	10	0	10	3
48- 72	10	0	10	3
72- 96	10	0	10	2
96-120	10	0	10	1
120-144	10	0	10	3
144-168	10	4	6	1
168-192	10	0	10	1
192-216	10	2	8	2
Total	90	6 (7%)	84 (93%)	19

Control Trial - No A.addoensis

Time (Hrs.)	Males at start	Males at finish	Males eaten	No. A.addoensis
0- 24	10	10	0	0
24- 48	10	10	0	0
48- 72	10	8	2	0
72- 96	10	10	0	0
96-120	10	9	1	0
120-144	10	9	1	0
144-168	10	8	2	0
168-192	10	8	2	0
192-216	10	8	2	0
Total	90	80 (89%)	10 (11%)	0

Table 28d.

The number of females of T.telarius, on lemon fruits, eaton by the predaceous mite, A.addoensis, in two trials each of 216 hours' duration.

Trial 1

Time (Hrs.)	Females at start	Females at finish	Females eaten	No. A.addoensis
0- 24	10	9	1	2
24- 48	10	9	1	2
48- 72	10	7	3	2
72- 96	10	7	3	2
96-120	10	6	4	2
120-144	10	9	1	3
144-168	10	8	2	2
168-192	10	9	1	2
192-216	10	9	1	2
Total	90	73 (81%)	17 (19%)	19

Trial 2

Time (Hrs.)	Females at start	Females at finish	Females eaten	No. A.addoensis
0- 24	10	7	3	3
24- 48	10	9	1	3
48- 72	10	8	2	2
72- 96	10	9	1	1
96-120	10	9	1	1
120-144	10	8	2	4
144-168	10	7	3	4
168-192	10	8	2	3
192-216	10	6	4	3
Total	90	71 (79%)	19 (21%)	24

Control Trial - No A.addoensis.

Time (Hrs.)	Females at start	Females at finish	Females dead	No. A.addoensis
0- 24	10	10	0	0
24- 48	10	10	0	0
48- 72	10	9	1	0
72- 96	10	9	1	0
96-120	10	9	1	0
120-144	10	9	1	0
144-168	10	10	0	0
168-192	10	10	0	0
192-216	10	10	0	0
Total	90	86 (96%)	4 (4%)	0

From observations on the behaviour of A.addoensis it would appear that these mites locate their prey by random searching (Klinokinesis), for the "area of search" was observed to be quite independent of whether it had been covered before or not. When an adult A.addoensis encountered an inaminmate object in its path, for example a piece of wax, it would explore the object with its forelegs and then resume its search. If the object in its path was a mite, however, then the period during which the forelegs were brought into contact with the mite was brief, and the predator attacked immediately.

From the above laboratory feeding experiments with A.addoensis it has been demonstrated that this predator will eat all stages of P.citri with the exception of the egg. It has also been demonstrated that it is not dependent on P.citri, but will accept mites, such as T.telarius, as a source of food. In addition to the above two species of mite, A.addoensis has also been observed in the field in close association with mites such as Tydeus munsteri Meyer and Ryke, Brevipalpus californicus (Banks) and the immature stages of an Oribiatid mite, Zygoribatula sp., and insects such as Thysanoptera. In the absence of P.citri, therefore, it is probable that A.addoensis might exploit these alternative food sources.

b. The Efficiency of A.addoensis as a Predator of P.citri.

Commenting on investigations concerned with the effect of a predator on its prey, DeBach (1958) has stated that:-

"In biological control projects today, one of the most important problems is that of scientific proof of the effect of natural enemies on the host populations. I have concluded that adequate and generally accepted proof of the effectiveness of natural enemies in host population regulation usually cannot be obtained by correlation between population changes of the host and parasite and/or predators.

Detailed field studies may convince the research worker that a given host population is regulated by a particular natural enemy. His problem is to prove to others that such is the case. I am sure that this can be best done by experimental techniques which eliminate one factor or a group of factors from one plot, and show by comparison with a plot otherwise comparable, but having natural enemies present, what difference and average population density develops".

In the light of the above statement, it was decided that in the study of the ability of A.addoensis to control P.citri populations under field conditions, use would be made of the sleeve check method as devised by Smith and DeBach (1942) and DeBach et al. (1949). A muslin sleeve, 24 inches in diameter and 48 inches in length, was used to eliminate or confine A.addoensis and P.citri on certain field units and thus permit a comparison of the population density achieved by the citrus red mite in the absence, and presence of the predaceous mite. A photograph of the type of sleeve cage used in this investigation is shown in Plate I.

Plate I: The type of sleeve cage used to investigate the effeciency of A.addoensis as a predator of P.citri.

From the untreated orchard at "Imiti", three trees were chosen at random, and from the southern aspect of each tree three twigs, each bearing 40 mature leaves, were selected. The selected twigs and leaves on each of the three trees were cleaned manually with cotton-wool and water, and then examined with a hand-lens to ensure that they were free from insects and mites. Each twig was then enclosed in a muslin sleeve, the ends of which were closed with tape.

Of the three sleeves on each tree, one sleeve, designated Sleeve 1, acted as the uninfested control sleeve into which no P.citri or A.addoensis were placed. On the leaves in the second and third sleeves, designated Sleeve 2 and Sleeve 3 respectively, five mature females and one male of P.citri were introduced and allowed to breed. When the number of female red mite in Sleeve 3 began to increase in numbers, which was taken to indicate that the population had established itself on the leaves, four adult A.addoensis were introduced on to the leaves in the sleeve. The proportion of P.citri males and females to adult A.addoensis, placed on the leaves in Sleeve 3, was obtained from the mean number of these mites per leaf recorded in leaf samples collected from the six experimental trees at "Imiti" at the time this investigation was started.

The position of the sleeves on the southern aspect of each tree was alternated so that no one sleeve occupied the same position. Thus, the effect of sleeve position on either P.citri or A.addoensis was eliminated from the results of this investigation.

This investigation on the ability of A.addoensis to control a field population of the citrus red mite was begun in March 1967 and terminated in October 1967. Weekly counts were made, using a headband magnifier, on the total number of red mite females and adult A.addoensis on 20 leaves chosen haphazardly from the 40 leaves in each sleeve. The results of this investigation, which are given as the mean population variation of female P.citri and A.addoensis per leaf in the sleeves on all three trees, are presented in Figure 29.

By the middle of July 1967 (Figure 29), both P.citri and A.addoensis had appeared in the control sleeves, and the predaceous mite was recorded from Sleeve 2 on all three trees. Because of this invasion of Sleeves 1 and 2 by P.citri and the predator mite, observations on these two sleeves was discontinued. It was decided to continue the observations on Sleeve 3 on each tree because of the interesting results obtained, while three new twigs on each tree were selected, cleaned and enclosed in muslin sleeves. Of these three new sleeves, Sleeve 1 again served as the uninfested control sleeve. On the 21st July five female P.citri and one male were introduced onto the leaves in the remaining two sleeves (Sleeve 2 and Sleeve 4), on all three trees. It was intended to place four adult A.addoensis into Sleeve 4 when the red mite populations in these sleeves had become established. By the end of August, however, the number of female P.citri recorded in Sleeve 4 was low, no increase in numbers having taken place, and by the beginning of September the sleeve had been re-invaded by A.addoensis from outside the sleeve. Between July and October 1967, no increase in the number of P.citri females in Sleeve 2 was recorded, and by August the predaceous mite had reappeared in the sleeves.

The absence of an increase in numbers of P.citri in Sleeve 2 during July to October 1967 was also shown on the six experimental trees at "Imiti" (Figure 8), where over the same period no build-up of citrus red mite was recorded.

From Figure 29, in Sleeve 2, where P.citri was allowed to breed, from March to April, in the absence of A.addoensis, a large population of citrus red mite developed. In contrast, no comparable increase in the number of P.citri was observed in Sleeve 3, where the predaceous mite was introduced in April. In Sleeve 3, throughout the entire period of the investigation there was an apparent oscillation between P.citri and the predator mite similar to that proposed by Lotka and Volterra (vide Andrewartha and Birch 1954), and to the interaction reported by Huffaker and Kennett (1956) between the cyclamen mite Tarsonemus pallidus Banks and the predaceous mites Typhlodromus cucumeris Oudemans and Typhlodromus reticulatus Oudemans.

In Sleeve 4, no increase in P.citri took place during the period this sleeve was under observation, and the appearance of the predator mite in the sleeves on the 31st August 1967 resulted in a decline in the density of the red mite.

In all four sleeves the appearance of A.addoensis either by intentional introduction or accidental invasion was coincident with a decline in the numbers of red mite, as estimated from female P.citri counts.

From the results of the above sleeve cage experiments it was concluded that the predaceous mite, A.addoensis, was an effective predator of P.citri, and under natural conditions could maintain a fluctuating population of citrus red mite to within an upper and lower limit of population density as specified in the definition of natural control by DeBach (1964).

c. The influence of A.addoensis on the Population Density of P.citri.

From the results of the effect of the predaceous mite, A.addoensis, on populations of P.citri confined to sleeve cages, and the feeding trials conducted in the laboratory, it was concluded that this predator mite is a natural enemy of the citrus red mite in the Sundays River Valley, and might be effective in regulating populations of the red mite in the field. The relationship recorded between A.addoensis and the population density of P.citri on the six experimental trees at "Imiti" is presented in Figure 30. In Figure 30 only the "active stages" of P.citri (larvae, protonymphs, deutonymphs and the adult forms), were considered, since it had been demonstrated in the feeding trials that the egg of the citrus red mite was not attacked by the predator.

In the relationship between P.citri and A.addoensis, it must be pointed out that the error of the sampling method with respect to the predaceous mite was found to vary between ± 30% and ± 35%. While cognisance is taken of this sampling error it has not been incorporated as such into the predator-prey relationship as my objective was to establish, from the information, the likelihood of a predator-prey interaction.

From Figure 30, at the beginning of March 1966 the numbers of A.addoensis on the six observation trees at "Imiti" was low. Thus at the start of the favourable climatic conditions between April and June, the mean population density of P.citri was initially permitted to increase on all six trees with little control by the predaceous mite. However, the increase in density of P.citri was soon followed by a rise in the numbers of A.addoensis. A second increase in the population density of the citrus red mite was observed in August 1966, and this second peak was also influenced by an increase in the number of the predator. By the beginning of October 1966, P.citri was recorded at a low level on the experimental trees.

From November 1966 to February 1967 the predaceous mite was recorded on all six trees at "Imiti", while the number of citrus red mite remained low. During February and March 1967, an increase in the number of P.citri was noticed, and peak populations occurred during March and April. As in 1966, the rise in the numbers of red mite was closely followed by an increase in the population density of the predator, and by July the population density of P.citri had been substantially reduced. After this decline in red mite numbers in July, no further increase in density was recorded.

From this field information contained in Figure 30, it was concluded that there was an interaction between A.addoensis and P.citri which took the form of an oscillation. The development of large populations of the citrus red mite was closely followed by a corresponding increase in the density of the predaceous mite, which in turn led to the fall in red mite numbers followed by a decline in the predator density.

From a study of the information in Figure 30, a critical phase in the development of citrus red mite populations appeared to be the relative numbers of P.citri and A.addoensis on the trees at the beginning of a climatically favourable period for the increase in population density of the citrus red mite. Accordingly it is possible to erect a hypothesis that if during March and April the predator mite density is low, then large populations of red mite develop on a tree, which are only controlled by a subsequent rise in the number of A.addoensis. On the other hand, if large numbers of A.addoensis are present on the tree during March and April, then the increase in the level of the citrus red mite is low and rapidly regulated by the predator. To test this hypothesis it was decided to determine whether a ratio existed between the number of A.addoensis and the citrus red mite which could be related to the density of P.citri on each of the six trees at "Imiti" (Figure 8), between the periods March to April 1966 and March to April 1967. This determination of the ratio between the number of predaceous mite and the active stages of P.citri is given in Tables 29a and 29b.

Table 29a.

A table showing the ratio between the mean number of active stages of P.citri (P.c.) and the mean number of A.addoensis (A.a.) per leaf, for the period March to April 1966, on each of the six observation trees in the natural control orchard at "Imiti".

		Tree 1		Tree 2		Tree 3	
Date		P.c.	A.a	P.c.	A.a.	P.c.	A.a.
March	5	0.00	0.00	0.10	0.10	0.00	0.05
	12	0.20	0.05	0.00	0.05	0.05	0.00
	18	0.10	0.05	0.10	0.05	0.05	0.00
	25	0.05	0.05	0.00	0.05	0.00	0.10
April	1	0.10	0.10	0.05	0.00	0.20	0.10
	9	0.25	0.00	0.05	0.00	0.55	0.00
	16	0.30	0.10	0.10	0.05	0.05	0.00
	23	0.80	0.10	0.00	0.00	0.35	0.00
	30	0.35	0.05	0.05	0.00	0.35	0.00
Total		2.15	0.50	0.45	0.30	1.60	0.25
Ratio		4.3		1.5		6.4	

		Tree 4		Tree 5		Tree 6	
Date		P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	5	0.00	0.00	0.00	0.00	0.00	0.00
	12	0.00	0.05	0.00	0.00	0.00	0.00
	18	0.10	0.10	0.00	0.00	0.05	0.05
	25	0.00	0.00	0.05	0.00	0.20	0.10
April	1	0.15	0.10	0.15	0.05	0.00	0.00
	9	0.10	0.05	0.15	0.00	0.15	0.00
	16	0.05	0.10	0.00	0.00	1.05	0.00
	23	0.05	0.00	0.40	0.00	0.45	0.10
	30	0.50	0.00	0.05	0.00	0.35	0.00
Total		0.95	0.40	0.80	0.05	2.25	0.25
Ratio		2.4		16.0		9.0	

Table 29b.

A table showing the ratio between the mean number of active stages of P.citri (P.c.) and the mean number of A.addoensis (A.a.) per leaf, for the period March to April 1967, on each of the six observation trees in the natural control orchard at "Imiti".

		Tree 1		Tree 2		Tree 3	
Date	2	P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	2	0.35	0.10	0.00	0.15	0.30	0.00
	9	0.15	0.20	0.05	0.10	0.35	0.00
	16	0.30	0.20	0.20	0.00	0.40	0.05
	23	0.20	0.15	0.45	0.15	1.00	0.05
	29	0.70	0.25	0.75	0.05	1.15	0.20
April	6	0.40	0.35	0.75	0.10	0.35	0.00
	13	0.80	0.30	0.70	0.10	0.25	0.25
	20	0.40	0.35	0.60	0.10	0.05	0.00
	27	0.65	0.15	0.95	0.10	0.20	0.10
Total		3.95	2.05	4.45	0.85	4.05	0.65
Ratio		1.9		5.2		6.2	

		Tree 4		Tree 5		Tree 6	
Date		P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	2	0.10	0.05	0.00	0.05	0.00	0.00
	9	0.10	0.15	0.00	0.05	0.05	0.00
	16	0.15	0.10	0.05	0.05	0.05	0.00
	23	0.15	0.05	0.10	0.05	0.00	0.05
	29	1.00	0.10	0.05	0.05	0.05	0.10
April	6	0.60	0.10	0.35	0.10	0.05	0.05
	13	2.10	0.00	0.10	0.10	0.25	0.00
	20	0.65	0.10	0.15	0.10	0.15	0.05
	27	0.85	0.20	0.25	0.15	0.15	0.10
Total		5.70	0.85	1.05	0.70	0.75	0.35
Ratio		6.7		1.5		2.1	

From the results contained in Tables 29a and 29b, the six trees at "Imiti" were divided into two groups according to the numerical value of the ratio calculated between the mean number of active stages of P.citri and the mean number of A.addoensis during the periods March to April 1966 and March to April 1967. In the first group were included all those trees on which the sum of the ratio's was 3.0 or less. This group contained trees 2 and 4 in 1966, and trees 1, 5 and 6 in 1967. The second group comprised all those trees on which the ratio was greater than 3.0, and included in this group were trees 1, 3, 5 and 6 in 1966 and trees 2, 3 and 4 in 1967. A comparison was then made between the development of the citrus red mite populations on each of the six experimental trees during March to June 1966 and 1967, of which four are shown in Figure 8, and the two ratio categories into which these trees had been placed. This comparison showed that on all those trees where the ratio of P.citri active stages to adult A.addoensis was greater than 3.0 during Autumn of 1966 and 1967, the total red mite populations were higher than on those trees where the ratio was less than 3.0.

From the above information, it was concluded that in the field there was a balance between P.citri and A.addoensis of approximately three active stages of P.citri to one predaceous mite, at which level A.addoensis could effectively control a red mite population. If for some reason, however, this balance was upset so that the ratio was greater than 3 to 1, large populations of P.citri could be expected to develop.

Collyer (1958) found that on seedlings of *Prunus insititia*, an initial ratio of 1:1, 1:5 and 1:10 of the predator mite, *Typhlodromus tiliae* Oudms. to the active stages of fruit tree red spider mite, *Metatetranychus ulmi* Koch, resulted in no damage to the seedlings, and the number of *M.ulmi* did not increase markedly. From field information, Collyer and Kirby (1955, vide Collyer 1958) suggested that if *T.tiliae* and *M.ulmi* were at approximately equal levels of abundance, the predator mite was able to control the pest at a constant level. If, however, the ratio between the predator and pest rose to 1:10, biological control of *M.ulmi* was not likely to occur. It was pointed out, however, that field experiments indicated that *T.tiliae* did not increase in response to a rise in the level of *M.ulmi* as it should if it were acting as an efficient predator. In addition, as the feeding capacity of the predaceous mite was limited to a few mites per day, no response could be expected if the population of red spider increased beyond a certain relatively low level.

From the close relationship which was found between the citrus red mite and *A.addoensis*, it is suggested that the variation in the numbers of *P.citri* on each of the six experimental trees at "Imiti" was probably due to the variation in the number of predator mites on each individual tree within the framework of the abiotic influences described earlier. This suggestion was supported by the estimated ratio between *P.citri* and *A.addoensis*, and the fluctuation in population density of the predaceous mite and citrus red mite on each of the six trees at "Imiti".

In the orchard at "Imiti", which had remained untreated for several years, it would appear that a balance had been attained in which the numbers of citrus red mite were regulated within an upper and lower limit.

So far the effect of natural abiotic and biotic factors on the numbers of P.citri have been examined. The application of insecticides for the control of California red scale, however, may seriously upset this balance, particularly the role of a natural predator. In this regard the intensive monoculture practiced in the Sundays River Valley provided an opportunity for examining the influence of insecticides on the population density of P.citri and A.addoensis.

12.

THE EFFECT OF RED SCALE INSECTICIDAL SPRAYS ON THE POPULATION DENSITY OF THE CITRUS RED MITE.

(Ebeling 1959) suggested that the advent of P.citri as a pest of citrus in the U.S.A. was brought about by the use of chemicals such as DDT. Both DeBach et al. (1950) and Ebeling (1959) maintain that applications of DDT resulted in high populations of the citrus red mite by the effective removal of the natural emenies.

In South Africa, the main pest of citrus is the California red scale, Aonidiella aurantii (Mask.), and the majority of insecticidal treatments are designed around the control of this pest. Up until 1950, A.aurantii was largely controlled in South Africa by the fumigation of infested citrus trees with HCN gas. However, with the appearance of organo-phosphorus insecticides such as Parathion in the early 1950's which could be applied to citrus trees in the form of a spray wash, the practice of fumigation was dropped in favour of this more rapid method of control.

In the Republic of South Africa it is now generally believed that the appearance of the citrus red mite as a pest of citrus was probably caused by the use of insecticides such as Parathion, although little is known of the effect of this red scale insecticide on P.citri populations.

In the light of the above assumption and the fact that chemical applications are an important ecological factor in the environment of a pest such as the citrus red mite, the influence of several different red scale treatments on the seasonal abundance of P.citri were investigated.

a. The Experimental Design.

Two insecticidal trials were laid down on two farms in the Sundays River Valley by Dr. A.B.M. Whitnall of African Explosives and Chemical Industries Ltd. One trial was situated in a section of a Washington Navel orchard, planted in 1946, on the farm "Ruimte". The second trial was sited on the farm "Littlecote", in part of an orchard consisting of midseason Valencia orange trees, Bailage variety, planted in 1955. Both farms were located in the Sunland area of the Sundays River Valley (See Figure 2).

The two insecticidal trials were begun in August 1964 and ran for a period of three years, being terminated in October 1967. The investigations on the effect of different red scale treatments on P.citri populations were carried out on several treatments within these two trials, and covered the period February 1966 to October 1967.

The chemical composition of the insecticides used in the two trials were as follows:-

1. Parathion - as a wettable powder containing 25% 0,0-Diethyl op-nitrophenyl phosphorothioate.

2. Trithion - as a wettable powder containing 25% S-((p-Chlorophenyl thio) methyl) 0,0-diethyl phosphorodithioate.

3. Gusathion - as a wettable powder containing 25% 0,0-Diethyl-5-(4-oxo-3H-1,2,3-benzotriazine 3-methyl) phosphorodithioate.

4. Rogor - as a wettable powder containing 20% 0,0-Diethyl S-(N-methylcarbamoylmethyl) phosphorothiolothionate.

5. Alboleum - a proprietary name for an insecticidal spray oil containing 80% by weight of hydrocarbon oil.

The time of application and the composition of the insecticidal sprays in the two chemical trials at "Ruimte" and "Littlecote" are given in Table 30.

All chemicals were applied to the trees by means of a power sprayer operated at a pressure of 500 p.s.i. Each tree was sprayed with approximately 11 to 15 gallons of spray wash, depending on the size of the tree.

The design of the insecticidal trials was a randomised block with single tree plots, replicated six times. The lay-out of the chemical treatments in these two trials is presented in Figures 31 and 32.

Not all the red scale treatments shown in Table 30 were studied, but several treatments which were most commonly practiced by citrus farmers in the Sundays River Valley, and certain treatments which promised to give interesting and rewarding results, were selected from both insecticidal trials. From the trial at

Table 30 The month and date of application and composition of the insecticidal sprays applied to the trial trees on the farms "Ruimte" and "Littlecote", during 1964 to 1967, for evaluating the effect of red scale chemical control on the population density of the citrus red mite, P.citri.

	Month of Application.				Date of Application.		
Treatment No.	August	October	December	March			
1	0.075% Parathion + 0.2% Alboleum				18. 8.64	19. 8.65	25. 8.66
2		0.075% Parathion + 0.2% Alboleum			14.10.64	22.10.65	14.10.66
3			0.075% Parathion + 0.2% Alboleum		7.12.64	3.12.65	13.12.66
4			0.075% Trithion + 0.2% Alboleum		7.12.64	3.12.65	13.12.66
5				0.075% Parathion + 0.2% Alboleum	18. 3.65	18. 3.66	2. 3.67
6		0.075% Trithion + 0.2% Alboleum			14.10.64	22.10.65	21.10.66
7				0.075% Trithion + 0.2% Alboleum	10. 3.65	18. 3.66	2. 3.67
8				0.05% Parathion + 0.04% Rogor + 0.2% Alboleum	10. 3.65	18. 3.66	2. 3.67
9	0.075% Parathion + 0.2% Alboleum	0.075% Parathion + 0.2% Alboleum			18. 8.64 14.10.64	19. 8.65 22.10.65	25. 8.66 14.10.66
10		0.075% Parathion + 0.2% Alboleum	0.075% Parathion + 0.2% Alboleum		14.10.64 7.12.64	22.10.65 3.12.65	14.10.66 13.12.66
11		0.075% Parathion + 0.2% Alboleum		0.075% Parathion + 0.4% Alboleum	14.10.64 10. 3.65	22.10.65 18. 3.66	14.10.66 2. 3.67
12				0.075% Trithion + 0.4% Alboleum	4. 3.65	11. 3.66	1. 3.67
13	0.075% Trithion + 0.2% Alboleum	0.075% Trithion + 0.2% Alboleum			18. 8.64 14.10.64	17. 8.65 5.10.65	23. 8.66 14.10.66
14		0.075% Trithion + 0.2% Alboleum	0.075% Trithion + 0.2% Alboleum		14.10.64 8.12.64	5.10.65 2.12.65	14.10.66 15.12.66
15		0.075% Parathion + 0.2% Alboleum	0.075% Trithion + 0.2% Alboleum		14.10.64 8.12.64	5.10.65 2.12.65	14.10.66 15.12.66
16		0.075% Parathion + 0.2% Alboleum		0.05% Parathion + 0.04% Rogor + 0.2% Alboleum	14.10.64 4. 3.65	5.10.65 11. 3.66	14.10.66 1. 3.67
17		0.05% Parathion + 0.02% Gusathion + 0.2% Alboleum			14.10.64	5.10.65	14.10.66
18		0.05% Trithion + 0.2% Alboleum			14.10.64	5.10.65	14.10.66
19	Control - No chemical treatment.						

"Ruimte", Treatments 2, 5, 7, 8, 9, 11 and 19 were chosen, and from "Littlecote", Treatments 17 and 19.

From each treatment studied in the two trials, leaf samples were collected from the six replicate trees at weekly intervals, from February 1966 to October 1967. Temperature and relative humidity readings were recorded on a thermohygrograph inside a Stevenson screen erected in the centre of the insecticidal trial on the farm "Ruimte".

b. The Unsprayed Control Treatment at "Ruimte".

The mean numbers of P.citri per leaf on the six replicate trees which constituted the unsprayed control treatment in the chemical trial on the farm "Ruimte" from February 1966 to October 1967, and the number of hours per week temperatures were greater than or equal to 18°C and relative humidity less than or equal to 30%, is presented in Figure 33.

From Figure 33, the maximum population density of P.citri occurred between the months of April and June 1966 and March and June 1967, both of which were periods of moderate temperature and relative humidity.

A comparison of the variation in the mean number of red mite in the untreated control at "Ruimte" with the same information recorded in the natural control orchard at "Imiti" (Figure 9), indicated that in both cases the seasonal fluctuation of the red mite populations were similar. In both localities and numbers of P.citri increased between April and June 1966 and March and June 1967. The decrease in population density in July 1966 and 1967 was followed by a second smaller red mite increase in August and September 1966 and 1967. Between September 1966 and February 1967, the red mite population density remained at a low level on all six trees in both orchards. However, there was a difference between the number of

P.citri recorded from the six observation trees at "Imiti" and "Ruimte". The population densities attained by the citrus red mite on the six control trees at "Ruimte" during April to June 1966 and March to June 1967 was higher than that recorded from the six experimental trees at "Imiti" (Figure 9). It is suggested that this difference in population density of P.citri was largely due to the fact that the trees at "Imiti" were selected from an original number of 15 trees, and were not chosen at random as were the six replicate trees at "Ruimte". Thus, the six trees at "Imiti" comprised two sets of three trees each with a relatively high and low population density of P.citri (Figure 8). At "Ruimte", however, the random choice of six trees resulted in two trees on which P.citri was virtually absent during the entire period of study and four trees with relatively high population densities of citrus red mite (Figure 34). Thus, it could be expected that the population density observed on the six replicate trees at "Ruimte" (Figure 33), would be higher than that observed from the six trees at "Imiti" (Figure 9).

The seasonal variation in the mean number of citrus red mite per leaf on four of the six replicate trees in the control treatment at "Ruimte" is presented in Figure 34.

From Figure 34, the population density of citrus red mite on the individual trees was markedly different. This again suggested that there was probably a relationship between the number of predator mites and the active stages of the citrus red mite during the months of March and April, which determined whether or not a large number of red mite would develop on a tree in Autumn. In view of this, the ratio between the mean number of A.addoensis and the mean number of active stages of the citrus red mite per leaf on each of the six trees within the unsprayed control treatment, for the periods March to April 1966 and 1967, was estimated. In this manner it was established whether the ratio of A.addoensis to P.citri was greater than 1:3 on those trees on which large populations of citrus red mite developed. The results of these calculations are shown in Tables 31a and 31b.

Table 31a.

A table showing the ratio between the mean number of active stages of P.citri (p.c.) and the mean number of A.addoensis (A.a.) for the period March to April 1966, on each of the six replicate trees in the unsprayed control treatment in the chemical trial at "Ruimte".

		Tree 1		Tree 2		Tree 3	
Date		P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	7	0.00	0.00	0.05	0.05	0.00	0.10
	14	0.00	0.15	0.00	0.15	0.05	0.05
	21	0.00	0.10	0.10	0.20	0.15	0.00
	28	0.00	0.05	0.00	0.25	0.00	0.00
April	4	0.00	0.10	0.05	0.10	0.05	0.00
	11	0.10	0.00	0.20	0.20	0.35	0.00
	18	0.00	0.00	0.00	0.10	0.05	0.00
	25	0.00	0.05	0.20	0.25	0.40	0.20
Total		0.10	0.45	0.60	1.30	1.05	0.35
Ratio		0.2		0.5		3.0	

		Tree 4		Tree 5		Tree 6	
Date		P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	7	0.05	0.00	0.00	0.00	0.20	0.00
	14	0.10	0.05	0.05	0.00	0.00	0.15
	21	0.15	0.00	0.00	0.05	0.10	0.10
	28	0.15	0.00	0.10	0.05	0.20	0.30
April	4	0.30	0.00	0.05	0.05	0.10	0.10
	11	0.45	0.00	0.10	0.00	0.85	0.15
	18	0.55	0.00	0.10	0.05	0.55	0.10
	25	0.90	0.00	0.00	0.05	0.25	0.10
Total		2.65	0.05	0.40	0.25	2.25	1.00
Ratio		53.0		1.6		2.3	

Table 31b.

A table showing the ratio between the mean number of active stages of P.citri (P.c.) and the mean number of A.addoensis (A.a.) for the period March to April 1967, on each of the six replicate trees in the unsprayed control treatment in the chemical trial at "Ruimte".

mite per leaf on each of the six trees within the unsprayed control treatment, for the periods March to April 1966 and 1967, was estimated. In this manner it was established whether the ratio of A.addoensis to P.citri was greater than 1:3 on those trees on which large populations of citrus red mite developed. The results of these calculations are shown in Tables 31a and 31b.

Table 31a.

A table showing the ratio between the mean number of active stages of P.citri (p.c.) and the mean number of A.addoensis (A.a.) for the period March to April 1966, on each of the six replicate trees in the unsprayed control treatment in the chemical trial at "Ruimte".

		Tree 1		Tree 2		Tree 3	
Date		P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	7	0.00	0.00	0.05	0.05	0.00	0.10
	14	0.00	0.15	0.00	0.15	0.05	0.05
	21	0.00	0.10	0.10	0.20	0.15	0.00
	28	0.00	0.05	0.00	0.25	0.00	0.00
April	4	0.00	0.10	0.05	0.10	0.05	0.00
	11	0.10	0.00	0.20	0.20	0.35	0.00
	18	0.00	0.00	[illegible]	0.10	0.05	0.00
	25	0.00	0.05	0.20	0.25	0.40	0.20
Total		0.10	0.45	0.60	1.30	1.05	0.35
Ratio		0.2		0.5		3.0	

		Tree 4		Tree 5		Tree 6	
Date		P.c.	A.a.	P.c.	A.a.	P.c.	A.a.
March	7	0.05	0.00	0.00	0.00	0.20	0.00
	14	0.10	0.05	0.05	0.00	0.00	0.15
	21	0.15	0.00	0.00	0.05	0.10	0.10
	28	0.15	0.00	0.10	0.05	0.20	0.30
April	4	0.30	0.00	0.05	0.05	0.10	0.10
	11	0.45	0.00	0.10	0.00	0.85	0.15
	18	0.55	0.00	0.10	0.05	0.55	0.10
	25	0.90	0.00	0.00	0.05	0.25	0.10

ratio was greater than 3.0, however, large numbers of citrus red mite developed. The only exception was tree 4, during March and April 1967, where the value of the ratio was infinity. In this case the ratio was due to the complete absence of A.addoensis from March to April.

It was concluded, based on the information obtained from both "Imiti" and the six control trees at "Ruimte", that there is a ratio between the predator mite and P.citri in the field of approximately 1:3, at which level the predaceous mite can effectively control a population increase of P.citri. If for some reason this balance is disturbed, so that there are more than three times as many red mite as predator mites on the tree, then large numbers of P.citri could be expected to develop.

The variation in the mean number of P.citri active stages and the mean number of A.addoensis on the six untreated control trees at "Ruimte", for the period February 1966 to October 1967, is given in Figure 35.

From Figure 35, the increase in density of P.citri during April to June 1966 was closely followed by a rise in the number of A.addoensis. With the decline of the red mite population in July, the predator mite also fell in numbers, but was still present in August in sufficient numbers to prevent a further P.citri increase at this time of year. The citrus red mite population remained at a low level between October 1966 and February 1967 as a result of the combined action of unfavourable weather, and the continued presence of the predator. In March 1967, the red mite population rose, but this increase was initially not accompanied by a corresponding rise in the predaceous mite population.

Thus, high densities of red mite developed. While the reason for the delayed increase in the predator population is not known, it is suggested that it may be related to the fact that certain treatments in the insecticidal trial were sprayed during this period. This spraying could have resulted in the production of spray drift which might have upset the balance between A.addoensis and the citrus red mite on these control trees.

With the decline of the citrus red mite populations in June 1967, which was coincident with a high population of predaceous mites and unfavourable weather, the P.citri numbers remained low until observations were terminated in October 1967.

From a comparison of the data obtained from the control treatment at "Ruimte" and the natural control orchard at "Imiti", it would appear that in the three years during which the control trees at "Ruimte" had been untreated, a state of control of P.citri, which closely approximated that at "Imiti", had been established. It will be shown later, in a statistical analysis of this information, that the only significant difference between the population fluctuations recorded at "Ruimte" and "Imiti", was the number of P.citri on the six replicate trees at "Ruimte" during March and June 1967. This difference may be explained, however, by the delayed increase in the number of predaceous mites at the start of this period, possible caused by spray drift from the application of sprays to trees in other treatments.

c. The Effect of Parathion on the Population Density of P.citri.

Of the six red scale insecticidal treatments studied at "Kuimte", four treatments, namely Treatment 2, 5, 9 and 11, were composed of 0.075% Parathion + 0.2% Alboleum. The only difference between these four treatments was the time of the year at which the sprays were applied.

In Treatment 2, the Parathion spray was applied to the six replicate trees in October 1964, 1965 and 1966. The mean population fluctuation of the citrus red mite (all stages including the egg stage) and the variation in the mean number of P.citri active stages and A.addoensis per leaf, from February 1966 to October 1967, is given in Figure 36a and 36b.

In Figure 36a, as observed in the control treatment, the maximum numbers of P.citri on the trees treated with Parathion in October occurred during March and June 1966 and 1967.

The influence of the October Parathion application had little permanent effect on the red mite population. The egg stage appeared to be the least affected by the insecticidal treatment, and after two weeks immature and female stages of P.citri were again recorded in the leaf samples. The Parathion spray also had little effect on the predaceous mite population, as can be seen from the mean variation of the number of red mite active stages and A.addoensis on the six replicate trees presented in Figure 36b.

A.addoensis was absent from the leaf samples for one week after the spray application of October 1966.

In general, therefore, the seasonal abundance of red mite recorded from Treatment 2 was similar to that observed from the unsprayed control trees. The apparent ineffectiveness of the Parathion spray to materially influence the P.citri population was probably due to the application time coinciding with a period when the climatic conditions were adverse for population development. Thus sufficient time was allowed for the predator population to overcome any possible effect of the red scale spray before the next period of red mite increase.

In Treatment 5, the red scale Parathion spray was applied in March 1966 and 1967, at the beginning of a major upward trend in the red mite population. The seasonal variation in the mean number of P.citri and the mean number of citrus red mite active stages and A.addoensis on the six replicate trees within this treatment, is presented in Figures 37a and 37b.

From Figures 37a and 37b, the Parathion spray eliminated the active stages of the red mite, but within two weeks the immature and adult stages were again recorded from these trees. Unlike Treatment 2 (Figures 36a and 36b), or the unsprayed control (Figure 35), there was a rapid increase in the number of red mite after the insecticidal application, and large numbers of red mite were observed from April to September 1966 and 1967. The greatest density of red mite, however, was recorded between the months of August and September 1966 and 1967, with very little P.citri observed on the six trees between October 1966 and February 1967.

It can be seen from Figure 37b, that whereas P.citri rapidly recovered from the influence of the March application, the predaceous mite was absent for a period of up to five weeks, during which time there was a rapid development of a high population density of citrus red mite. The ratio between the mean number of A.addoensis and P.citri active stages on the six experimental trees within this treatment, between March and April 1966 and 1967, was 3.1 and 14.8 respectively. It is concluded that the March Parathion application was responsible for the production of this imbalance between the red mite and predator populations and resulted in the development of a high density of P.citri during March and September 1966 and 1967.

In comparing the effect of a red scale Parathion spray, applied in either October or March, on the citrus red mite, it appeared that the March application had the effect of shifting the population peak from April-June to August-September. This increase in the numbers of red mite during August and September resulted in the development of a high density of A.addoensis, which together with the early summer temperatures, was responsible for the decline of the red mite population in October.

The effect of two closely spaced applications of Parathion for the control of red scale, Treatment 9, on the population density of P.citri and A.addoensis, is given in Figure 38a and 38b.

It was found that applying two seperate Parathion sprays, one spray in August and the second in October, resulted in the production of extremely high numbers of P.citri from April to October 1966 and April to June 1967 (Figure 38a). In this treatment, as in Treatments 2 and 5, the egg stage of the red mite appeared to be least affected by the spray, and all stages of the citrus red were found on the six replicate trees shortly after the August spray was applied.

The red scale spray in August resulted in a reduction in the number of predator mite, which in turn led to a rapid rise in the P.citri population (Figure 38b). This increase in the density of P.citri between

August and October 1966 was checked by the second Parathion spray in October, the occurrence of unfavourable summer temperatures and the increase in the numbers of A.addoensis prior to the October spray.

Both the red mite and predaceous mite were recorded from the six trees between October 1966 and February 1967. However, the red mite population was maintained at a low level during this period by the unfavourable weather and the presence of A.addoensis.

The reason why extremely high numbers of red mite should develop on the trees within Treatment 9 between April and October 1966 and between April and June 1967, is not clear. It is concluded, however, that the August Parathion spray was possibly responsible for the development of the large red mite populations on these trees, since it has already been shown that the October Parathion application by itself has little effect on the natural abundance of P.citri (Figure 36).

The effect of a single application of Parathion in March and October, on the population density of P.citri, the mean number of active stages of P.citri and the predator mite, A.addoensis, is presented in Figures 39a and 39b.

The influence of the two separate applications of Parathion in March and October, which comprised Treatment 11, on the citrus red mite population could have been predicted from the information obtained on the effect of these two individual sprays on P.citri (Figure 36 and Figure 37).

It was found that a single Parathion spray in October (Figure 36), had little apparent effect on the normal seasonal abundance of the red mite, and that peak populations occurred in March and June. The March

Parathion spray (Figure 37), however, resulted in the development of large numbers of citrus red mite during August and September. A combination of these two treatments would therefore be expected to produce a population fluctuation of the citrus red mite similar to that observed from the single March application.

A comparison of the results obtained from Treatment 11, (Figure 39a), with those from the single March spray (Figure 37a), indicated that the greatest number of red mite occurred, as predicted, in August to September 1966 and 1967. However, the population density of P.citri resulting from the two Parathion sprays applied in March and October was not equivalent to that recorded in Treatment 5. This was probably due to the long absence of the citrus red mite on the trees after the March application, coupled with the reappearence of the predaceous mite several weeks after the spray application.

From the study of these four different red scale Parathion treatments, it is interesting to note the difference in the effect of the March and October sprays on the predaceous mite population. The March applications appeared to have a greater influence on the predator population than the October spray. In Treatment 5 (Figure 37b), and the March application in Treatment 11 (Figure 39b), the predaceous mite was completely absent from the leaf samples for several weeks after the spray was applied. In comparison, A.addoensis appeared to recover rapidly from the effect of the October Parathion application (Figure 36b). However, the reason for this variation in the effect of the March and October Parathion sprays on the predaceous mite is not understood.

d. The Effect of the Insecticides Trithion, Rogor and Gusathion on the Population Density of the Citrus Red Mite.

Although the material Trithion is not widely used for the control of red scale, but against the soft brown scale, *Coccus hesperidum* (L.), this insecticide was included in the chemical trials at "Ruimte" as a comparison with Treatment 5, Parathion being substituted for Trithion.

The effect of a spray of 0.075% Trithion + 0.2% Alboleum applied in March, Treatment 7, on the mean population density of *P.citri*, the mean number of active stages of the red mite and the mean number of *A.addoensis*, is given in Figure 40a and 40b.

On all six replicate trees the red mite population started to increase towards the end of February 1966, but after the March application the number of red mite fell sharply, and by the end of April 1966 *P.citri* was absent from the leaf samples. The citrus red mite reappeared in the leaf samples in August 1966, and a marked increase in numbers was observed between January and February 1967, which corresponded with a period of relatively low summer temperature (Figure 33).

After the March 1967 spray application, the density of *P.citri* fell sharply, but the mite was once again recorded on the trees in April. An increase in the population density of the red mite was observed between May-June and August-September 1967. However, the reason for the reappearence of the red mite after the 1967 application, when compared with the long period of absence after the 1966 spray, is not understood.

The influence of the Trithion spray on the mean number of *P.citri* active stages and *A.addoensis* on the six replicate trees within Treatment 7, is shown in Figure 40b.

The Trithion spray resulted in the absence of the predaceous mite from the trees for several weeks after the spray applications. From the information presented, however, it sppeared that A.addoensis was not as affected by the spray as P.citri, for the predator mite was the first to reappear on the trees after the sprays had been applied. This was in contrast with the March Parathion spray (Figure 37b), in which the red mite was found to be the least affected by the spray applications.

A weak interaction between the population density fluctuations of red mite and the corresponding variation in the numbers of A.addoensis was observed in Treatment 7 (Figure 40b). There was, however, a marked increase in the numbers of the predaceous mite between September–November 1966, which was coincident with a low number of citrus red mite on the six replicate trees. It is suggested that the increase in the population density of the predator mite during this period, which corresponded with the production of new foliage and blossoms by the tree, could be due to A.addoensis feeding on an alternative source of food which had developed on the trees at this time.

Treatment 8, which comprised a red scale spray of 0.05% Parathion + 0.04% Rogor + 0.2% Alboleum applied in March, was different from Treatments 5 and 7 in that it contained both Parathion and the insecticide Rogor. This late spray for the control of A.aurantii contained the material Rogor for its action on red scale infestations on the maturing fruit.

The effect of this composite Parathion–Rogor spray on the mean number of P.citri on the six replicate trees within Treatment 8, is given in Figure 41a.

After the spray application in March 1966, the numbers of red mite dropped sharply, and P.citri was recorded at a low level until August-October 1966, when the numbers increased with the favourable climatic conditions.

A small increase in the population density of the red mite was observed within Treatment 8 from January to February 1967, and after the March 1967 spray the mite quickly reappeared on the trees. With the exception of the decline in numbers during July, the numbers of P.citri on the Parathion-Rogor treated trees gradually rose to a maximum density in August-September 1967.

The influence of Treatment 8 on the mean number of A.addoensis and P.citri active stages on the six replicate trees, is illustrated in Figure 41b.

In 1966 and 1967, no A.addoensis were recorded from the trees for several weeks after the insecticidal sprays were applied. The period of the predator mite following the spray treatments varied from two weeks in 1966 to six weeks in 1967. The increase in the population density of P.citri during August to October 1966, January to February 1967 and August to October 1967 was in all cases followed by a corresponding rise in the numbers of predator mite.

A comparison of the variation in the mean numbers of red mite, from February 1966 to October 1967, exposed to red scale Treatments 5, 7 and 8 (Figures 37a, 40a and 41a respectively), indicated that the seasonal abundance of P.citri on those trees treated with either Parathion alone, or a Parathion-Rogor mixture, was similar. The variation in the numbers of red mite throughout the period of study were almost identical, and the only difference between the two treatments was the increase in red mite numbers from April to June 1966 shown in Treatment 5. A similar increase was not recorded in Treatment 7. It has been advanced that this was due to the appearence of A.addoensis soon after the spray application, which prevented an increase in the low numbers of red mite present on the trees at this time. It was concluded therefore, that the addition of Rogor to the Parathion spray did not affect its action on the red mite population cycle.

The greatest difference, however, in the effect of these March red scale sprays on P.citri, was that between Treatment 7 and Treatments 5 and 8. In Treatment 7 (Figure 40), the mean population density of red mite recorded from the six replicate trees was low, when compared with the numbers of red mite which developed on the trees in Treatments 5 and 8. No large increase in the number of red mite was observed during 1966 on the Trithion treated trees, and the three periods of high P.citri populations in 1967 corresponded with similar increase in red mite density in Treatments 5 and 8, although at a lower density.

Of the three red scale treatments applied in March, the Trithion applications resulted in the development of the lowest populations of red mite, and because of the reappearence of A.addoensis soon after the sprays were applied, Trithion appeared also to have the least affect on the predator mite population.

Of the 14 different red scale control treatments in the insecticidal trial on the farm "Littlecote", only two treatments were studied, namely Treatment 17, which comprised a red scale spray of 0.05% Parathion + 0.025% Gusathion + 0.2% Alboleum applied in October 1964, 1965 and 1966, and the untreated control, Treatment 19.

In the unsprayed control treatment, the mean population variation of P.citri, A.addoensis and the active stages of P.citri on the six replicate trees, from February 1966 to October 1967 are presented in Figures 42a and 42b.

On the experimental trees within the control treatment at "Littlecote", the population density of red mite was extremely low when compared with the control treatment at "Ruimte" (Figure 33), but the reasons for this are not clear. To account for the difference in the density of red mite between these two control treatments, several explanations are possible. Firstly, the variety of citrus tree in the trial at "Littlecote" was the mid-season Valencia, Bailage variety, which is different to that at "Ruimte" where Washington Navel trees were used. It is possible that the mid-season Valencia was not as attractive as the Navel as a host plant for the development of red mite. Secondly, no temperature or humidity records were kept for the orchard at "Littlecote" since this farm was situated only a few miles away from "Ruimte" (Figure 2). "Littlecote" is, however, at a higher altitude than "Ruimte", and as such the daily climatic variations were possible more extreme and adverse to the increase of the citrus red mite. Finally, the low populations observed on the control trees may have been due to the fact that the population of red mite was initially low, and the presence of the predator mite prevented the development of a large population of P.citri.

Apart from the low numbers of red mite recorded in the unsprayed control treatment at "Littlecote" the observed seasonal fluctuation in the numbers of P.citri was essentially the same as that observed in the control treatment at "Ruimte" (Figure 33), with a slight increase in the number of P.citri on the untreated trees at

"Littlecote" from April to June 1966 and 1967. The decline in the population density of citrus red mite after these peak populations was coincident with a rise in the level of the predaceous mite. There was an increase in the number of A.addoensis from August to September 1966 and July to August 1967, during which time the number of red mite was low. However, it is possible that this rise could be related to an increase in the population density of an alternative food source which had developed on the trees during this period.

The addition of the chemical Gusathion into an October red scale application of Parathion, and its effect on the population density of P.citri and A.addoensis, is given in Figures 43a and 43b.

The incorporation of Gusathion in the Parathion spray applied in October 1964, 1965 and 1966 was found to result in an absence of the predator mite from October 1966 to April 1967, with the exception of a small number of A.addoensis which occurred on the trees in February 1967. The red mite population was similarly affected by the red scale spray, but recovered early in January 1967, and by March large numbers had developed in the absence of the predaceous mite (Figure 43b). The reappearence and development of large numbers of A.addoensis was observed from April to October 1967, and this was coincident with a decrease in the red mite population from June to October 1967.

In comparing the effect of the Parathion-Gusathion spray on the red mite and predaceous mite populations with that observed in the untreated control (Figure 42b), it was concluded that the development of the large numbers of P.citri on the trees within Treatment 17, was mainly due to the effective elimination of the predator mite by the red scale spray.

In order to determine whether there was a significant difference between the population density of P.citri in the red scale treatments studied at "Ruimte" and "Littlecote", and the population density recorded in the natural control orchard at "Imiti" considering the marked variation in red mite population density between the replicate trees within each treatment, a comparison was made between the insecticidal treatments and "Imiti" by means of an analysis of variance. In this analysis, the four periods of red mite density considered were (a). March to May 1966, (b). August to October 1966, (c). March to May 1967, and (d) August to October 1967. For each treatment during these four periods, a value of "F" was calculated for the red mite population variations on the six experimental trees. A comparison was then made between treatments by testing the significance of the "F" values using Student's - t test. The result of this analysis is given in Table 35.

From Table 35, many comparisons may be made between the effect of the different red scale treatments on the population density of P.citri at "Ruimte", "Littlecote", and the natural control orchard at "Imiti". However, the most important results were:-

a. There was no significant difference between the population densities of citrus red mite recorded from the six trees in the natural control orchard at "Imiti", and the untreated control trees at "Ruimte" (Treatment 19), with the exception of the period March to May 1967. It is suggested that the difference between these two treatments during March to May 1967 was possibly caused by spray drift affecting the predator/prey balance on the replicate trees at "Ruimte".

Table 35.

Table 135 The results of a statistical analysis, expressed as a value of "t", on the difference between the P.citri population densities in the red scale insecticidal treatments studied at "Ruimte" and "Littlecote", and the natural control orchard at "Imiti", for the periods March to May 1966 and 1967, and August to October 1966 and 1967.

KEY.

a. = March to May 1966
b. = August to October 1966
c. = March to May 1967
d. = August to October 1967

(R) = "Ruimte".
(L) = "Littlecote".
* = "t" significant at the 5% level of significance.

Treatment									
5 (R)	a.0.09 b.4.15* c.3.71* d.5.17*								
7 (R)	a.1.19 b.0.08 c.5.59* d.0.45	a.1.29 b.4.23* c.1.88 d.4.72*							
8 (R)	a.1.05 b.4.29* c.5.24* d.3.03*	a.1.14 b.0.13 c.1.53 d.2.13*	a.0.15 b.4.36* c.0.34 d.2.58*						
9 (R)	a.7.21* b.5.64* c.5.42* d.0.65	a.7.11* b.2.31* c.9.13* d.4.52*	a.8.40* b.5.71* c.11.00* d.0.20	a.8.26* b.1.35 c.10.66* d.2.38*					
11 (R)	a.1.28 b.2.20* c.5.35* d.1.69	a.1.37 b.1.95 c.1.65 d.3.47*	a.0.08 b.2.28* c.0.24 d.1.25	a.0.23 b.2.08* c.0.11 d.1.34	a.8.49* b.3.44* c.11.24* d.1.04				
19 (R) Control	a.1.24 b.0.76 c.0.46 d.0.40	a.1.15 b.3.39* c.3.25* d.4.76*	a.2.44* b.0.83 c.5.12* d.0.04	a.2.29* b.3.53* c.4.78* d.2.63*	a.5.97* b.4.88* c.5.88* d.0.25	a.2.52* b.1.45 c.4.89* d.1.29			
"Imiti"	a.0.47 b.1.24 c.4.49* d.0.00	a.0.37 b.2.92* c.0.78 d.5.17*	a.1.66 b.1.31 c.1.10 d.0.45	a.1.52 b.3.05* c.0.76 d.3.03*	a.6.74* b.4.40* c.9.90* d.0.65	a.1.75 b.0.97 c.0.86 d.1.69	a.0.77 b.0.48 c.4.02* d.0.40		
17 (L)	a. – b.1.55 c.2.27* d.0.35	a. – b.2.61* c.1.44 d.5.19*	a. – b.1.62 c.3.32* d.0.77	a. – b.2.74* c.2.06* d.3.19*	a. – b.4.09* c.7.68* d.0.96	a.– b.0.66 c.2.16* d.1.94	a. – b.0.79 c.1.80 d.0.73	a. – b.0.23 c.2.22* d.3.47*	
19 (L) Control	a. – b.0.22 c.5.57* d.0.36	a. – b.4.37* c.1.86 d.5.20*	a. – b.0.14 c.0.02 d.0.78	a. – b.4.50* c.0.33 d.3.20*	a. – b.5.86* c.10.99* d.0.97	a. – b.2.42* c.5.46* d.1.95	a. – b.0.97 c.5.11* d.0.74	a. – b.1.29 c.1.08 d.3.57*	a. – b.1.76 c.3.30* d.0.01
Treatment	2 (R)	5 (R)	7 (R)	8 (R)	9 (R)	11 (R)	19 (R) Control	"Imiti"	17 (L)

From the comparison between the untreated trees at "Ruimte" and at "Imiti", together with the information presented in Figures 33 and 36, it was concluded that during the three years in which the control trees at "Ruimte" were untreated, the control of P.citri by A.addoensis was similar to that of the natural control orchard at "Imiti".

b. There was no significant difference between the citrus red mite density on the untreated trees at "Imiti" and Treatment 7 (Trithion spray in March) and Treatment 11 (parathion spray in October and March). This result indicated that these two insecticical treatments did not produce a variation in P.citri population density that was significantly different from that observed in the natural control orchards at "Imiti" The reason for this similarity between the citrus red mite variation in these two treatments and "Imiti" was probably due to the long absence of the red mite on the trees after the chemical applications and the reappearence of the predator mite soon after the sprays were applied.

In the case of the untreated control trees at "Littlecote", (Treatment 19 L) and Treatment 2 (Parathion spray in October) at "Ruimte", these treatments differed significantly from the red mite fluctuation in the natural control orchard only during March to May 1967.

c. Those treatments in which the P.citri density was significantly greater than that at "Imiti" on more than one occasion were Treatment 5(Parathion spray in March), Treatment 8 (Parathion-Rogor spray in March and Treatment 9 (Parathion spray in August and October) at "Ruimte", and Treatment 17 (Parathion-Gusathion spray in October) at "Littlecote". These results indicated that the development of high densities of citrus red mite was related to these particular red scale insecticidal treatments.

In general, the red mite recovered rapidly from the effect of the spray application and with the absence or reduction in the numbers of the predaceous mite, increased in density. It appeared that the main reason for the rapid reappearence of the citrus red mite after treatment of the trees was that the egg stage was the least susceptable to the insecticide. Thus, after the red scale treatment the eggs of P.citri hatched and gave rise to a new population.

Beament (1951) and Lees (1961) have shown that the eggs of the mite Panonychus ulmi Koch and Petrobia latens Muller are covered with an extremely waterproof wax which probably plays a role in the retention of moisture within the egg. It is suggested that the eggs of the citrus red mite are also covered with a waxy envelope, and that it is this waxy covering which is responsible for the ability of the eggs stage of P.citri to withstand the effect of the insecticidal treatments.

From the evidence presented, it is considered that the application of 0.75% Parathion and 0.2% Alboleum at different times of the year had little effect on the P.citri populations, a fact which has also been found by Cressman, Munger and Broadbent (1950). In most cases, however, the effective removal of the predaceous mite by these sprays resulted in a red mite increase. This point has also been substantiated by Ebeling (1959) who has stated that it:-

"was once believed that the citrus red mite could not survive the hot and presumably climatically unfavourable citrus areas of the San Joaquin and Sacremento valleys. However, in 1938, a few infestations were found in these valleys where DDT had been applied. It is likely that the mites had long existed in the orchards but were held to extremely low populationsdensities until DDT destroyed their natural enemies".

From these observed effects of red scale Parathion-oil sprays on both P.citri and A.addoensis populations in the Sundays River Valley, it is suggested that the injudicious use of these sprays for the control of California red scale could well have been responsible for the establishment of the citrus red mite as a pest of citrus in South Africa. The broad spectrum of toxicity of Parathion to many important insect and mite predators of P.citri, and the rapidity with which Parathion treatments can be applied to citrus orchards result in the temporary elimination of the predator component from the environment of the citrus red mite. Thus in the absence of predation, and with favourable climatic conditions, heavy infestations of P.citri are able to develop in citrus orchards.

13.

DISCUSSION.

While the understanding of the processes which regulate the abundance of animal populations is important to both applied biology and ecology in general, it is a subject on which there is considerable difference of opinion. These differences may be attributed to two major factors. Firstly, to a confusion and misunderstanding that has arisen over the use of certain ecological terms, and secondly:-

> "the theories presented are simply different ways of regarding and evaluating the same thing, conditioned by personal experience, preference and aptitude; but mention of the fact is necessary because of the uncompromising way in which some leading theorists have adhered to their viewpoint." (Clark *et al*. 1967).

Several workers, for example Andrewartha and Birch (1954) and Nicholson (1954a, 1954b) have, from the results of research on individual insect species, formulated general concepts of the role of ecological factors on the regulation of animal abundance. While the results of this research serve the useful purpose of stimulating further ecological thought and experimentation, the conclusions drawn, although obviously applicable to those insects under investigation, may not necessarily apply to all organisms in general.

Davidson and Andrewartha (1948a, 1948b) and Andrewartha and Birch (1954) observed after a careful study of the apple blossom thrips, *Thrips imaginis*, over a period of 14 years, that the population density of this insect was closely correlated with the changes in the weather. From these and other observations, they postulated that the characteristic population levels attained each year by a species was due to a balance between the favourability and unfavourability of the weather (Andrewartha and Birch 1954).

A study of the population variation in laboratory populations of the sheep blowfly, Lucilia cuprina, (Nicholson 1954a, 1954b), led Nicholson to propose that it was the density of the animals themselves which governed the degree by which the population increased or decreased in numbers.

"Populations are self-governing systems. They regulate their densities in relation to their own properties and those of their environment. This they do by depleting and imparing essential things to the threshold of favourability, or by maintaining reactive inimical factors, such as the attack of natural enemies, at the limit of tolerance.
The mechasism of density governance is almost always intraspecific competition, either amongst the animals for a critically important requisite, or amongst natural enemies for which the animals concerned are requisites." (Nicholson 1954b).

Clearly the environments of T.imaginis and L.cuprina differ, and it is suggested that this environmental difference may result in an increase in the relative importance of certain controlling factors over others. Thus the relationship between the population density of T.imaginis and weather, found by Davidson and Andrewartha (1948a, 1948b) may be correct, while in the case of the blowfly, L.cuprina, weather may be of relatively little importance, and the main controlling ecological factor could well be intraspecific competition. This point is well taken up by Clark et al. (1967) who state that:-

"Insect species differ greatly in their characteristics as do the environments in which they live. Consequently, any attempt to generalise about the determination of insect numbers can serve as only a guide for the study of particular populations".

The failure of ecologists to produce a wholly acceptable explanation for the changes in the distribution and densities of natural populations, has lead to the realisation that there is a need for a generalised description of the manner in which animal abundance is determined. Two such generalised concepts have been put forward by Huffaker and Messenger (1964) and Clark *et al*. (1967).

In the model proposed by Huffaker and Messenger (1964), it is the combined action of the whole environment which is responsible for the maintainence of population density.

"The environment acts as a totality, and the elements of this whole are in important, sometimes delicate, interaction. In classifying roles or factors we tend to break apart the inseparableness of the environment which lies at the core of natural control".

These workers go on to state that:-

"Natural control has two checking components. First there is a limit to the general favourability, and to variations in favourability, depending on the basic climate and edaphic elements of a region, or more particularly, for specific locales. This is coupled with the fact that species have intrinsic limitations. Secondly, for any given level of conditions as ultimately set by the environment, governing mechanisms check populations within such a framework."

The approach adopted by Clark *et al*. (1967) is simply to regard the study of the dynamics of specific populations as that part of the ecosystem which determines the existence, abundance and evolution of a particular population. This "life system" concept:-

"is composed of a subject population and its effective environment which includes the totality of external agencies influencing the population, including man (in practice, those biotic and abiotic agencies whose influence can be observed and, preferably measured." (Clark *et al*., 1967).

It is in the light of these two generalised concepts of population control that the effect of temperature, relative humidity predation and red scale insecticidal treatments, on the seasonal abundance of the citrus red mite in the Sundays River Valley, is considered.

Laboratory studies have shown that temperature could explain the seasonal abundance of P.citri by modifying the life cycle and controlling the rate of growth, reproduction and survival. It was also found that the occurrence of extreme temperatures had a direct effect on red mite populations by causing the death of the active stages. Relative humidity had little effect on the development of the citrus red mite, but had a direct influence on the rate of oviposition by the females. The variations of temperature and humidity in the field could therefore produce periods which were favourable or unfavourable for red mite population development.

In field experiments it was observed that a rise in the numbers of red mite was coincident with an increase in the population density of the predaceous mite, A.addoensis. Such an interaction between the citrus red mite and the predator mite tended to produce an oscillation of both populations.

From the results of the study of temperature, relative humidity and predation of P.citri, a hypothetical model was constructed to illustrate the probably influence of these three ecological factors on the annual variation in the numbers of citrus red mite. This hypothetical model is shown in Figure 44.

On a citrus tree in the Sundays River Valley, infested with P.citri, an increase in population density occurred during March and May, at a time when temperature and relative humidity were favourable for red mite development[1].

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[1]When temperatures of less than or equal to 5°C, greater than or equal to 35°C and greater than or equal to 40°C and relative humidities of less than or equal to 25% were not frequently recorded in the field (Figure 25).

A decline in the population numbers during June and July was coincident with an unfavourable climatic period,[1] and an increase in the numbers of A.addoensis (Figure 30). The predator population declined towards the end of July, but temperature and relative humidity were again favourable for the development of P.citri from August to October, and this red mite population increase was followed by a resurgence in the numbers of predaceous mite. The occurrence of summer temperatures greater than or equal to 35°C and the continued presence of A.addoensis resulted in a low level of P.citri from November to February.

Throughout this study, the only predator which has been considered is the predaceous mite, A.addoensis. It must be pointed out, however, that many different species of entomophagous insects also attack the citrus red mite, as indicated by the work of DeBach *et al.* (1950), Fleschner and Ricker (1953a, 1953b), Ebeling (1959) and van Rooyen (1966). While the effect of these insect predators on the seasonal abundance of P.citri has not been studied, their influence on the population density of the citrus red mite in the field cannot be ignored.

Observations carried out on the six untreated trees at "Imiti" from March 1966 to October 1967, showed that the greatest numbers of citrus red mite were found during the months of March and May, and August and October (Figure 9). Of these two periods, the largest density of P.citri occurred between March and May. It is suggested that although temperature and relative

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[1] When temperatures of less than or equal to 5°C and relative humidities of less than or equal to 25% were frequently recorded (Figure 25).

humidity during August and October were favourable for the development of high densities of P.citri, relatively low numbers were observed because of the combined action of A.addoensis and insect predators. The activity of these insect predators could possibly be greatest at this time of year because of the development of many insect species, such as Thysanoptera and Aphids, on the new foliage and blossom of the citrus tree.

Deviations from this seasonal cycle of P.citri abundance observed in the Sundays River Valley may occur as a result of the variation in climate, or the occurrence of predators. This suggestion is supported by the work of van Rooyen (1966) at Zebediela, Transvaal, where the maximum numbers of citrus red mite occurred between November 1962 and January 1963, a period in which weather in this area is favourable for the development of the citrus red mite. In addition, there are other ecological factors, apart from predation, that were rot examined in this study, but which may also play a role in regulating the population density and seasonal abundance of P.citri. Such factors include the influence of leaf damage (Henderson and Holloway 1942 and Wedding, Riehl and Jeppson 1958), the seasonal growth cycles of the host plant (Jeppson et al. 1957, 1961), host plant resistance (Fleschner 1952) and interspecific competition (Ebeling 1948).

From this study of the citrus red mite in the Sundays River Valley, several important aspects of the role of abiotic and biotic environmental factors, on the seasonal abundance of P.citri, have been demonstrated. The physical environment may:-

(a) influence the development of the citrus red mite, thus determining those periods within which governing mechanisms, such as predation, act.

(b) have a direct effect, of a density independent nature, on red mite populations by increasing the mortality or decreasing the reproductive rate. I consider, however, that this factor is really an aspect of the favourableness of the period.

Within these periods of favourable weather, predation regulates the abundance and population density of P.citri. Thus, collectively, weather and predation interact with one another, with differing intensities, to produce a continuous, but varying distribution and density of the prey species in time and place.

In the apparent oscillation of P.citri and A.addoensis in the field, the ability of the predaceous mite to exploit other sources of food must be considered an important factor. The ability to utilise alternative food sources probably prevents the extinction of the predator population at very low densities of P.citri thus making possible the rapid recovery and reproduction of the predator when the density of the red mite increases. A similar situation has been reported by Huffaker and Kennett (1956) between the cyclamen mite, Stenotarsonemus pallidus (Banks), and the predator mites Typhlodromus cucumeris Oudemans and T.reticulatus Oudemans. These two workers found that the utilisation of honeydew produced by aphids or aleyrodids, or possibly plant exudates, enabled these predators to survive in spite of low densities of their normal host, S.pallidus.

From the results of laboratory experiments, and field trials, it was found that the predaceous mite, A.addoensis, was an effective predator of the citrus red mite in the Sundays River Valley. There was a ratio of approximately one adult A.addoensis to three active stages of P.citri, which if undisturbed, could maintain a field population of citrus red mite at a low density. However, if this ratio was upset, so that there were more than three red mite active stages to one predator mite, high densities of P.citri were found to develop on a citrus tree. Kuenen (1947) has pointed out that predators of which an individual consumes a large number of prey, such as coccinellid predators, starve when the prey is still relatively abundant, whereas predators that individually consume few prey can maintain themselves when the prey is scarce, and thus continue to reduce it to a low level. It may be argued therefore, that many insect predators are only truly effective during peak populations of P.citri, and that during these periods their action is complementary to that of the predaceous mite, while during the intervening periods of low red mite density, A.addoensis is probably the major predator limiting the population.

The distribution of the host and predator populations on a tree is also important in the effectiveness of a predator. Anderson and Morgan (1956) found that the restricted distribution of two predominant species of Typhlodromus to the lower surface of apple leaves, indicated that they were not efficient predators of the phytophagous mite, Metatranychus ulmi Koch. These workers found that in warm weather one half of the eggs and active stages of the host were on the upper surface of the leaf, and consequently out of range of the Typhlodromid mites.

in darkness at room temperatures of 27°C to 28°C, and at relative humidities of 43% to 55%. As the food supply was progressively reduced, or the oranges deteriorated in condition, a number of oranges from each tray were replaced with fresh ones at regular intervals. Apart from the controls, the experiments were begun by infesting one or more oranges in each tray with E. sexmaculatus, and later with the predator mite T. occidentalis.

By varying the arrangements of the oranges among the rubber balls, Huffaker (1958) demonstrated that in those systems in which the predator was included, the number of E. sexmaculatus rose to a peak and then declined, closely followed by a similar variation in the density of the predator. In all systems, T. occidentalis starved to death after reducing the prey to a low level. On the other hand, in some systems E. sexmaculatus was also eliminated, while in others it increased again in the absence of the predator. By increasing the complexity of the "orange systems", without rubber balls, Huffaker (1958) and Huffaker et al. (1963) could maintain the oscillating populations of predator and prey for much longer periods than in the less complex arrangements used initially. From these experiments Huffaker et al. (1963) found that:-

> "When the food was uniformly distributed in the absence of predation, a much more uniform distribution pattern of the prey species occurred than when the predators were present. Thus the predators altered - and in that sense controlled - the distribution of the prey population, as well as reducing its density. Thus, in nature, predator action may be suspected if no other factors account for the very irregular distribution of phytophagous insects on uniformly distributed plants or on plants grown in monocultures."

The effect of Parathion sprays in increasing

An examination of the distribution pattern of A.addoensis and P.citri indicated that the majority of the predator mites were found on the more interior leaves of the citrus tree, while the greatest number of red mite occurred on the peripheral leaves of the tree. Nevertheless, field observations and leaf samples showed that this predaceous mite was not confined to the interior of the tree, and frequently occurred on both the upper and lower surfaces of red mite infested leaves. Thus, the findings of Anderson and Morgan (1956) do not apply to the relationship between P.citri and A.addoensis.

In studying the seasonal abundance of the citrus red mite, one of the most confusing facts was the marked variation of red mite populations between individual trees within the same orchard (Figures 8, 27 and 28). In this study it has been suggested that the variation was probably related to the different population densities of A.addoensis on each tree. It is interesting to note that in laboratory studies on dispersion and predator/prey relations, using the phytophagous mite Eotetranychus sexmaculatus (Riley) as prey, and the mite Typhlodromus occidentalis Nesbitt as predator, Huffaker (1958) and Huffaker et al. (1963) suggested that predation could account for the irregular distribution of phytophagous mites on uniformly distributed plants. In these laboratory experiments, oranges partly covered with paper or wax were distributed in various ways among waxed and lint-coated rubber balls on open trays. The uncovered portion of the orange was also coated with lint to create a surface similar to the fine hairs on the surface of many plant leaves. The trays were kept the population density of P.citri has been demonstrated in the U.S.A. by Spencer and Norman (1952), while in South Africa, Schoeman (1960) suggested that this insecticide was probably responsible for the appearence of several new pests of citrus at Zebediela, including the citrus red mite. In this study of P.citri in the Sundays River Valley, it has been shown that sprays for the control of red scale can produce large numbers of red mite, by the effective elimination of predation during periods favourable for development. It is suggested, in the light of this information, that the change over from the practice of fumigation to the more rapid method of applying Parathion sprays could well account for the establishment of the citrus red mite as a pest of citrus in South Africa.

At Zebediela, Parathion was first used in 1950 (Schoeman 1960), and in the same year P.citri damage was reported from orchards in this area. Within two years of the commercial use of Parathion, P.citri damage had been reported from all the Transvaal citrus producing areas (Smith 1953). In the Sundays River Valley Parathion was also used for the first time in 1950, but the first recorded injury to citrus was not reported until 1963 (Hanekom 1967). This could be explained by the fact that P.citri may not have been present in the Valley before its introduction on nursery stock from Nelspruit, Transvaal.

The efficiency of natural enemies in regulating the population density of P.citri suggests that the pest status of this mite could be reduced by the judicious timing of red scale sprays so as to produce the minimum effect on the predator population. An alternative approach would be to bring the orchards under permanent biological control. The effectiveness of biological control in reducing the pest status of several insects and weeds has been well documented by DeBach (1964). In South Africa, the effect of biological control on the citrus red mite has also been demonstrated, not only in this study, but also in a report on the control of red and circular purple scale issued by the Rustenberg Co-operative Packhouse Company Limited (1966). In this report it was shown that in Parathion treated orchards, the citrus red mite was the second most important pest of citrus after the California red scale, while in untreated biological control orchards the red mite was only of minor importance.

In California, a great deal is known about the biology of the citrus red mite because it is a major pest of citrus in many areas areas of this State. In South Africa, however, this mite problem is of comparatively recent origin, and consequently much of our information is based on the results of investigations undertaken in California. Thus, there is a need for a study of the citrus red mite under South African conditions so that the cyclical patterns and numerical changes can be confirmed. It is essential to examine the environment of an animal so that we may understand the natural limitations of the population. Before we can explain the fluctuations in population density in the field, we should know something about the interaction between organisms and their environment. In this regard the work of van Rooyen (1966), and the results of this study may give citrus entomologists in South Africa a better understanding of the ecology of P.citri, and also a basis for further investigations. Some investigations which would increase our knowledge of the citrus red mite in the Republic are the effect of P.citri infestations on the yield of citrus trees, the reason for the apparent absence of the citrus red mite in the Koonap-Kat River area of the Eastern Cape, the influence of the seasonal growth cycles of the host plant and the interaction between insect and mite predators on the population density of P.citri.

14.

SUMMARY.

1. In this study the influence of temperature, relative humidity, the predaceous mite, *Amblyseius* (*Typhlodromalus*) *addoensis* van der Merwe and Ryke, and red scale insecticidal control measures on the population density and seasonal abundance of the citrus red mite, *Panonychus citri* (McGregor), were investigated. These investigations consisted of both field and laboratory experiments in the Sundays River Valley, a citrus producing area of the Eastern Cape Province, between March 1965 and March 1968.

2. In South Africa the citrus red mite was first reported as a pest of citrus in 1950, but has now become distributed throughout the major citrus growing areas in the Transvaal, Natal and Cape Province. This mite species does not appear to be indigenous to the Republic, and it is thought to have been introduced on imported citrus stock at the beginning of this century.

3. The economic importance of *P.citri* is discussed, and the defoliation caused by the citrus red mite to young citrus trees grown in the laboratory was examined.

4. The geological, climatic and citricultural practices in the Sundays River Valley are presented.

5. The life cycle and general biology of the citrus red mite was examined and discussed in relation to work on the same and other species of mites undertaken by other investigators. The measurements of the body length of the different instars in the life history of *P.citri* were found to agree closely with

those of the citrus red mite in the U.S.A. (Ebeling 1959) and from Zebediela, Transvaal (van Rooyen 1966).

6. It was found that the dispersal of the red mite from one tree to another in an infested orchard was largely due to wind. The direction of dispersal took place against that of the prevailing wind.

7. The efficiency of the mite brushing machine, paper impression method and microscope examination of citrus leaves in estimating the relative number of red mite on a citrus tree in the field, were evaluated. The microscopic method was found to be the most accurate method for estimating P.citri density. In addition, the distribution of P.citri and A.addoensis on a citrus tree was investigated. These studies led to the development of a sampling method which consisted of haphazardly collecting 20 mature leaves into a container, at any height between ground level and eight feet, from the southern aspect of a citrus tree. The accuracy of this sampling method for estimating the population density of P.citri on a tree was found to vary between ± 10% and ± 13%, while the sampling error for the predaceous mite, A.addoensis varied between ± 30% and ± 35%.

8. In an orchard situated on the farm "Imiti", Addo, which had not been treated with insecticides since 1961, the peak numbers of citrus red mite were recorded between March and June, and August and September. These findings indicated that the variation in the number of red mite in this orchard were related to the fluctuations of temperature and relative humidity.

9. From an evaluation of several different breeding techniques, a satisfactory rearing unit was constructed, which employed a lemon fruit as the

substrate.

10. It was observed, in laboratory trials, that unfertilised eggs produced by virgin females of P.citri gave rise to only males.

11. In an environment room, programmed to simulate summer, autumn and winter conditions of temperature and relative humidity, it was found that these seasonal conditions had a marked effect on the development of P.citri. The development of the red mite was most rapid under summer conditions, the mean generation time being 31 days. Under autumn and winter regimes, the mean generation time increased to 50 days and 70 days respectively. It was found that the simulated climatic conditions had the greatest effect on the incubation period of the egg stage.

12. In a factorial experiment, the effect of constant temperatures of $17^{o}C$, $22^{o}C$ and $27^{o}C$ and near constant relative humidities of 30%, 60% and 90% on the development of P.citri were investigated. Temperature was shown to be significantly related to the development of the eggs, larvae, protonymphs, deutonymphs and female stages of P.citri. Relative humidity was significantly related to the development of the deutonymphal stage and to the rate of oviposition of the females. No significant interaction between temperature and relative humidity and the development of the different stages of P.citri was noted.

13. It was found that field temperatures of greater than $35^{o}C$ resulted in the death of the males, while temperatures of greater than $40^{o}C$ were lethal to all active stages of P.citri.

14. From the results of the above temperature and relative humidity experiments, an attempt was made to explain the occurrence of high populations of P.citri at "Imiti" between March and June and between August and October. An attempt was also made to explain the observations of van Rooyen (1966) on the population fluctuations of P.citri at Zebediela.

15. The population density of the citrus red mite on trees within an infested orchard was not uniform, but varied markedly from tree to tree. From the results of a single set of analyses of citrus leaves, no significant difference was found between the nitrogen and phosphorus content of the leaves and the population density of P.citri on each tree. However, there was a significant correlation between the potassium content of the leaves and red mite density.

16. In laboratory feeding experiments, the predaceous mite, A.addoensis, was observed to feed only on the immature and adult stages of the red mite, but not on the eggs. However, all stages of the red spider, Tetranychus telarius (L.), including the egg stage were eaten by A.addoensis.

17. Using the sleeve check method devised by Smith and DeBach (1942), it was found that under natural field conditions, A.addoensis alone could effectively contain a fluctuating population of citrus red mite within an upper and lower limit of density.

18. From the relationship between the citrus red mite and A.addoensis, the variation in the numbers of P.citri observed on the individual trees within the natural control orchard at "Imiti" was examined in greater detail. It was concluded that the difference

in population density of the citrus red mite on each tree could be explained by the variation in the numbers of predator mite on each tree. It was suggested that there is a ratio between the number of adult A.addoensis and the active stages of P.citri of approximately 1:3. If this ratio was altered, so that there are more than three red mite active stages to one predaceous mite, large population densities of P.citri could be expected to develop.

19. In two field trials to evaluate the effect of different insecticidal treatments for the control of red scale, on the farms "Ruimte" and "Littlecote", red scale control sprays were found to have a definite effect on the population density of the citrus red mite. Red scale treatments consisting of either Parathion or Gusathion led to the development of large densities of red mite. It is suggested that the build-up of large numbers of P.citri was due to the effective removal of the predator, A.addoensis, by the insecticidal spray.

20. The rapid recovery of the red mite population observed after the chemical applications was caused by the fact that the red mite eggs appeared to be at least susceptable to the insecticide.

21. In the untreated control treatments, the population variations of P.citri, and the relationship to temperature, relative humidity and A.addoensis was similar to that recorded from the natural control orchard at "Imiti".

22. From the evidence presented on the effect of Parathion red scale sprays on the citrus red mite and predaceous mite populations, it is probable that the widespread use of Parathion could well explain the appearence of P.citri as a pest of citrus in South Africa.

15.

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APPENDIX 1.

The Distribution of P.citri and A.addoensis on a Washington Navel Citrus Tree in the Sundays River Valley - A Comparison of Three Height Levels and Seven Segments on Inside and Outside Leaves (See Page 42).

The data were analysed as coming from a randomised block experiment with height levels as blocks, and segments as treatments. The square root transformation was used on all variates analysed. No analyses were done on P.citri males and the predaceous mite A.addoensis on the outside leaves, or P.citri males on the inside leaves, because of the large number of zero values in the information. The observations on the outside and inside leaves were analysed seperately.

The tables of yields, the square roots of the numbers observed and residuals, are given in a standard order. Columns 1 to 7 represent Segments 1 to 7, and rows A, B and C represent height levels A, B and C respectively. The means of Segments and height levels have been added.

1. Outside Leaves.

(a). Variate 1 - Number of P.citri eggs.

Yields.

	Segments						
Height	1	2	3	4	5	6	7
A	19.091	20.579	29.555	41.079	33.682	16.628	12.429
B	13.209	15.411	39.249	35.895	35.277	19.196	12.509
C	14.983	19.222	36.242	31.788	40.081	20.359	11.247

Residuals.

	Segments						
Height	1	2	3	4	5	6	7
A	3.262	2.107	-5.527	4.757	-2.732	-2.167	0.299
B	-2.291	-2.732	4.494	-0.098	-0.809	0.728	0.707
C	-0.971	0.624	1.033	-4.659	3.541	1.438	-1.007

Analysis of Variance.

	df	Mean Square
Height Levels	2	0.384000
Segments	6	345.235830
Error	12	12.906046 S.E. = 3.5925 or 14.57%

Segment Means

1 - 15.761
2 - 18.404
3 - 35.015
4 - 36.254
5 - 36.346
6 - 18.727
7 - 12.061

Height Level Means

A - 24.720
B - 24.392
C - 24.846

(b). Variate 2 - Number of immature P.citri.

Yields

	Segments						
Height	1	2	3	4	5	6	7
A	6.204	5.147	10.747	20.796	18.316	8.860	5.873
B	3.674	5.244	15.636	13.133	14.230	7.516	4.847
C	5.873	6.363	12.227	15.182	14.230	9.924	4.636

Residuals

	Segments						
Height	1	2	3	4	5	6	7
A	0.040	-1.350	-3.035	3.512	1.811	-0.819	-0.158
B	-0.823	0.412	3.519	-2.484	-0.608	-0.497	0.481
C	0.782	0.938	-0.483	-1.028	-1.202	1.317	-0.323

Analysis of Variance

	df	Mean Square
Height Levels	2	4.991850
Segments	6	.73.731483
Error	12	4.473358 S.E. = 2.1150 or 21.28%

Segment Means

1 - 5.250
2 - 5.584
3 - 12.870
4 - 16.370
5 - 15.592
6 - 8.766
7 - 5.118

Height Level Means

A - 10.849
B - 9.183
C - 9.776

(c). Variate 3 - Number of P.citri females.

Yields

Segments

Height	1	2	3	4	5	6	7
A	4.062	3.535	5.049	11.291	9.192	4.636	2.738
B	2.915	2.345	7.778	8.972	7.648	4.415	1.870
C	3.240	2.915	6.363	6.892	12.020	3.807	2.121

Residuals

Segments

Height	1	2	3	4	5	6	7
A	0.289	0.236	-1.714	1.872	-0.794	-0.016	0.128
B	-0.206	-0.302	1.665	0.204	-1.687	0.413	-0.088
C	-0.083	0.065	0.048	-2.077	2.482	-0.396	-0.039

Analysis of Variance

	df	Mean Square	
Height Levels	2	0.778265	
Segments	6	26.705746	
Error	12	1.988420	S.E. = 1.4101 or 26.02%

Segments Means

1 -	3.405
2 -	2.931
3 -	6.396
4 -	9.051
5 -	9.620
6 -	4.286
7 -	2.243

Height Level Means

A -	5.786
B -	5.135
C -	5.337

From the above analysis of Variates 1, 2 and 3, it was found that the Segment effect was highly significant in all three variates. From the Segment means, the number of eggs, immature and female P.citri were highest on the southern part of the tree (Segments 3,4 and 5). For all three variates the height level means were of the same order, which indicated that on an average, a fairly uniform distribution of P.citri from the lower to the upper parts of the tree.

2. Inside Leaves.

(a). Variate 1 - Number of P.citri eggs.

Yields

Height	Segments 1	2	3	4	5	6	7
A	12.589	4.847	8.455	6.363	10.368	7.106	6.519
B	12.469	11.423	12.903	16.232	10.931	7.582	8.336
C	19.583	12.389	16.718	14.300	17.219	10.368	12.708

Residuals

Height	Segments 1	2	3	4	5	6	7
A	1.073	-1.340	-0.871	-2.570	0.893	2.119	0.696
B	-2.421	1.859	0.200	3.923	-1.918	-0.780	-0.862
C	1.348	-0.518	0.671	-1.352	1.025	-1.338	0.165

Analysis of Variance

	df	Mean Square
Height Levels	2	79.021050
Segments	6	17.128400
Error	12	4.426509 S.E. = 2.1039 or 18.45%

Segment Means

1 - 14.880
2 - 9.553
3 - 12.692
4 - 12.298
5 - 12.839
6 - 8.352
7 - 9.187

Height Level Means

A - 8.035
B - 11.411
C - 14.755

(b). Variate 2 - Number of immature P.citri.

Yields

Height	Segments 1	2	3	4	5	6	7
A	4.527	2.345	3.535	3.240	6.442	3.391	3.240
B	3.391	3.391	4.301	6.819	5.338	3.535	1.870
C	5.612	4.949	4.062	4.062	6.284	4.636	3.674

Residuals

Height	Segments 1	2	3	4	5	6	7
A	0.421	-0.812	-0.027	-1.063	0.824	-0.059	0.716
B	-0.990	-0.041	0.464	2.241	-0.554	-0.190	-0.929
C	0.569	0.854	-0.437	-1.178	-0.270	0.249	0.213

Analysis of Variance

	df	Mean Square
Height Levels	2	1.623810
Segments	6	2.933596
Error	12	1.116913 S.E. = 1.0568 or 25.03%

Segment Means

1 - 4.510
2 - 3.561
3 - 3.966
4 - 4.707
5 - 6.021
6 - 3.854
7 - 2.928

Height Level Means

A - 3.817
B - 4.092
C - 4.754

(c). <u>Variate 3</u> - Number of <u>P.citri</u> females.

Yields

Height	Segments 1	2	3	4	5	6	7
A	2.915	1.581	2.549	2.738	2.915	1.870	2.121
B	2.915	2.345	3.391	3.674	3.391	2.345	2.345
C	3.535	2.345	2.915	2.345	2.915	3.082	2.549

Residuals

Height	Segments 1	2	3	4	5	6	7
A	0.113	-0.189	-0.082	0.138	0.161	-0.242	0.102
B	-0.417	0.043	0.228	0.543	0.106	-0.298	-0.204
C	0.304	0.146	-0.145	-0.682	-0.267	0.541	0.102

Analysis of Variance

	df	Mean Square
Height Levels	2	0.555150
Segment	6	0.501380
Error	12	0.151039 S.E. = 0.3886 or 14.37%

Segment Means

1 - 3.121
2 - 2.090
3 - 2.951
4 - 2.919
5 - 3.073
6 - 2.432
7 - 2.338

Height Level Means

A - 2.384
B - 2.915
C - 2.812

(d). Variate 4 - Number of A.addoensis.

Yields

Height	Segments 1	2	3	4	5	6	7
A	2.738	3.535	3.807	2.549	3.937	3.674	2.915
B	5.244	3.535	4.301	3.807	4.527	5.244	3.535
C	3.082	3.535	3.391	4.301	4.743	2.915	3.082

Residuals

Height	Segments 1	2	3	4	5	6	7
A	-0.524	0.425	0.399	-0.578	-0.040	0.155	0.163
B	0.975	-0.580	-0.112	-0.325	-0.455	0.719	-0.222
C	-0.451	0.154	-0.287	0.903	0.495	-0.874	0.059

Analysis of Variance

	df	Mean Square
Height Level	2	1.894790
Segments	6	0.442651
Error	12	0.443673 S.E. = 0.6660 or 17.84%

Segment Means

1 -	3.688
2 -	3.535
3 -	3.833
4 -	3.552
5 -	4.402
6 -	3.944
7 -	3.177

Height Level Means

A -	3.308
B -	4.313
C -	3.578

From the analysis of the distribution of P.citri on the inside leaves, it was found that Segment 1, (North), had a significantly higher number of red mite eggs than the adjacent segments 2 and 7. Segments 3, 4 and 5, (South), were again high compared with the adjacent Segments 2 and 6. The number of eggs increased markedly from the lower to the higher parts of the tree.

There were no significant differences in the number of red mite immature stages on the inside leaves, even though fairly large differences between Segments did occur.

Segment 1 had more female P.citri on the inside leaves than the adjoining Segments 2 and 7. Height levels did not differ significantly.

There was no significant difference in the number of A.addoensis on the leaves from the different inside segments, but there appeared to be some concentration of the predator mite at height level B.

APPENDIX 2.

The Distribution of *P.citri* on a Washington Navel Citrus Tree in the Sundays River Valley - A Comparison of Four Height Levels, Five Sub-aspects and the Leaf Area on the Outside Leaves. (See Page 42).

Before analysis, the square root transformation was applied to the number of eggs and immature stages of *P.citri*. The eggs and immature stages of *P.citri* and the total leaf area were designated Variate 1, 2 and 3 respectively. The data on the females and males were not analysed on account of the large number of zero values in the information.

The means of the three variates in each group are arranged as follows:-

P.citri eggs (Square Roots)

Sub-aspect

Height	1	2	3	4	5	Mean
A	7.09	9.29	6.51	7.11	6.33	7.27
B	7.87	7.03	5.43	5.82	5.08	6.25
C	7.19	5.97	6.97	6.09	5.04	6.25
D	4.98	3.80	3.22	4.50	4.98	4.30
Mean	6.78	6.52	5.53	5.58	5.36	6.01

P.citri immature stages (Square Roots)

Sub-aspect

Height	1	2	3	4	5	Mean
A	2.13	2.95	1.81	2.06	1.49	2.09
B	3.18	2.21	1.69	1.96	1.39	2.09
C	2.70	2.21	2.54	2.58	1.22	2.25
D	1.23	0.65	0.45	1.43	1.40	1.03
Mean	2.31	2.00	1.62	2.01	1.38	1.86

Leaf area in square centimetres

Sub-aspect

Height	1	2	3	4	5	Mean
A	49.1	53.2	45.6	39.5	46.1	46.7
B	44.2	42.2	40.2	49.2	40.5	43.3
C	40.3	43.3	45.3	41.5	41.6	42.4
D	39.5	46.1	40.0	43.8	38.2	41.5
Mean	43.3	46.2	42.8	43.5	41.6	43.5

Analysis of Variance

Variate	with Variate	Total	Within	Between
df		399	380	19
Mean Squares				
1	1	7.8167	6.1255	41.64[illegible]
2	2	1.8255	1.3888	10.5[illegible]0[illegible]
3	3	135.17	126.58	306.95
Standard Deviations				
1	1	2.7958	2.4749	
2	2	1.3511	1.1784	
3	3	11.62	11.25	
Correlations				
2	1	0.6583	0.5710	
3	1	0.3033	0.2745	
3	2	0.2650	0.2582	

The variance ratio, mean squares between divided by the mean squares within, were significant at the 1% level for all three variates. This indicated that the eggs and immature P.citri were not distributed at random throughout the southern aspect of the tree. From the square root table given above, it was clear that the main difference in Variates 1 and 2 occurred between height levels, level D giving much lower numbers than the others. There was also a difference between sub-aspects, but these differences were not consistent over all height levels.

The correlation between the numbers of eggs and immature stages of the citrus red mite was fairly high, and highly significant, but this is to be expected. The correlation of leaf area with the number of eggs and immature mites respectively, was significant but rather low, and it was concluded that these variates were related but that the relationship varied from leaf to leaf and sample to sample.