

THE BIOLOGY OF THE FALSE SPIDER MITE
DOLICHOTETRANYCHUS FLORIDANUS:

A PEST OF
PINEAPPLES IN CENTRAL QUEENSLAND

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B.App.Sci. (Biol.)

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A thesis submitted in part fulfilment of the requirements for the degree
Master of Applied Science.

by

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Declaration:

I declare that the work described in this thesis is entirely my own and has not previously been submitted in any other form at any other university, institution or tertiary education centre for the award of a higher degree. The information derived from the published or unpublished work of any other person has been acknowledged.

A handwritten signature in black ink, appearing to read 'R Poli', is written over a horizontal dotted line.

Richard C.D. Poli.

Statement of Access.

I, the undersigned author of this thesis understands that the University College of Central Queensland will make this work available within the library, and that it will be accessible to library users and other approved libraries. This thesis should not be copied, or closely paraphrased without the consent of the author, and written acknowledgement of the assistance gained from this work. Beyond this, I do not wish to place any restrictions on this thesis.

A handwritten signature in cursive script, reading "R. Poli", written in dark ink. Below the signature is a horizontal dotted line.

Richard C.D. Poli.

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Dedication:

Their wisdom and knowledge was bestowed on me, their courage and strength was not all they gave.

Dino and Rose Poli.

Abstract

The false spider mite (or red mite) Dolichotetranychus floridanus has been recorded on pineapple crops throughout the world. It reaches pest proportions sporadically, particularly in areas with hot dry weather patterns.

In the late 1980's D. floridanus caused significant economic losses in the Yeppoon district of Central Queensland. Current literature on the false spider mite biology is limited with most publications orientated to taxonomy or records of presence/absence in crops. Anecdotal evidence is often vague or contradictory.

In the current study, field populations of D. floridanus and the predatory mite, Amblyseius benjamini were studied using three experimental regimes: normal horticultural practices, reduced pesticide treatment and reduced fertilizer treatments. Extraction and sampling procedures were developed to estimate field populations of all life cycle stages. Populations were sampled at six week intervals on 3 farms * 3 treatments * 5 plants * three leaves * 2 duplicates.

The false spider mites distribution along the axis of the pineapple crown was highly aggregated on the fifth and sixth basal leaf axils. The predatory mite A. benjamini did not develop substantial and aggregated populations within the leaf axils of the crown. In contrast it was prevalent on the subterranean stems and root material.

A high degree of seasonality within the false spider mite population was evident as population densities increased to damaging levels during the summer months and decreased in the winter months. The correlations of population densities with seasonal weather agreed broadly with anecdotal evidence but the statistical level of significance was not high. The coefficients of determination between mite numbers and rainfall, maximum and minimum temperatures were 0.28, 0.21 and 0.081 respectively.

The intra-plant variability and inter-plant variability were high when populations were low (during winter) but markedly less during periods of high population densities (summer).

Normal farming practice incorporates high levels of fertilizer application and use of a wide range of pesticides directed at various insect pests. Populations densities of D. floridanus were reduced by routine pesticide regimes, however residual populations are always present. Population densities were also lower on minimal fertilizer treatments. Juvenile stages were generally more sensitive to these treatments than the adult stages.

Predatory mite numbers were low in all treatments and probably exerted minimal control on the false spider mite populations. The pathogenic fungus Hirsutella sp. was sporadically present on false spider mites but exerted minimal control.

False spider mite dispersal in space and time is strongly linked with the use of crowns for plant propagation. New crowns are colonized early by mites from both the parent plant and adjacent plants. Storage of the crowns influenced both the condition of the crowns and the mite infestation levels.

Significant populations of false spider mites were found in soil and 'volunteer' plants. They provide intercrop and temporal dispersal. An additional important determinant of crop health and mite population densities is soil moisture. The level of which at planting and the time of year, may promote false spider mite infestations.

The results of the study provide foundations for future research into the effective control of the false spider mite. Further research is required on the detailed effects of temperature and rainfall (soil moisture and humidity) on population dynamics of D. floridanus. Such research will be required before an IPM program can be developed.

1.0 Introduction.

1.1 History of False Spider Mites in Australia:

The red spider mite or false spider mite, Dolichotetranychus floridanus, (Banks) (Acarina: Tenuipalpidae), is phytophagous and monospecific, living only on pineapples, Ananas comosus (Family Bromeliaceae). It is known to inhabit all pineapple growing regions of the world including Australia (Elder, 1988). In other parts of the world the introduction of the false spider mite into new agricultural regions has been on planting material (Carter, 1967). After the false spider mite has established itself, it proves extremely difficult to eradicate. D. floridanus is likely to have entered Australia contained within the first pineapple plant imports early last century. In the period since then it has spread throughout the pineapple growing regions along the east coast of Australia. Since pineapples were introduced to Australia, the false spider mites have not been generally recognized as a significant pest. It was not until 1983 that the false spider mite was formerly identified and described as being a problem in Queensland. The outbreak was reported by farmers at Kandanga in southeast Queensland after they became concerned about the necrotic lesions on the leaf bases of their crops (Elder, 1988). Since this publication, farmers throughout the state have reported the presence of the false spider mites and their damaging effects. D. floridanus outbreaks have been sporadic and short lived, up to three years in most instances. The largest outbreak in Australia to date, occurred in Yeppoon, Central Queensland, during 1987/1989 with recent outbreaks occurring in Nambour during late 1990/1991.

1.2 Mite Description and General Distribution:

Mites generally have been known to infest crops and stored products since monoculture crops have been grown. Most economically significant mites belong to the super-families Tetranychioidea and Eriophyoidea (Jeppson *et. al.*, 1975). The false spider mite has been known to infest pineapple plants since the turn of the century (Jeppson *et. al.*, 1975; Pritchard and Baker, 1958) when the mite was first identified and classified as Stigmaeus floridanus Banks (1900). Since then the false spider mite has been reclassified several times passing through the following series: Pseudoleptus floridanus, Oudemans (1900); Dolichotetranychus

floridanus, Sayed (1938); Trichadenus floridanus, McGregor (1949). The false spider mite is currently referred to as D. floridanus and its only known host is Ananas sp. D. floridanus has a very narrow host range and is known from several countries (Pritchard and Baker, 1958). It is reported as a pest of pineapples in Florida, Cuba, Puerto Rico, Panama, Honduras, Mexico, Hawaii, Phillipine Islands, Japan, Java and now Australia, although it has not yet (1991) been listed in C.S.I.R.O.'s index of Australian insects.

D. floridanus is commonly referred to as the false spider mite and belongs to the family Tenuipalpidae. The mite is very small with the adults measuring 0.3 mm in body length and approximately one third as wide. The mites are characteristically bright orange in colour. The body of each sex is characteristically shaped. That of the female is somewhat oval and that of the male is extremely pointed posteriorly, (Figs. 1 to 3). For a more detailed description refer to Appendix one.

Although distributed throughout all pineapple growing areas, D. floridanus occurs in pest proportions mainly in the Yeppoon region. Yeppoon is situated on the east coast of Australia in Central Queensland. The production area is restricted to an area within a 20km radius of the township, (Fig. 5). The area produces approximately 12 % of the state's canning fruit. Within the Yeppoon region there are approximately 400 acres of smooth leaf pineapples producing fruit for canning. The area is suitable for the production of pineapples having good soil types and climatic conditions favouring good growth. The mean annual maximum temperature is 25.7 C and the mean minimum temperature of 17.7 C. Rainfall is 111.8 mm (Bureau of Meteorology, Climatic Averages of Australia.)

Fig. 1: The Male False Spider Mite.

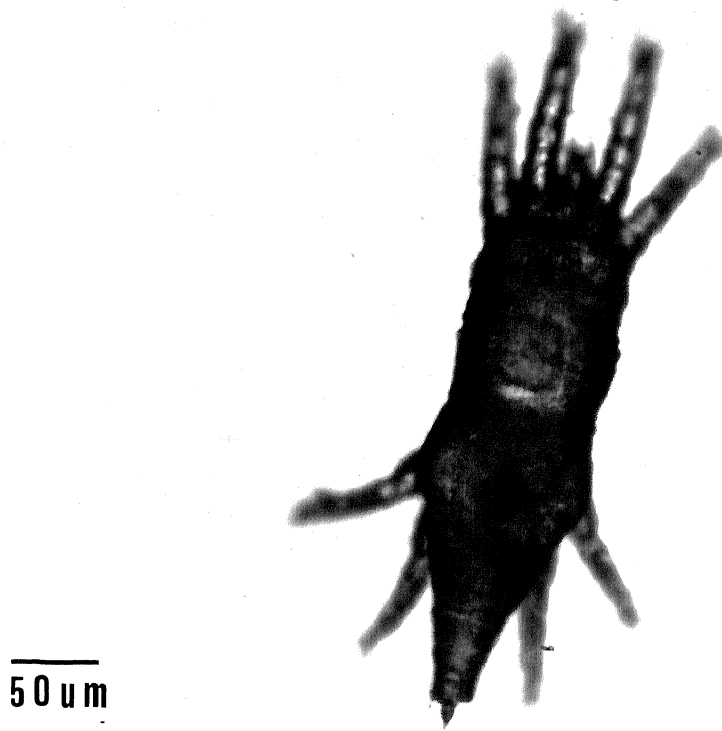


Fig. 2: The Female False Spider Mite, Stage 2 and Stage 1.

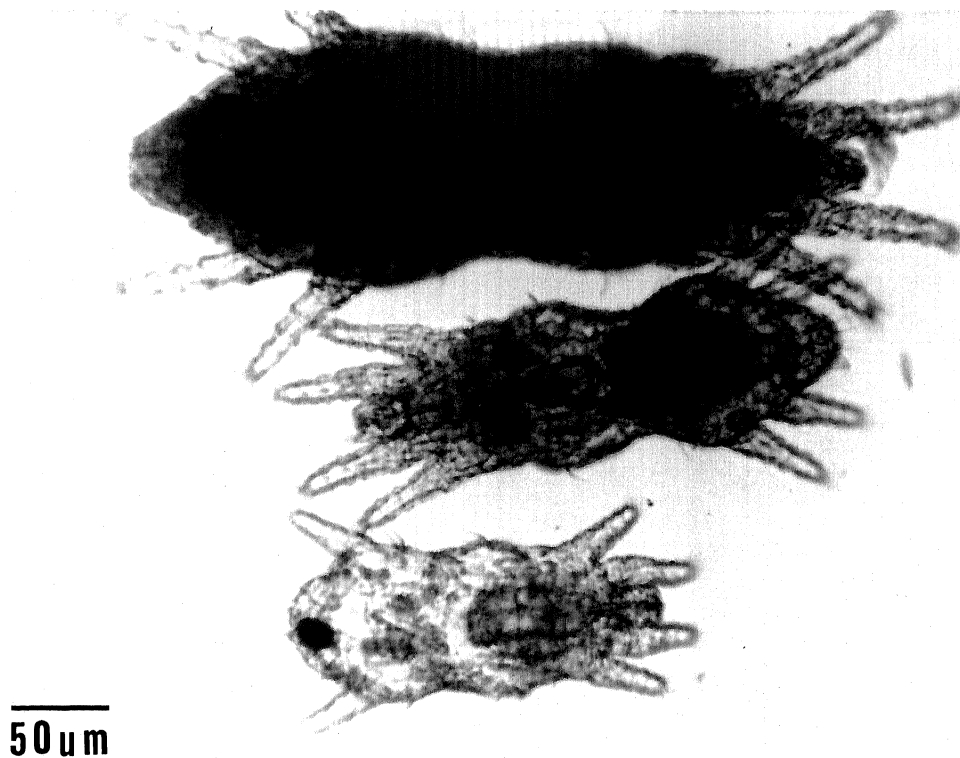


Fig. 3: The False Spider Mite Egg.



Fig. 4: The Adult Predatory Mite.

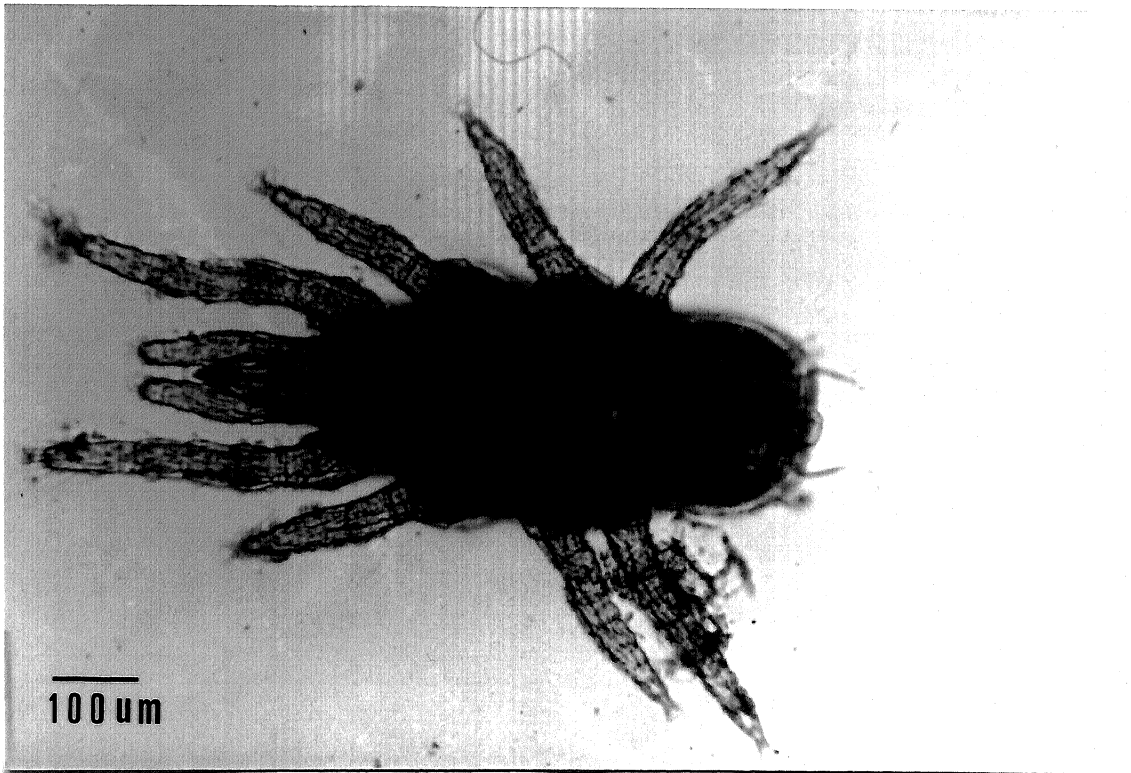
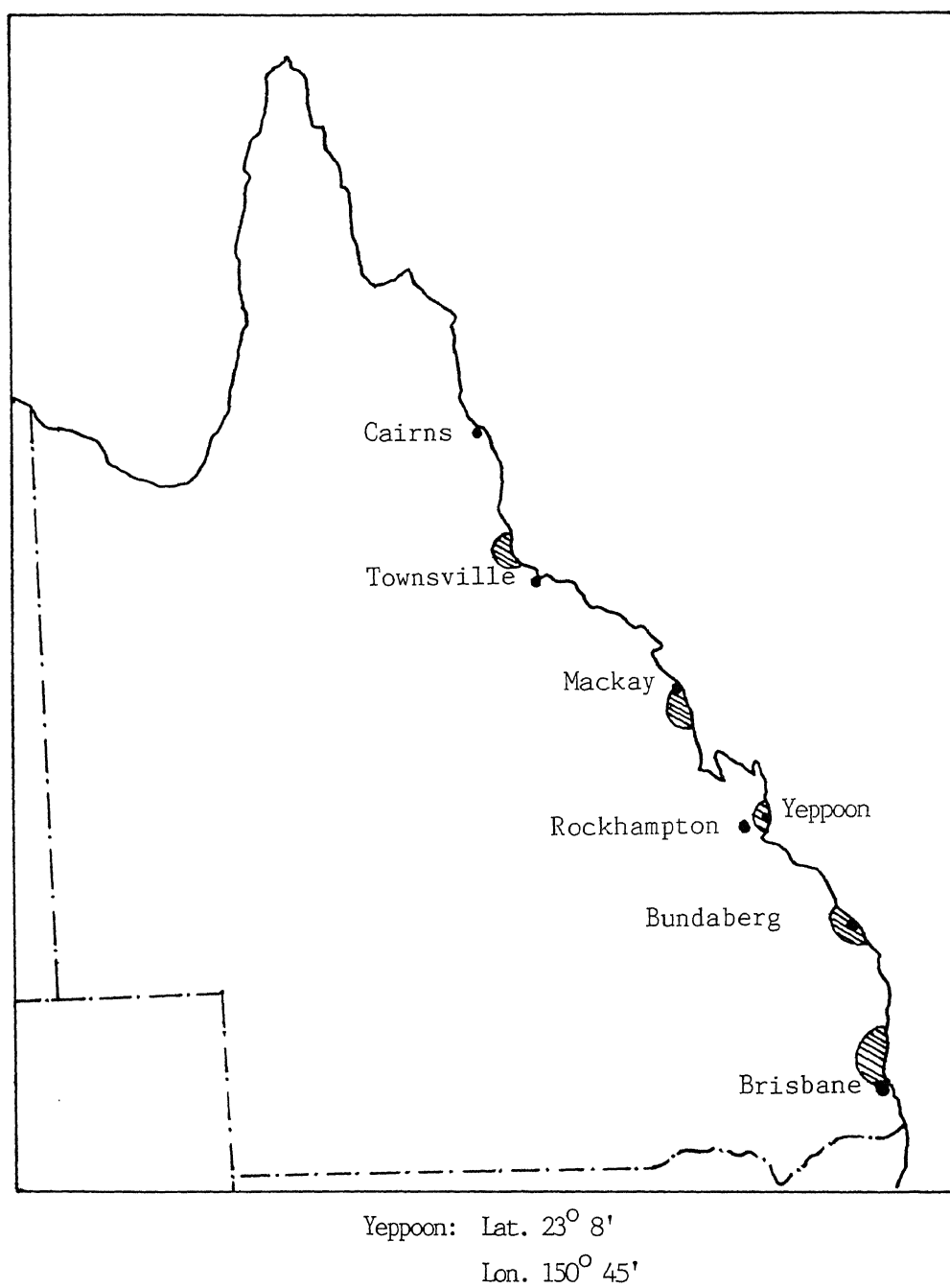


Fig. 5:. The Pineapple Growing Regions In Queensland, Australia



1.3 Economic Impact Assessment:

The false spider mite does not appear to have any preference for a particular variety of pineapple; affecting all varieties and clones equally. In the Yeppoon district, false spider mites cause damage at all stages of production. The false spider mite is responsible for tissue damage to both leaf and fruit components of the plant as well as planting material. Mites feeding on the epidermal tissue cause it to dry and crack. These cracks then allow the entrance of fungal and bacterial plant pathogens causing tissue rot (Jeppson *et. al.*, 1975; Sanches and Zem, 1978). These lesions when dry cause major scarring and tissue deformation (Sanches and Zem, 1978). Although D. floridanus has only recently been recognized as a pest, most local farmers can recall the visible defects on pineapple leaves before the false spider mite was established as the causal agent (Burrowes, B., Pers. Comm.).

The damage that the false spider mites cause, produce severe alterations to the normal crop cycle. Damage can cause severe underdevelopment of the crop resulting in uneven crop establishment and extended harvesting periods. This is further exacerbated in ratoon crops and ultimately leads to higher production costs. Yeppoon produces approximately 12 % of Queensland's canning fruit, in which losses have been estimated at approximately \$1 million in the 1988/1989 period (Hutton, P., Pers. Comm.).

1.4 Background to Study:

At the time the project was being planned there was considerable debate about the recommended control procedures. After D. floridanus was established as the causal agent for the losses in production, various *ad hoc* trial measures were undertaken by farmers. Knowing that D. floridanus was responsible for the damage, several hypothesis for their resurgence in recent times were suggested. The first hypothesis is that farming practices have changed, and a certain degree of genetic resistance to insecticides has evolved. The second hypothesis suggests that the recent occurrence of several relatively dry seasons have promoted the population outbreaks.

The treatment of pineapple pests varies in different countries depending on the insecticide registration laws (Scott, C., Pers. Comm.). Trials have

been undertaken by the Queensland Department of Primary Industries (Q.D.P.I.) assessing methods of control for the false spider mite within the local region. An inherent problem in most of these chemical control programs was that the ecology of the pest organism was not known. Little has been published on the life cycle of D. floridanus, and statements from farmers on seasonal fluctuation were inconsistent and unsubstantiated. Information on the population dynamics of D. floridanus was needed to enable the development of effective and economic spraying regimes, tightly correlated with the natural population dynamics.

In view of the paucity of data, the Yeppoon Fruit Growers and Local Producers Association established a research scholarship (1989/1990) to investigate the ecology of D. floridanus.

1.5 Project Aims:

Overall the aim of the project was to monitor the population dynamics of the false spider mite, and the predatory mite Amblyseius benjamini, (Schicha) over an entire crop cycle (18 to 24 months). It was generally considered that the biology of the false spider mite needed prompt investigation to avoid enhancing its status as a pest through unsatisfactory control practices.

The specific project aims were to quantify and qualify the false spider mites' life cycle, seasonal population variations, host-plant associations, dispersal methods and reactions to cultural practices. Specifically those cultural practices which were likely to lead to, or promote-population changes within the Yeppoon district.

A subsidiary aim was to monitor the microclimate in pineapples crops with a view to correlating population changes with seasonal weather changes. The aim was to discern which factors promote or restrict population increase or decrease. The data was to be assessed for its usefulness in the development of predictive modeling programs.

In summary, the overall aim was to document the population dynamics and life-cycle biology of the false spider mite, D. floridanus, and its predator, A. benjamini, under field environments. It was hoped that quantification of factors influencing the false spider mite populations would enable effective control procedures and more effective or

appropriate timing of insecticide applications to be developed. By contributing to a greater understanding of the false spider mites' biology it was hoped that in the longer term, populations would be effectively managed in the pineapple agro-ecosystem in a manner consistent with sustainable agricultural practices. The information from projects such as these provide the framework for the establishment of sound Integrated Pest Management programs.

2.0 Materials and Methods.

2.1 Extraction Methodology:

The method of extraction of mites for the purpose of studying population numbers varies depending on the result desired by the experimenter. Techniques of extraction and enumeration are numerous and reviewed by Williams, (1987).

This investigation was designed to estimate numbers within each cohort and general population dynamics of D. floridanus under normal and altered cultural practices of the pineapple crop. Work undertaken by Elder (1988) lead to the development of an index for rating false spider mite numbers per leaf surface. The purpose was to describe positive or negative change to population numbers prior to or after experimental procedures. Although adequate for such research, it was considered of little use in the current investigation, as mite numbers and age composition of the population were to be quantified.

Trial mite extractions from pineapple plant material were performed, as suggested in other literature, by immersing the crowns or plant material in Mineral Turpentine for 24 hours or longer (Carter, 1967). This method proved unsuccessful as the Mineral Turpentine removed the extensive waxy cuticle present on the leaves and conglomerated the false spider mites into one mass that was not acceptable for microscopic examination. Consequently an alternative method was developed which employed an ethanol wash containing 10 % detergent.

Extraction fluids were tested with ethanol concentrations of 30, 50, 70 and 90 % containing 10 % detergent ("Rocky's Own")#. The latter was used for the breakdown of the waxy cuticle and to prevent false spider mites from being conglomerated into a single mass. The crowns were broken up and immersed in each ethanol mixture for at least 24 hours. Following this the plant material was rinsed in the same solution. The leaves were immediately inspected under a stereo-dissection microscope for the presence of mites. Mite presence on the leaves after the wash caused that respective concentration to be rejected. The concentration used was that which gave the highest removal of the mites from the leaf surface.

Registered Trade Name.

2.2 Enumeration Procedure:

For the purpose of this study absolute mite numbers were required, together with quantification of the numbers in each cohort within a population. The term 'cohort' is used throughout this study to refer to either the eggs, juveniles, adult males or adult females collectively. It does not refer strictly to animals of a particular age, but rather the stage of development. Using the methodology previously outlined mites were totally removed from the leaf surface using 25 mL of the extraction fluid. Five sub-samples of 1 mL were obtained from the extraction fluid by removing without replacement. These sub-samples were placed in a Sedgewick Rafter (1 mL cell volume) and the number of individuals within a cohort scored using a binocular compound light microscope on 40x total magnification. The removal of a 1 mL sub-sample was replicated five times to compensate for any error associated with the technique.

2.3 Mite Identification:

The mite responsible for the damage to the pineapples in the Yeppoon region was identified as D. floridanus, by E. Schicha. (B.C.R.I. Rydalmere N.S.W., 1987) from field samples (Elder, 1988). Mites identified as D. floridanus have since been reconfirmed and associated mites have been identified as oribatid and predatory mesostigmata A. benjamini, mites by E. Schicha. (Schicha, E., Pers. Comm.).

2.4 A Preliminary Investigation; Mite Distribution along the Plant Axis:

In March 1989, prior to planting, ten pineapple crowns were selected at random from planting material stored in large wooden bins (approximately 2x1x1 meters). From each crown, one spiral of leaves on opposite sides of the axis was selected and removed by pulling each leaf back and out simultaneously. Each leaf in the spiral was individually placed in a sample tube and treated for mite extraction. Initially, false spider mite numbers were scored in four groups, adult males, adult females, juveniles and eggs (the term juvenile refers to the combination of the larva and protonymph in one category). The purpose of this experiment was to investigate the region along the plant axis in which the mite numbers were highest. The presence of the predatory mite

A.benjamini was also noted, and scored in three groups; adults, juveniles and eggs.

2.5 Establishment of Field Trials:

Field trials were established on three farms which had a severe false spider mite infestation problem during March 1989. These farms were selected to cover the growing region and variations in the soil types in the Yeppoon district. The first farm is owned and managed by D. and G. Clayton and is north of Yeppoon at Cooberrie. It is on rich, red, well drained volcanic soils. The second farm is centrally placed in the Yeppoon district and owned and managed by B. Burrowes, and is on poorly drained white gravel; clay/loam mixture. The third farm is owned and managed by P. Hutton and is at the southern region of the Yeppoon growing area and is the driest of the three farms. The soil on this third farm is a decomposed granite/clay mixture.

Experimental trial plots comprising three treatments were established on each farm as follows:

- 1) Treatment A = normal farming practices.
- 2) Treatment B = no insecticides applied.
- 3) Treatment C = no fertilizers applied.

Treatment "A" comprising a typical farming regime can be considered as a control. Mite populations influenced by these standard practices were used to analyse for variations between farms.

Treatment "B" consisting of a reduced insecticide application was instigated to test if insecticides in normal cropping practices were effective and if they were differentially affecting the population dynamics of the false spider mite and the predatory mite.

Treatment "C" comprising a reduced fertilizer application was instigated to test if mite populations were sensitive to altered nutrient supplies within plant tissues: a result often reported in the literature (Rodriguez, 1951; Hamstead and Gould, 1957; Henneberry, 1962).

The term 'reduced insecticide' is more appropriate than 'no insecticide' as there will always be some residual insecticide within the soil from a

previous crop. Similarly the next treatment is more correctly termed a 'reduced fertilizer' treatment rather than a 'no fertilizer' treatment.

To avoid any possible interactive associations, the treatments were duplicated and a randomized block design (Fig. 6) was employed across the three farms, under statistical advice. (White, G., Statistical section, Q.D.P.I and Tickle, K., Maths Department, U.C.Q., Rockhampton, Qld., Pers. Comm.).

2.6 Selection of Sampling Sites:

Experimental plots were selected from crops of freshly planted, highly infested crowns at the start of the 1989 autumn planting. Since false spider mite numbers were high throughout the area, these crowns, which had been stored, also had high mite infestations. The crops used in this study were typical of those being established in this area at that time. Each experimental plot contained approximately 250 plants, thereby eliminating the possibility of sampling from one plant twice within a short sample time (Figs. 7 to 9). Different farms vary in the number of pineapple rows per 'bay'. They range from eight to thirteen (double rows) per bay (Figs. 7 to 9). Selecting half of a single bay for each treatment plot gave access to eight single rows minimum, and provided easy maintenance of the treatments for the farmer.

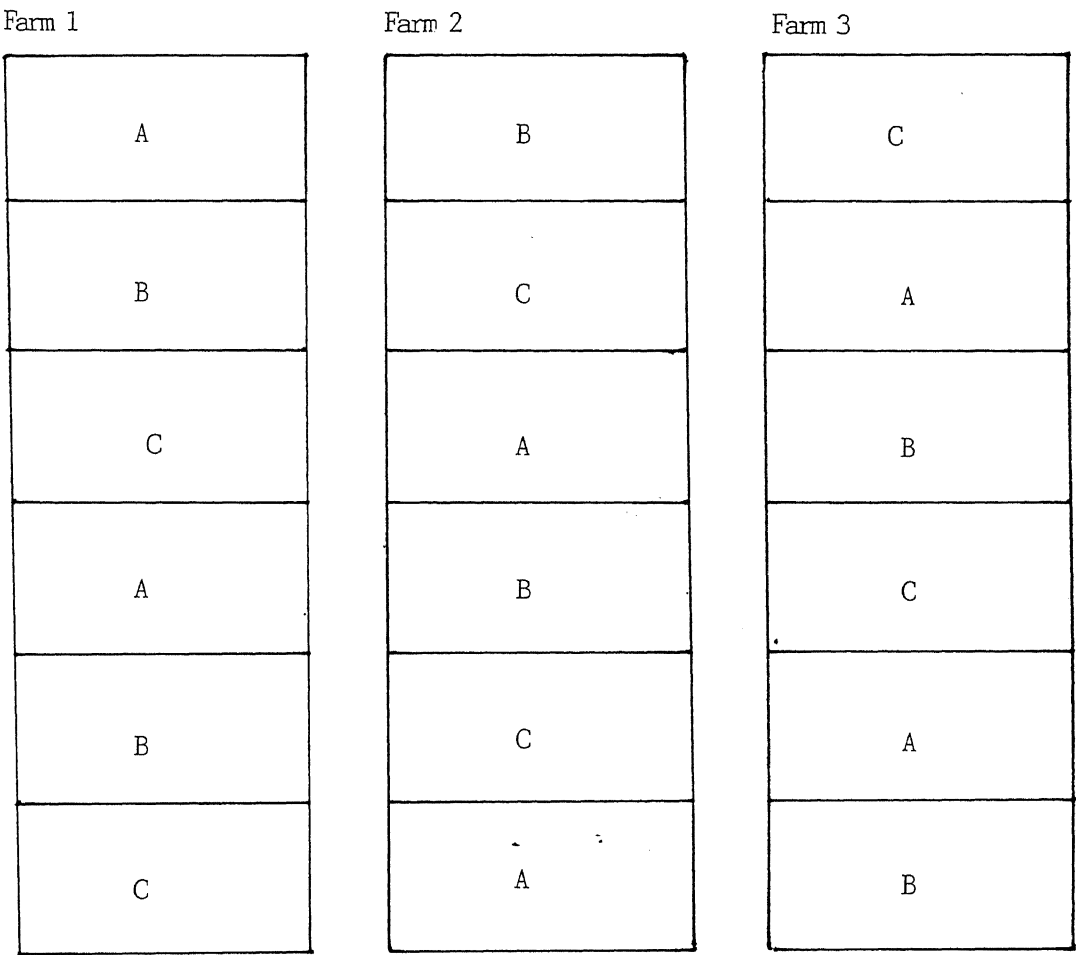
2.7 Sampling Procedures:

The sampling procedure consisted of randomly selecting a row number (1-8) and the corresponding pineapple numbers (1-25). Within each of the three experimental treatments, five pineapples were randomly selected, as described on each sample date. From each pineapple, three leaves were removed from the region of highest population density, see 3.4.

Pineapple leaves grow from the basal region where the intercalary meristem is situated. Consequently the lower three centimetres of the leaf lacks chlorophyll, and it is in this region that the false spider mites colonizes. Leaf samples had the chlorophyll containing tissue removed and the white tissues which possessed the mite colonies were stored individually in 30 mL tubes. On returning to the laboratory the 270 samples (3 farms * 3 replicated treatments * 5 plants * 3 leaves) were each immersed in 25 mL of the extraction liquid.

Fig. 6:

Randomized Block Layout for Field Sampling.



TREATMENTS:

- A = Normal Farming Regime.
- B = Reduced Fertilizer Regime.
- C = Reduced Pesticide Regime.

Fig. 7: Trial Plots on Farm One.



Fig. 8: Trial Plots on Farm Two.



Fig. 9: Trial Plots on Farm Three.



The false spider mites and predatory mites were extracted and preserved from each individual leaf using the previously described methods.

After extraction, five 1 mL sub-samples were taken from each sample tube and mite numbers for each were scored in the following groups: adult males (Fig. 1), adult females (Fig. 2), stage 2 (Protonymph) (Fig. 2), stage 1 (Larva) (Fig. 2) and eggs (Fig. 3) for the false spider mites; adults (Fig. 4), juveniles and eggs for the predatory mites.

The period February 1989 to April 1991 approximates to one full crop cycle, that is from freshly planted crowns through to flowering and fruit production. The entire procedure of sampling, extractions and enumeration was replicated every sixth week during this crop cycle producing a total of 19 sample periods. In carrying out the sampling procedure care was taken to avoid disturbing the plants unnecessarily. Although leaves showed some signs of damage by the end of the study, the main plant was almost certainly not disturbed to the point where mite populations would be affected.

2.8 Soil Moisture:

Soil moisture can be viewed as an approximate index of plant stress (English-Loeb, 1989). To obtain estimates of soil moisture, a corer was employed to sample the top 15cm of the soil within each treatment. The corer was developed using a section of high density P.V.C. pipe with an internal diameter of 55mm and a length of 150mm.

Replicate soil samples were taken from each treatment (1-3) on each farm (1-3). They were taken from the rows either side of the bay centre and placed in air-tight containers. These samples were later weighed fresh (wet weight) and reweighed after oven drying for 24h at 100 C. The differences in weights were expressed as percentage soil moisture. This prior procedure was replicated every sixth week when leaf samples were taken.

2.9 Assessing Mite Presence in Soil:

Various mite species avoid winter extremes by overwintering in some protected area of the plant by means of a dormant stage (Bengston, 1965). To avoid extremely low temperatures in pineapples it was hypothesized

that the false spider mites retreat to the root system of the pineapple or the subterranean section of the plant stem.

As false spider mites have been observed to feed on root primordia in young plants (Carter, 1967), it is not unreasonable to postulate that residual populations are maintained in these areas throughout the season. To test this hypothesis, soil samples were taken from farm three, which had a mature crop that had not been treated with insecticide. Samples were also taken from young plants that had not been treated with insecticide.

To take the soil samples, the plant was cut off approximately three centimetres below soil level. The soil sampler was centred beside the remaining stem and driven in. The extracted cores were transported back to the laboratory in air-tight containers. Mite extractions were performed over two weeks using the standard Berlese-Tullgren Funnel in which the heat source was provided by a 25 watt incandescent lamp. Mites were collected in a container containing 70 % ethanol and mite presence or absence was scored after inspection with a stereo-dissection microscope.

In addition to this, the plant material from above where the cut was made was taken and dissected to confirm the presence or absence of mites.

2.10 Weather and Micro-Climate Data:

As discussed in more detail latter, arthropod ecology is strongly affected by the influences of the weather, or more precisely, micro-climate. Data on local weather conditions, over the period 1989-1990 were obtained from the Meteorological Department at the Rockhampton Airport. This Meteorological Department is 40 Km away but is the closest site to Yeppoon.

A fully automated remote weather station (Envirodata) was installed on site to gather field microclimate data. The weather station was programmed to record average daily maximum/minimum air temperatures, maximum/minimum soil/plant temperatures, wind speed, wind run and relative humidity during the spring and summer months of 1990/91. These parameters were recorded at hourly intervals. Data was retrieved approximately every four weeks using a portable computer and dedicated software for downloading the weather station data.

The weather station was positioned on farm two. This site was chosen for several reasons. The farm was intermediate between the northern and southern farms in terms of locality, plant size, mite infestation level and soil moisture. The other major determinate was that the crop was clear on all sides from obstructions that could interfere with data recordings.

2.11 Mite Movements:

It is well known that mites disperse from their environment in situations where the conditions are not favourable eg. crowded conditions or limited resources (Wrensch and Young, 1978; Potter, 1981). Most mites rely on the perception of environmental parameters to initiate dispersal (McEnroe and Dronka, 1971). Methods of migration include walking, (Bernstein, 1984; Brandenburg and Kennedy, 1982), vector borne dispersal (Dickie and Sabelis, 1988) and air borne dispersal, (Fleschner *et. al.*, 1956; Boykin and Campbell, 1984).

Mite movement was considered to be an important component of population dynamics. Beginning in summer 1990/91 the following experiment was performed to investigate the false spider mite infestation of new fruit/plants. Pineapple plants within treatment B (reduced insecticide) were selected since their false spider mite populations were most likely to illustrate typical dispersal. Prior to the experiment a sample of ten young fruit were taken to the laboratory to confirm that mites were not present within the new crown, young flowers and bracts.

Other pineapple plants that had a small young fruit emerging from their hearts were tagged in the field with a metal plant tag.

These young pineapples were isolated from the parent plant by painting a band of "Stickem"* around the stem between the young fruit and the parent plant. This physically isolated the young plant/fruit from being infected with mites walking from populations on the parent plant. The only means in which new plant material could be infected is by aerial or phoretic dispersion. At two week intervals, until the crop had been harvested, ten protected pineapple fruit/crowns were taken to the laboratory and dissected and were scored for the presence or absence of mites.

*Registered Trade Name.

Ten 'unprotected' pineapple plants and fruits were also selected at random on each sampling occasion from within the same treatment. They were dissected out and then scored for the presence or absence of mites within the crowns, flowers and bracts.

2.12 Volunteer Assessment:

'Volunteer' is the term used to describe the plant material that, without cultivation, become self established. Despite establishing themselves on a volunteer basis, these plants are usually inferior specimens. They are inferior because they are not in synchrony with the rest of the crop and insecticide, herbicide and fertilizer applications may not be optimally timed. To test if the volunteers were providing a population reservoir they were periodically removed from the field, dissected out in the laboratory and scored for the presence of mites. The results were recorded as a percentage of infestation.

2.13 Statistics:

The data which were collected were analysed using a number of techniques. The data obtained from assessing the mite distribution along the crown axis were relatively small. To handle the data and plots of the mite distribution the spread-sheet packages, Lotus 123 ver 3.0, (Lotus Development Corporation, 1986) and Quattro Pro ver. 2.0, (Borland International, Inc., 1990) were used.

The data obtained from field samples were rather extensive and were initially formatted with a Line Editor called, "Emacs". The formatted flat files from this program enabled the data to be exported and imported to and from other statistical packages. The Anova's and Scheffe's multiple range tests were performed on a mainframe computer (vax) using SPSS-x (SPSS-x Users' Guide, 3rd Ed., SPSS Inc., 1988). Other smaller data sets that warranted statistical assessment were analysed on a micro computer using a statistical graphing package called, Statsgraphics, (Statistical Graphics Corporation, A PLUS*WARE Product, U.S.A., 1986).

3.0 RESULTS.

3.1 Extraction Methodology:

As stated in section 2.1 the removal of mites from leaf surfaces can be achieved by numerous means. In this project, the removal of mites from pineapple leaf surfaces was achieved with a modified technique, outline in section 2.1. The literature relating specifically to the removal of mites from pineapple leaves is limited. Previously published methods proved to be unsatisfactory for the efficient removal and preservation of the false spider mites from leaf surfaces. Consequently, an alternative method, which employed an ethanol wash with a detergent base was developed. The detergent base was set at a concentration of 10 % with various ethanol levels being trialed. The ethanol wash levels tested were set at 30, 50, 70 and 90 %.

50 % Ethanol and 10 % Detergent:

This wash level produced the desired results. The mites were totally removed from the leaf surface and the tissue did not putrefy.

70 % Ethanol and 10 % Detergent: -

This wash level achieved the same results as the 50 % ethanol wash.

In summary it was found that the 50 % ethanol wash proved to have the highest efficacy for removing mites from the leaf surface. The leaves that were inspected after being washed in this concentration were preserved and did not putrefy after a considerable length of time. The mites were believed to be dislodged more efficiently by this ethanol concentration than by the higher percentages, because the mites were irritated by the lower ethanol concentration and this caused them to dislodge prior to their eventual preservation. The 50 % concentration of ethanol was selected in favour of the 70 % ethanol wash because it was less expensive.

3.2 Mite Distribution in Stored Crowns:

3.2.1 The False Spider Mite:

A preliminary investigation into the false spider mites distribution within a pineapple crown was conducted as outlined in section 2.4. In this preliminary investigation the false spider mites were categorized into adults, juveniles and eggs. The predatory mites were also recorded and categorized into the same groups. From the counts per leaf, the false spider mite distribution along the crown was plotted against the leaf number. The distributions are shown in (Figs. 10 to 12 and Figs. 13 to 15) for the false spider mites and predatory mites respectively. All graphs show the means and associated standard errors. The false spider mite population is shown to spread from the basal leaves up to the 15th leaf. Although the mite population spreads up to the 15th leaf, the density at this leaf level is extremely low. The main population peak is from leaves three to seven. Figures 10 and 11 show the population to be distributed along the entire length of the crown, with the major population at leaf 5 to 7, and a slight secondary population at leaf nine.

A characteristic of the pineapple crown is that the leaves senesce and die from the bottom (butt) to the top (heart). This in effect forces the false spider mite population to move upwards as the leaves senesce. The secondary peak is suggested to be new colonies that are establishing on the higher, maturing leaves. This is considered to be a colonization stratagem that enables the establishment of new populations within an optimum feeding zone.

The egg stage of the false spider mites has a distribution that was somewhat different, (Fig. 12). The distribution is modal, but does not have the same characteristic secondary peak on leaf nine. The absence of a second peak at leaf nine suggests that the individuals colonizing those areas are predominantly juveniles. If adult cohorts comprised the colonies that were established in these sites, then there should be a corresponding rise in the number of eggs. The absence of a second egg peak at leaf nine supports the suggestion that juveniles make up the major proportion of the colonies inhabiting the upper leaves.

Fig. 10:

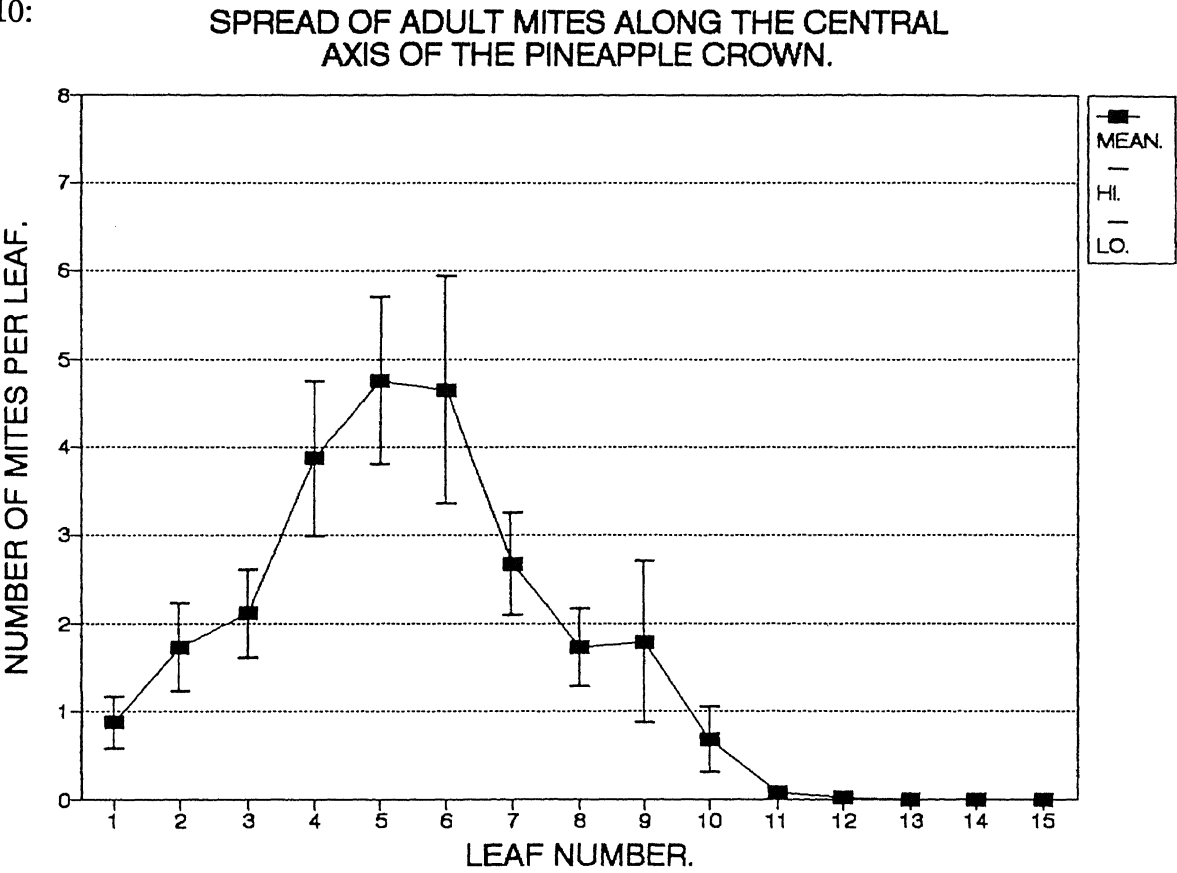


Fig. 11:

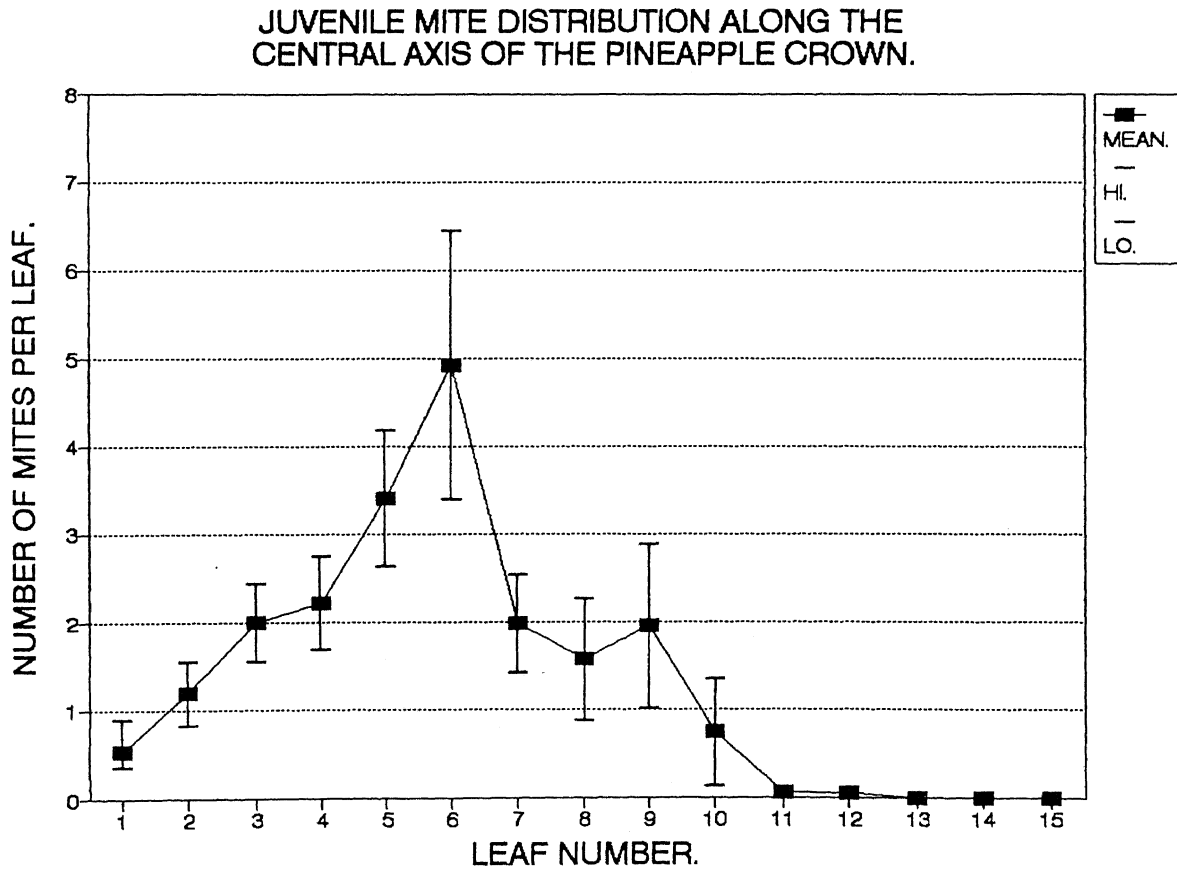


Fig. 12: SPREAD OF MITE EGGS ALONG THE CENTRAL AXIS OF THE PINEAPPLE CROWN.

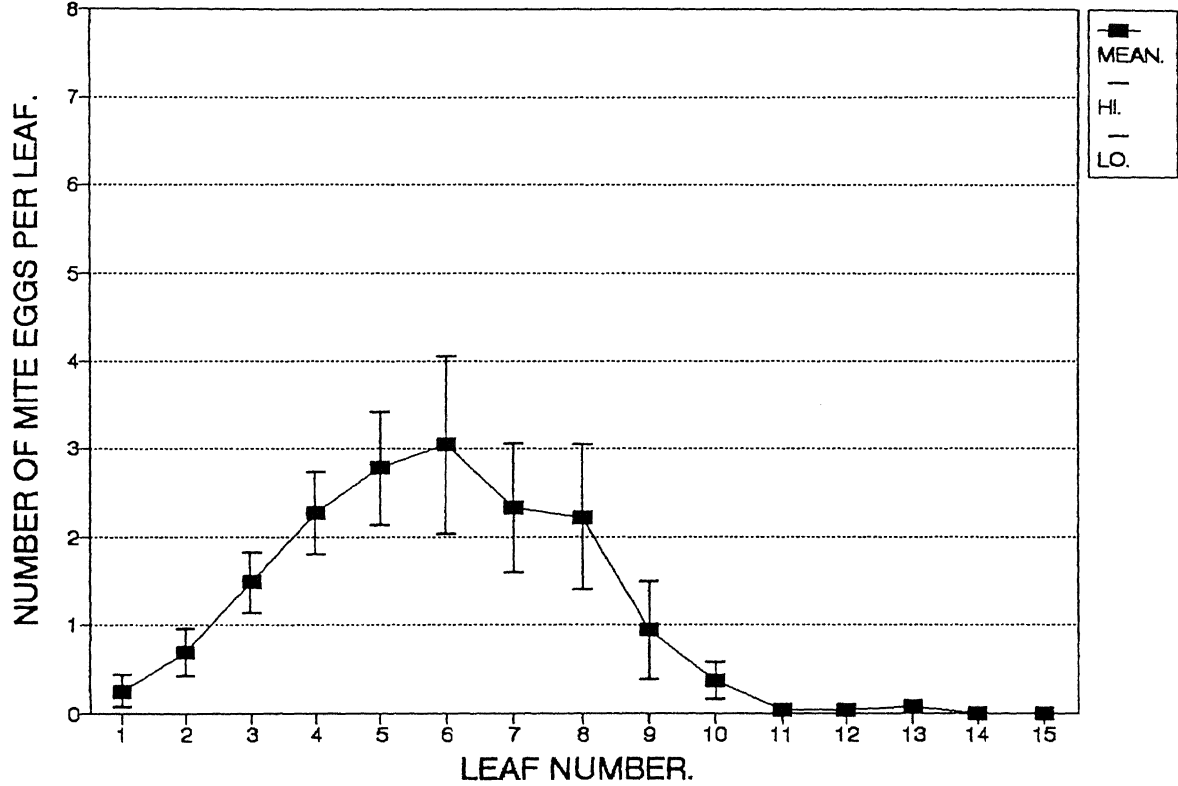


Fig. 13: SPREAD OF ADULT PREDATORY MITES ALONG THE CENTRAL AXIS OF THE PINEAPPLE CROWN.

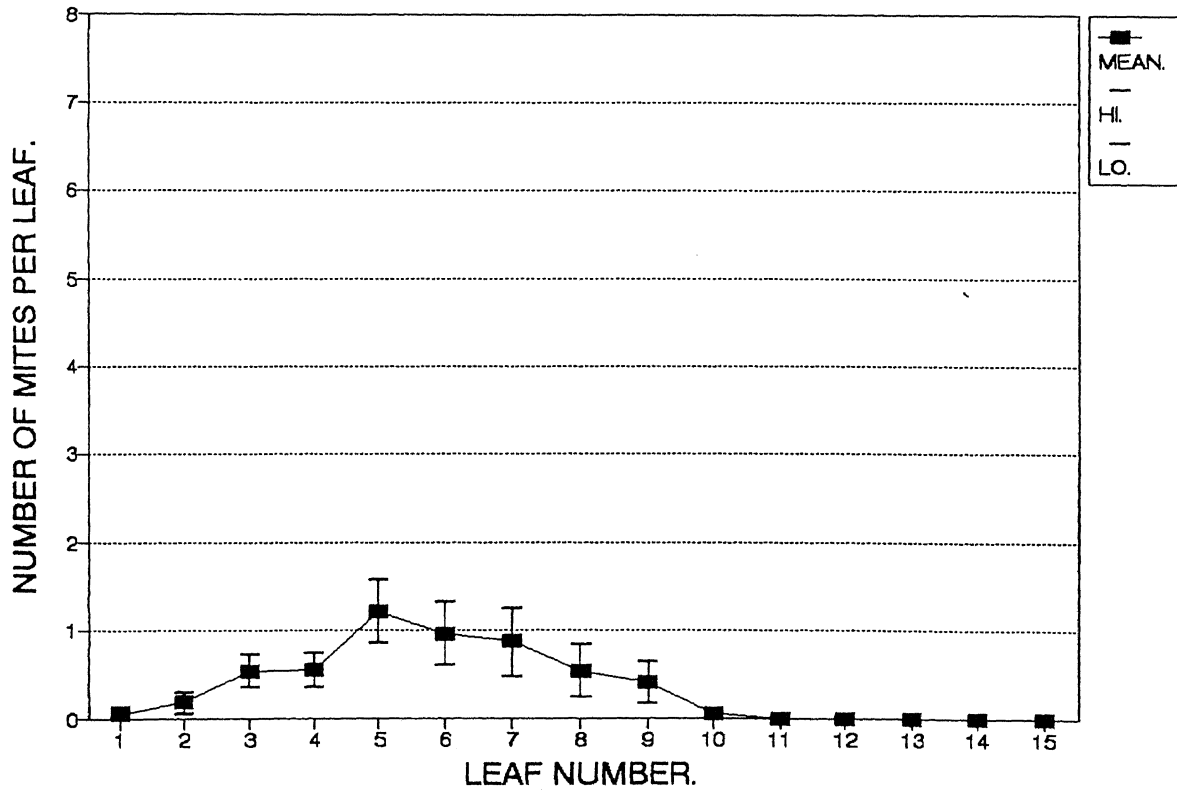


Fig. 14:

JUVENILE PREDATORY MITE DISTRIBUTION
ALONG THE CENTRAL AXIS OF THE PINEAPPLE.

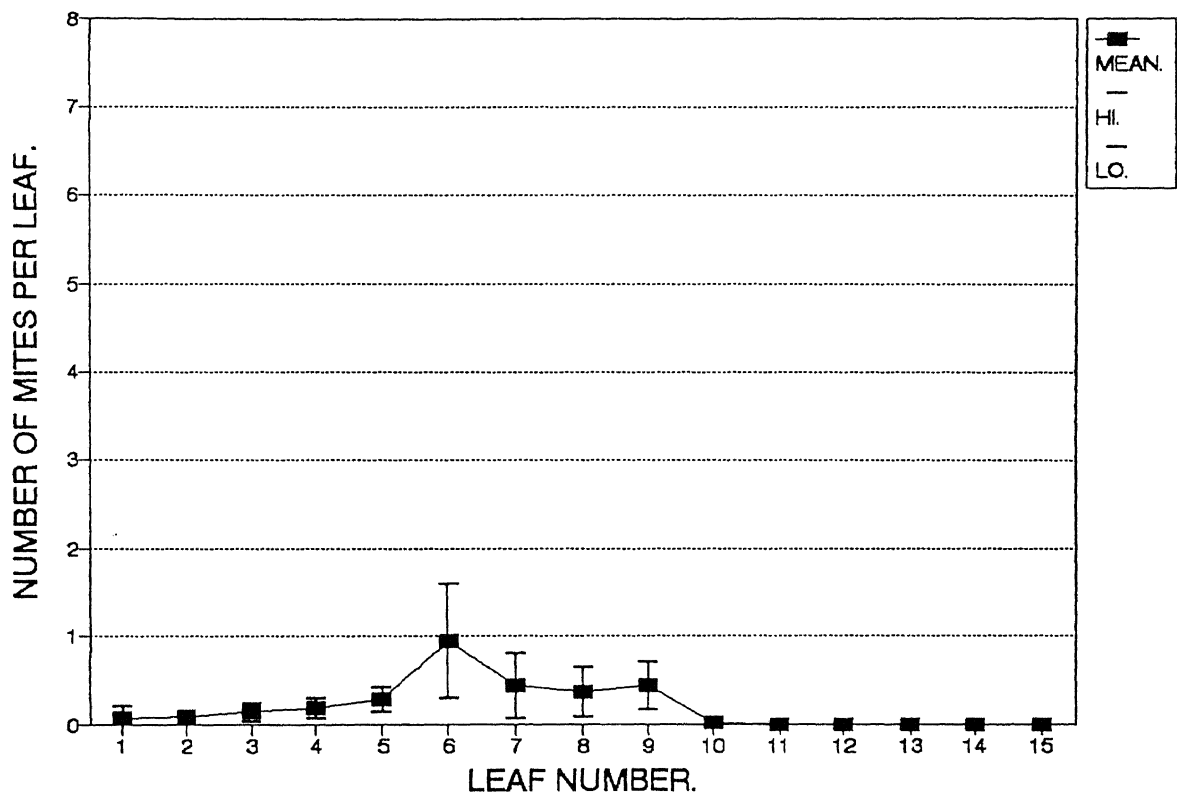
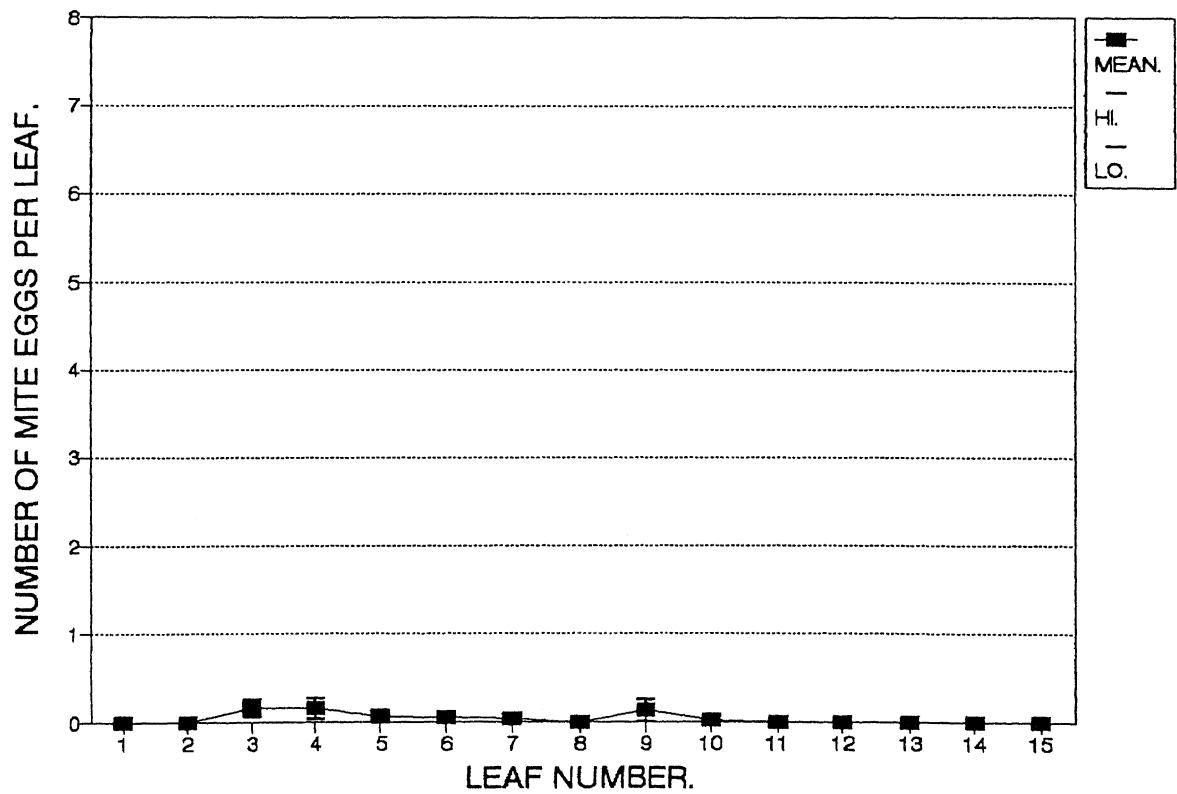


Fig. 15:

SPREAD OF PREDATORY MITE EGGS ALONG THE
CENTRAL AXIS OF THE PINEAPPLE CROWN.



3.2.2 The Predatory Mite:

The predatory mite population is significantly lower than the false spider mite population with a ratio of 1:6, predatory:false spider mite, while the crowns are in storage bins. This ratio is considered to be extremely favourable for the control of the false spider mite, (Elder, R., Q.D.P.I., Rockhampton, Pers. Comm.). A significant feature in Figure 13 is that the predatory mite population distribution is uniform along the plant axis in comparison to the false spider mite distribution. The predatory mite numbers do not peak as intensely at the fifth and sixth leaf regions as do the false spider mites. The predatory mites are highly motile and it is suggested that their motility has enabled them to become uniformly dispersed along the crown axis. Predatory mites were observed to feed on all stages of the false spider mite, therefore they are not forced into inhabiting any one region. The number of eggs deposited in the leaf axil by the predatory mite is extremely small when compared to the false spider mite. The number of eggs deposited within the leaf axils by the predatory mite would constitute approximately 10 per plant in contrast to the 500 per plant for the false spider mite. This low number would suggest that the predatory mites are laying their eggs elsewhere, or have an extremely low reproductive potential.

3.3. Variations between Farms and Treatments:

As outlined in section 2.5 and 2.6 the sites on which the experimental treatments were established consisted of three farms across the Yeppoon region. Due to the degree of crop failure within the trial blocks on farm three (Fig 16) these data were not generally considered in the statistical analysis. The effects of extremely high mite densities and various anomalies that occurred on this farm may be mentioned throughout the following text on a descriptive basis.

The results from the field samples were graphed as shown in Figures 17 to 28. As a consequence of the way the analysis program was written, all results in Figures 17 to 28 are expressed in terms of No/75 leaves. This is adequate for comparative purposes but where absolute numbers per plants are required they have been mentioned separately in the discussion. From these graphs it can be said that a marked degree of

Fig. 16: The Effect of the False Spider Mite:



Above: Crop unaffected
although mites are present.
Right: Crop of equal age
and severely affected by mites.



Fig. 17:

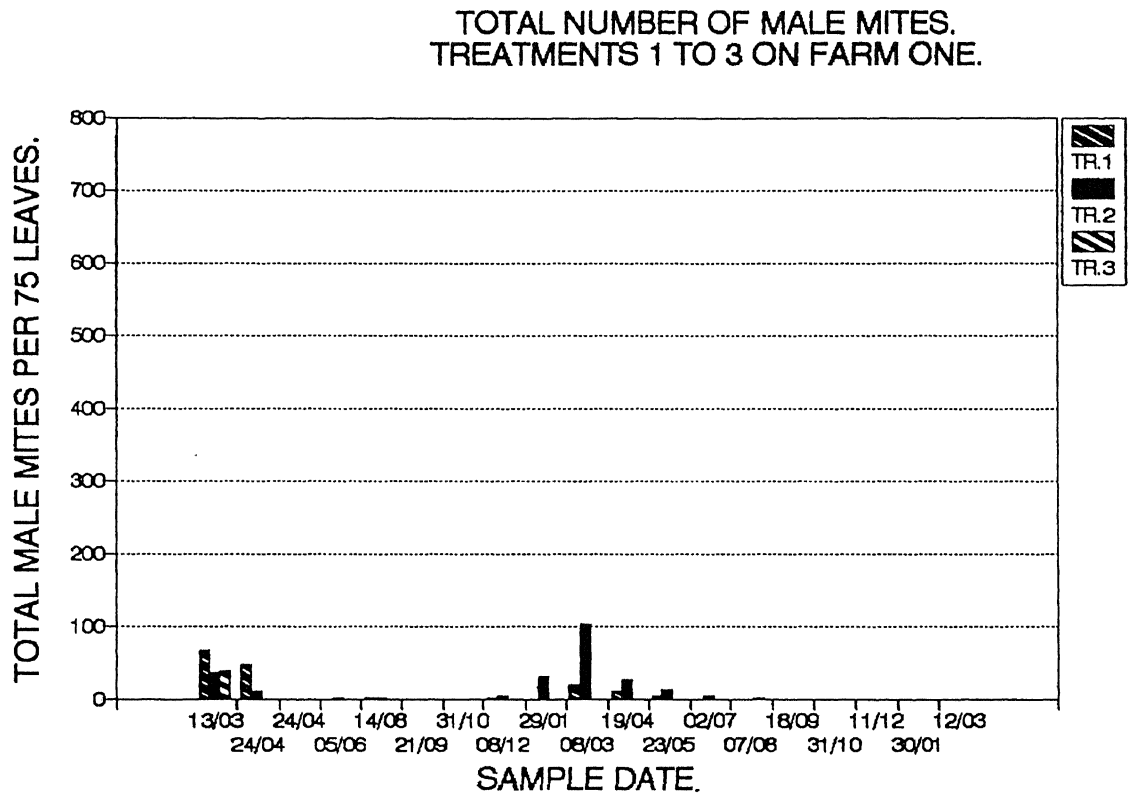


Fig. 18:

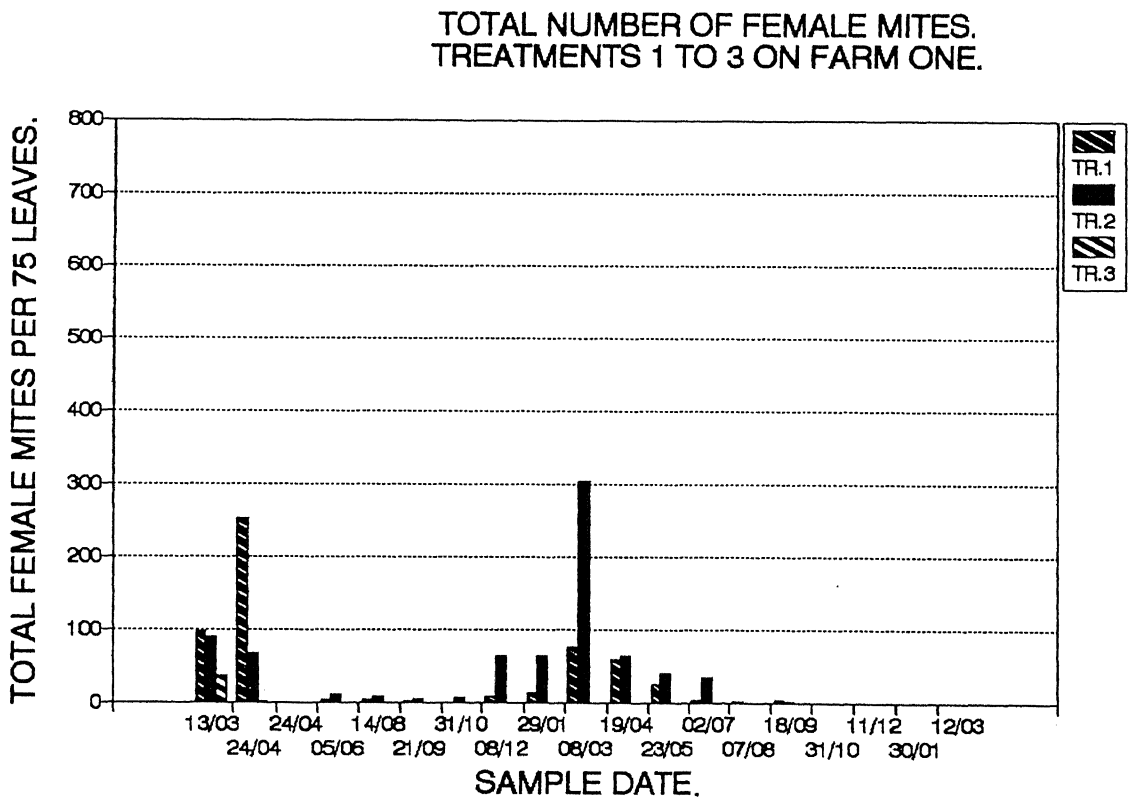


Fig. 19:

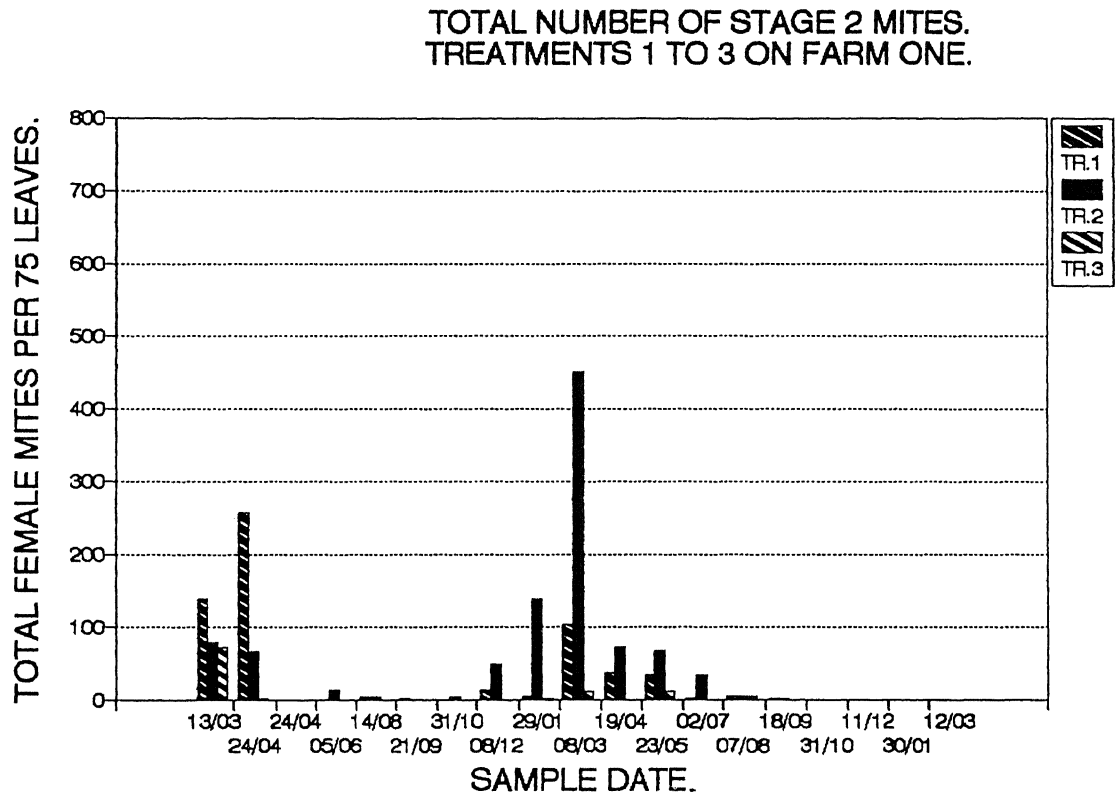


Fig. 20:

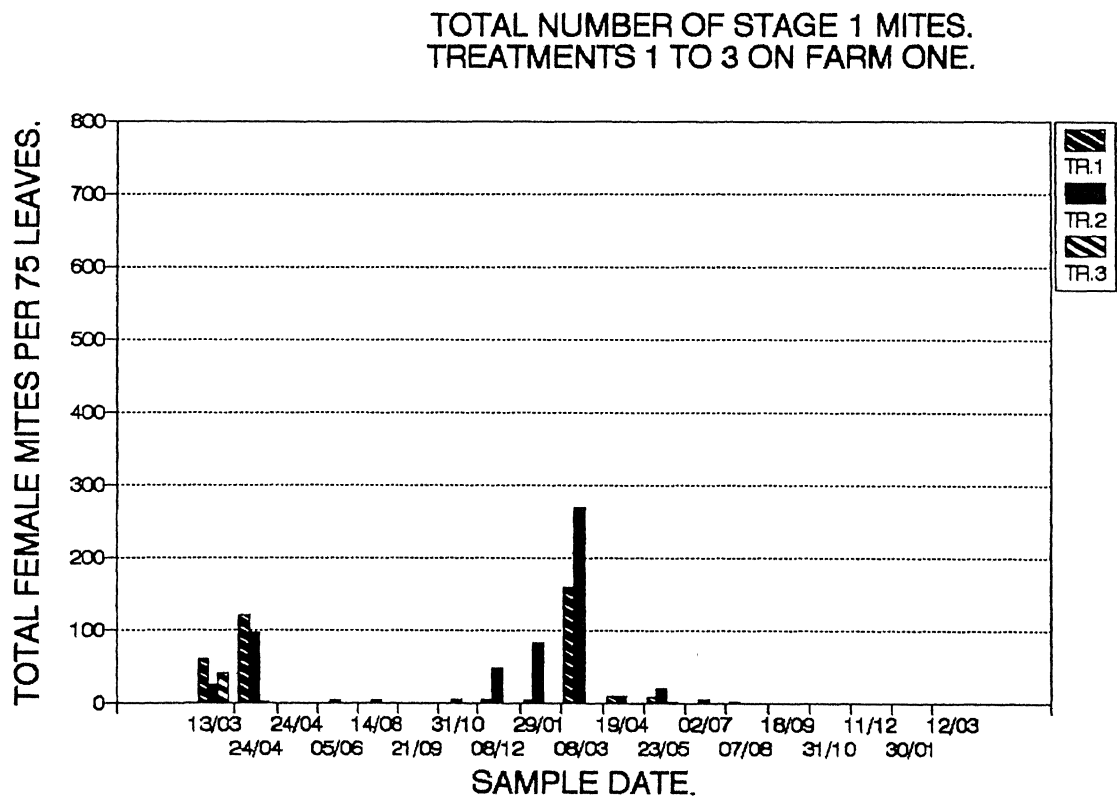


Fig. 21:

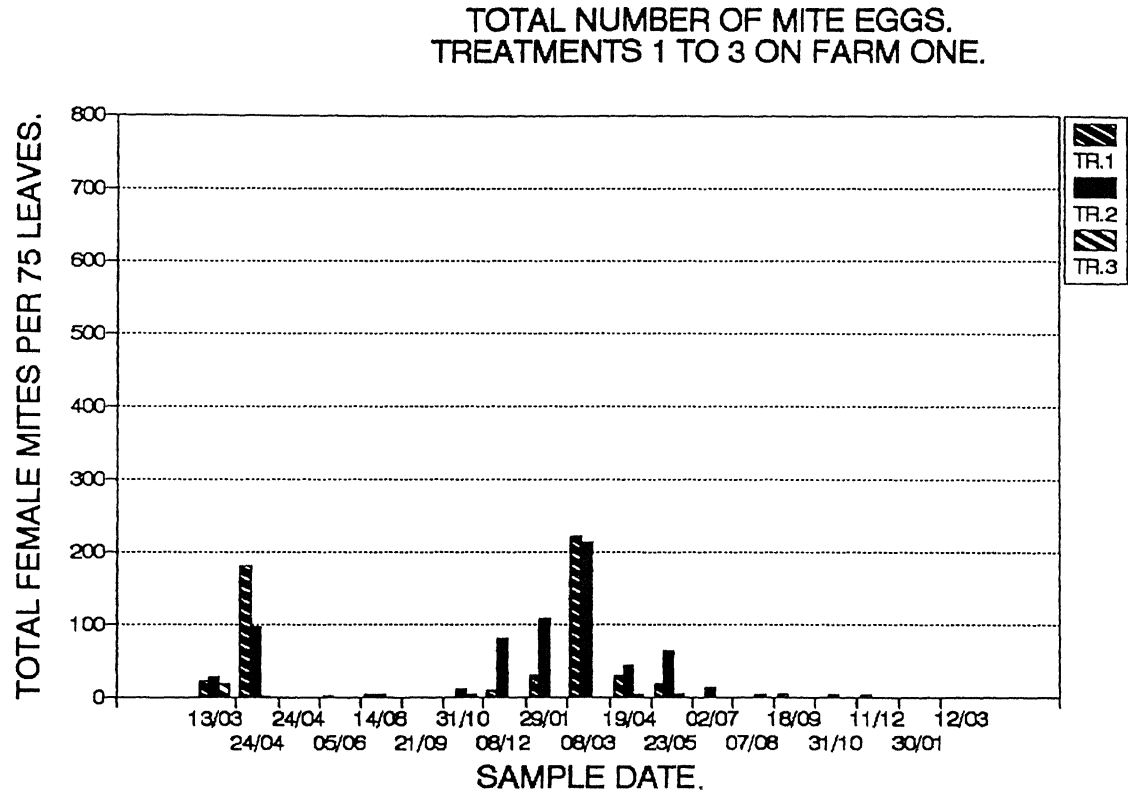


Fig. 22:

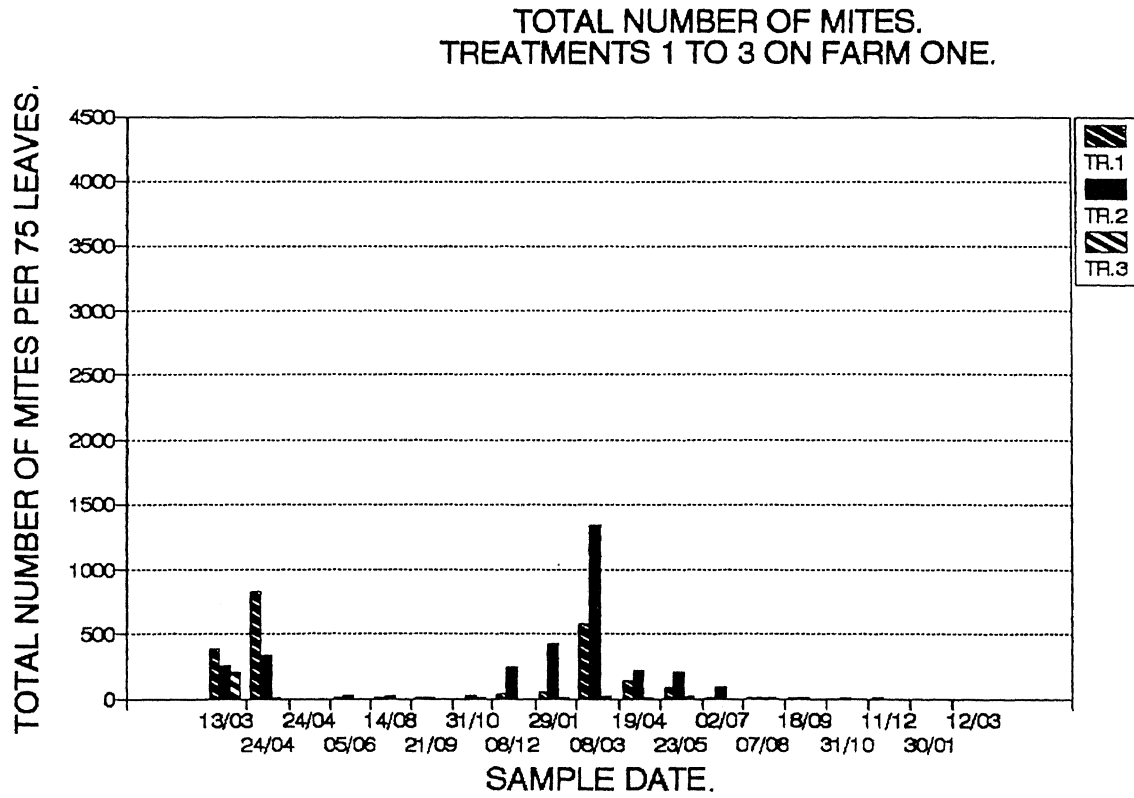


Fig. 23:

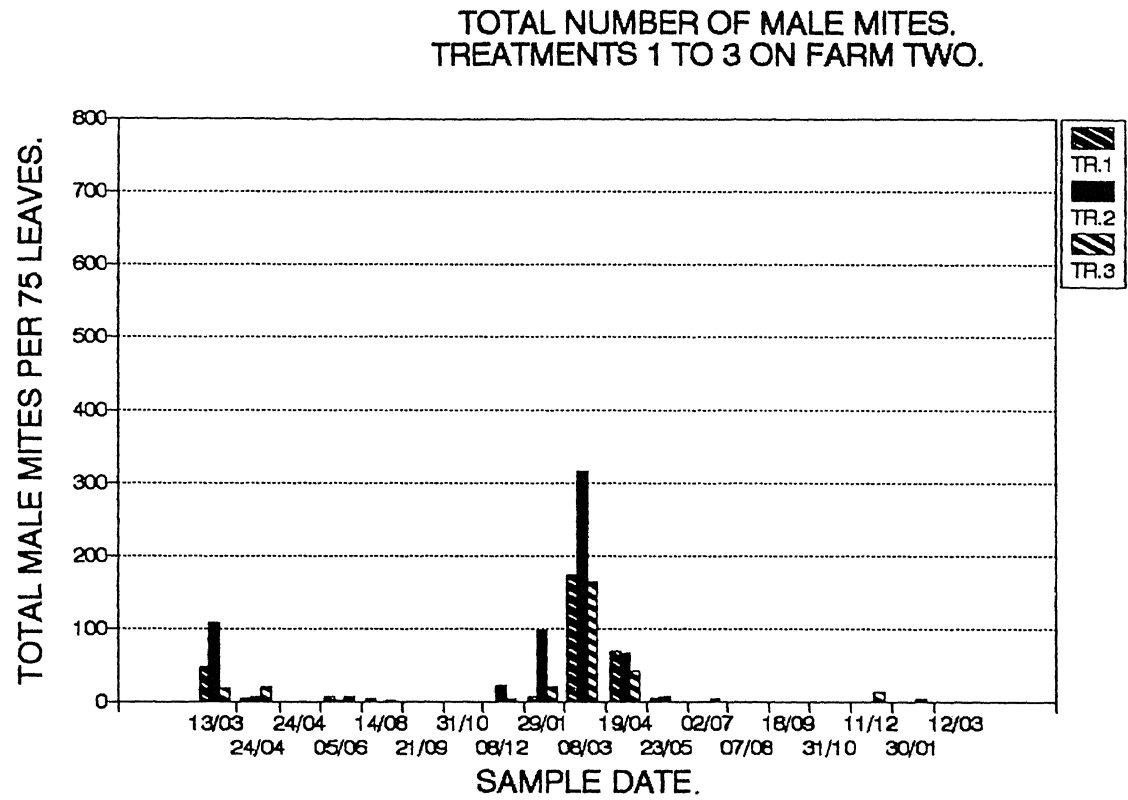


Fig. 24:

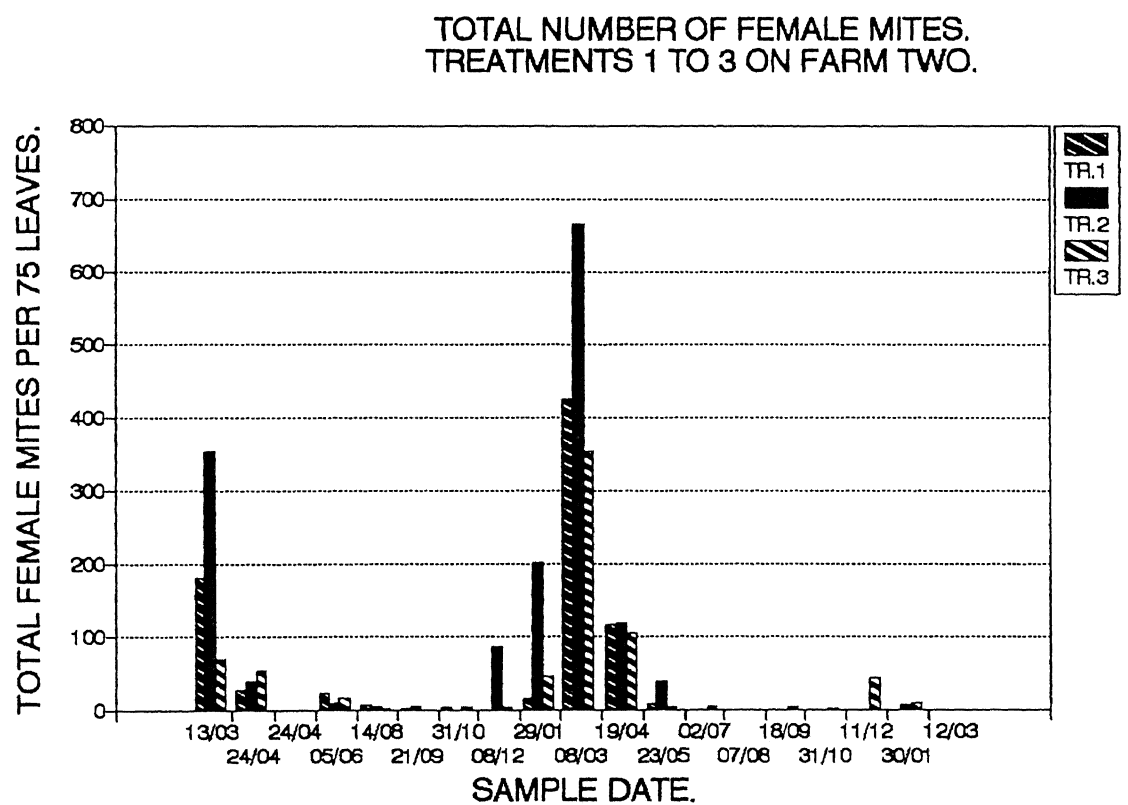


Fig. 25:

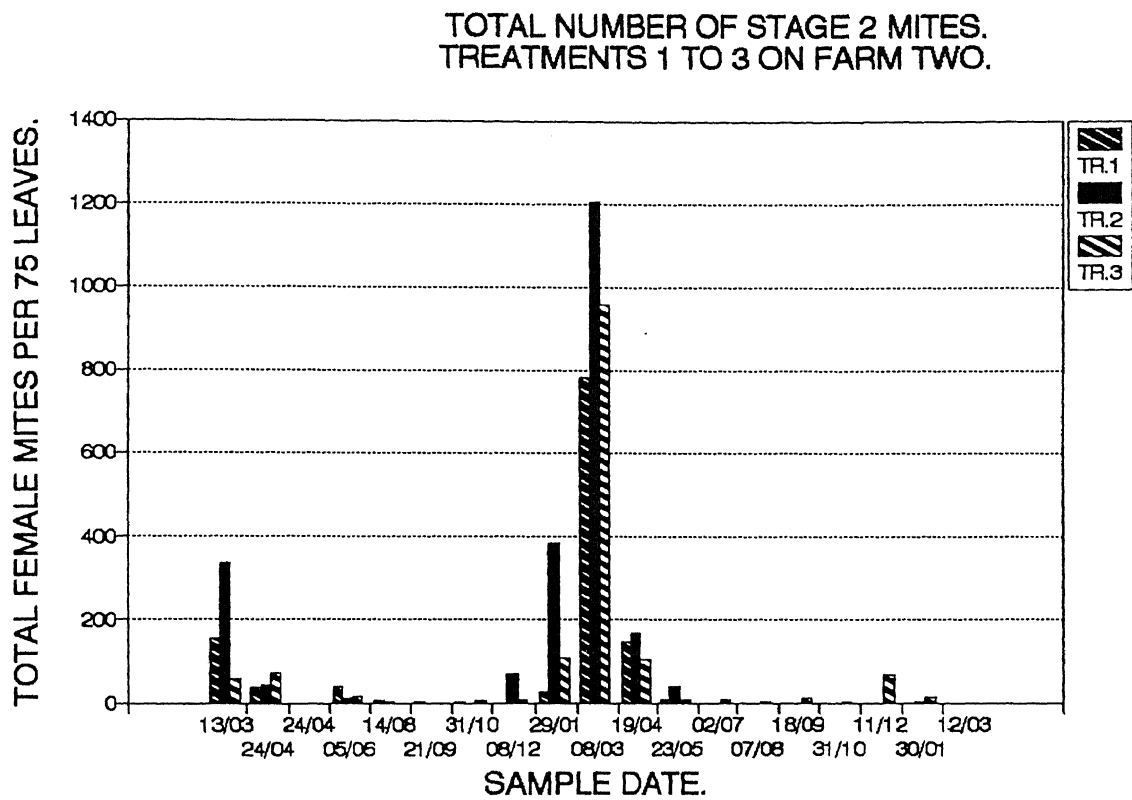


Fig. 26:

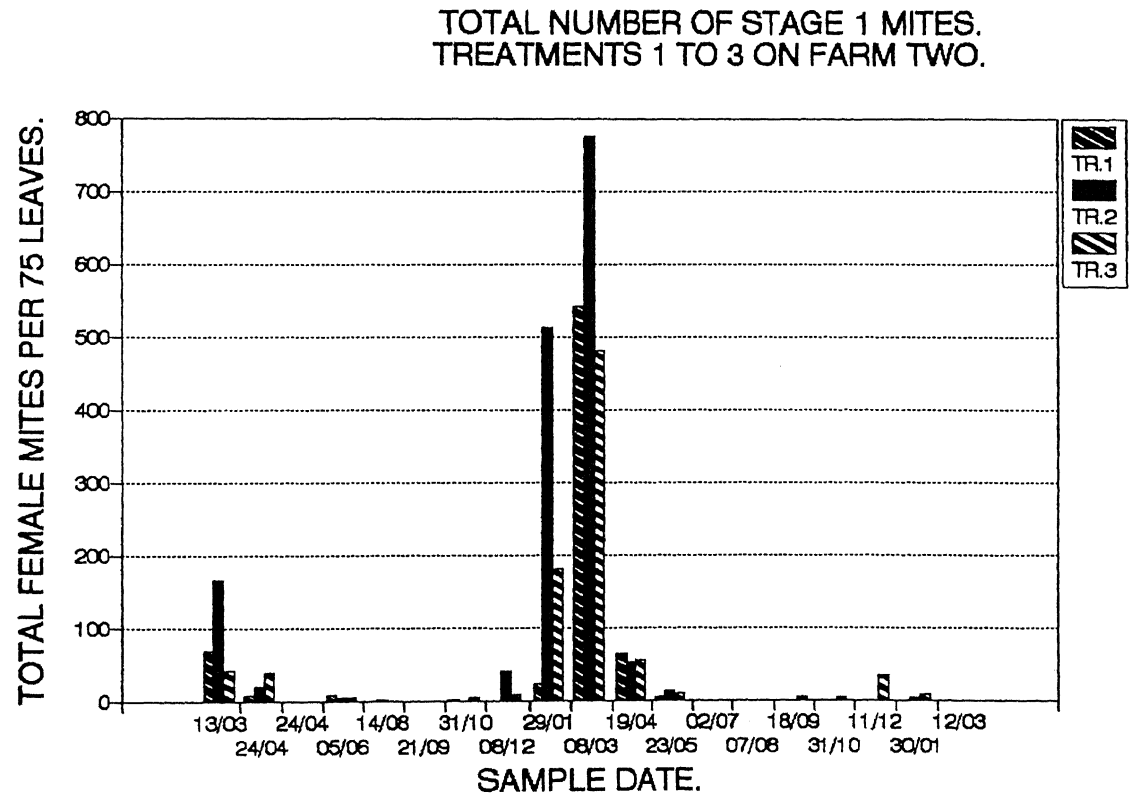


Fig. 27:

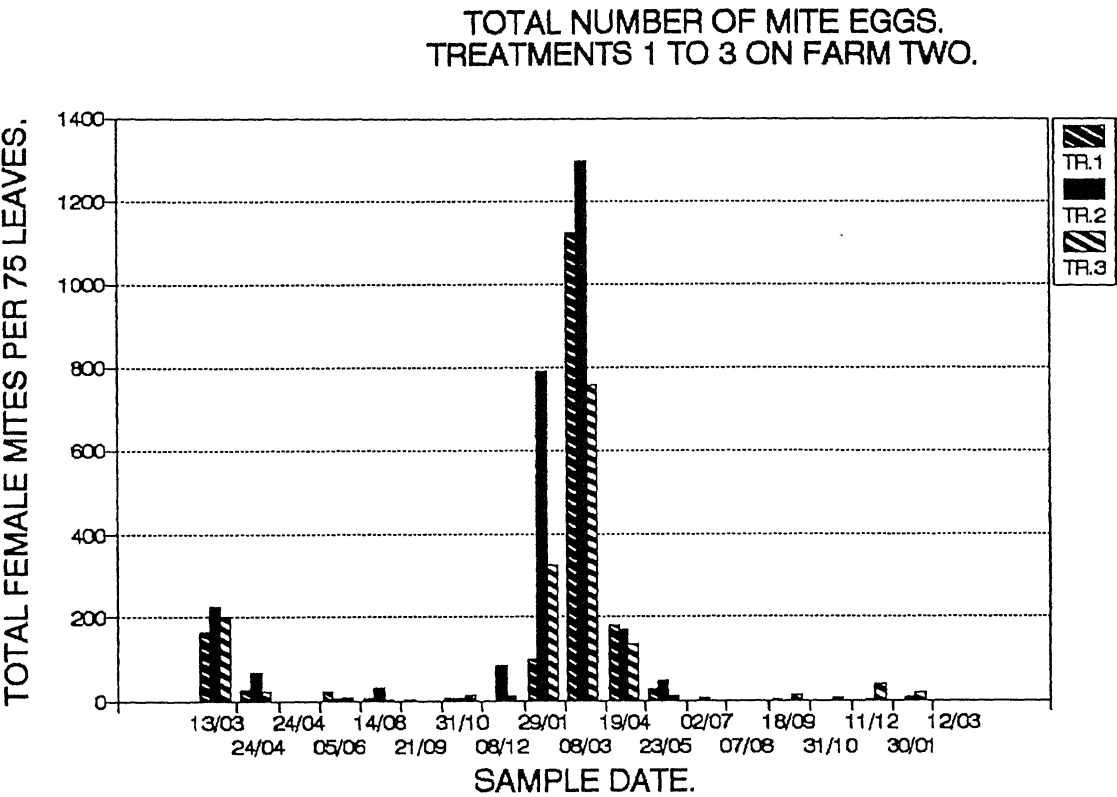
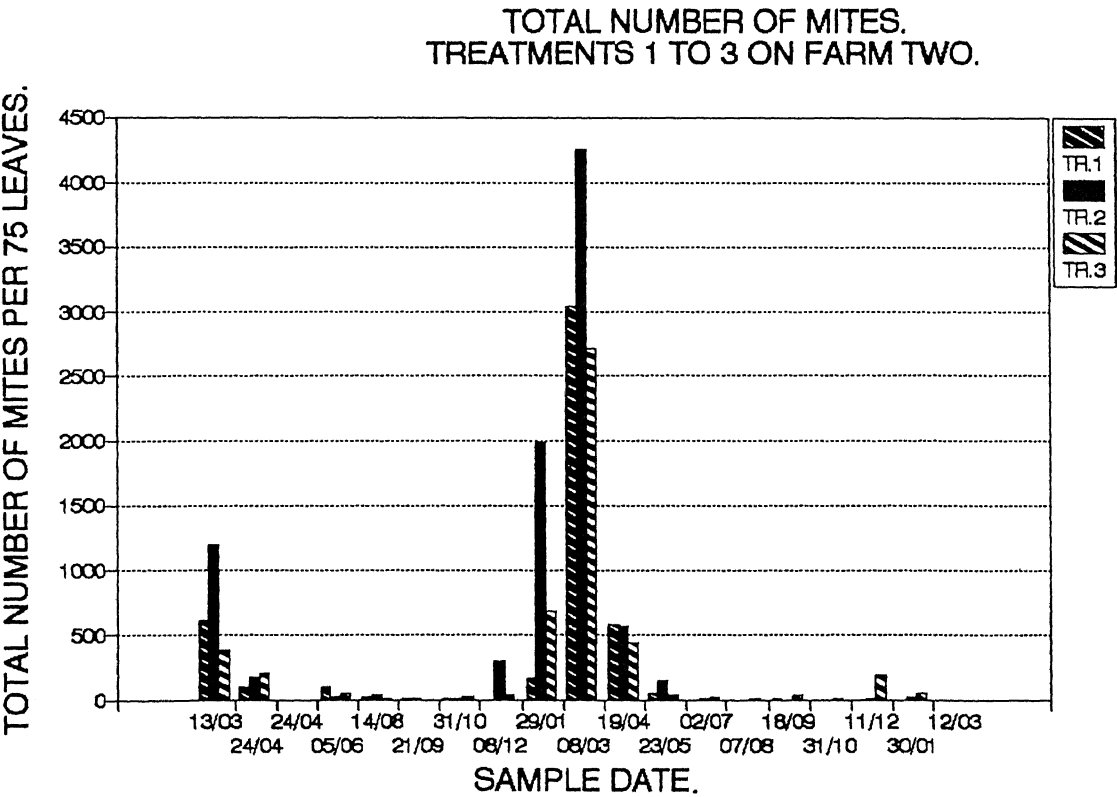


Fig. 28:



variability exists in seasonal population densities. That is, the false spider mite populations are not static throughout the seasons. The seasonal factor/s responsible for the change in population densities appears to affect all stages equally, irrespective of the treatments. A Two-factor analysis of variance (ANOVA) was conducted to determine if mean mite numbers were significantly different between farms and between treatments. The Null hypotheses are as follows, following the format outlined by Zar (1984):

H_{O1} : The mean mite numbers between the farms are not significantly different.

H_{A1} : The mean mite numbers between the farms are significantly different.

H_{O2} : The mean mite numbers between the three treatments are not significantly different.

H_{A2} : The mean mite numbers between the three treatments are significantly different.

H_{O3} : There is no interaction effect between the farms and the treatments.

H_{A3} : There is an interaction effect between the farms and the treatments.

The Null hypotheses were rejected if the probabilities of the farm and treatment means being equal, was less than 0.05. The probabilities generated by the Two-factor ANOVA are presented in Table 1. The farms are shown to have significantly different means therefore (H_{A1}) is accepted.

The various treatments produced significant effects on the population means on all farms. As they were shown to be significantly different at $P < 0.05$, (H_{O2}) was rejected and (H_{A2}) accepted. The interaction between the farms and treatments was considered to be significant at $P < 0.05$, consequently (H_{O3}) was rejected and (H_{A3}) accepted.

The interaction between the farms and treatments is not easily explained, as many factors could have interacted to produce results such as these. The factors can include variations in plot aspect, soil types and moistures (and plant vigour), cultural practices or simply variations in the microclimate of the farms. The elucidation of the factor/s is warranted in

future investigations and may provide insight into the sporadic nature of the mite distribution across the Yeppoon district and within the farms.

The difference between the farms is suggested to be mainly a result of the variability in the soil types which ultimately affects the health and establishment of new plants. The establishment of the plants depends on the correct soil moisture at planting followed by favourable changes to the soil moisture, post planting, (Cranny, M., Pers. Comm.). As the soil types on the third farm differ markedly in their ability to hold or lose moisture, the crop cycles were also affected.

In accepting (H_{A2}), it was shown that the various treatments cause significant differences between the means at the probability level set. Therefore further testing was warranted to determine which treatment constantly produced the highest and lowest means. To determine which treatment consistently produced better results (that is lower means) a one-way ANOVA was carried out. The ANOVA was used to test the following Null Hypotheses, thereby determining the effects of each treatment on the densities of the various cohorts within the population.

- H_{O1} : The mean number of adult male mites in each treatment are not significantly different.
- H_{A1} : The mean number of adult male mites in each treatment are significantly different.
- H_{O2} : The mean number of adult female mites in each treatment are not significantly different.
- H_{A2} : The mean number of adult female mites in each treatment are significantly different.
- H_{O3} : The mean number of stage 2 mites in each treatment are not significantly different.
- H_{A3} : The mean number of stage 2 mites in each treatment are significantly different.
- H_{O4} : The mean number of stage 1 mites in each treatment are not significantly different.
- H_{A4} : The mean number of stage 1 mites in each treatment are significantly different.
- H_{O5} : The mean number of mite eggs in each treatment are not significantly different.

Table 1:

Probabilities calculated from Two-Way ANOVA on cohort by Farm and Treatment.

Cohort	* Category	Probabilities: F Ratio.	2-way Interaction: F Ratio.
Male.	* Farm. Treatment.	0.000: 72.6 0.000: 38.7	0.000: 8.9
Female.	* Farm. Treatment.	0.000: 88.0 0.000: 74.5	0.000: 18.6
Stage2.	* Farm. Treatment.	0.000:137.7 0.000: 46.9	0.000: 14.0
Stage1.	* Farm. Treatment.	0.000:129.5 0.000: 40.8	0.000: 22.5
Eggs.	* Farm. Treatment.	0.000:213.1 0.000: 42.4	0.000: 9.2
Total Mites.	* Farm. Treatment.	0.000:184.0 0.000: 62.7	0.000: 17.2

Note: In the above computer generated tables, probabilities of <0.001 are scored as 0.000 and are highly significant.

Table 2:

Probabilities calculated from One-Way ANOVA on cohort by Treatment.

Cohort	F Ratio.	Probabilities.
Male.	38.4	0.000
Female.	73.7	0.000
Stage2.	46.3	0.000
Stage1.	40.2	0.000
Eggs.	41.6	0.000

Note: In the above computer generated tables, probabilities of <0.001 are scored as 0.000 and are highly significant.

Table 3:

Scheffe Multiple Range test performed on the means of each cohort, in each of the three treatments. Mean values were taken from the One-way ANOVA.

Cohort	Treatments			Homogeneous Groups
	3	1	2	
	Treatment	Mean		
Male.	3	0.0703		Nil.
	1	0.094 *		
	2	0.1434 * *		
	Treatment	Mean		
Female.	3	0.1636		Nil.
	1	0.2275 *		
	2	0.358 * *		
	Treatment	Mean		
Stage2.	3	0.313		3 & 1
	1	0.3448		
	2	0.5345 * *		
	Treatment	Mean		
Stage1.	3	0.207		3 & 1
	1	0.2239		
	2	0.351 * *		
	Treatment	Mean		
Eggs.	3	0.3531		Nil.
	1	0.4403 *		
	2	0.6175 * *		

(*)

Denotes Pairs of Groups Significantly Different at $P < 0.050$ Level.

Homogenous Groups: Groups, whose highest and lowest means do not differ by more than the shortest significant range for a group of that size.

H_{A5} : The mean number of mite eggs in each treatment are significantly different.

The probabilities generated by the ANOVA are summarized in Table 2. From these probabilities it is clear that all H_0 s are rejected and the alternative hypotheses are accepted. To assess the relationship further, a Scheffe Multiple Range test was conducted to distinguish the relationship that the various treatments have on each cohort. Homogeneous groups are defined in the SPSS-x users guide as: subsets of groups (treatments), whose highest and lowest means do not differ by more than the shortest significant range for a subset of that size. The results from the tests on each cohort are summarised in, Table 3.

It is note-worthy that for the cohorts; male, female, and eggs the three treatments produce significantly different means. In all of these cohorts, the means are consistently higher in treatment two (reduced insecticide). The next highest mean is in treatment one (control), with treatment three (reduced fertilizer) producing the lowest number of mites in each cohort. The reduced fertilizer treatment produced visible deficiencies within the leaf. The lower leaf nutrient content and reduced plant vigour produced lower false spider mite densities. A different trend exists for the stage 2 and stage 1 cohorts. The means for treatments one and three are not significantly different, although both these treatments have significantly lower means from treatment two. In other words, insecticide applications and reduced fertilizers caused decreases in the false spider mite densities.

In summary, while the ANOVA indicated significant differences between all treatments and all stages; the Scheffe Multiple Range Test indicated that cohort stage 2 and stage 1 in treatments one and three were not always significantly different.

3.4 Intra-Plant and Inter-Plant Variability of Mite Numbers:

Anecdotal evidence from many farmers suggests that the false spider mite population can be very large but unevenly dispersed within a field. That is, some plants can be infested while nearest neighbours may be relatively unaffected or not at all affected.

To assess the variability of false spider mite infestations, intra-plant and inter-plant distributions were analysed. To assess the variability of the

infestations, samples were analysed during times when false spider mite numbers were considered to be at extremes. The variability during 'low' infestation samples was analysed from mid to late spring. To assess the variability of the 'high' infestation levels, samples were analysed from mid to late summer. Due to the degree of crop failure on farm three it is not considered for analysis.

3.4.1 Intra-Plant Variability:

Intra-plant variability was assessed on two farms for each cohort. The values for each leaf resulted from samples taken under established sampling protocols.

The variability of the intra-plant samples was determined via a one-way ANOVA and multiple range tests. These tests were performed to assess the following hypotheses on each of the two farms during 'high and low' levels of infestations:

H_{O1} : The mean number of mites per leaf within a plant are not significantly different.

H_{A1} : The mean number of mites per leaf within a plant are significantly different.

H_{O2} : The mean number of mites in each cohort, per leaf, within a plant are not significantly different.

H_{A2} : The mean number of mites in each cohort, per leaf, within a plant are significantly different.

The results of the analysis are summarized in Tables 4 to 5. The results establish that during times of high false spider mite infestation the populations between leaves are not significantly different, that is accept (H_{O1}) (Table 4). The results indicate that the cohort composition between leaves is not significantly different, therefore accept (H_{O2}). The results show that during low mite infestations the populations between leaves are significantly different, therefore accept (H_{A1}) (Table 5). The results also prove that the cohort composition between leaves are significantly different, therefore accept (H_{A2}). Both these assumptions were proven to be true with a probability, $P < 0.05$ set during the analysis.

In viewing the results shown in Tables 4 to 5, the accepted hypotheses outlined above hold true in each farm. The only slight discrepancy is that

Table 4:

Probabilities calculated from ANOVA, mean number of mites per leaf and homogenous groupings, calculated on mite numbers obtained from leaf samples during "high" mite infestation levels on farms one and two.

FARM ONE. ANOVA PROBABILITIES.				FARM TWO. ANOVA PROBABILITIES.			
Cohort	(P)	Leaf Position	Mean Treatment 3 1 2	(P)	Leaf Position	Mean Treatment 3 1 2	
Male.	0.1807	3	0.2 *	0.5055	3	1.32 *	
		1	0.22 *		1	1.51 *	
		2	0.38 *		2	1.52 *	
Female.	0.3479	3	0.72 *	0.0839	3	2.72 *	
		1	0.76 *		1	3.39 *	
		2	1.04 *		2	3.5 *	
Stage2.	0.4342	3	1 *	0.0000	3	5.17 *	
		1	1.25 *		1	6.74 *	
		2	1.3 *		2	7.72 *	
Stage1.	0.0625	3	0.64 *	0.0662	3	3.56 *	
		1	1.04 *		1	4.08 *	
		2	1.17 *		2	4.33 *	
Eggs.	0.6846	3	0.89 *	0.0018	3	5.69 *	
		1	0.91 *		1	7.51 **	
		2	1.08 *		2	8.02 *	

(*)
Denotes pairs of groups significantly different at P<0.050 level.

Homogenous Groups: Groups, whose highest and lowest means do not differ by more than the shortest significant range for a group of that size.

Table 5:

Probabilities calculated from ANOVA, mean number of mites per leaf and homogenous groupings, calculated on mite numbers obtained from leaf samples during "low" mite infestation levels on farms one and two.

FARM ONE. ANOVA PROBABILITIES.				FARM TWO. ANOVA PROBABILITIES.			
Cohort	(P)	Leaf Position	Mean Treatment 3 1 2	(P)	Leaf Position	Mean Treatment 3 1 2	
Male.	0.0000	3	0.00 *	0.0000	3	0.00 *	
		1	0.00 *		1	0.03 *	
		2	0.00 *		2	0.04 *	
Female.	0.0000	3	0.00 *	0.0372	3	0.00 *	
		1	0.00 *		1	0.08 *	
		2	0.00 *		2	0.26 *	
Stage2.	0.0000	3	0.00 *	0.0953	3	0.00 *	
		1	0.00 *		1	0.22 *	
		2	0.00 *		2	0.22 *	
Stage1.	0.0000	3	0.00 *	0.1364	3	0.02 *	
		1	0.00 *		1	0.06 *	
		2	0.00 *		2	0.15 *	
Eggs.	0.0000	3	0.00 *	0.3125	3	0.04 *	
		1	0.00 *		1	0.08 *	
		2	0.00 *		2	0.14 *	

(*)
Denotes pairs of groups significantly different at P<0.050 level.

Homogenous Groups: Groups, whose highest and lowest means do not differ by more than the shortest significant range for a group of that size.

which exists in farm two. During low false spider mite infestations the findings outlined above are not consistently applicable to the variability within cohorts and between leaves.

3.4.2 Inter-Plant Variability:

Inter-plant variability was assessed on two farms for all cohorts. The values for each sample (plant) position resulted from samples taken under established protocols. To assess the variability of the inter-plant samples a one-way ANOVA and multiple range tests were performed to test the following hypotheses. The hypotheses apply to each of the two farms during 'high and low' levels of infestations:

H_{O1} : The mean number of mites per plant within a treatment are not significantly different.

H_{A1} : The mean number of mites per plant within a treatment are significantly different.

H_{O2} : The mean number of mites in each cohort per plant, within a treatment are not significantly different.

H_{A2} : The mean number of mites in each cohort per plant, within a treatment are significantly different.

The results from the analysis are summarized in (Tables 6 to 7). The results establish that during times of high false spider mite infestation the mite populations between plants are not significantly different, that is accept (H_{O1}) and reject (H_{A1}). The results also indicate that the cohort composition between plants is not significantly different, therefore accept (H_{O2}). The results also prove that during low false spider mite infestations the populations between plants are significantly different, therefore accept (H_{A1}). The results also show that the cohort composition between plants are significantly different, therefore accept (H_{A2}).

Both findings were proven to be true with a probability, $P < 0.05$ set during the analysis. In reviewing the results shown in Tables 6 to 7, it can be said that the assumptions outline above hold true in each farm.

3.5 Sex Ratios:

The sex ratio of a normal population of animals is considered to be 1:1, male:female (Fisher, 1930). From the counts obtained during the sampling period sex ratios were calculated for each treatment at each six

Table 6:

Probabilities calculated from ANOVA, mean number of mites per sample site and homogenous treatments, calculated on mite numbers obtained from plant samples during "high" mite infestation levels on farms one and two.

FARM ONE. ANOVA PROBABILITIES.					FARM TWO. ANOVA PROBABILITIES.				
Cohort	(P)	Plant Position	Mean	Treatment 1 2 3 4 5	(P)	Plant Position	Mean	Treatment 1 2 3 4 5	
Male.	0.0041	3	0.16 *		0.0163	5	1.04 *		
		4	0.16 *			3	1.23 **		
		5	0.16 *			2	1.61 **		
		1	0.34 **			1	1.65 **		
		2	0.57 *			4	1.72 *		
Female.	0.0019	3	0.37 *		0.2578	5	2.78 *		
		5	0.51 *			2	3 *		
		1	0.85 **			3	3.18 *		
		4	0.93 **			4	3.18 *		
		2	1.54 *			1	3.85 *		
Stage2.	0.0000	5	0.41 *		0.0004	4	5.64 *		
		3	0.42 *			5	5.83 *		
		1	1.2 *			2	6.1 *		
		4	1.41 *			1	7.14 **		
		2	2.8 *			3	8.02 *		
Stage1.	0.0103	3	0.42 *		0.0767	4	3.42 *		
		5	0.82 **			2	3.6 *		
		1	0.87 **			1	4.22 *		
		4	1.17 **			5	4.28 *		
		2	1.45 *			3	4.22 *		
Eggs.	0.1712	1	0.56 *		0.0005	4	5.41 *		
		3	0.81 *			1	6.28 **		
		5	1.04 *			5	6.63 ***		
		4	1.17 *			2	8.27 **		
		2	1.21 *			3	8.76 *		

(*)

Denotes pairs of groups significantly different at P<0.050 level.

Homogenous Groups: Groups, whose highest and lowest means do not differ by more than the shortest significant range for a group of that size.

Table 7:

Probabilities calculated from ANOVA, mean number of mites per sample site and homogenous treatments, calculated on mite numbers obtained from plant samples during "low" mite infestation levels on farms one and two.

FARM ONE. ANOVA PROBABILITIES.					FARM TWO. ANOVA PROBABILITIES.				
Cohort	(P)	Plant Position	Mean	Treatment 1 2 3 4 5	(P)	Plant Position	Mean	Treatment 1 2 3 4 5	
Male.	0.0000	1	0.00 *		0.0000	1	0.00 *		
		2	0.00 *			2	0.00 *		
		3	0.00 *			3	0.00 *		
		4	0.00 *			4	0.00 *		
		5	0.00 *			5	0.13 *		
Female.	0.0000	1	0.00 *		0.0000	1	0.00 *		
		2	0.00 *			2	0.00 *		
		3	0.00 *			3	0.00 *		
		4	0.00 *			4	0.00 *		
		5	0.00 *			5	0.47 *		
Stage2.	0.0000	1	0.00 *		0.0000	1	0.00 *		
		2	0.00 *			2	0.00 *		
		3	0.00 *			3	0.00 *		
		4	0.00 *			4	0.00 *		
		5	0.00 *			5	0.73 *		
Stage1.	0.0000	1	0.00 *		0.0000	1	0.00 *		
		2	0.00 *			2	0.00 *		
		3	0.00 *			3	0.00 *		
		4	0.00 *			4	0.00 *		
		5	0.00 *			5	0.38 *		
Eggs.	0.0000	1	0.00 *		0.0000	1	0.00 *		
		2	0.00 *			2	0.00 *		
		3	0.00 *			3	0.00 *		
		4	0.00 *			4	0.02 *		
		5	0.00 *			5	0.43 *		

(*)

Denotes pairs of groups significantly different at $P < 0.050$ level.

Homogenous Groups: Groups, whose highest and lowest means do not differ by more than the shortest significant range for a group of that size.

Table 8:

Mean sex ratios for farm one and two calculated at each sample date. Mean sex ratios for each treatment on farms one and two.

Sample Date.	Mean Sex Ratio (F:M)		Farm.	Treatment.	Mean Sex Ratio F:M.
	Farm One	Farm Two			
1	1.62:1	3.74:1	1	1	1.69:1
2	3.82:1	5.21:1	1	2	3.23:1
3	0.0000	0.0000	1	3	0.05:1
4	3.67:1	5.17:1			
5	3.67:1	1.00:1	2	1	1.30:1
6	0.0000	0.0000	2	2	1.84:1
7	0.0000	0.0000	2	3	1.39:1
8	7.69:1	1.57:1			
9	0.69:1	2.22:1			
10	2.32:1	2.23:1			
11	2.58:1	2.02:1			
12	3.08:1	2.78:1			
13	2.33:1	0.56:1			
14	0.0000	0.0000			
15	0.0000	0.0000			
16	0.0000	0.0000			
17	0.0000	1.19:1			
18	0.0000	1.00:1			
19	0.0000	1.51:1			

0.0000 signifies no adult mites present at this time period.

Table 9:

Analysis results of average maximum and minimum temperature, and average rainfall correlated to each cohort. Adjusted Coefficient of Determination, Standard Error of Estimates and Regression Equations summarized.

Correlate	Cohort	Adjusted R-Squared	Standard Error	Regression Equation.
Average Maximum Temp.	Male.	7.46	0.2512	$Y = -0.18 + 0.0003 \times X^2$
	Female.	7.33	0.5514	$Y = -0.36 + 0.0007 \times X^2$
	Stage2.	9.62	0.9728	$Y = 3.16 - 0.13 \times X \times \ln(X) + 0.01 \times X^2$
	Stage1.	14.06	0.6418	$Y = 3.42 - 0.13 \times X \times \ln(X) + 0.01 \times X^2$
	Egg.	12.63	1.12	$Y = 5.36 - 0.21 \times X \times \ln(X) + 0.01 \times X^2$
	Total.	11.47	507.3133	$Y = 205.86 - 84.59 \times X \times \ln(X) + 7.63 \times X^2$
Average Minimum Temp.	Male.	10.27	0.2474	$Y = 0.76 + 0.06 \times X \times \ln(X) - 0.22 \times X$
	Female.	11.59	0.5386	$Y = 1.53 + 0.13 \times X \times \ln(X) - 0.46 \times X$
	Stage2.	10.93	0.9657	$Y = 0.75 - 0.08 \times X \times \ln(X) + 0.01 \times X^2$
	Stage1.	10.59	0.6546	$Y = 0.51 - 0.05 \times X \times \ln(X) + 0.008 \times X^2$
	Egg.	9.68	1.1434	$Y = 0.84 - 0.09 \times X \times \ln(X) + 0.01 \times X^2$
	Total.	10.98	508.7298	$Y = 394.72 - 0.43 \times X \times \ln(X) + 6.15 \times X^2$
Average Rainfall	Male.	-0.05	0.2612	$Y = 0.11 + 0.0007 \times X^2 - 0.01 \times X$
	Female.	-0.57	0.5745	$Y = 0.24 + 0.0001 \times X^2$
	Stage2.	-0.13	1.0239	$Y = 0.49 + 0.002 \times X^2 - 0.05 \times X$
	Stage1.	0.85	0.6894	$Y = 0.34 + 0.001 \times X^2 - 0.04 \times X$
	Egg.	0.64	1.1993	$Y = 0.61 + 0.003 \times X^2 - 0.08 \times X$
	Total.	0.27	538.4719	$Y = 275.27 + 1.44 \times X^2 - 34.77 \times X$

Adjusted R-Squared = Adjusted Coefficient of Determination.

week sample period. The false spider mite sex ratios for the two farms were recorded for each treatment at each sample period. The mean sex ratios were calculated and summarized in Table 8.

In general the number of female false spider mites was always larger than the number of male false spider mites irrespective of the time of year or type of treatment. For this reason the proportions were stated as female:male sex ratio. The overall sex ratio for farm one and two are 1.65:1 and 1.51:1, F:M respectively. Overall these figures indicate a slight tendency for a female biased sex ratio.

Of interest is the larger sex ratio in treatment two (minimal insecticide) irrespective of farm. The ratios 3.2:1 and 1.8:1 for farms one and two respectively are much higher in comparison to the ratios in the other treatment. It is also clear that treatments one (insecticide applied) and three (reduced fertilizer) have a lower female to male ratio than the reduced insecticide treatments. This skewed sex ratio also exists during seasonal outbreaks. That is, during late spring through until late summer when the population 'explodes'. During this period the sex ratios become increasingly biased towards females. There exists a high degree of variability throughout the season with values increasing up to 7.67:1 females:males. These variable sex ratios are unusually high, but, when the total number of mites are considered throughout the year, the sex ratios are consistent between farms.

3.6 Soil Moisture:

Soil moisture is an important component in maintaining a plants' health and vigour. The soil moistures for each farm were recorded from January 1990 until March 1991 to compare the differences, caused by the various treatments. Soil moisture records were taken one year after the plants were established. This was to allow plants sufficient time to be effected by their respective treatments. Overall the soil-moisture was primarily taken to assess the variation which may exist within the farming regions (between farms).

The soil moistures were recorded as percentage of dry weight and plotted against time. The variation between each farm mean is highly significant and is shown in (Fig 32).

It was hypothesized that the plants that received minimal fertilizer would produce a smaller leaf area index. This would allow more radiation to reach the soil surface and for the soil to rapidly dry out, which could cause stress within the plants. From Figures 29 to 31 it is shown that the effect of the various treatments on the plant canopy produces no measurable effects to the soil moisture. This was shown to be correct in all farms participating in the trials.

The major variations within soil moistures was between farms rather than between treatments. Farm two was shown to have a consistently lower soil moisture than farm one. The mean difference between the farms was recorded to be 6 %. This value may seem insignificant, however, when this value is considered in the context of soil moistures rarely exceeding 17 % it may be biologically significant. Thus as farm one has an average soil moisture of 13 %, farm two has on average, a lower soil moisture of 7 %. The soil moistures on each farms can vary enormously with the lowest soil moisture recorded at farm three (Fig. 31), where it reached 2 % of dry weight. During these low levels of soil moisture plant health was visibly affected depending on the age and degree of plant establishment.

Pineapple plants are said to suffer from low soil moistures if the wilting point is maintained for periods longer than 2 months, (Wassman III. R., Golden Circle Cannery, Qld, Pers. Comm.). The variation between the farms was indicative of the variation the health of the crop. For example, farm two had plants whose growth was stunted and vigour reduced, while farm three had a total crop failure.

3.7 Climate and the Effect on the Mites:

Seasonal weather patterns have been speculated to correlate with numerous mite outbreaks (Harrison and Smith, 1961; Bengston, 1965; Ferro and Chapman, 1979).

To clarify these assumptions, weather data was collected over the two year sample period on a regional basis. In association with these regional observations the crop microclimate was recorded using a remote weather station (Envirodata). The seasonal rainfall, maximum and minimum temperatures were recorded from January 1989 to March 1991. The environmental components were partitioned into data units of six weeks, to coincide with the sampling dates. The means were calculated over the

Fig. 29:

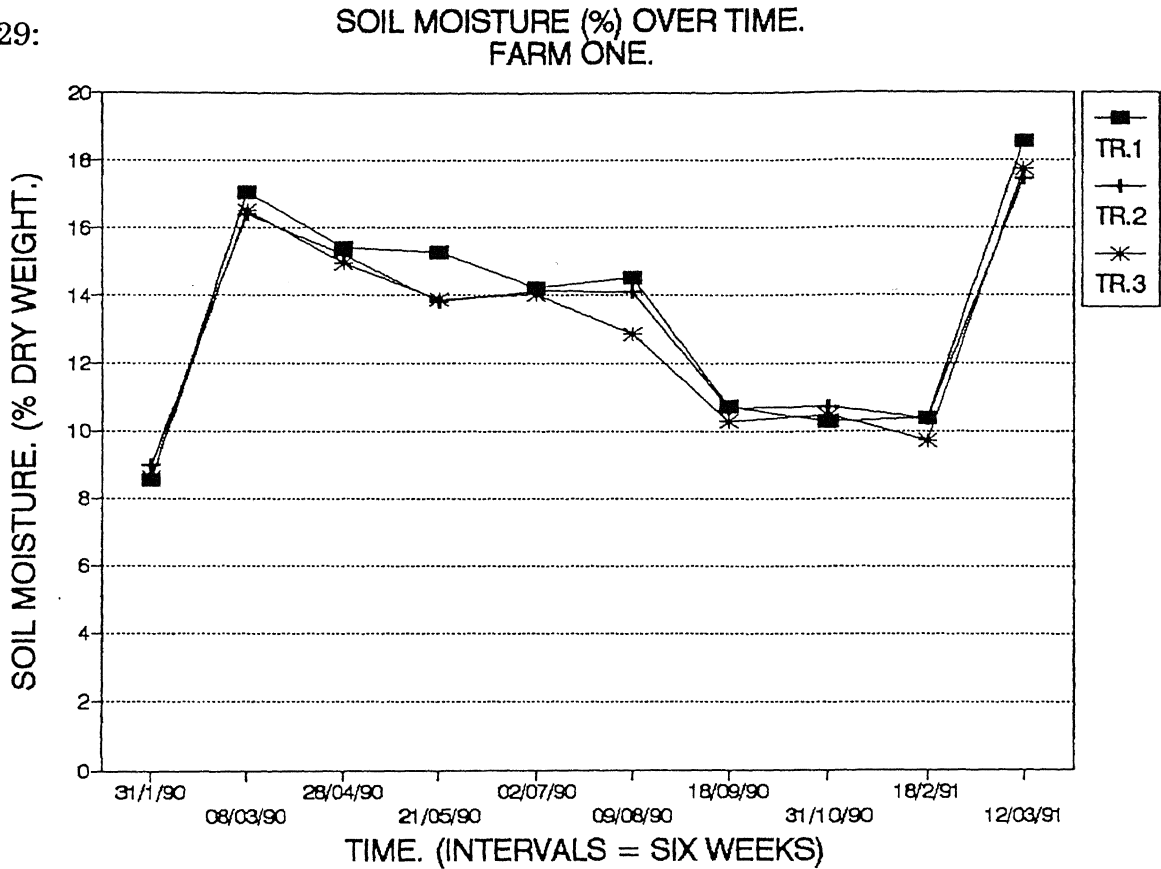


Fig. 30:

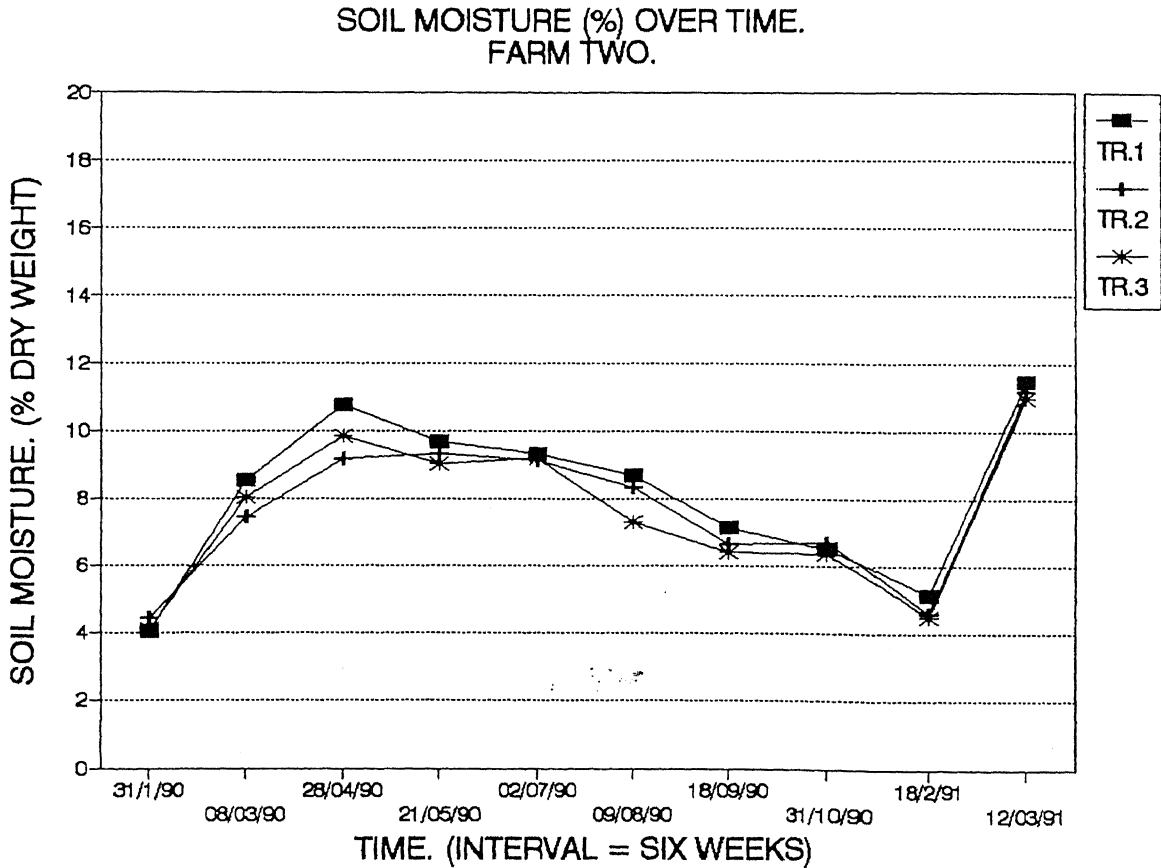


Fig. 31:

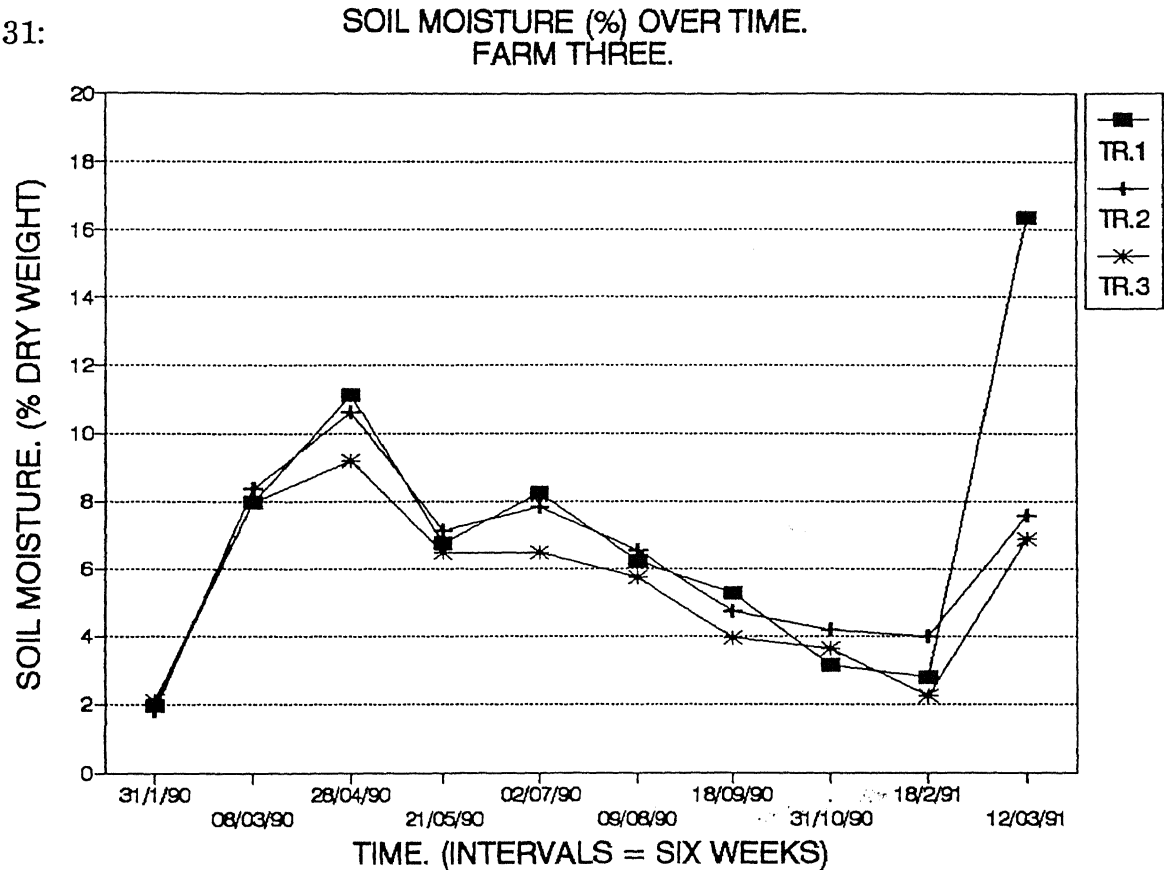
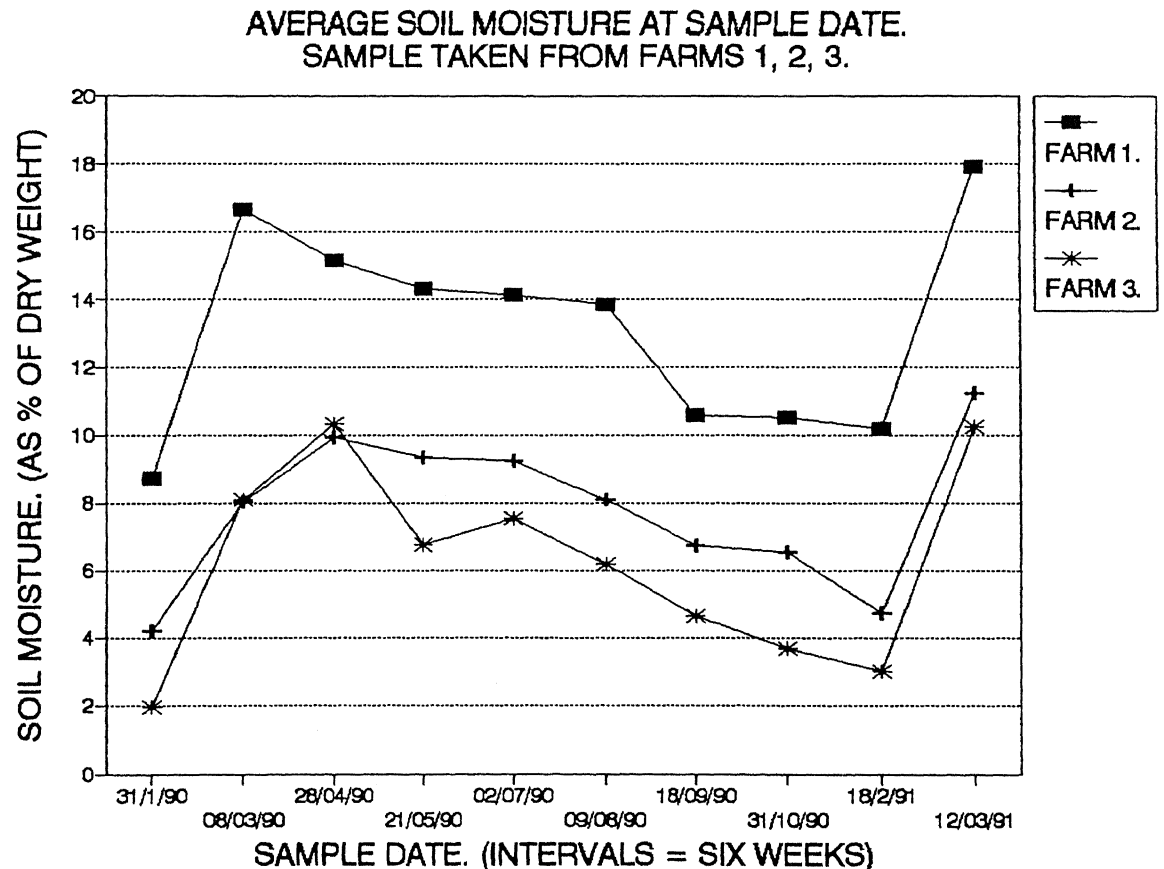


Fig. 32:



three weeks prior to the sampling date. The means were calculated on this time interval as it was shown to have a stronger correlation on the false spider mite population than means calculated at six week intervals.

3.7.1 Rainfall:

The recorded rainfall is shown in (Fig 33). Rainfall was shown to be the highest and most constant during the summer months, extending into late summer. Rainfalls are highest during the summer of 1991 with an average three weekly recording of 5 mm per day. The largest daily maximum during the project was recorded in may 1989 and march 1990 in which 105.2 mm and 160.6 mm respectively fell during a 24 hour period. Winter rains occur, but not to the extent as that which occurs in summer. Within the first year of the sample period, winter rains were unseasonably high in comparison to the previous summers and extended over a considerable period of time.

3.7.2 Temperature:

The seasonal temperature maxima and minima are shown in Figure 34, these averages are based on the recordings three weeks prior to the sample dates. The average seasonal maxima and minima are 27 C and 17 C respectively. The temperatures fluctuate widely, with the highest summer maximums reaching 38 C and 45.3 C during 1989 and 1990 respectively and winter minimums of 2.7 °C and 2.9 °C during 1989 and 1990 respectively.

3.7.3 Correlation of Mite Numbers with Weather Data:

Correlations were performed with the three weather parameters on mite numbers within each cohort and on the total false spider mite population. The results of these correlations are summarized in Table 9 with the regression equation of best fit. The adjusted R-squared value is the coefficient of determination. This figure indicates what percentage of the variation within the population is explained by the correlation equation provided. The adjusted R-squared values are too low to be considered for use in estimations and predictions. The extremely low adjusted R-squared values indicate that despite the hypothesis that mite numbers were related to weather, there are probably other factors intrinsic to false

Fig. 33: Mean Daily Rainfall Three Weeks Prior to the Sample Date.

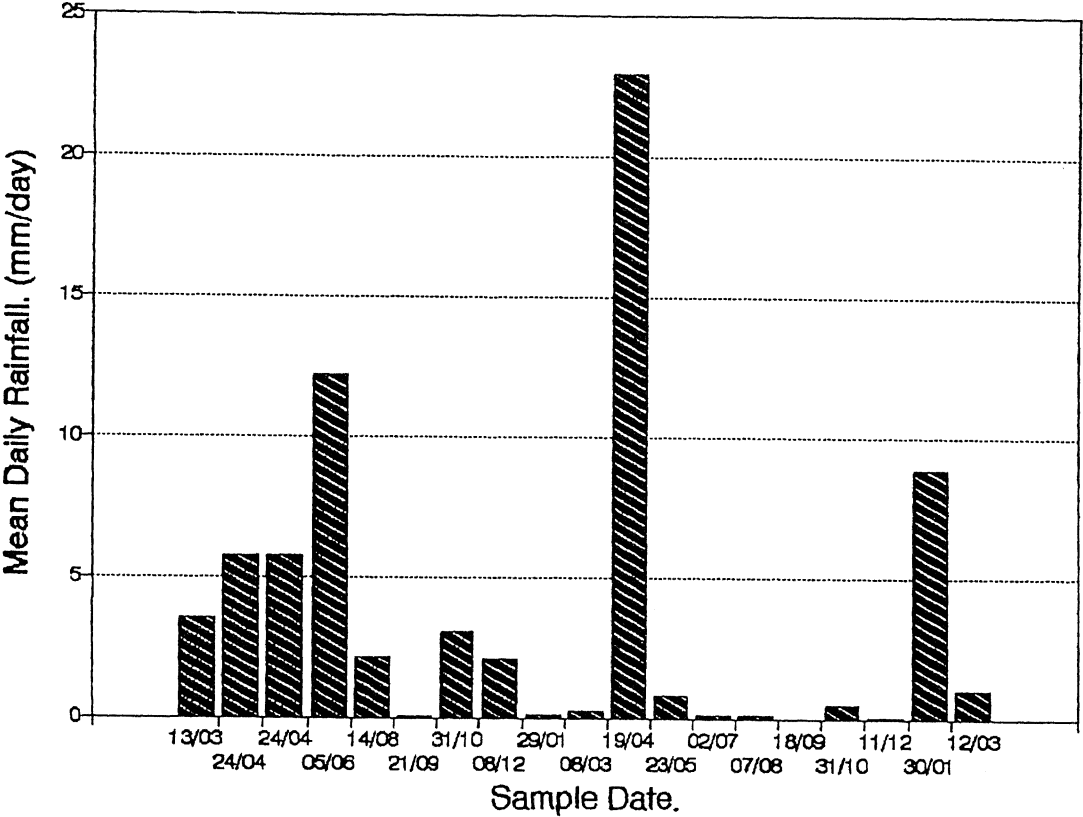


Fig. 34: Mean Daily Temperatures Three Weeks Prior to Sample Date.

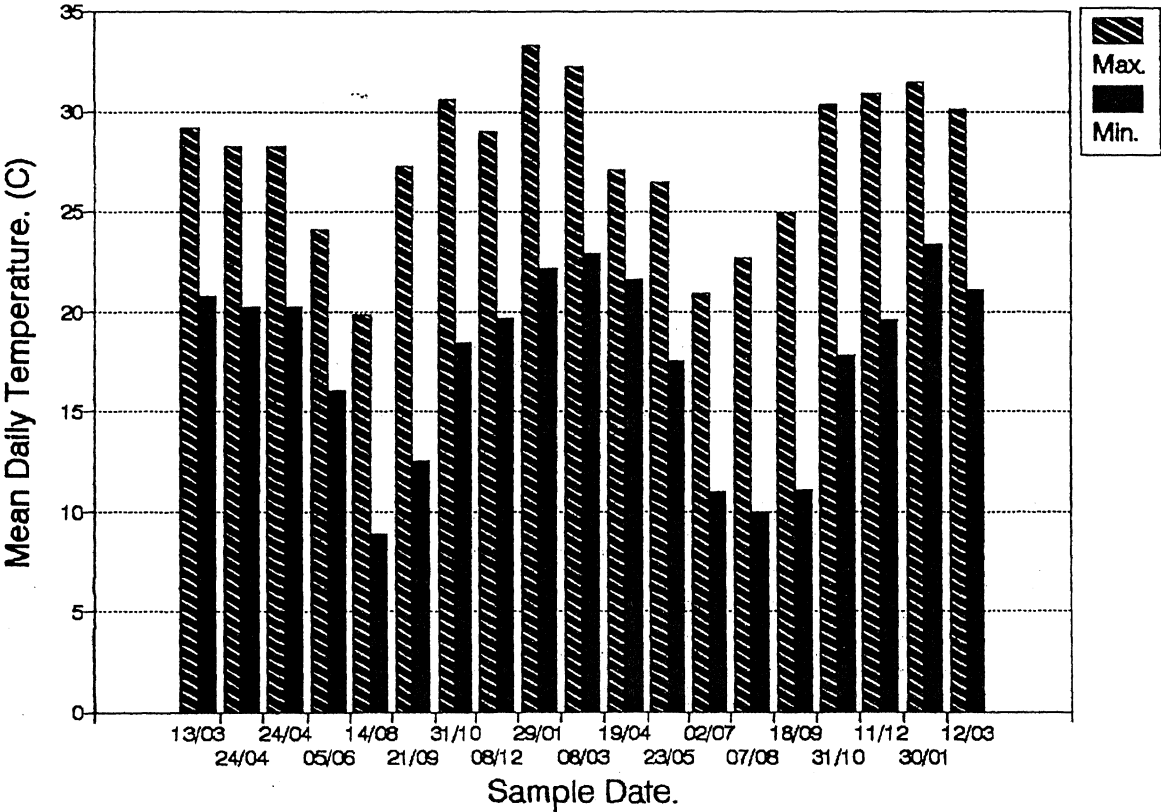


Fig. 33:

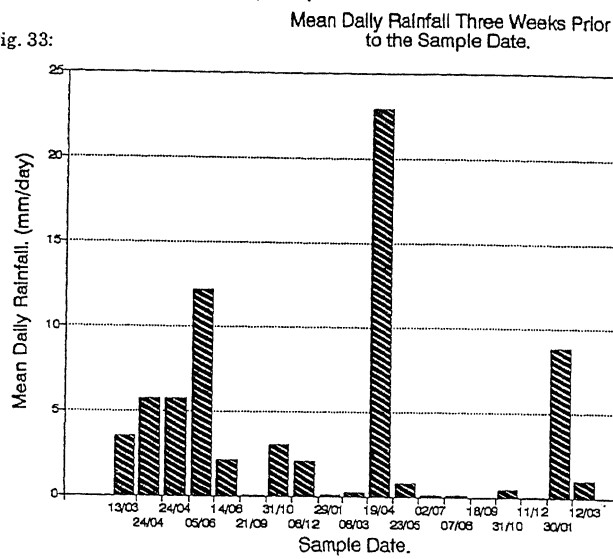


Fig. 34:

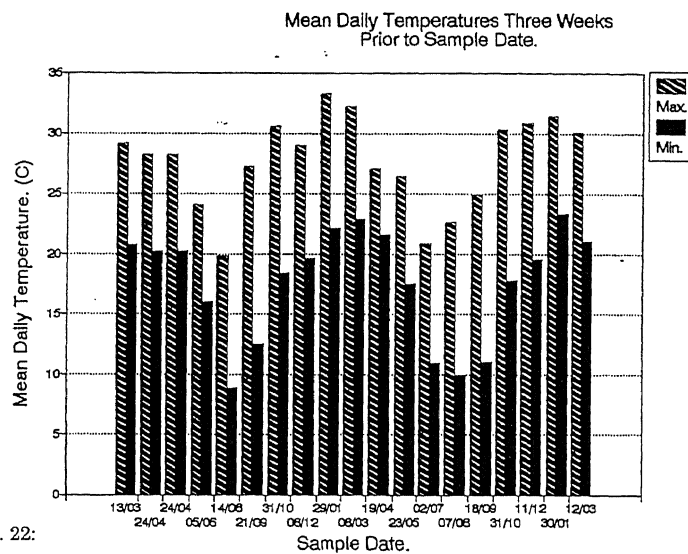


Fig. 22:

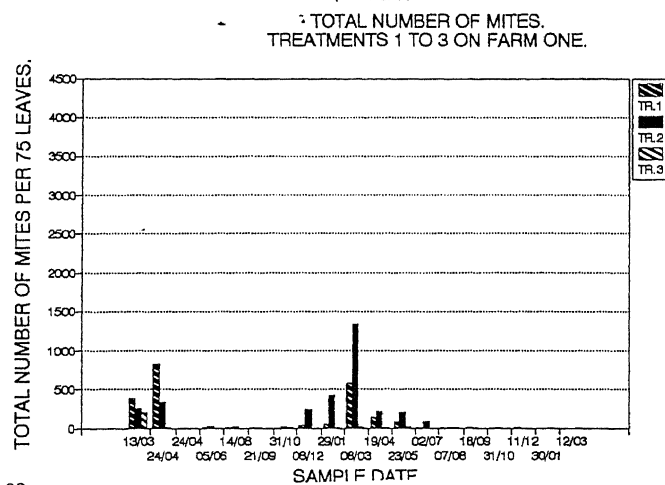
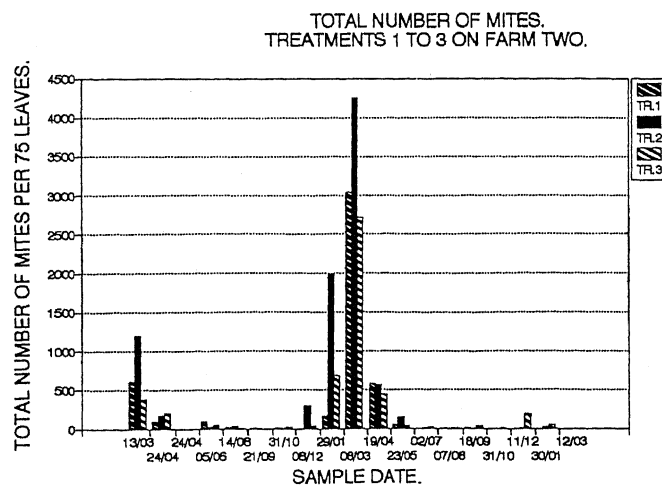


Fig. 28:



spider mite life cycle or plant physiology that contributes to population fluctuations.

Due to the variability that exists within the false spider mite numbers during 'low' mite infestation it was decided to reanalyse for correlations of mite numbers with the weather data during 'high' infestation levels alone. The totals at each sample period over the summer outbreak of 1990 were correlated with the weather data for that corresponding period. The adjusted R-squared values for the rainfall, maximum and minimum temperatures were 28.45, 20.83 and 8.10 respectively. These values are considered to be an improvement on the previous values, but still not considered useful in predictive analysis.

3.8 Mite Presence in Soil:

The presence of mites along the entire plant was clearly demonstrated in this study. Mite colonies within the leaf axils can attain very high densities particularly if the crown is kept in storage for long periods prior to planting. At planting, the false spider mites that are associated with the lower leaves are now positioned underground. Carter (1967) has documented false spider mites feeding on the root primordia within young and unestablished crowns. To ascertain whether this potential habitat is used by the false spider mites in the Yeppoon district, soil samples were taken from the field trials as outlined in section 2.8. All the extractions from these samples were observed to have false spider mites. The numbers of false spider mites extracted from these soil samples were relatively small in comparison to the numbers that can develop within the leaf axils. Despite this, the results confirm the presence of false spider mite populations on the subterranean portion of the plant stem. These mites are probably living in close association with the root primordia and roots proper as suggested by Carter, (1967).

Examination of the extracted mites revealed that there was more than one mite species occupying the subterranean portion of the pineapple plant. The other mites were identified (Schicha, E., B.C.R.I. Rydalmere, N.S.W.) as being oribatid mites and a predatory mesostigmata. The predatory mite was identified as A. benjamini. This species is far more prevalent within the soil samples than is D. floridanus. By contrast it is present but relatively rare in the above ground samples.

3.9 Mite Movements:

The false spider mites are known to pass from one pineapple crop to another and establish sizable populations within newly infested crops. Numerous methods of dispersal have been preposed based on anecdotal evidence. Suggestions such as crawling, wind dispersal, transmission on agricultural equipment and vector borne dispersal (phoretic dispersal) are all considered possible. All these methods are evaluated in more detail later in the discussion.

New crowns were assessed prior to their isolation and 20 % of these new crowns had small but noticeable populations established in the axils of the leaf bases. The size of the newly established colonies never exceeded five to ten individual including eggs. The composition of the colonies were usually made up of two or three adult females (no males) and several intermediate stages and eggs.

After isolation of the developing pineapples with "stickem" the plants were left for the duration of the maturation period (approximately 16 weeks). After this, the crowns were picked and dissected out for the presence of false spider mite colonies. The infestation rate at the end of this isolation period was 80 % of all crowns. Therefore, during the 16 weeks isolation period the infestation rate increased four fold. Since the new pineapples could not be colonized by animals walking along the plant axis there is considerable support to the proposition, that the false spider mites are relying on other means for the infestation of the new plant material.

To test the suggestion that the false spider mites first infest the new inflorescences while they are deep within the heart of the parent plant, 40 pineapples were assessed along with the corresponding crown. Of the 40 plants assessed 85 % had established false spider mite colonies within the crown. Of the 40 plants assessed, 100 % of the plants, including the 85 % with false spider mites in the crown, did not have any mite colonies present within the fruit. There was no evidence of false spider mite infestations within the fruitlets or the basal bracts associated with the fruit.

The evidence above suggests that the false spider mites infest the new crown via two means: 1) A percentage of the mites infest the new crown while it is still within the heart of the plant and ride up with the emerging

inflorescence and crown. 2) In addition the false spider mites are able to use other avenues such as aerial dispersal for the infestation of new crowns. This is considered further in the discussion section 4.11.

3.10 Mite In Volunteers:

Mites that live in agricultural crops, which are harvested, periodically face an absence of host plants to colonize. The lack of an inter-crop host plant threatens temporal dispersion and population continuance. The false spider mite population is faced with a loss of a host approximately every three to four years under standard cultural practices (first crop, two years plus a ratoon crop).

Despite this forced loss of plant hosts, the false spider mites are able to survive between crops by occupying volunteer plants. Between cropping cycles, plant material that has not been totally destroyed may attempt to regrow. These pieces of the parent plant attempt to voluntarily re-establish themselves within the field.

From the assessment of these volunteer plants it was shown that 30 % of the plant material at this early stage was infested with false spider mite colonies. The percentage of infestations is probably higher in most instances as many factors including time of year and age of the volunteer plants would normally produce higher infestation rates than was recorded. These factors are discussed in detail in section 4.12.

3.11 Summary of Results:

Overall the false spider mite population dynamics are shown to be strongly seasonal. The seasonality of the population is not a result of one component of the immediate environment.

The three treatments produced significant responses in the population dynamics. The highest level of false spider mite infestations were recorded in the no insecticide treatment. Although the false spider mite populations in the remaining treatments had been reduced they were significant and caused noticeable damage.

Seasonal weather conditions were shown to affect the false spider mite populations, but the data did not permit the development of predictive models.

The variation between farms was significant and is due to plant establishment rates and vigour. Other factors that resulted in variations between farms may not be associated with the rigid cultural practices of the pineapple agro-ecosystem.

False spider mites were found in other microhabitats associated with the pineapple crop. These habitats included volunteers, soil and roots. Evidence suggests that the mites depend on several means to accomplish inter-crop dispersal.

Predatory mites were generally present in low numbers in all treatments. Predatory mite populations were relatively higher in soil than elsewhere.

4.0 Discussion.

4.1 Mite Extractions:

Methods for the extraction of mites from plant tissue are highly varied and are summarized in Boudreaux, (1953) and Williams, (1987). The basis for their implementation is dependant upon the plant tissue and the type of results the researcher requires from the techniques. These include simple observations for the presence or absence of mites on leaf surfaces, or more complex methods such as indexing where an exponential scale (eg 1=10, 2=10 to 100. etc) is used. Other techniques such as removal by solutions (Jones and Prendergast, 1937; Newell, 1947), are more direct, providing accurate estimates of mite populations. Other methods include, paper impressions, (Venables and Dennys, 1941), beating twigs and foliage, (Boudreaux, 1953), and mechanical brushing of mites from the leaves (Williams, 1987). The methods outlined above are advantageous in that they are very accurate for the enumeration of mites but these procedures are usually tedious.

Previous workers have suggested that the best extraction technique for removal of false spider mites from shredded plant tissue is to soak it in Mineral Turpentine for 24 hours (Ito, 1963; Carter, 1967). This method (Ito, 1963) proved unsuccessful as it extracted the waxy cuticle from the plant tissue. As the wax from the cuticle was not miscible with Mineral Turpentine it conglomerated into a single mass. This made taking a uniform subsample from the mother solution problematic. The problem was exacerbated when the mites conglomerated with the waxy material, thereby making the extraction of a subsample and enumeration virtually impossible.

One potential advantage of this method is that the mites could be concentrated and therefore removed from the supernatant *en masse*. This was trialed and the conglomerate dispersed with 100 % ethanol. Ethanol only partially dissolved the wax component, so this technique was of limited use.

Further problems with the recommended method were: mineral turpentine is not a pleasant substance to work with, it is not a

preservative and allowed the plant material to putrefy, after 48 hours Mineral Turpentine strips the false spider mites of their red colour and makes them difficult to distinguish from the dead mites. Mineral Turpentine also has the effect of degrading plastics which therefore makes it difficult to work with since most of the equipment used contains plastic.

Considering the problems outlined above an alternative method was developed. The extraction fluid was changed to an ethanol based fluid. To overcome the problem of the waxy cuticle, a detergent base was incorporated into the extraction fluid. Of the range of ethanol tested, 50 % ethanol and 10 % detergent was judged to have the highest efficacy in extracting the mites and preserving them for extended time periods.

The extraction fluid did not fix the mites immediately as it did in the 70 % solution, but it did offer the advantage of irritating them and causing them to stop feeding, move and dislodge. Thus the majority of mites were self dislodging and were latter preserved by the ethanol. The 50 % ethanol concentration was sufficient to prevent the plant tissue from putrefying; a problem with the lower ethanol concentrations.

4.2 Mite Distribution along the Plant Axis:

Saprophytic, predacious and phytophagous mites live in numerous environments and occupy areas as diverse as: leaf domatia (O'Dowd and Willson, 1989); leaf axils (Petty, 1978); leaves, stems and cracks within bark (Williams, 1987; Buchanan, 1976); within flowers, bracts, roots and on fruit, (Carter, 1967; Petty, 1978; Moore *et. al.*, 1989).

Mite populations have been shown to be affected by various aspects of microclimate (Jeppson *et. al.*, 1957; Harrsion and Smith, 1961; Perring *et. al.*, 1984). Mites therefore occupy areas in which their microclimate is relatively stable and minimally affected by fluctuations of environmental variables.

Within the pineapple plant there are five whorls of leaves with 13 to 15 leaves in each whorl and a 5/13 phyllotaxy. The adult plants reach a height of approximately one meter with the stem being compressed to approximately one third of this height. As stated in Appendix three the root system is very shallow with the highest density of roots being mostly in the immediate vicinity of the main stem. In general the mite

populations are found in axils of leaves of pineapples but the distribution is quite distinct for D. floridanus and A. benjamini.

4.2.1 False Spider Mite Distribution:

D. floridanus has been observed to occupy all above ground regions of the pineapple plant. To enable representative sampling of the false spider mite population and to investigate the distribution, extractions were conducted as per section 2.1. The false spider mite populations were highest on the leaves within the region of the fourth to the seventh leaf, (Fig. 10)

The distribution of all developmental stages is modal with the main peak at leaf six, with a further insignificant rise in population numbers occurring at leaf nine. The eggs are evenly distributed along the entire axis of the crown so that even the higher leaves that are not as yet heavily colonized do have eggs present.

With the highest false spider mite population existing at the fifth leaf, one could argue that this position has an appropriate microclimate and leaf age to provide optimum resources for the physical development and nutrition of the mites.

Work undertaken by Hamstead and Gould (1957), has shown that mites prefer plants and leaves that have a 'good' nutritional status. Rodriguez (1951), has shown that with increasing plant nutrition as a result of increased fertilizers, mite numbers increase almost linearly. The clover mite Bryobia praetiosa was also found to benefit from increased supplies of nitrogen, phosphorous and potassium in its host plant (Morris, 1961). It would be advantageous for the false spider mite to select leaves with a high nutrient content to benefit their own development. This ability of mites to establish themselves on nutritionally 'superior' leaves within the plant has been outlined by Henneberry (1962). Although the sixth and ninth leaves on the pineapple are relatively mature, they are still actively growing. Therefore the false spider mites are positioned on the region of the leaf that is actively translocating nutrients and metabolic by-products. If these leaves are, as a result of their age, involved in nutrient storage or relocation, then it would be advantageous for the false spider mites to occupy this zone. This region of the leaf lacks chlorophyll, has a thin

epidermis and a less well developed waxy cuticle, all of which makes piercing the surface for the attainment of food, a relatively easy process.

Within the pineapple plant the stem is responsible for the storage of various plant products, (Wassman III, R., Golden Circle Cannery, Qld, Pers. Comm.). The leaves where maximum mite populations occur occupy the region along the stem corresponding to maximum carbohydrate storage areas (Bartholomew, 1989). The false spider mites are in close proximity to the stem on which they feed as evidenced by tissue scarring.

When densities are extremely high, false spider mites have been noted to direct their feeding to the root primordia and the stem (Carter, 1967). Leaves one to three are small leaves and usually senesce in sequence from the basal region upwards. These senescing leaves start to shrink and become 'leathery' and progressively discolour. As these leaves become senescent they dry and curl back, consequently the axil becomes larger and therefore alters the microclimate. Presumably leaf nutrients are translocated out of the senescing leaf, making it a poor substrate on which to feed. It has been shown that mites occupying older and nutritionally poor leaves respond to environmental cues (Overmeer *et. al.*, 1989) and migrate in response to them (McEnroe, 1971a,b). Leaf senescence probably causes false spider mites to migrate up into new tissues, suitable for population establishment and growth.

The false spider mite populations above leaf nine tend to gradually decrease. The higher leaves are not considered to be entirely suitable for the establishment of large colonies. It is suggested that these higher positions are not colonized as extensively due to environmental and physical conditions rather than nutritional factors. The upper leaves are more tightly imbricated, which directly and indirectly produce conditions not conducive for large mite colonies (eg. reduced leaf axils, increased humidity and exposure to the sun). This gradual decrease represents those mites that migrate and colonize the new leaves. These leaves will become the next set of mature leaves that will support the establishment of a new population peak.

The second population peak, at leaf nine (Figs. 10 to 11), substantiates the previous statement. This is further verified because new smaller colonies have established within the higher leaf regions. As the plant grows and

the bottom leaves senesce it should follow that the population peak moves up the stem at a rate consistent with the rate of senescence.

The number of false spider mite eggs on leaves is consistently lower than the number of adults and juveniles. This is suggested to be a reflection of the mites' biology and life cycle. Fisher (1930) states that in a stable population there is usually a balanced sex ratio and more young than adults. Fisher's theory implies, that enough offspring are produced to replace the parents, even though juvenile mortality is high (Hamilton *et. al.*, 1986). It is suggested that the false spider mite population structure is unusual for a number of reasons. Females lay large eggs which are approximately one third adult body size. Due to this extremely large egg size such females would produce less per day than other species of mites which typically have smaller eggs relative to the size of the female. The length of a life cycle is usually recorded from hatching to the pre-ovipositional stage of the female (hence the term 'egg to egg'). The egg to egg time for Tetranychus urticae is approximately 20 days (Liang, 1969) and for Oligonychus pratensis (Banks), it is approximately 24 days (Perring *et. al.*, 1984a,b). The presumed longevity of the false spider mite and the relatively short egg stage produces an 'inverted pyramid' population with more adults than there are juveniles and eggs. The false spider mites eggs have been shown to hatch relatively quickly, a maximum of ten days at 25 C under laboratory studies (see Appendix four for details). While feeding in their optimum environment the false spider mites life span, although not documented, is presumed to be rather long in comparison to other species. It is presumed that egg to adult development is rapid and that the parents are relatively long lived.

In summary, an 'inverted pyramid' population is the result of female false spider mites only producing a relatively lower number of eggs per day; and the life span is presumed longer than other mites. Consequently the females false spider mites may in effect produce the same quantity of eggs per generation time as T. urticae and O. pratensis. There is however a need for further research to define the life cycle more precisely.

4.2.2 Predatory Mite Distribution:

Predatory phytoseiids and mesostigmata mites do not always feed on other species of mites. Some of the phytoseiids have been shown to live and reproduce without other mites as food items (El-Banhawy, 1975).

These mites can survive and reproduce on items such as pollen grains. The association that exists between A. Benjamini and D. floridanus is a typical trophic relationship as the former preys on the latter.

In any trophic relationship it is generally accepted that there are more primary consumers than there are secondary consumers, than there are tertiary consumers. On the leaves, A. benjamini is less numerous than D. floridanus. The population density is far lower than that of its prey items. The distribution A. benjamini parallels the false spider mite distribution because of the need to search for food. Although the density is significantly lower, the predatory mites are considered capable of controlling the population of D. floridanus, (Elder, R., QDPI, Rockhampton, Pers. Comm.). The ratio of predatory mites to the false spider mite is one in six. This ratio is sufficient for the predatory mite to be considered a natural biological control agent. A. benjamini has been observed feeding on D. floridanus, but it is not known whether D. floridanus is the sole prey item.

Figures 13 to 15 show that the predatory mite distribution approximately parallels that of the false spider mite. The major difference between the two populations is that the predatory mite distribution lacks the secondary peak on leaf nine. The population peaks at the same leaf level as that of the false spider mite. If A. benjamini occurs in the same region as D. floridanus it will expend less energy searching for food and its feeding efficiency will increase. Interesting differences between the predatory mite population and the false spider mite population are as follows. The population attains a maximum peak at leaf three, but does not diminish as rapidly past leaf six as does its prey. The population density despite being much lower and is more or less constant along the length of the plant axis. The population is evenly distributed and constant along leaves four to ten. The predatory mites are highly mobile and have been observed to feed on all stages of its prey.

The predatory mite is larger than the false spider mite (approximately double) and has been observed to be capable of physically manipulating a false spider mite. Not only are the predatory mites larger than the false spider mite but, they are highly motile, dispersing and searching for food with proficiency. The active searching behaviour of A. benjamini probably contributes to its more even distribution

Mites classified as predatory are highly motile, their front legs being equipped with an abundance of sensory organs (Alberti and Crooker, 1985). These sensory organs enable the mites to decipher their immediate environment probing with their legs as they move around (Fleschner, 1950; Bostanian and Morrison, 1973). Personal observations of A. benjamini have shown that when they are feeding they constantly roam and sense their immediate environment until they find prey. Alberti and Crooker (1985) have shown this behaviour to be indicative of predatory mites and is found in other species such as T. urticae and T. lintearius.

In summary, the predatory mite, is far less numerous than D. floridanus but is large, active and more evenly distributed along plant axis. The evidence does not necessarily indicate that the predatory mite has only one prey item. Rather the possibility exists for it to have others as its distribution patterns are not restricted to only the leaves along the plant axis. As discussed in section 4.10.2 the predatory mite also occurs on the roots where it is proportionally more numerous.

4.3 Geographical Variation.

4.3.1 Variations in the Mites Distribution:

The false spider mite is a potential threat to the pineapple industry both within Australia and overseas. The false spider mites geographic distribution is widespread, covering those pineapple growing countries that typically have a hot dry summer and moderate winter. Most of these countries are thought to have had false spider mites introduced simultaneously with the plant material when the industry was established, (Wassman III, R., Golden Circle Cannery, Pers. Comm.). Wassman also stated that the false spider mites most likely entered Australia during the mid 1800's with the first import of plant material. Since then the mite has established itself within the pineapple fields along the eastern coast of Australia. During this study the false spider mites were identified as being present in areas between Brisbane and Cairns. The false spider mite problem is particularly severe in the Yeppoon area and mites are most prevalent during a succession of dry years (eg. 1987/1988). The succession of relatively dry seasons in 1989/1991 has caused the false spider mite to be considered a problem in those southern region of the state that were not previously affected. During the wet seasons, the mite populations are reduced but never eliminated from the

pineapple crops. The false spider mite has the ability to maintain a temporal distribution, although seasonally populations undergo dramatic changes.

4.3.2 General Seasonal Abundance Trends:

It is clear from the literature that mite populations undergo marked periodic or seasonal fluctuations in their numbers (Hamstead and Gould, 1957; Jeppson *et. al.*, 1957; Bengston, 1965; Goodwin, 1990). These fluctuations can result from limited resources (Hamstead and Gould, 1957), a change in the combination of resources (Overmeer *et. al.*, 1989) or directly as a result of climate (Jeppson *et. al.*, 1957; Bengston, 1965). Thus resources such as food, and mates and environmental parameters such as humidity or photoperiod may cause changes in populations either individually or in combination (Van Houten, 1989). These parameters can be biotic or abiotic. Both biotic and abiotic factors can influence the mite population numbers in negative or positive ways.

Most predatory mite populations fluctuate as a result of one limiting resource: food, which is itself directly influenced by seasonal parameters. In such situations, populations typically rise (explode) and fall (crash) around a given mean population.

In phytophagous mite communities, populations do not usually crash as a result of limiting food resources. Rather the populations are influenced by environmental cues such as weather (Jeppson *et. al.*, 1957). Should numbers become too large within a population, mites commonly migrate from their habitat to areas where resources are not as limiting. Environmental cues have been shown to stimulate migration (McEnroe and Dronka, 1971a). In view of the false spider mite size, new resources may only be millimetres away. Observations in this study have shown that within the leaf axils, the basal section of larger leaves can support two or three small colonies of D. floridanus. These small colonies can be considered as two or three separate sub-populations. Fluctuations within false spider mite population occur primarily as a result of seasonal influences. These seasonal influences can be rainfall, temperature, or changes in day length, to name a few.

The Yeppoon pineapple industry has probably always maintained a potentially detrimental mite population due to its naturally hot dry

known. This trend for the false spider mites to favour hot dry climates was evident from the early part of the century (Carter, 1941). Since their initial discovery farmers have noted mite outbreaks to occur when these conditions prevail. Mites that live in southern areas or more temperate areas typically die or enter diapause to overwinter (Bengston, 1965; Buchanan 1976).

The collection of field data to monitor the populations biology and seasonal distribution commenced in March 1989 after the summer crop had been planted. This followed several years of severe mite infestations. Sampling continued until March 1991 with mite samples being taken every sixth week. The population totals for each farm at each sample interval are shown in (Figs. 27 to 28). The graphs show marked seasonal variations with population explosions starting in spring but mainly occurring during mid to late summer. The population then remains stable until late autumn when it decreases dramatically and quickly.

Overwintering often allows mites to go into dormancy to survive the winter extremes. This diapause has shown to be induced by photoperiod changes (Van Houten, 1989); changes in the nutritional status of the plant (Hamstead and Gould, 1957; Overmeer *et. al.*, 1989); or by weather parameters alone (Bengston, 1965). This survival strategy is not without it's consequences as many mites fail to come through the diapause process's (Buchanan, 1976). The mites that survive a winter diapause provide the nucleus for the next seasonal population. During the winter months residual mite numbers were shown to be present on all farms and in all treatments. Although they were present the procedure employed did not allow diapausing and active individuals to be distinguished. Personal observations of fresh leaf samples have shown false spider mites diapausing.

In summary D. floridanus populations follow a typical seasonal fluctuation, with maximum numbers developing in late summer. Low population densities of overwintering false spider mites (all stages) are present in the cooler months serving as a nucleus for the population in subsequent summers.

4.3.3 Variation Between Farms:

Following the first reported outbreak of false spider mites in the Yeppoon district (1987/1988), anecdotal evidence suggested there was considerable variation in the level of infestation between blocks and farms. Some farmers claimed to be 'clear' of false spider mite infestations while others reported severe mite damage. The problem was made more intriguing when farmers admitting to mite infestations commented on the patchiness of mite infestations within small areas. Evidence from the early part of this century indicates that this is a trait of the false spider mite population in general (Anon., 1926) and not simply due to farmers not observing the mite or its effect. By the end of the study (1991) almost all farmers in the Yeppoon district admitted to some degree of mite infestations.

Nevertheless, one could argue that variations in cultural practices between various farms was responsible for the differences in infestation levels. As outlined in Appendix three the pineapple crop is governed by a rigid cultivation cycle. Since most farmers adhere to this rigid cycle it would suggest that variations in infestations as large as those found between farms are not simply the result of alterations to this regime.

It is argued that the differences between farms are not a result of differences in cultural practices, rather they are due to different features in each farm. These features include differing soil types, plot aspects and slopes.

The differences that exist between farms across the Yeppoon district were assessed by the analysis of variance performed on the sample data. The ANOVA calculations, summarized in Table 1, show that the farms are all significantly different. Mite numbers in freshly planted crowns were significantly higher in farm two than in farm one. The observed differences between the farms are considered to be a result of several factors.

Planting material is usually stored in several ways prior to planting. Initially the plants are stored on top of the parent plants when fruit is picked. This storage enables the fresh ends of the plant to dry, therefore preventing base rot once planted. This practice is extended further in Hawaii where farmers are advised to store crowns in an upright positions

to enable moisture collection which reduces false spider mite problems (Schmidt, 1941). The crowns are later stored in bins which enable rapid handling of large quantities for the planting procedure. The mite problem is exacerbated when the new crowns are left for excessive periods within these bins. Mite populations tend to increase rapidly when the crowns are kept in storage prior to planting. The plant vigour is dramatically reduced and eventually the crown dies as a result of excessive mite damage. Some planting material used on farm three in 1989 had reached this stage. Mite damage varies with population densities. It may be slight damage of the sclerotic leaf tissue during low populations, but can extend to the root primordia and the stem proper when densities are high. In the latter situation, crown health and vigour are severely reduced. Damage therefore ranges from minimal to high, the latter of which causes the crown to be damaged beyond recovery.

Due to the long life cycle and slow growth rate, pineapple crowns that appear to be initially unaffected may later perish when planted in the field (Fig 16). Prior to the start of this research farm two had left crowns in storage several weeks longer than farm one. This was a result of excess soil moisture due to seasonal rains, which prevented soil preparation and planting. Consequently false spider mite levels are consistently higher in all treatments on farm two compared to farm one. Although farm two delayed planting due to wet conditions, the soil structure within this farm does not allow large field capacities to develop before water logging becomes a problem. The soil moisture on farm two does not persist as long as on farm one. Pineapple crowns require adequate soil moisture to initiate root growth. Should soil moisture be limiting, plants are not able to establish themselves quickly and rely on reserves for survival during this induced dormancy and is believed to place tremendous stress on the plants as they encounter dry periods soon after planting.

Mite feeding activities rapidly increase during hot dry periods (Pritchard and Baker, 1952; Boudreaux, 1958). If the feeding intensity of D. floridanus increases during the quiescent periods within the pineapples, then vital nutrient reserves can be depleted. Therefore, the combined effect of low soil moisture, reduced plant growth and increase feeding intensities can further reduce crown establishment and growth. This reduced health manifests itself throughout the entire length of the crop cycle. Thus the difference in soil moistures as a result of differing soil

types may cause some farms to be apparently more prone to false spider mite infestations than others. It was noted that crowns planted in early summer tend to suffer the previously outlined events more severely than crowns planted during late summer. Crowns planted in late summer suffer less from excessive heat and are likely to receive adequate rainfall after planting. Should those crowns that are planted in early summer receive adequate rainfall then mite damage appears to be reduced.

Farm two had consistently lower soil moistures than farm one. Farm two has a more open and decomposed granite composition allowing faster drainage but is easily water logged over a short term. By contrast, farm one possesses a rich red volcanic soil with good retention capacity. When farm two becomes water logged, severe damage occurs when pathogenic organisms (causing rot) develop in the leaf regions that have been colonized by the false spider mite. The ability to plant in soils that have correct soil moisture allows new planting material to set roots and establish itself within short time periods. Mites do not appear to be able to develop potentially damaging capacities in plants that have established faster and are more vigorous. As farm two tends to dry out more easily, plants are unable to establish as well.

It appears that the relationship between mite numbers is a positive feedback system. That is, as the mite numbers increase, plant vigour is severely reduced. This relationship also works in the other direction: as the plant size and vigour increases mite colonies do not become as large and tend to remain stable in density. It is suggested that the combination of these factors are responsible for the constantly lower number of mites in all treatments on farm one.

4.4 Variations between Treatments:

Various horticultural practices have been suggested to influence mite numbers. Increases in nitrogenous fertilizers have been positively associated with increases in mite numbers associated with fruit trees (van de Vrie and Delver, 1979). Similarly, increases in the use of certain insecticides have shown to increase mite numbers over time (Cutright, 1944; Hueck *et. al.*, 1952). The non-selective use of insecticides have also long been recognized to pose a serious problem to non-target and beneficial species of predatory mite (Cutright, 1944).

4.4.1 The Effect of Reduced Insecticide:

Treatment two was a reduced insecticide treatment and was set up primarily to test the hypothesis that insecticides reduce predatory mite numbers. A secondary objective was to assess how effective current insecticide regimes were in controlling false spider mite numbers. The insecticide regime outlined in Appendix two was designed specifically for the control of the false spider mite. This and other insecticide regimes are primarily to protect the pineapple plants against scale insects and other insect pest.

It has been suggested that the natural predator A. benjamini could potentially control the false spider mite population. This suggestion was based on the relatively high ratio of 1:6, predatory mites:false spider mites that was evident while the crowns were in storage bins. In the field, D. floridanus populations always diminished during late summer early winter. The reduction of the mite numbers was not as a result of the predatory mites. Despite the favourable ratios in planting material, populations of A. benjamini did not establish in the field; to the level that would feasibly control the false spider mite. Individual predatory mites were noticed in leaf samples taken from the field only seven times throughout the year. Although sporadically present, A. benjamini frequencies within the leaf axil did not permit statistical analysis. The presence of the predatory mite within crowns while in storage suggests that conditions were more favourable here than those that are found within the field. These conditions enabled the predatory mite to rapidly reproduce within this area, where food was in ample supply.

Work performed by Fleschner (1950) has shown that predator-prey relationships are highly modulated by phototropic and geotropic responses. The specific predators of the mites possessed an array of tropic responses that aided them in occupying the most favourable niche while also enabling them to find food resources. Fleschner (1950) stated that the predator and prey have preferred sites in which they search for resources. These preferred sites are determined by the response to tropisms within their environment. The majority of phytophagous mites tested possessed a negative phototropism and a negative geotropism. This combination enabled them to find a balance and locate within a favourable niche. Predators such as Stethorus picipes (Casey) are shown to correlate

positively with their prey distribution, while others such as Chrysopa californica (Coquillett) are shown to positively correlate with their prey distribution but not as tightly (Fleschner, 1950). The most interesting of all is Conwentzia hageni (Banks) whose distribution is the reverse of its prey. In this instance the prey item has a positive phototropism and a negative geotropism, while the predator has a positive geotropism and a negative phototropism. This forces both predator and prey into different preferred sites. The predatory mite in this instance is not strongly governed by the geotropism and migrates to the site where prey are found during the night.

The lack of predatory mites within the field situation suggests that the microclimate is not suitable for its development within the pineapple crown under field conditions. This is a topic which requires further investigation since it may be possible to enhance predatory mite numbers by optimizing their environmental requirements.

The seasonal reduction in the false spider mite population occurs at the end of autumn and low numbers persist well into winter. This occurs twice in the crop cycle: once for the small, establishing plants and again in the mature plants during the second year of the crop cycle. This reduction is not as a result of the insecticide regimes, rather it is due to the change in seasonal temperatures. As a result it occurs in all experimental treatments equally (Figs. 17 to 26). Although the false spider mite density diminishes during the winter months a residual population remains, providing the nucleus that enables the next seasonal population to develop rapidly. In comparison to the other treatments, treatment two tends to develop very large populations over a short period of time from early spring to late summer. This large population suffers minimal toxic or inhibitory effects from insecticides. Despite the large population, it became apparent that the established plants were not affected to the extent that they would of been if they had been newly planted.

The rapid development of large populations would indicate a relatively high biotic potential (r). Calculations of r (for treatment two) were conducted on the results that cover the sample periods corresponding to active population growth. These sample periods coincided with the normal spring/summer population explosion (i.e. seven to ten inclusive). The r value calculated on the total population number gave an average

value of 0.02, This r value is quite small when compared to other species such as T. urticae ($r=0.2$) (Liang, 1969). This depressed r value (compared to other mites) is probably due, at least in part, to the fact that they lay relatively large eggs but few of them. Although the false spider mites have a small r value in the field environment (compared to other mites) they are still able to develop extremely large population densities during the summer months. On established plants the densities during this period do not produce the devastating effects that they would have on smaller plants. Mites that establish large populations in a field situation on small plants cause severe stress on the host plant. The effect of high densities on large actively growing and established plants appears to be buffered by their large size and nutrient reserves. Despite this, leaf damage still occurs, but it is uncertain whether the plants have a reduced yield as a result. Although the false spider mite populations become extremely large their densities do not last for extended period of time. With seasonal changes producing cooler temperatures the natural population diminish relatively quickly.

4.4.2 Effects of Reduced Fertilizer:

Variation in the level of fertilizer applied to horticultural crops and the effects on mite population have been studied on numerous occasions. Mites have been shown to have a preference for those plants that have a higher nitrogen content (Henneberry, 1962). Mites such as T. telarius have been shown to prefer plants with higher soluble nitrogen content. They also show a preference for those leaves within a plant that have higher nitrogen levels and leaves that are actively growing (Hamstead and Gould, 1957; Henneberry, 1962). Rodriguez (1951) found that, when concentrations of all the major mineral elements in a nutrient solution were doubled, T. telarius produced twice as many progeny. Certain compounds used in insecticides can also provide nutrients for mites. Attiah and Wahba, (1971) have shown that residual phosphorous compounds that are used in insecticides can result in mite increases once the toxic components have diminished.

Prior to this study there had been disagreement within the industry as to whether false spider mite infestations were more severe on crops that were nutrient poor or whether they were more severe on crops that had been over fertilized.

Treatment three was implemented to test the hypotheses that a reduced nutritional status in pineapples will effect the false spider mite populations. On the basis of information in the literature one would predict that mite numbers would not be as high in plants of reduced vigour. In all figures (17 to 28) for farms one and two, there appears to be two different results. Within farm one, the reduced fertilization has minimised the population outbreaks, keeping false spider mite numbers at a residual level. Farm two had significantly higher false spider mite numbers than farm one, but were lower than in the normal farming treatment where insecticide were applied. Irrespective the farm, the minimal fertilizer treatment causes populations to be lower than those treated with insecticide regime. The results suggest that lower nutrient contents within a relatively healthy plant limits mite development. The reduction is greater than that which occurs in the insecticide treatment.

The plants that received the reduced fertilizer treatment were generally of poorer quality showing obvious nitrogen deficiencies and can be seen in the plants as a yellowing (Figs. 7 to 9). The deficiency showed as a marked yellowing of the crop. In addition to this the plants were much smaller and underdeveloped. The leaves were smaller, the crown and leaf axils were visibly more open compared to normal plants in treatment one. This would immediately alter the microclimate within the axils. Consequently this would produce an altered humidity level and an increased ability for precipitation to enter the zone colonized by mites. Because the leaf has an extremely waxy cuticle, water bridges between the two leaves creating an air pocket in the region colonised by the false spider mites. High relative humidity levels are known to reduce the feeding efficiency of all mites (Boudreaux, 1958). If water bridges across the leaf axil and the false spider mites are sealed in for extended periods, then asphyxiation may be responsible for the majority of deaths.

The overall effect was that the mite populations were reduced under decreasing nutrient supplies and associated factors that resulted from decreased nutrient supplies. Mite numbers within the juvenile cohorts were affected by the reduced fertilizer application more than the adults. Therefore one could argue that increased nutrient supplies enhance the development of large populations by favouring juvenile development.

The drawback is that the crop will not produce the quantity of fruit that is economically viable. In this situation the plants produced fruit that was acceptable for market, but ratoon crops will not be as good. From the results it is suggested that the potential for mite increases are highly dependant on the nutritional status of the plants on which they feed. The problem exists where the plant is unable to maintain a certain level of nutritional status. It is suggested that this ability to expand rapidly is an inherent feature of the false spider mite populations as a response to a diminishing resource. Van de Vrie *et. al.* (1972) stated: mites that are produced in excess of the colonies holding capacity when the plant is no longer suitable may disperse and colonize nearby plants that are uninfected and healthy (Boykin and Campbell, 1984). The results clearly establish, that host nutrient status is an important feature in determining the potential size of mite populations. Despite this, there is a need for further study which quantifies the relationship. Since the production of quality fruit is the ultimate aim, it is necessary to look for the optimum fertilization rates that will not exacerbate false spider mite infestations.

4.4.3 Overview of Normal Farming Practices:

The normal farming practices within the Yeppoon district and throughout the pineapple industry in general are outlined in Appendix two. Depending on whether the crop is planted to produce a winter or summer harvest, the schedule varies little. The aim of treatment one was to document the effects that normal insecticide regimes have on the total number and cohort composition of the false spider mite population. Huffaker *et. al.* (1970) states that the rise of mites to world wide pest status followed an increase in the use of synthetic organic insecticides after World War II. They propose that the rise in pest status is explained by three theories: (1) The predators are inhibited by the insecticide application; (2) Improved host plant health and vigour resulting from increased fertilization rates and cultural practices or insecticide induced changes in plant physiology (trophobiosis); (3) Direct stimulation of the mite as a result of sub-lethal doses of a insecticide (Hormologosis) (see also Jones and Parrella, 1984). Mite numbers have however been shown to increase after selective insecticides have been applied (Attiah and Wahba, 1971). Mite populations are reduced by these insecticide applications, but after the toxic effects have passed, insecticides based on phosphorous compounds actually leave nutrients which are beneficial to mite

development. Mite populations are affected by spray schedules that are targeted at them directly (Gough, 1990) as well as those directed at other species present within the same crop (Elder, 1988).

Predatory mite populations found in stored crowns did not develop under normal field situations. It could be argued that this is the result of routine spray schedules. Phytoseiid mites are known to be severely affected by other peripheral chemicals that are used in crops to control pests other than mites. Hoy and Ouyang (1986) state that substances such as clofentezine and hexythiazox which are proven acaricides are virtually harmless on the predatory phytoseiids. In contrast, other chemicals such as chlorpyrifos and dimethoate are noted for their deleterious and toxic effects to the predatory phytoseiids (Elder, 1988). The predatory mite A. benjamini is highly motile and actively searches for its food items. Due to this high degree of motility it is regularly exposed to the toxic effects of insecticide residues as it actively enters various microhabitats.

Treatment two, which as discussed previously was a minimal insecticide crop. Under the conditions of this crop it was hypothesized that the predatory mite would not be affected by insecticides and develop a larger population than in typical farming practices. Despite the crop having no insecticides applied to it, the predatory mite failed to develop a population within the leaf axils. Although the predatory mite was not able to develop a population within the leaf axil there was a consistently large population in the subterranean portions of the plant stem (see discussion section 4.10.2). Predatory mite densities and distributions are probably related to the various aspects of microclimate rather than the farming practices.

D. floridanus populations within the normal farming treatment were never particularly high over the 1989-1991 research period. The highest number of false spider mites per leaf was recorded during summer 1990. Even within the minimal insecticide treatment the average was only forty mites per leaf.

The most common form of insecticide used for the control of false spider mite in Central Queensland is dimethoate. Attiah and Wahba (1971) and Gough (1990) have shown dimethoate to be relatively ineffective as a miticide under field environments. In trials conducted by Gough (1990), dimethoate was least effective in its ability to reduce the mite numbers in comparison to the other miticides trialed. The failure of dimethoate was

attributed to a resistance factor (Gough, 1990). Dimethoate had previously been used extensively for the control of aphids and scale insects with no consideration given to non-target species. The practice of 12 to 13 sprays per year for the various ornamental crops has enabled mite populations to develop a resistance to these insecticides within an extremely short period of time (Gough, 1990). Elder (1988) has also stated that dimethoate used in pineapples to control the false spider mite is not as effective as other insecticides trialed. It appears from the literature, that various insecticides can succeed or fail depending on the method of application and the previous history of the crop with respect to other closely related insecticides. The current study demonstrated that existing insecticide regimes do appear to offer some degree of control in field crops.

Due to the ability of mites to become resistant to insecticides, current treatments may not offer long term control of mite populations. It is now possible to control mite outbreaks with an array of chemicals. The indiscriminate use of miticides may ultimately lead to the development of resistance. The need exists for the development of sound long term agricultural practices. These procedures would include the effective use of insecticides rather than indiscriminate spraying, as well as developing easily implemented integrated pest management (IPM) programs. These IPM programs can be developed around the use of biological control agents such as predatory mites or various mite pathogens. Although there is currently insufficient data to consider IPM programs for D. floridanus it is instructive to consider briefly some parallel studies.

Research has recently been directed into the development and use of highly selective insecticides. These insecticides have the potential to selectively reduce the pest species and not affect the beneficial predatory species (Brun *et. al.*, 1983). Other research has been directed at the use of mite pathogens for the control of outbreaks within an agricultural crop. The use of the fungus Hirsutella thompsonii has been trialed for its efficacy in controlling the mite Eriophyes guerreronis Keifer, which causes severe damage and yield losses within the coconut industry (Moore *et. al.*, 1989). The fungus assumes epizootic proportions within the mite colonies feeding under the floral bracts. In the current study Hirsutella sp. was observed to attack D. floridanus on pineapples but it never reached sufficient densities to control the population. As with the predatory mite

there is a need to investigate the environmental factors which are preventing it from exerting more control.

Various chemicals are presently used on the pineapple to control numerous fungal pathogens such as, Phytophthora, Ceratocystis and Penicillium species. Just as these plant pathogens are controlled by fungicides so to Hirsutella sp. which attacks the false spider mite may also be severely restricted. Work performed by Moore *et. al.* (1989) has shown that this genus of fungus has the potential to be easily cultured and developed into an emulsion for spray application. Further testing may develop a fungicide resistant strain of this fungus for the use as an effective biological control agent.

4.5 Intra and Inter-Plant Variations in Distribution:

Numerous reports outlining the sporadic and uneven distribution of the false spider mites warranted the assessment of inter and intra-plant distributions. Although dispersal through agro-ecosystems is an important feature of mite ecology, the methods of dispersal are not considered here. Kennedy and Smitley (1985), state that mite populations in natural ecosystems are in dynamic equilibrium and rarely cause severe damage to their host plants. Factors which contribute to population differences between natural and agricultural ecosystems include, the suppression of natural enemies by modern insecticides, the stimulative effects of certain insecticides on mite population growth, the use of cultural procedures which improve plant growth and nutrition (van de Vrie *et. al.*, 1972; Kennedy and Smitley, 1985).

4.5.1 Intra-Plant Variability:

The distribution of false spider mites along the plant axis has already been discussed (section 4.2.1). On the bases of this pilot study, sampling was confined to those leaves where false spider mite populations were shown to be highest. Even with this narrowing of the range of leaves selected, there was still considerable intra-plant (inter-leaf) variability.

During periods of relatively low population numbers (mainly winter) the mite populations were unevenly distributed between the plants leaves. Not only is there considerable variation between leaves, but within leaves there is a tendency for the mites to aggregate as colonies. It is these

sporadic colonies which survive winter and re-established populations in the following spring.

During periods of relatively high population numbers, the false spider mite distribution was more even. Mite populations generally are characterized by cycles of initial colonization by mated females followed by rapid population growth and localized host exploitation with subsequent dispersion or migration to new resources (Kennedy and Smitley, 1985). In the pineapple plant the leaves are closely imbricated and new resources are often only several millimetres away. New colonies are founded by females walking to new feeding sites. Immature stages are rarely found in young colonies. In severe infestations adjacent colonies merge and significant leaf damages occurs.

4.5.2 Inter-Plant Variability:

During periods of relatively low population numbers the false spider mite population distribution between plants was again found to be uneven. These sporadic colonies presumably survive winter conditions due to microenvironmental conditions within the host plant. The nature of the factors within the plant environment which contribute to the false spider mites survival requires further research.

During periods of relatively high population numbers, the mite colony distribution was shown to be uniform, with colonies present in all plants sampled. Kennedy and Smitley (1985) suggest that irrespective of the colony size on the leaf that is inhabited, a certain proportion of the females will disperse. Therefore the probability of one or more disperses from a colony landing on a suitable host plant and successfully founding a new colony is related to both the abundance and distribution of suitable hosts within the dispersal range of the mites, and the number of disperses (Wrensch and Young, 1978). The cultivated pineapple crop makes an ideal habitat for false spider mites to colonize. Although initial mite populations within the pineapple plant are low and unevenly distributed, with favourable seasonal conditions the population can reach enormous proportions relatively quickly. These populations can be detrimental to the plant health particularly if plants are placed under stress due to high temperature or low water availability. In mites generally, as the host plant conditions deteriorate and space and nutrient resources are depleted, reproductive females are induced to migrate and disperse,

(Kennedy and Smitely, 1985). In the pineapple crop, plants are closely associated being only 27 centimetres apart. As these plants reach maturity their leaves tend to intermesh and new resources for the migrating individuals are easily reached by females walking to new sites.

In summary, during winter populations are both small and unevenly distributed within and between plants. In spring-summer the population expands and females disperse to produce not only a larger population but more evenly distributed populations with decreased inter and intra-plant variability.

4.6 Sex Ratios:

Sex ratios were calculated for the false spider mite population inhabiting the pineapple crop over the 1989/1991 period. The ratios were shown to be unbalanced and varied depending on the time of year and the farm. Fisher (1930), states that a normal population of animals is considered to be 1:1 male:female. There are of course many documented exceptions to this ratio, particularly among arthropods. In this study the proportion of males to females varied considerably. Arrhenotokous mite species normally have more females than males (Helle and Pijnacker, 1985). These authors also state that a ratio of 3:1 females:males is very often found and considered to be the normal ratio for mites. In general the results in the current study indicate that the female:male sex ratio is lower in farm two compared to farm one and is also lower in treatments one and three irrespective of farm. This may be the result of various factors such as, greater production of female progeny or lower female mortality.

The average sex ratio throughout the year indicates a slight tendency toward females, being 1.65:1 and 1.51:1 female:male for farms one and two respectively. This ratio can increase during the summer population explosions to values of 7.67:1, female:male. Overmeer (1972) states that with increasing matings the proportion of females in a generation will increase. The proportion of males to females is determined by genetics more than environmental factors (Helle and Pijnacker, 1985), although the latter can modulate the former.

The first egg of some mites are male determined (Helle and Pijnacker, 1985) furthermore, the physiology and morphology of both sperm and

ovary is such that some oocytes are not fertilized (Helle and Pijnacker, 1985). Sex determining mechanisms such as these may explain the biased sex ratios during the summer months. During the summer months female mites are dispersing to form new colonies. The first eggs of dispersing females will usually produce male progeny. These males mate with other female progeny. As the colony size increases the number of successful matings increase. With increased matings the number of females produced will increase also.

Increasing the proportion of female mites indefinitely will eventually result in a female being unmated, since by chance these will not encounter males. When this occurs male progeny will again be produced. This process of male producing parthogenesis (arrhenotoky) may explain the female biased sex ratios present in the false spider mite populations during periods of rapid growth (Helle and Pijnacker, 1985).

4.7 Soil Moisture:

The importance of soil moisture when planting the pineapple crop cannot be emphasised enough. The ability of the soil to hold a certain level of moisture is termed the field capacity. The structure of the soil determines this value to a large extent. Tightly packed soils such as clays are not capable of holding as much moisture as loams. The structure of the soil can be improved by the addition of high organic loads. Pineapples are a relatively hardy plant and can establish themselves in most soil types. Despite a high degree of tolerance, young pineapple crowns establish best in soils that have an adequate level of moisture.

The moisture content within the soil has the ability to affect its properties; being sticky when wet or powdery when dry. The ideal soil moisture level for pineapples is that which allows the soil to fall in and around the stem as it is planted. Therefore the soil can not be too wet or it will not fall into the leaf axils and lower stem. If the soil is too wet when the crown is planted it will form a 'cup' in which the crown sits as the soil dries out. The latter does not allow stimulation of the root primordia and also reduces their success in penetrating the soil.

Alternatively, if the soil is too dry it will adequately cover the base, but the lack of moisture will not stimulate root growth. If crowns are planted in adverse conditions and seasonal precipitation does not follow then false

spider mite damage can cause extreme plant set-back. The false spider mites, which prosper in hot dry conditions, develop high population densities that cause severe stunting. The problem is further exacerbated when seasonal rain follows and promotes conditions that are conducive to the growth of bacterial and fungal plant pathogens in wounds produced by the feeding of the false spider mite.

Crowns that are planted in early summer are likely to sustain mite damage if seasonal rains are delayed. This results from two factors, increased false spider mite densities and feeding, and extremely high ground temperatures surrounding unestablished plants.

Those crowns that are planted in late summer are more likely to encounter post planting seasonal rains. These summer rains not only help reduce mite numbers but also initiate good root growth and plant establishment.

Soil moisture levels for each farm were recorded from January 1990 until March 1991 to compare differences between farms and treatments. The soil moisture were taken as an indicator of the overall variation which exists across the Yeppoon region. The soil moistures are shown in (Figs. 29 to 32). From these results it can be said that the treatments, including the reduced fertilizer treatment, produced no measurable differences to the soil moisture. It was suggested that the reduced fertilizer would produce a smaller leaf area which would allow increased radiation to reach the soils, resulting in increased evaporative losses. The loss of moisture was suggested to cause plant stress and would be reflected in the increased mite densities. Although false spider mite populations were higher in this treatment it was not due to soil moisture levels, as there were no significant differences between the treatments.

The differences in soil moistures between farms was shown to be significant. Soil moistures were lower in the southern regions than they were in the northern regions. Primarily this was considered to be a result of the differences in the soil types. The northern farm (farm one) had higher soil moisture as soil consisted of a rich red loam. Lower soil moistures existed on the southern farm (farm three) as the soil is primarily a decomposed granite and clay mixture. Higher false spider mite densities on farm three resulted from the initially high mite numbers at planting and to the inherently lower soil moistures year round. The

false spider mite problem on this farm became so severe and the crop so retarded that it was omitted from most analyses.

4.8 The Effect of Rainfall.

4.8.1 General Rainfall Patterns:

Seasonal rainfall for the period March 1989 to March 1991 was obtained from the Meteorological Department, Rockhampton. To examine the correlation of Meteorological Departments records to the field data, observations were sorted into three week blocks. The data were averaged over these three-week blocks. The basis for this was to enable a more accurate assessment of the effects of the rainfall during that period. It was argued that averaging over a six week block would 'smooth out' the effects that variation in daily rainfall causes on the false spider mite population.

Several noteworthy trends occurred over the two year research period. Within the first twelve months of the crop cycle, pineapple plants were subjected to rainfall in each three week block, but the rainfall was not excessively high. Maximum rainfall reached eight millimetres per day, with the lowest fall being around 0.5 millimetres per day (over the three week block). During the summer of 1990 a different trend was evident with rainfall being compressed into a three month period and the highest fall was approximately 22 millimetres over the three week block. In early summer 1991, at the end of the crop cycle the rainfall was comparatively low but mid-summer rainfall was consistently higher at eight millimetres per day over the 12 week block. Despite the high level of winter rain in the first year, there is a general seasonal trend for high levels of late summer rainfall, with lower winter rainfall.

4.8.2 Effects on the False Spider Mite Population:

The total mite numbers in this study show a negative correlation in relation to rainfall, but the significance is low. The highest mite numbers occurred when precipitation was lowest and diminished rapidly when rainfall approaches an average of eight millimetres per day, although there is considerable variation. The correlation for the three-week block compared to the six-week block was significantly higher, with an adjusted coefficient of determination of 0.0027 for the overall population using the

three week block data. This value is far too low to consider the use of rainfall alone as a predictive measure. Prior to this study there was postulated to be a negative relationship between rainfall and false spider mite numbers (Carter, 1967; Various farmers, Pers. Comm.). The highest false spider mite numbers did occur when rainfall is lowest and do fall dramatically after rainfall began. The correlation between total mite numbers and rainfall was not statistically significant for either the six-week block or three-week block data.

Due to the small and variable nature of the false spider mite populations an alternative analysis was undertaken using only data from the warmer months when populations were larger and less variable. The adjusted coefficient of determination was then 0.3115. This was better, but still not considered to be a sufficiently reliable estimator for predictive analysis. It is believed that the correlation is low because the period between samples was too great. To improve the predictive model it would be necessary to sample population numbers at intervals of perhaps one week.

One interesting point is that outlier populations exist when rainfall approaches an average of 24 millimetres per day. These outlier populations are suggested to be those populations that are situated within leaf axils that, being protected by higher leaves, did not bridge over with water. The presence of residual populations are highly significant to the ecology of D. floridanus. These outliers pass through unseasonal weather and later establish new populations. In analysing these outlier populations they are shown to consist primarily of female false spider mites.

The high rainfall level not only has potential dislodging capabilities but can also bridge the leaf axil. Due to the leaf arrangement within the pineapple plant, heavy rainfall would not have a substantial physical impact on the mites that inhabit the lower leaves. Bridging the leaf axil isolates the mites from the immediate environment thereby preventing gaseous exchange leading to asphyxiation. In the early part of the century the common practise was to store pineapple plant material upright to allow for the accumulation of water within the plant heart (Schmidt, 1941). This was reported to cause a marked decrease in the number of false spider mites inhabiting the plant material, (Schmidt, 1942).

It is not known whether mite death is attributable to the presence of water alone or other factors associated with the leaf axil. It is not the highest volume of precipitation *per se* that is important, rather, small but consistent quantities have been shown to have a far greater impact (Putman, 1970). The number of days in which rainfall was recorded was correlated with mite numbers. The literature suggests that it is the consistency of rainfall that is important rather than the maximum absolute amount (Putman, 1970). In the present study there was no significant correlation between the number of days rainfall and false spider mite numbers.

Constant precipitation that would maintain moisture or water in the leaf axil for a substantial period time would prove beneficial to pineapples. It would be advantageous if the freshly planted crowns were lightly irrigated when seasonal rains did not follow the planting. The irrigation would allow faster plant establishment maintaining a reduced mite population. If rainfall was to occur in winter, then the combined effects of precipitation and low temperatures may be more effective in the reduction of the mite populations. It is interesting to note that crops that are periodically irrigated show marked decreases in the level of mite presence (Putman, 1970). Therefore if irrigation was proven to be economically feasible it would not only benefit the pineapple crop but also reduce false spider mite levels. These two factors alone would enhance the crops health resulting in superior yields.

4.8.3 Effects on the Adult Mites:

As the adults mites are highly motile it is suggested that the females disperse and establish new colonies in favourable environments. Whether these false spider mites are able to survive an average daily rainfall of 24 millimetres per day by chance or by an inherent feature within their ecology is unknown.

It is shown that in most mites the external cuticle is highly convoluted and in some cases has extra projections (Alberti and Crooker, 1985). These convolutions are believed to increase the surface area to volume ratio greatly (Boudreaux, 1958). This increased ratio allows moisture to be lost from the body surface with efficiency and metabolic energy is not consumed in concentrating and expelling excess moisture (Pritchard and Baker, 1952; Boudreaux, 1958). The convoluted cuticle is advantageous to

the false spider mite because it accentuates the concentration of soluble components from the cellular cytoplasm on which it feeds.

The disadvantage of this mechanism to the false spider mite is that where the relative humidity drops and the mites are not feeding then they are in danger of dehydration. If the mites are feeding during periods of low relative humidity and ambient temperatures are high, then the mites have a potential to attain nutrients efficiently and develop extremely rapidly. This has been demonstrated in research where developmental rates are far greater during periods of high temperatures and low humidity (Ferro and Chapman, 1979; Perring *et. al.*, 1984a,b). This feature seems to be constant for the majority of the mite species, including, Oligonchus pratensis (Banks); T. urticae (Koch) and T. telarius. Therefore the correlation between mite numbers and rainfall (albeit low) has a known physiological basis.

Although female false spider mites are motile and can avoid water within the leaf axil, they too would be indirectly affected by rainfall. High, consistent rainfall would cause the relative humidity to increase. Even if water doesn't lodge in the axil, the surrounding air will have such high relative humidity that feeding would be inhibited. As noted before all mites require the loss of moisture from the body surface to facilitate feeding (Boudreaux, 1958). The effects on the female mites will be reflected in the whole population as egg production diminishes. If the body moisture is not lost, feeding effectiveness within the females will be suppressed and egg production diminished (Boudreaux, 1958).

Female mites in general are capable of producing more than one egg per day (Crooker, 1985). D. floridanus is rather large in comparison to other mites and also produces relatively large eggs; up to one third of the female body size. The energy requirement to produce such large eggs suggests that the maximum egg production would not exceed more than two per female per day.

4.8.4 Effects on the Non-motile Stages:

Numerous mite species produce silken canopies under which they live. The details are too exhaustive to mention here but see for example, Gerson (1979). Unless mites are able to produce a protective canopy (eg. silk) over their colony, they have little protection from being dislodged, by

events such as rainfall or wind. The silken webs protect the egg and diapause stages occupying highly exposed leaves and also enable the adults to attain buoyancy during aerial dispersal (Fleschner *et. al.*, 1956; Gerson, 1979).

D. floridanus within the pineapple leaf axils, are enclosed deep within an extremely narrow space, and do not produce silk for their protection. The eggs are not actually tied down with silken strands as are the eggs from the families Bdellidae, Camerobiidae and Cheyletidae (Gerson, 1985). It was noticed that the egg become bonded to the substrate after they have been deposited. Other eggs that come into contact with them eventually become permanently bound together. The chemical compound responsible for attaching the egg to the substrate is unknown, but is believed to be a waxy material (Gerson, 1985). It would appear likely that the non-motile stages of the false spider mite (that is, diapausing individuals or eggs) are more at risk than the mobile stages. These non-motile stages are unable to avoid being trapped within the leaf axil.

The eggs of some mite species studied by Herne (1968) are resistant to and are able to be immersed in water for lengthy periods without harmful effects. The majority of mite species studied have eggs that are permanently sealed from the external environment (Putman, 1970). The embryos are only exposed to the outside atmosphere for a few hours prior to their hatching (Dittrich, 1971); possibly for their exoskeleton to harden and to allow eggs to hatch more effectively. It is this stage that can be adversely affected by factors such as high humidities or precipitation. Therefore in terms of false spider mite control it is more advantageous to have a constant level of precipitation over a long period rather than a few heavy rain events.

Although Waite (1990) states that the false spider mite life cycle (egg to egg) is in the order of ten days, preliminary observations in the current study suggest that the mite life cycle is approximately 20 to 30 days at 25 C under laboratory conditions. It is not known whether the false spider mite eggs are able to survive immersion. As noted before the false spider mite favours hot dry climates in which it readily accomplishes all life processes. Periods of rainfall or high humidity are not conducive for population growth. If farmers can modify these conditions in field crops control may be effected, but further research is required.

4.9 The Effects of Temperature.

4.9.1 An Overview of Response to Temperature:

As in all ectotherms, the rate of physiological processes is determined by ambient temperatures. Mite population dynamics are therefore influenced by ambient temperature. Mite populations are highly dependent on the ambient temperatures to be maintained within their physiological range. Mites occupy those geographic areas in which the environmental conditions rarely exceed the range of their critical tolerances. (Nickel, 1960). Where resources are available within an environment that does not possess an optimum climate, mites employ various seasonal adaptations which enables them to overcome unfavourable environmental conditions. Mites that inhabit areas possessing adverse seasons are able to tolerate temperature extremes by hibernation or aestivating. Saunders (1982) has described hibernation and aestivation as a state of dormancy (diapause or quiescence) which occurs in the winter or summer months respectively. These processes ensure the survival of mite populations through unfavourable seasons (Veerman, 1985).

Within the false spider mite colonies on pineapples, the mite populations were known to have survived unfavourable seasons (eg. minimal winter temperatures of 2.7 C. Colonies were also recorded with individuals which were presumed to be diapausing. Irrespective of the farm location across the Yeppoon district and the treatments applied to the crop, the false spider mite population was shown to fluctuate seasonally. Casual observations by farmers during the previous seasons had indicated high summer and low winter populations. Mite numbers recorded over the last half of the 1989 summer through to the summer of 1991 followed a similar pattern. The number of false spider mites were high in both summer periods. The mean temperatures were approximating 28 C. Low seasonal populations have occurred in the winters of 1989 and 1990. Populations during this time have reached very low numbers with a minimum of one individual, from an individual cohort per leaf. These extremely low mite numbers present no threat to the plant health during this period. This period of low mite numbers is probably beneficial to the plant as it allows time to recover from summer mite damage.

The lowest winter temperatures averaged 17 °C, but overnight minimums were recorded as low as 2.7 °C. Correlations of total mite numbers against average daily temperatures for the three weeks prior to the sample date have produced positive correlations (Table 9). The adjusted coefficients of determination were 0.1147 and 0.1098 for the mean maximum and minimum temperatures respectively. These low values indicate that variations in the average daily temperatures are not solely responsible for the alterations to the false spider mite population. During winter the false spider mite numbers were not only extremely low but were extremely variable. Correlations were performed with data from samples taken during high mite infestations alone. The adjusted coefficient of determination were 0.0810 and 0.2083 for the respective maximum and minimum temperatures recorded during high false spider mite infestations. The correlation between minimum temperatures and false spider mite numbers produces a stronger relationship. From this it is inferred that minimum temperatures have a greater effect on the life cycle of the false spider mite than maximum temperatures.

Due to the low coefficient of determination in the correlation analysis it is suggested that other factors other than temperature alone are contributing to the alteration of mite numbers. Other environmental factor that may be of importance include relative humidity and plant nutritional status. Helle (1962) demonstrated the importance of maintaining a high relative humidity to ensure survival through a diapause state. It was shown that *T. urticae* could survive a diapause stage at -2 °C for eight months provided it was not allowed to desiccate (Veerman, 1985). In this situation it was shown that, the higher the relative humidity, the longer the time period a diapause state could be maintained.

4.9.2 Response to Adverse Temperatures:

The process of overwintering can be achieved where adult mites actively go into winter but produce diapausing eggs (Gutierrez and Helle, 1985). This process is relatively hazardous as decreases in ambient temperature, may result in high mite mortality (Cranham, 1971). Overwintering can also be achieved through the use of a diapause stage within the members of the adult cohort (Veerman, 1985). Helle and Sabelis (1985) state that mites induced to overwinter, feed very little prior to their entering the

diapause state. When mites enter diapause, their bodily processes are dramatically reduced and their susceptibility to low winter temperatures is reduced (McEnroe, 1961). Two possible strategies are employed in overwintering. Within a mite population some members will continue life activities when entering into winter. Within this population females respond by producing a diapause egg. This allows a population temporal dispersion should conditions destroy all active mites. The second strategy occurs when all mites in the population specifically enter diapause in response to changes in environmental conditions (Van Houten, 1989; McEnroe and Dronka, 1971; Overmeer *et. al.*, 1989). Mites actively seek out protective microhabitats within the plant on which they feed (and elsewhere) (Gutierrez and Helle, 1985). These microhabitats usually take the form of a protective space within soil, roots, bark and dormant leaf buds (Veerman, 1985; Williams, 1987). It is generally argued that the female diapause, rather than the egg diapause is more advantageous to the population survival. It is further considered that after reactivation, adult females have a greater survival potential and an increased ability to disperse when compared to the newly emerged larvae (Gutierrez and Helle, 1985).

In the current study, false spider mite numbers dramatically decrease at means temperature below 17 C, but residual populations still remain at temperatures of 9 C. In mites generally, large temperature reductions are not necessarily fatal but, the developmental and ovipositional rates are reduced (Perring *et. al.*, 1984a,b). While freezing is fatal for all stages of mites, they are able to tolerate temperatures below 0 C in a supercooled state (Veerman, 1985). The diapause state enables the mites a greater degree of success in overwintering than supercooled individuals (Veerman, 1985).

The low overwintering populations of D. floridanus were mainly composed of females. This conforms with other studies which have also found overwintering populations within protective microhabitats composed of females (Gutierrez and Helle, 1985). Helle and Sabelis (1985) have shown that females that are entering a diapause state are inseminated prior to entering the diapause.

Examination of overwintering D. floridanus did not reveal their reproductive status. It is not known whether the females present within

the pineapples during winter are gravid or inseminated. However, it is suggested that these female false spider mites are responsible for the establishment of the next seasonal generation. It is hypothesized that the pineapple plant requires temperature to be approximately 28 C for the initiation of flowering (Sinclair, 1989). This corresponds to a high degree of nutrient remobilization within the plant tissues (Bartholomew, 1989). Mites that are able to access this remobilized nutrient supply, are considered to be able to increase their ability to grow and reproduce. False spider mite numbers increase, and peak when average daily temperatures are above 28 C.

Mite numbers tend to decrease after the average daily temperatures reach 33 C or more. There were many days 1989/1990 in which temperature fluctuated above this level, with the maximum for the summer of 1990 reaching 44 C. In this situation the temperature within the leaf axil and stem at ground level can be up to 5 C lower than the air temperatures.

Temperatures recorded within the plant heart during midday reached 32 C. Laboratory observations show that this can be lethal to false spider mites that are not feeding. Although the mites are reliant on higher temperature regimes for population growth they are influenced to a greater degree by winter temperature as indicated by the higher coefficient of determination.

4.10 Mite Presence in Soil:

Mites inhabit numerous environments. Within each environment there are many microenvironments that can be occupied. Mites that inhabit plant material have potential access to an enormous array of microhabitats (Williams, 1987; O'Dowd and Wilson, 1989). Nevertheless many mites are restricted to certain regions of the plant anatomy as a result of particular biological and physical factors. Biological factors that may influence mite distribution within a plant include, presence or absence of domatia, presence or absence of leaf hairs and cuticle thickness (Buchanan, 1976; Williams, 1987; O'Dowd and Wilson, 1989). In general the physical factors of the microclimate within the microhabitat will also influence the distribution and life processes of the mites.

4.10.1 The False Spider Mite:

D. floridanus is known to inhabit those geographical regions that possess hot dry climates and its distribution in subaerial (soil) environments has not previously been considered in detail (Pritchard and Baker, 1952; Jeppson *et. al.*, 1975). Soil samples taken from beside the root system had false spider mites present in 80 % of samples. The mites were rarely present in large numbers in comparison to those found on the leaf, but none-the-less are a significant component of the life system.

It has been suggested that at certain times of the year, mites are not able to tolerate temperatures within the leaf axil. Laboratory studies have shown that when D. floridanus does not feed during high temperatures and is likely to die from desiccation. To avoid the summer temperature extremes the mite may migrate down the stem. The subterranean portions of the pineapple plant stem originated from the base of the crown when it was first planted. The basal leaves when placed at ground level or below die off. These leaves tend not to rot in dry weather, rather they dry out and form protective scales. It is at the basal region of the young crown that root primordia exist, which in contact with the soil, grow into the main root system. It has been shown that during high infestations, the false spider mites direct their feeding activities towards these young root primordia, Carter (1967).

Intensive feeding on the root primordia severely extends the establishment time of the plant up to six weeks in moderate cases (Schmidt, 1941). Consequently this results in the uneven establishment of the crop. In other situations the crop can be so severely affected that the pineapples never set root. These plants eventually dry out in hot weather which leads to crop failure, (personal observations).

The base of the pineapple stem, despite being underground, could theoretically support a population of false spider mites. This niche would have a relatively stable temperature in comparison to the air temperature. Humidity would also be relatively stable and the area would provide the necessary requirements to satisfy their haptotropic disposition.

The false spider mite has a very specific niche within the leaf axil. One could then ask what is the need for the mite to occupy this subterranean niche.

It is suggested that the mite populations that occupy this niche are better able to survive winter extremes. Winter diapause of mites usually occurs in protected regions of the plant. As noted earlier these positions are under the bark of the plant stem or in this situation along the subterranean portions of the plant stem (Veerman, 1985). Depending on the structure of the soil the false spider mites may survive better in time of light rain by being under ground rather than in the leaf axil. Even the lightest precipitation, such as dew may cause water to lay in the leaf axil and cause asphyxiation. Maintaining a population in all portions of the plant spreads the risk of a population decimation due to extremes in abiotic and biotic factors (Veerman, 1985), although the concept of group selection has largely been discredited. During late summer, 1990 an unseasonal daily maximum air temperature of 45 C was recorded. During extremes such as these it may be beneficial for the false spider mites to occupy an area within the plant structure that was more in their optimum range (17 to 28 C). As mentioned previously if false spider mites are not feeding during these high temperature it can prove lethal. Therefore the subterranean portions of the stem and root primordia provide a secondary niche for the survival of the false spider mite.

4.10.2 The Predatory Mite:

Two other major groups of mites were present in the soil samples; the oribatids and the predatory mesostigmata. The oribatids are presumably feeding on the decaying leaf tissue and associated fungi. The predatory mesostigmata were observed feeding on the false spider mite whilst in the leaf axil and it is assumed that the predatory mite feeds on both species when occupying the subterranean portions of the plant.

Although found within the leaf axil while the crowns were in storage, the predatory mite A. benjamini never develop a large field population in the crowns after planting. This suggests that the predatory mites' environmental requirements are different to those found within the leaf axil. These requirements could be higher humidity levels, lower temperatures, decreased light intensity or a combination of all factors. Fleschner (1950) has shown that the predatory mite C. californica is constrained in an environment by its phototropic and geotropic responses. This mite is shown to be negatively phototropic and positively geotropic. The prey on which it feeds has the opposite tropism. The mites are thus

partially restricted to two dissimilar environments. At night, one tropic response was 'disengaged' enabling the predatory mite to override the remaining tropism; allowing it to migrate upwards. This enabled the mite to actively seek out its prey in the non-preferred site.

It is likely that constraints such as tropisms or unsuitable humidity exist in the pineapple plant while in the field. Light intensity would be decreased and humidities raised while the crowns are in storage bins. This would allow the predatory mite to develop extensive populations. Increased humidity and low light intensities also exist in the subterranean portions of the stem. These factors in combination with a positive geotropism may explain why the predatory mite distribution is more extensive in the subterranean stem portions. This is an area that requires further research should the predatory mite be considered for biological control agents.

4.11 Mite Movements.

4.11.1 Mite Transport in Crowns:

Planting material used to establish another pineapple crop is obtained by three methods as outline in Appendix three. The main type of planting material is obtained from the newly developed fruit crowns. Mites that migrate into or are inhabiting these crowns are ensured physical and temporal dispersion within the pineapple crops. The transport of infected planting material from one block to another, one farm to another and one region to another is probably the primary means by which false spider mites are able to establish or re-establish themselves within extremely short time periods on often clean plots. It is a common procedure (often economically favourable) to obtain planting material from various external sources.

Anecdotal evidence suggested that the appearance of mites on the new crowns takes place within a short period of time and this has been quantified in the present study. It is suggested that there exists a critical period in which D. floridanus migrate from the parent plant to the crown in response to environmental cues. Migratory response is believed to be elicited in response to environmental cues and enables mites to colonize new resources (Kennedy and Smitley, 1985). Presumably dispersion has the effect of prolonging the supply of food available to the established

colony. Moreover the false spider mites are able to exploit fully the available colonization sites within and between host plants. This process eliminates the possibility of population extinction resulting from induced or naturally occurring biotic and abiotic factors.

4.11.2 Migration into New Crowns:

To examine when and how the false spider mites migrate into the new planting material, the trials outlined in section 2.11 were implemented. Potential planting material was taken from the parent plant prior to fruit maturation and observed for the presence of mites. At the flowering stage the false spider mites had not infested either crowns or slips.

Young pineapple fruit take up to 16 weeks to mature. Therefore, one would consider that there is ample time for migrating individuals to develop a population within the new crown. It is evident that maturing crowns on infested adult plants always have a well established mite population.

Immature crowns emerging from the adult plant heart in November 1990, were dissected and scored for the presence or absence of false spider mites. All new fruit and crowns at this early stage showed no signs of infestation by mites, although numerous mealy bugs, Dysmicoccus brevipes (Cockerell) existed on the base of the crown and new fruit. Mites in general rely on certain environmental cues that initiate a migrating response (McEnroe and Dronka, 1971; Kennedy and Smitley, 1985). Various cues elicit a response and they are correlated to various aspects such as plant physiology, host quality, limited space, humidity changes and variations in the length of the photoperiod (McEnroe and Dronka, 1971; Kennedy and Smitley, 1985). The pineapple plant undergoes various physiological changes during the formation and maturation of the new fruit (Bartholomew, 1989). The remobilized carbohydrates and sugars are believed to nourish the developing fruit. This nourishment is believed to be further supplemented when the developing crown has matured and is actively photosynthesizing. It has been shown that new fruits that have reduced crowns sometimes do not produce quality fruit, (YFG and LPA members, Pers. Comm.).

The pineapple plant only flowers at maturity under natural situations (Bartholomew, 1989). Therefore it is hypothesized that the level of

nutrients within the parent plant are at a maximum prior to the flower initiation. During the plant maturation process, the mite populations are able to increase. At this point in time, the physiology within the plant is considered to be relatively stable. Upon the induction of flowering small changes in the plant nutritional status will occur. It is suggested that the mite relies on detecting several of these parameters to initiate dispersal. The feeding mites will detect this change. This detected change in combination with stimuli provided by increased colony densities may elicit a migratory response. Plants are known to be more receptive to flower induction under stress (eg as a result of dry weather) (Bartholomew, 1989). Suski and Naegele (1966) have shown that mites are stimulated to enter a dispersal mode under low relative humidities.

Therefore in summary mites may be stimulated into migrating when the plants physiology changes during flower induction. Flower induction and mite migrations may also be initiated under dry seasonal weather. Suski and Naegele (1966) have shown that mites are positively phototactic when dispersal is initiated. They also noted that the mites moved upwards concentrating on the peripheries of their host plant. This may explain the sudden appearance of false spider mite colonies within crowns of mature fruit. The degree in which the above mentioned factors combine, may explain why, mite infestations within the crowns are high at some times of the year and at others they are not.

Insecticide control studies performed by C. Scott, (Golden Circle Cannery) suggests that the false spider mite is present within the plant crown while it is within the parent plant. Therefore as the young inflorescence and crown are emerging from within the plants heart, the mites simply 'ride up' with the new plant. The trials, described in section 2.11, were used to determine if the mites literally 'ride up' with the emerging crown, migrate *en masse* as a result of environmental cues or are transported by vectors.

In November 1990 young pineapple crowns that were observed prior to their physical isolation from the parent plant had approximately 20 % with false spider mite colonies on them. The plants that had been isolated until fruit pick and dissected for the presence of mites were found to have mite colonies within 80 % of the crowns. During these dissections the population sizes were noted to be no more than five to ten individuals including eggs. These populations were considered to be relatively new

and too large to have developed from an initial colonizer during the early development of the crown and fruit.

This suggests that several false spider mites are responsible for the formation of the new colonies. The probability of one or more dispersing individuals from a single colony landing on a suitable host and colonizing it depends on several factors. The successful establishment of a new colony is related to both the abundance and distribution of suitable hosts within their dispersal range and the number of disperses (Kennedy and Smitley, 1985).

It is suggested that the false spider mites enter the new crowns by dislodging from neighbouring plants whose leaf tips can be above the developing fruit and crown of a neighbouring plants. Wind dispersal can also be a major consideration in the dispersal of mites as it is employed by many mite species (Fleschner *et. al.*, 1956; Kennedy and Smitley, 1985).

Slips are easily colonized as they originate from eyes along the parent plant stem (see Appendix three). The slips' basal leaves are in close association with those infested with the false spider mite and would be relatively easy to infest, even with the limited degree of mobility displayed by the mite. It would be advantageous for the D. floridanus to employ various strategies of dispersal. If the mites were reliant on one vector alone then their potential for dispersal would be severely limited should the population of vectors be reduced by biotic or abiotic factor/s.

4.11.3 Vector Dispersal:

Other alternatives could be via some vector that itself is associated with the pineapple plant. Butani (1975) classified the false spider mite as being a parasite of scale insects, however the false spider mite is solely phytophagous. This prompts thought into why the mite has been described as being associated with various scale insects. It is possible that the false spider mites are using these relatively large scale insect as a means of phoretic dispersal. The mealy bugs are rather mobile and capable of spreading throughout crops in short intervals of time (Various pineapple farmers, Pers. Comm.). Personal observations on the mealy bug have shown large populations to exist within two regions on the developing pineapple. The main location is at the base of the fruit within the folds of the bracts. The other moderately infested region is around the

basal leaves of the crown. Thus, if the mealy bug is located within the regions cohabited by the mites, then it is possible for phoresis to occur; be it active or passive. This may provide a mechanism for the false spider mites to establish themselves within the new crowns in relatively short time intervals. Most crowns dissected had both mealy bugs and false spider mites present. If this relationship is valid it may also provide an insight into how the false spider mites are able to disperse so quickly throughout those plants that have been 'sterilised' as described in (Elder, 1989).

4.12 Volunteers as a Cause of Re-Infestations:

In the pineapple industry "volunteers" are known as those plants that are self establishing. High levels of volunteer material can establish within the pineapple bays from the plant stems of the previous crop. Should the bay be inadequately cultivated, then the number of volunteers in the following crop will be high. All plant components such as, crowns, slips, suckers and old stems are capable of self establishment. The conditions needed for self establishment do not appear to be critical. Volunteers can establish in hostile areas such as roadways between pineapple bays. In general the volunteers are inferior plants and rarely reach maturity. The volunteers are very stunted and show obvious signs of nutrient stress, characterised by yellowing and leaf tip browning (Broadley, 1990).

It has often been suggested by industry members, that volunteers are a means by which the false spider mites re-enter a crop. Spraying along headlands and roadways reduces the grasses and weeds that could be used by the false spider mite as alternative hosts. Some species of the same genus are known to inhabit grasses (Crocker *et. al.*, 1981), but due to the absence of grasses in pineapple fields there are no alternative hosts for D. floridanus. Mites were found to be present within 90 % of volunteer pineapple plants during relatively high mite infestations. Despite widespread infestations, the number of mites or colonies per plant are generally low.

In order to totally eliminate false spider mites from a crop it is necessary for the planting material to be sterilized and the planting bay be free of all infested volunteer material. Although fumigation trials on plant material produced favourable results it would not be economical to treat broad

expanses of land. The best option to minimize infestations from volunteers would be to keep the number small by adequate cultivation.

Volunteer material that had not long been self established was assessed for the presence of mite. These volunteers, were selected from within numerous volunteers which had survived as a result of good seasonal rainfall. At this early stage thirty percent of the plants had become infested with false spider mites. It is likely that the percentage of infestation would increase with time. Mite presence was based on observation of dissected volunteer material and unless the mite colonies were composed of more than several individuals, their presence is not always detected. Therefore, mite colonies that were on the leaf bases or on the plant stem would not always be detected until a sizable colony had established, thereby producing an underestimate.

D. floridanus has the same effect on the volunteer plants as they do on the normal cultivated plants. The populations that inhabit these volunteers have the potential to become large and more uniformly spread along the plant axis. It has been shown that mites in unstable habitats tend to disperse, thereby increasing the survival chances of the mite colony (Kennedy and Smitley, 1985). False spider mite densities within volunteers are known to reach levels that cause severe stress and contribute significantly to the eventual death of the plant material. Limiting or degrading resources and increased population densities can initiate migration (Kennedy and Smitley, 1985). In situations where high mite numbers exist within volunteers, various cues would probably initiate a response to migrate. As volunteers often become established within the immediate vicinity of cultivated plants then migration to these plants may be possible using one or more of the means outlined in the literature (Fleschner *et. al.*, 1956; Boykin and Campbell, 1984; Kennedy and Smitley, 1985).

Although fumigation trials have been shown to be effective in eliminating false spider mites from the planting stock, it is known that the plants regain normal populations of mites by the following season (Elder, 1988). The reoccurrence of mites in the crop after fumigation indicates that the mites enter the crop by means other than on the original plant material. Due to the close association of volunteers with newly planted crowns it would be unreasonable to not consider volunteers as a means of false

spider mite transmission. In general increased hygiene practices to eliminate infected plant material from crop sites controls dispersion and population outbreaks (Kennedy and Smitley, 1985). It is suggested that the false spider mites do not rely on this process as a sole means of ensuring survival between cultivated crops. Rather it is considered to be simply another niche occupied by the false spider mites, from which normal periodic dispersal occurs. The use of volunteers as an alternative niche is considered to be consistent throughout the year. The mites are not specifically using volunteers as a temporary host which enables inter-crop dispersion. Therefore it would be beneficial to ensure that the majority of the volunteers within fallow paddocks be destroyed.

5.0 Conclusion.

Prior to this research project little was known about the biology of the false spider mite, D. floridanus, and the information that was available was largely anecdotal. The lack of information about the false spider mites' biology made it difficult to instigate control practices.

This study focussed mainly on field populations on pineapples growing in Central Queensland. The false spider mite population was shown to be highly seasonal. Populations were low and variable in winter but rapidly expanded in spring. Summer populations were high and more evenly distributed. Correlations with temperature and rainfall were positive and negative, respectively, but the coefficients of determination were small. The data did not permit further analysis, however further research is warranted. The false spider mite distribution within and between plants during relatively low densities was extremely variable. During higher densities in the warmer months the variability between and within plants was markedly reduced.

The predatory mite A. benjamini and the fungal pathogen Hirsutella sp. were both found during the study but were never present in sufficient numbers to control D. floridanus populations. The low population densities of A. benjamini appear not to be the result of insecticide inhibition, so it seems probable that other aspects of its' abiotic environment are suboptimal. The fungus is believed to be ineffective due to the array of fungicides used to maintain the pineapple crop's health, however this is unproven.

The sampling, extraction and counting protocols developed enabled adequate data collection but is labour intensive. Analysis of the population as a whole and of individual cohorts produced similar results. Therefore future field based ecological research may concentrate on assessing whole populations rather than individual cohorts. Although this would be adequate for field based studies, analysis of cohort composition during laboratory assessment may prove beneficial. There is still a need to investigate further the life history of D. floridanus in relation to temperature, humidities and soil moistures.

Of those parameters that were investigated, rainfall was shown to have the greatest influence with high or consistent rainfalls depressing the population. There is a need for further study so that more complex models including factors such as humidity, photoperiod and plant nutritional status can be investigated.

The routine insecticide regime was shown to reduce false spider mite densities significantly (particularly in immature stages) but not to the level that D. floridanus was no longer considered a pest. Insecticide applications during the autumn and winter months are not warranted as population densities do not pose a threat to the plant health. Insecticides should be applied during late spring and summer months for the most efficacious control of mites. The false spider mite life cycle could probably be disrupted at its most vulnerable stage, just as populations are expanding and females are moving into new leaves and crowns. Due to constraints imposed by the morphology of the pineapple plant and the microhabitat of D. floridanus, contact insecticides are less likely to be effective than systemic insecticides. Decreases in the plant nutritional status also caused population reductions, through effects on the immature stages.

Mite populations expand rapidly in tops stored in bins and damage can be minimized by avoiding long storage periods prior to planting. Mite damage to plants decreases, and survival rate increases if crowns are planted in late summer rather than early summer. Soil moisture is a critical component in successful plant establishment and general health during this period. Increased establishment rates and plant health resulting from adequate soil moisture suppresses the effects of false spider mite feeding and damage. Although older established plants suffer seasonal increases in mite infestations they do not suffer to the extent that young crowns do.

The false spider mites ability to disperse within and between pineapples, between paddocks, between farms and farming regions is mainly achieved by physical dispersion of crowns for planting. Volunteers provide mites with an intra-crop host on which residual populations are maintained. These populations are able to reinfest newly planted crops. Dispersal on planting material enables transportation between farms and farming communities.

The false spider mites life cycle can probably be controlled by disrupting the dispersal phase. The mites are known to disperse from heavily infected plants into newly formed crowns. Dispersal on planting material can be suppressed by insecticide application between flowering and fruit maturation. The insecticide regime reduces the level of colonization in new crowns. Uninfected or partially infected crowns do not suffer the damaging effects of feeding mites and have increased establishment rates.

The false spider mite was found to be associated with the subterranean portions of the pineapple plant. The predatory mite A. benjamini was proportionally more prevalent in the subterranean microenvironment surrounding the plant stem. By contrast D. floridanus was more prevalent in the leaf axils than the predatory mite.

Many aspects of the biology of the mite were revealed and many more unanswered problems arose. The future direction of research needs to establish an increased data base on the false spider mites responses to seasonal weather influences. There exists an urgent need for the thorough investigation and documentation of the mites life cycle to develop life tables. Laboratory work to investigate the role of environmental factors and toxicology is essential. The laboratory assessment of the pathogenic fungus as an acaricide and biological control with predatory mites is warranted. With increasing public demands for insecticide free products these avenues should not be overlooked. These projects are an immediate necessity for the development and implementation of an Integrated Pest Management program.

5.1 List of Papers Presented:

Poli, R. and Newby R., 1990. The Population Dynamics and Biology of Dolichotetranychus floridanus, a Pest of Pineapples in Central Queensland., The Ecological Society of Australia., Biennial Symposium., University of Melbourne.

Poli, R. and Newby R., 1991. The Population Dynamics and Biology of Dolichotetranychus floridanus, a Pest of Pineapples in Central Queensland. C.O.D., Pineapple Industry Farm Committee., Pineapple Field Day., Beerwah, Queensland, Australia.

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Appendix One.

A Description of the False Spider Mite:

Introduction:

Mites (Acarina) exist in a bewildering variety of habitats: on plants, in rotting humus, in soil, on birds and animals, both inside and out. They came into special prominence as agricultural pests when DDT came into widespread use (Jones and Parrella, 1984). Many pests were controlled but mites increased in number and some species, hardly recognized up to that time as pests became a serious problem (Huffaker, *et. al.*, 1970).

Phytophagous species of mite feed on the bark of plants in the floral heads, under leaf sheaths of grasses, and the most specialized members of the family form plant galls within which they feed. Most species of mites in the family Tenuipalpidae are not considered to be of economic importance, either because their hosts are not economically important plants or their populations remain below economically injurious levels.

Mites of pineapples have received little attention but have occasionally been recorded as being pests responsible for damage in varying degrees both through direct feeding injuries and through their potentialities as vectors of disease. The state of information available at the present time is incomplete, since preliminary surveys have shown that there may be more species involved than had been previously hypothesized (Carter 1967). These species may be entirely new with nothing whatsoever being known of either their potentialities as pests or their habitats. Of the recorded species there are but a few that have been capable of inflicting damage to the plant. The false spider mite D. floridanus, has recently emerged as a significant pest. The mites are particularly prevalent in drier areas, building up populations of alarming proportions which merits the employment of control measures.

Mite Description:

Adults:

Members of the family Tenuipalpidae to which Dolichotetranychus floridanus belongs are commonly known as false spider mites (Jeppson *et. al.*, 1957; Pritchard and Baker, 1958). D. floridanus is very small; the adult measures about 300 um in length and approximately one third as wide. The false spider mite is usually bright orange in colour. The body of each sex is characteristically shaped: that of the female is somewhat oval and that of the male is markedly pointed posteriorly, (Fig. 1)

The length of the male body is 253 um, (300 um including rostrum) greatest body width is 120 um. Length of the female body is 300 um (including rostrum 366 um) greatest width of the body 130 um, (Fig. 2).

The family Tenuipalpidae, described by Berlese (1913) in a private publication, has long been neglected as a family of economic importance (Jeppson *et. al.*, 1975). The group has been known by several names: Trichadenidae, Pseudoleptidae and now Tenuipalpidae.

The genus differs from Tetranychus the common spider mites in structure, but it is closely allied in habits, forming colonies on leaves. The body is elongate and usually more or less constricted in the middle; the legs are short and stout, scarcely as long as the width of the body.

Knowledge of the biology and control of the Tenuipalpidae or false spider mites is fragmentary. Some investigators, however, have made important contributions concerning those species important to agricultural and horticultural crops.

Juveniles:

Juvenile mites are split into two groups based on size. The size difference between the deuteronymph and protonymph can only be distinguished via measurements taken under microscopy. Visible size difference are apparent when conspecifics are aligned and viewed simultaneously. For the purpose of this study the juveniles are classified into one group (stage 2) for convenience in counting. The juveniles are morphologically identical to the adults, they too exhibit sexual dimorphism, with the male having a highly pointed posterior abdomen. At this age the juvenile false spider mites are coloured bright orange and are quite motile. At this age they are actively feeding on the plant tissues. Individuals have been observed in a dormant stage presumably a diapause. This diapause event is not carried out simultaneously with other members of its cohort. Thus it is assumed that the juveniles enter diapause and ecdysis as a result of reaching maturity, in terms of development or sexuality and not as a response to environmental cues. In addition winter conditions are believed to initiate a diapause irrespective of the level of maturation. This statement is based on observations where a high percentage of mites was seen to be diapausing in those samples collected during the winter months. The diapausing individual is identified in two ways, depending on whether they are preserved or living. In living specimens the individuals are not motile and do not react to prodding. The diapausing individuals also lack the intense colouration of the parents. If the preserved sample is fresh the diapausing mites can be discerned although there is considerable uncertainty. Diapausing individual have the first two sets of legs positioned forward and close together, while the last two sets point immediately backwards and close together. Those false spider mites that are not diapausing and are preserved have their legs spaced in a somewhat radial arrangement.

Larva:

The larvae for the purpose of study were recorded as stage 1 while counting samples. The larvae are approximately one third the size of the adult false spider mites. Being morphological similar although not identical to the adults they to exhibit sexual dimorphism. With the male having a highly pointed posterior abdomen. At this age the juvenile false spider mites are not as intensely coloured, some are even without pigmentation. The larval stages are somewhat restricted in their motility as a result of their morphology. The larval false spider mites only possess three pairs of legs. They possess at hatching the front two sets and only the anterior one of the second set. The fourth set of legs are present after diapause and ecdysis. In the juvenile stage their motility is at it greatest. The fourth pair of legs enable the mite to push more from behind, than from the side. In adults, mobility is decreased somewhat due to their larger size. This size increase physically impairs its' movement as a result of less contact between the legs and leaf surface.

The larval stage, is assumed not to be actively feeding on the plant tissues. This assumption is based on observations where juveniles that were assumed to be feeding where prodded. The response to move was quicker than in the adults and juveniles while feeding. It is assumed that the adults and juveniles take more time to respond as they have to extract their rostrum first before they can move. Similarly, feeding mites appear to have a characteristic posture when feeding, as if they were 'standing on their heads'. Presumably this position enables deeper penetration with their rostrum and stylets, making food attainment more effective. The larval stages were not observed in this position.

Further to this point the colouration obtained by the mites is a result of the food on which it feeds (Alberti and Crooker, 1985). Given that the larval mite is very pale (almost translucent) it may not feed relying instead on embryological yolk supplies. Some larvae have been observed with partial or blotchy colouration which is thought to be as a result of the nutrients supplied through the embryological yolk.

Larval mites are known to go into a diapause which is not carried out simultaneously with other members of its cohort. Thus it is assumed that the larva enter diapause and ecdysis for reasons similar to that of the juvenile.

Eggs:

The female false spider mites produce eggs which are laid in close association with each other and to the colony. The eggs are only superficially oval. Rather, they are on close observation more cylindrical with hemispherical ends. The size of the eggs are approximately 1/3 that of the female false spider mite. The eggs have the same characteristic red colouration as that of the adult false spider mite. Given that the larval mites are not coloured this indicates that the egg case is pigmented. The characteristic colouration of the mites does not usually occur prior to the juvenile stage. Prior to hatching two red to black eye-spots are noticed to correspond to the head region. As these mites have these eye-spots present throughout their life they are assumed to be of some functional significance, possibly a light receptor. The development of these spots is indicative of the imminent emergence. The spots have been observed to be present in eggs up to 3 days prior to hatching in laboratory situations see Appendix four.

As mentioned previously, the eggs are usually laid in close association to each other. As the false spider mite is known not to produce silk, it relies on alternative means to secure the egg to the leaf surface. Within this species the eggs are bonded onto the leaf surface. It is presumed that the eggs are coated with some compound which on contact with the air dries and bonds the eggs to any contacting surface. Thus it is not unusual to find several eggs not only bound to the leaf but to each other.

Distribution:

Geographical:

D. floridanus is only found on pineapples. The mite is known to occur in Florida, Cuba, Puerto Rico, Panama, Honduras, Mexico, Central America, Hawaii, Philippine Islands, Japan, Okinawa and Java, Africa and more recently in Australia. Within Australia the mite was first described in Kandanga, southeast Queensland, when farmers became aware of the

necrotic lesions that were affecting the basal portion of the leaves within their crop. Since being first described the mite has been recorded to occupy all areas along the east coast that produce pineapples. To date the most severe outbreak was recorded at Yeppoon, in Central Queensland (Fig. 5).

Experience in South Africa indicates that these mites prefer hot dry climates. It is therefore possible that they may only be a problem during very hot dry summers such as those that occurred within Queensland during 1983 and 1989.

Within the Plant:

The false spider mites are slow moving and usually feed on plant leaves, most commonly on the lower surfaces near the mid ribs or veins. They occur in very large numbers in the narrow space between the bottom part of the leaf and the plant stem feeding on the sclerotic leaf base. The mites have also been found colonizing the lower leaves of the crowns, the fruit itself and the root system. Similarly false spider mite colonies have been found occupying sclerotic leaf tissue within suckers and slips. The mites have also been found to colonize plant tissues around subterranean portions of the stem and roots.

In the locations in where they flourish, between the bases of the tightly imbricated leaves, all stages are found: eggs, larvae, and adults. Though they are almost microscopic in size their presence is indicated by their reddish colouration contrasting on the white tender tissues of the leaf and by the brownish colour which forms on the leaf as a result of their feeding activities.

This false spider mite is a gregarious species and large colonies usually develop over much of the sclerotic leaf tissue. This mite can build up large populations at any stage of plant development, and it is always present during the winter months. In severely infested crowns colonies have been recorded to cover the complete width of the leaf base. Within these colonies mite numbers can approach 50 individuals. Moderate populations usually develop among the basal leaves of the crown. Heavy infestations further develops on crowns detached and stored for planting over along time. *D. floridanus* is best adapted to relatively hot, dry climates and for this reason it is generally more abundant on pineapple plants in the areas which accommodate this climate than in the other regions.

The Effect of the Mites:

A number of plants were collected during the research period, and the effects of false spider mite injury determined. In addition observations were noted from farmers that have observed the devastation within their own fields. During the examination of individual plants, leaves were stripped off successively from the outside toward the centre. As is the case with most severely affected plants the outer leaves were dead. In plants taken from storage bins, more leaves were dead and completely brown at their bases but devoid of living mites. Inside of this layer the successive leaves were observed with large brown lesions on both adaxial and abaxial leaf surfaces. It is a characteristic of the mites that when feeding they do so at the advancing edge of the lesions. Infested leaves can continued approximately 2/3 of the way towards the centre of the plant. The lesions within these inner leaves become gradually smaller towards the centre.

The injury caused by feeding itself appears to be insignificant. The danger exists when the injury produced allows an entrance for bacteria and fungi, which cause the buds to rot (Sanches and Zem, 1978; Pritchard and Baker, 1985).

Plants of all ages may be infested but it is the young plants which are most seriously damaged or killed. This is exemplified when comparisons are made of similar aged crops that are shown in (Fig. 16). The false spider mite is a most serious pest only on young plants, usually those crowns that are freshly planted.

If the plants are not killed by heavy infestations and associated pathogenic organisms, fruit yield is believed to be reduced. Infested leaf bases become progressively discoloured, necrotic and have a brown dehydrated appearance. Asymmetrical crowns, that is with more growth on one side than on the other, were found to be heavily infested on the side with the least growth (Lear, P., Pers. Comm.). If the mites were responsible, however, they probably had disturbed crown growth at a very early stage in its' development.

An unusual effect of the false spider mite feeding has been recorded: the swellings induced by the mite feeding sometimes, but not always, developed green spotting or greening along the edge of the feeding lesion but only after the chlorophyll develops after exposure to light. These areas are then said to form dimples within the leaf surface as the leaf matures. This series of events could be interpreted as a toxic effect on the immature chloroplasts, or purely a result of the structural damage caused by probing rostrum and stylets

After the initial feeding these raised tissues scar, die and finally dry out. If the drying is severe then the wound cracks. This phenomenon allows the entrance of various plant pathogens as would the process of feeding itself. Similarly those sunken areas of tissue on which the mite feeds also follow the same process to form darkened necrotic blotches. At this stage the 'rot' pathogens have invaded the tissue and eventually kill the leaf on which it is on.

Previous Methods of Crown Storage and Mite Elimination:

It is more than likely that for any case of suspected mite damage, the problem is to learn at what stage the mites are important and what conditions are necessary to permit the mite to develop injurious populations. Control measures currently consist of applying a broad range insecticides to the plants, depending on rain and dew to carry insecticides down into the depths of the leaf axils.

In Hawaii, insecticide trials have shown that the spraying of established plants have not resulted in satisfactory mite control (Schmidt, 1941, 1942). Good control of the false spider mite was achieved with the same insecticides before planting. The problem that exists with trial and error type of insecticide applications are numerous. Inherent in these activities is the potential to destroy beneficial non-target species. Similarly unnecessary spraying may appear to rid the pest, but concurrently enabling a resistance to develop.

In the early part of the century control of the false spider mite on planting material was considered a relatively simple matter, if the planting material is stored butt down rather than butts up (Schmidt 1941). The

reasoning to substantiate these practices is that it allows water to remain in the hearts when the plants are subjected to the occasional shower. Under these condition the mites are said to essentially disappear as it is an organism of drier environments. This would enable the young plant to establish quickly avoiding the stress induced by mite activities.

Previous reports on the progress of a control method for the Florida red mite on planting material have indicated that again placing plants on wire racks, butt down, resulted in a marked diminution of mite numbers. The preliminary report was based on simple observation alone (Schmidt, 1942).

Sulphur appears to be the most effective lethal agent, applied as either a fine dust or in combination with liquid lime-sulphur (Schmidt 1942). It was thought that fumigation would prove effective but this method, which appeared to be particularly well adapted to the treatment of slips, suckers and tops intended for planting, has proved unreliable, costly and can be potentially dangerous to the operator (Elder, 1988).

In present field practice, however, planting material is seldom stored for a long time. Consequently the incidence of severe damage appears to be rather diminished. If a protective measure is needed in the future, several miticides, already being evaluated, can be used as part of an integrated pest management program.

Appendix Two.

The Treatments Used in the Yeppoon Field Trials:

The insecticide treatment used in the Yeppoon district was based on the product "Rogor"® whose active constituent is 300g/L dimethoate. The program consisted of several sprays applications during the season.

The program was:

- Spray 1: Initial.
- Spray 2: 7 days post initial.
- Spray 3: 14 days post initial.
- Spray 3: 21 days post initial.

This spray application program was applied when insecticide application were normally applied. The treatments that comprised a reduced fertilizer and insecticide application were prevented from receiving the products when normally applied to the remaining crop. The current list of chemicals used within the pineapple crop and those awaiting approval are listed below. The chemical is mentioned initially followed by a listing of the forms it is available in.

Herbicides:

Pineapples:

Ametryn: Flowable Primatol Z
 Viking Herbicide.

Bromacil: Bromacil 800 wp.
 Hyvar X Herbicide.

Bromacil + Diuron: Krovar Herbicide.

Diuron: Diurex 500 Flocol.
 Diurex 80.
 Diurex 900 wg.
 Diuron 500 sc.
 Diuron 80.
 Diuron 80 wp.
 Diuron 800.
 Diuron 800 wp.
 Diuron BL.
 Diuron Flo.
 Diuron Liquid.
 Flowable Diuron.
 Farmex Weedkiller.

Fluazifop-p: Fusilade 212.
Fluometuron: Fluometuron.

Insecticides:

Pineapple Plants and Planting Material:

Diazinon:	Diazinon 800.
	Gesapon 800.
Methyl Bromide:	awaiting board approval.
	Agrigas M.
Metaldehyde:	Defender Pellets.
	Defender Powder.

Pineapples:

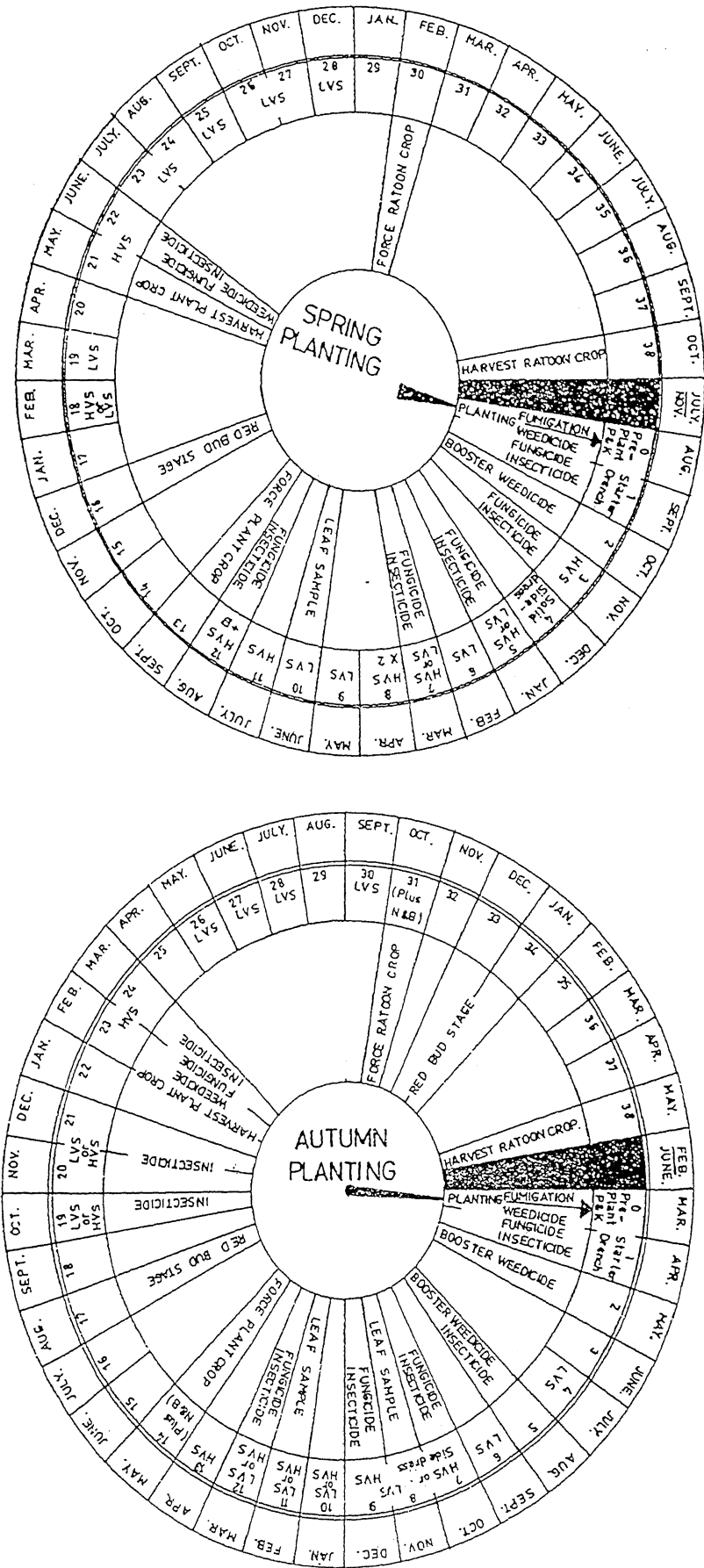
EDB:	EDB 210.
Chlorpyrifos:	Chlorfos.
	Lorsban 500 ec.
	Suscon Blue.
Diazinon:	Diazinon 800.
	Gesapon 800.
Endosulfan:	awaiting board approval.
Lindane:	awaiting board approval.
	Lindane 20.
Fenaminosulf:	Le San dx.
Fenamiphos:	awaiting board approval.
Fosetyl-aluminium:	Aliette.
Metalaxyl:	Ridomil 250 ec.
Sulphur:	awaiting board approval.

Fungicides:

Benomyl:	Benlate.
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The general crop cycle in the pineapple industry is best summarized in (Fig. 35). Depending on when the crop was planted the cycle varies little from these protocols.

Fig. 35 Standard pineapple crop cycle for the spring and autumn plantings.



Appendix Three.

The Pineapple Plant:

The following description of the pineapple is a brief summary of the chapter outlined in (Broadley, 1990).

The cultivated pineapple, Ananas comosus (Family Bromeliaceae) grows to a height at maturity of 0.6 to 1.2m depending on the variety and the conditions under which it is grown. It has a dense shallow root system, arising from the base of the stem and concentrated mainly in the upper 150mm of soil.

The fruit is a compound structure, having a number of fruitlets or 'eyes', each of which is formed from a single flower. The fruit arises from the apex of the stem at the centre of the plant. Only one fruit is produced from each plant crop plant or ratoon sucker. The fruit stalk runs through the fruit as the core, and ends in a cluster of small leaves constituting the 'top' or 'crown'.

In vigorous plant crop plants, offshoots usually known as 'slips' arise from the fruit stalk as fruit matures. Each has a small pinelet at its base. A slip will not produce fruit while attached to the parent plant.

Another type of offshoot, the 'sucker' arises in a leaf axil of the stem. Suckers on a plant crop produce the first ratoon. The number of suckers per plant depends on the clone type and plant vigour.

The Crop Cycle:

In Yeppoon the pineapple plant will start to form a fruit 8 to 15 months after planting. The time taken depends largely on the size and type of planting material used and the growing conditions. The fruit is harvested 7 to 9 months after it starts to grow. The first ratoon crop may be harvested 12 months after the plant crop but usually it takes 15 to 18 months. The plant and first ratoon crops normally make up one cycle on a commercial plantation. The cycle take 3 to 4 years to complete.

In the tropical areas of Queensland, where summer and winter temperatures are higher and there is a longer growing period each year, fruit is usually harvested within 18 to 20 months post planting. Under these conditions, the complete crop cycle occupies a shorter period and the summer harvesting peak is more pronounced than in Southeastern Queensland.

Production Districts:

Practically the whole of the Australian pineapple crop is produced in Queensland on normally frost-free land along the coastal region. Pineapples are grown from Brisbane to Cairns for the fresh fruit markets but production for processing is concentrated in Brisbane to Nambour, Gympie-Mary Valley, Maryborough, Bundaberg and Yeppoon districts. Nearly Three quarters of the crop is grown between Brisbane and Gympie.

The area under pineapple in Queensland is now fairly constant at around 6000 hectares. Production is about 125 000 tonnes each year. Of this total some 110 000 tonnes is processed. The annual gross value is approximately \$12 000 000. Of this Yeppoon contributes 10 000 tonnes for processing and 5 000 tonnes for the fresh fruit market.

Varieties:

The cultivated varieties of the pineapple may be classified into three major groups: The Cayenne, the Queen and the Spanish. The Smooth Cayenne is by far the most important group being principal fresh fruit and canning variety. Varieties of the Queen group are grown to a lesser extent, and exclusively for the fresh fruit markets. Spanish group pineapple are not grown in Australia.

Smooth Cayenne:

The smooth Cayenne plant is typically stocky and robust, with tapering, fleshy leaves up to 1m long and 60 mm wide. The leaf margins are smooth with the exception of a few spines near the tip. The flowers are light purple in colour with bright red bracts and the number on a single spike ranges from 130 to 170.

The fruit is cylindrical in shape and weighs about 1.5 to 3 kg. The fruitlets or 'eyes' are typically broad and flat. As the fruit ripens the shell acquires a deep yellow to coppery yellow colour, which first appears at the base and progresses upwards to the shoulders. The flesh is firm, close textured and juicy, with a light yellow colour at maturity.

Origins:

The Bromeliaceae are adapted to the low rainfall and well drained soils. A. comosus is believed to have originated in South America where the Indians probably selected and grew a seedless mutation of one of the many similar species that occur in that region. Europeans have known pineapple since November 1493, when Christopher Columbus and his men discovered some growing in the West Indies.

Nearly all pineapples grown for processing throughout the world are cultivars of the Cayenne and are generally called "Smooth Cayenne" because of the relative absence of leaf spines. Smooth Cayenne has excellent yield and canning properties. The various clones available in Queensland are selections from the Smooth Cayenne variety. The rough-leaf pineapple grown in North Queensland for the fresh fruit market are from the Queen group.

Botany:

Roots: There are soil roots and axillary roots to be found on pineapple plants. Soil roots push out into the soil and may become as long as 2m. They are quite shallow, and rarely are found more than 90mm depth. They may branch. Most of the water absorption occurs near the root tip, especially through the microscopic root hairs which grow just behind the root tip. Loss of the root tips can severely affect nutrient and water uptake.

Root primordia can be found on the stem to within 1 or 2 cm of the stem apex. These arise in axils of the leaves and are therefore axillary roots.

These root primordia develop into axillary roots, usually on the lower half of the stem, they grow up to about 100mm long.

Stems:

The stem is the central support of the whole pineapple plant. If a stem is cut across it can be seen to have two zones. The larger zone is the central stele, which is surrounded by the relatively thin zone called the cortex.

The stele, and to a lesser extent the cortex, have large storage cells, storing starch. Starch storage usually increases as the plant matures and is used in sucker and slip production and most importantly by the maturing fruit, but the mechanisms for this are not clear. On the top of the stem is the apical meristem which is responsible for the production of the new stem and leaves as well as the fruit stem, fruit and crown after flower induction.

Leaves:

Leaves spiral up the stem to the left or right. The pineapple plant has a leaf phyllotaxy which in this case equals $5/13$. Leaves grow from basal meristematic tissue and so elongate from their base. The basal white tissue is the youngest. The "D" leaf is the youngest fully mature leaf and generally the longest. It is easily identified, and is used in growth and nutrient studies. The channel type construction of the pineapple leaves gives them strength, and also helps direct water into the stem and root area. Pineapples have stomata only on the underside of the leaf and number about $80/\text{mm}^2$. Trichomes partly cover the stomata, and are believed to assist the pineapple to restrict its water loss through these openings. Another system which helps pineapple survive drought is that its leaves have special water storage cells just under the upper surface of the leaf.

Peduncle:

The fruit is borne on the peduncle or fruit stalk which is an extension of the apex of the stem. The peduncle carries modified leaves, each with its own axillary bud.

Fruit:

The fruit of the pineapple is a "sorosis" is actually a fusion of more than 100 individual fruitlets. Each individual fruitlet develops from a flower with three petals. These fruits are trilocular, and each locule is separated from its neighbour by a nectary gland, which secretes nectar during flowering. These nectary glands also provide a path for the entry of disease causing organisms. Each individual fruitlet develops in succession from the bottom up to the top of the fruit. The mature fruit is 80 % water, 10-18 % sugars and 2 % acids, with the remainder being various minerals, pigments and proteins. Sugars and acids are not distributed evenly throughout the fruit. The bottom portion of the fruit has more sugars than the top, simply as a factor of older and mature fruits.

Crowns:

On top of the fruit, the crown "top" is a continuation of the apical meristem. It has a short, starch filled stem with a meristem and leaves.

It can be planted to produce another pineapple plant. Crowns are the most commonly used planting material in the pineapple industry today.

Slips and Suckers:

Suckers arise from axial buds on the stem, and slips from the axial buds on the fruit stalk and grown suckers arise from the stem below the ground. In Queensland, slips usually occur only on the plants initiated during winter time. Sucker and slips continue to grow whilst they are on the mother plant. Developing suckers exhibit and apical dominance of their own, which tends to suppress the development of further suckers. Suckers tend to be the youngest buds at the time that apical dominance is lost.

Appendix Four.

Culture of the False Spider Mite:

Introduction:

Various methods can be employed to study the detailed life cycle of mites, (Helle and Overmeer, 1985). They include a detached leaf disc culture, the rearing cell culture and rearing on the host plant. The main disadvantage with these methods is that the requirements of the mite to be studied have to be known prior to implementation. Other methods include the raising of mites on artificial diets in which various nutritional or toxilological methods can be assessed. The decision on which technique is to be implemented, is based on what was known about the mites. All methods are useful in that they enable the life table parameters to be recorded or assessed under various conditions.

Once these techniques are examined and the limitations of each is known, the most appropriate technique may be applied. Problems arise when the organism to be studied has a relationship with the host-plant that makes isolation and study extremely difficult. Although these experimental procedures were largely unsuccessful they provided some insight into the complex relationship that exists between the pineapple morphology, the microclimatic conditions within the leaf axil and the mites habits and physiology. The following report is a summary of the attempts to culture D. floridanus for the purpose of documenting its life cycle.

Methods:

Method One:

Two similar techniques were trialed: 1) plant material with established colonies was used and 2) uncolonized plant material from the region normally infested with mites was used. The plant material was lightly cleaned and a new colony (5 males, females and eggs) were positioned on the sclerotic leaf tissue.

The plant material from both 1) and 2) was isolated within a Petri-dish and observed once every 24 hours, minimizing disturbance. The Petri-dishes were place in the laboratory at 25 C with a 8/16 day/night photoperiod. The colonies were observed under a compound stereo-dissection microscope.

Method Two:

The second procedure was an extension of the first technique:

- a) Two leaves were placed in the dish to replicate the normal arrangement of leaves found within the pineapple plant.
- b) The dishes were partially sealed and held together with 'Parafilm'® enabling humidity to rise.
- c) The containers were placed in the same conditions, and covered with black plastic and were observed as previously described.

Method Three:

The third procedure employed a nutrient medium on which the mites could feed. Macerated leaf material was strained of its fibrous components to obtain a supernatant. The supernatant was used as the base of the nutrient medium. The nutrient media consisted of 30, 50 70 90, 100 % juice set into a 1 % agar matrix. The various percentages of

juice and agar were autoclaved for 21 minutes at 15psi and 121 C. To prevent the spread of fungal and bacterial pathogens Nippagen was applied to the nutrient agar matrix at the rate of 4g per litre. Half of the plates received Nippagen and substrate and the remaining half received substrate only. The latter were the controls.

A total of five female mites were placed on each plate over the various nutrient concentrations with and without Nippagen. The replicate plates were then incubated at 25 C in the manner previously described.

Method Four:

The following procedures were attempted to culture the mites using living plants. Fresh whole crowns were used for this experiment. A flexible cell position within the leaf axil to contain the mites was developed. Due to the nature and arrangement of the leaves within a pineapple crown, a method was developed which enabled the placement of the cell and daily observations. This enabled the sclerotic leaf surfaces on which the mites normally colonize and feed to be exposed for observation. Each cell was provided with a mite colony consisting of five females and eggs. The crowns received a 8/16h light/dark photoperiod at 25 C. Observations were made every 24 hours.

Additionally crowns with normal mite populations and crowns with induced mite colonies were placed into a phytotron, at 32 C, 8/16h light/dark photoperiod. Mite populations were observed as described previously

Results:

Results from Method One:

After 24 hours the detached leaf culture were observed. Under the stereo-dissection microscope the leaves were shown to have no visible colonies remaining. Some mites were positioned on the abaxial leaf surface in close contact with the base. The mites were not feeding, were wedged between the leaf and base and move when disturbed. The remaining mites were found wandering around the outer edge of the Petri-dish.

The mites eventually perished during the next two days, their shrivelled appearance suggested that the humidity within the chamber was too low. The eggs that where on the leaf material did not hatch and also shrivelled over the forthcoming days.

Results from Method Two:

The mites in these experiments were covered with a second leaf and placed under the black plastic to reduce the light intensity. The partially sealed lid allowed the humidity to rise. As the humidity increased within the chamber, condensation formed producing unfavourable conditions; 1) the humidity enabled fungal hyphae to cover the open ends of the leaf where they were detached from the stem. The hyphae entrapped some mites that wandered into the strands. Due to the limited mobility of the mites condensation droplets posed severe problems and most wandering mites perished within these droplets.

Results from Method Three:

Initial observations of the mites after 24 hours produced encouraging results. The mites had settled themselves between the agar and the dish wall. The mites failed to produce eggs throughout the term of the experiment. The plates containing Nippagen did not support the mites and death resulted within four days, possibly induced by the toxic effects of Nippagen. In those plates without Nippagen the mites survived more than four days. The fungal hyphae started to become very prominent after five days, but the mites live until the tenth day, after which the hyphae

entrapped most of the remaining mites. The result indicates that the mites were susceptible to the Nippagen, and may survive if the fungal colonies were to be controlled without affecting the mites. Fungicide that are non-toxic to mites should be investigated further.

Results from Method Four:

The cells that were positioned using silicone were problematic. The acetic acid released by the silicone sealant caused severe burning to the leaf after which it turned brown and started to deteriorate. The acetic acid present in sealant that had partially cured caused similar problems, but the effects were delayed. The use of double-sided sticky tape to make the cells proved successful.

Observations after 24 hours that the mites had not escaped and the eggs were showing no obvious signs of dehydration. The mites did not settle and failed to survive for more than ten days. During this time several mites produced eggs but it was not consistent between cells or over time. The eggs that were in these cells had a change of colour prior to hatching. The embryos were noticed to develop two dark red to black 'eye' spots on their dorsal surface about 1/3 the way along the body. These eye spots became apparent three days prior to hatching. After ten days the mites had not settled or started to feed and perished. Those larvae resulting from the eggs did not settle and died before moulting. Even if the larvae had moulted into the nymphal stage the tissue was already degenerating and would not have supported them.

Those mites subjected to 32 C in the phytotron produced significant results. Those mites that were on the naturally infested plants were able to survive in excess of 7 days, at which the experiment was terminated. Those mites within the cells, died within 24 hours and were highly shrivelled indicating that dehydration may be a major cause of death.

Discussion:

Detached leaf cultures were not considered to be a viable proposition as the technical problems associated with their usage, made trials and replicates time consuming.

The second procedure aimed to provide the mite with a protective recess in which it could settle into. It has become apparent that once the mites microhabitat is destroyed by removing a tightly imbricated leaf they fail to settle in recreations of its previous environment. The degree to which a habitat would have to be recreated for the mites to settle makes the detached leaf culture an unfeasible method to studying the mites. This is exacerbated further when the mites are exposed at least once every 24 hours for observations. Condensation on the wall of the Petri-dish was problematic for the mites. The mites limited degree of mobility caused them to perish as they failed to emerge from the droplets.

The use of artificial diets in the culturing of mite has only been achieved for one major species of mite, *T. urticae*. With the wealth of knowledge that exists on this mite, it is only recently that artificial diets have been developed which enable it to survive for more than one generation. Artificial diets are complex as some anti-fungal compounds kill the mite directly or kill symbiotic organisms essential to their digestive system. The moisture evaporating from the agar provides a high humidity that is favourable for the mites. As these mites are prone to dehydration when they are not feeding, then high humidities may protect them until they settle and resume feeding.

The use of rearing cells to control breeding mites is mentioned throughout the literature. The detached leaf procedures outlined in the literature are not practical due to the constraints imposed by the pineapple plants

morphology and the mites habits. The mites were unable to escape when placed within the cells positioned on the leaf. This cause the mites to wander at first but eventually they settle after the first 24 hours. On the first observations the mites where wedged firmly against the cell walls and the leaf surface. During the next few days some eggs were deposited but were considered to be a carry over from when the mites were in their natural environment. This was substantiated when the mites failed to produce eggs after the initial settling phase. The 'eye' spots are considered to be a reliable sign for the prediction of hatching. The development of the these 'eye' spots could signify the period in which the mite cuticle hardens and various pigments intensify in colour on exposure to the atmosphere. The eggs that where laid on the leaf surface hatched after 7-10 days. This is not considered the accurate length of time for mites to hatch as the sample size was small. Based on other developmental times for other mite species it is estimated that the life cycle of the mite would approximate 25-30 days at 25 C.

Conclusion:

It is suggested that future experimental trials be conducted using the modified crown and leaf cell. This technique allowed easy collection of results, although they were not statistically significant. This technique may be improved with the use of alternative materials and different techniques. Discerning the effects of temperature, humidity and toxicological studies requires further attention.