Studies of the distribution of the European red spider mite, *Panonychus ulmi* (Koch) (Acarina: Tetranychidae) and the apple rust mite, *Aculus schlechtendali* (Nal) (Acarina: Euriophyidae) in an Experimental glasshouse and a Commercial orchard.

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ABSTRACT

Studies of the distribution of spider mites, *Panonychus ulmi* (Koch) (Acarina: Tetranychidae) and *Aculus schlechtendali* (Nal) (Acarina: Eriophyidae) were started during the 1988 season. Several leaf ages (young, middle aged and older) and tree zones (inner and outer) were investigated. Significant differences in the distribution of mites on different leaf ages and tree positions were found in both 1988 and 1989. An experiment was conducted to investigate the movement or dispersal of spider mites from untreated branches to pesticide treated branches under controlled environment and field conditions. Significantly higher numbers of mites were found on untreated branches than treated ones in the glasshouse experiment. The numbers of mites were recorded on the treated and untreated branches in the field experiment were not significantly different. This may have been due to predation by *Typhlodromus pyri* (Schuet) (Acarina: Phytoseiidae) which were observed only on the untreated branches. Studies on spray distribution were also carried out on leaf ages and tree zones by different pressures in a commercial orchard. Significant differences were found between different tree zones and pressures but was not significantly different on leaf ages.

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Chapter 1

DISTRIBUTION OF PHYTOPHAGOUS MITES

INTRODUCTION

Apples have been an important crop for pest management studies because of the high value of the fruit and the complexity of pest problems. Many pests attack apples, these include: the Codling moth, *Cydia pomonella* (Lin), *Archips podana,* (Lepidoptera: Tortricidae); the Green apple aphid, *Aphis pomi* (De Geer), the Woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Homoptera: Aphididae), the Two spotted spider mite, *Tetranychus urticae* (Koch), the European red spider mite, *Panonychus ulmi* (Koch), (Acarina: Tetranychidae) and the Apple rust mite, *Aculus schlechtendali* (Nal) (Acarina: Eriophyidae).

Pest problems differ from place to place and a pest which is found in one locality may not be found elsewhere. Among these pests *C. pomonella* is widely distributed throughout the world in apple growing areas (Metcalf et al., 1962). The two spotted spider mite occurs on a wide range of host plants especially in warm and dry areas of the world. In New Zealand, it was found on apple trees in drier districts (Collyer, 1964). Spider mite populations also differ between well maintained orchards and neglected orchards. Strickler et al. (1987) observed that several species of spider mites including 6 phytophagous species and 18 predator species with high numbers in abandoned orchards were low in number or were absent in commercial orchards. Similarly, Robart et al. (1979) reported that *P. ulmi*, *T. urticae* and *A. schlechtendali* with high densities were the principal mite species in commercial orchards. Abandoned orchards contained many mite species in relatively low numbers. *Amblyseius fallacis* (Garman) (Acarina: Phytoseiidae) was the principal predator in commercial orchards and *Typhlodromus pomi* (Parrott) (Acarina: Phytoseiidae) were found in greatest numbers in abandoned orchards. Results of survey carried out by Kropczynsk and Tuovinen (1988) in sprayed and unsprayed apple orchards in Finland indicated that phytoseiid mites were found in 24% of the samples from sprayed orchards compared with 95% in unsprayed ones. *P. ulmi* averaged 15 mites / leaf in sprayed orchards compared with 1 mite / leaf in unsprayed ones. There are several reasons which make the spider mite an important pest (Lienk, 1969) includeding the elimination of old varieties, the removal of marginal orchards, chemical thinning, improved cultural practices, tree nutrition and change of pesticides. Tar oils used against the winter eggs of red spider mite caused increases in mite numbers in the summer due to side effects on the natural enemies of mites (Massee, 1929). Spider mite and woolly apple aphid numbers increased when DDT was introduced (Childs, 1947). Similarly, Chapman and Lienk (1950) discovered that prior to the use of DDT, two spotted spider mites were unknown. Dean (1945) did not find any serious infestations of mites when DDT was used against the codling moth and apple maggot.

In commercial apple orchards wide spectrum pesticides are sprayed to control more than one pest. These chemicals change the natural faunal balances and phytophagus mites *P. ulmi* (Koch) and *A. schlechtendali* are often the first pests to increase after these changes (Sanford and Herbert, 1970). Because of the continuous use of broad-spectrum pesticides for many years, some insects, and in particular red spider mites, have developed resistance to them. These pesticides include clorobenside, parathion, most organophasphates and some acaricides like tetradifone, and dicofol (Cranham and Helle, 1985; Pree and Wagner, 1987).

Synthetic pyrethroids, used for the control of pests such as codling moth, aphids, leaf miners and plum curculio, may kill their predator *A. fallacis* cause resurgance of *P. ulmi* and *T. urticae*, (Hall, 1979). Another reason for increased mite populations may be the use of some pesticides for long periods of time. Croft et al. (1975) and Morgan and Madsen (1979) have divided the use of pesticides into three eras i.e. the lead arsenate era, the DDT era and the OP era, spacing 10 - 30 years in each case. The OP era reflects the DDT era which was initially very effective but later failed as a result of secondary pest outbreaks and the development of resistance (Croft and Hoyt, 1978). Regular spray programmes with wide - spectrum pesticides affect both pest mites and predatory mites. If selective pesticides or selective doses are used, however, the pest may be controlled effectively with savings in insecticide cost (Headley and Hoyt, 1987). Predators will also survive and may contribute to effective pest control. Bostanian and Coulombe (1986) reported results which supported this hypothesis. By releasing organophasphate resistant predatory mites (*A. fallacis*) and by timing the pesticide applications, they reduced the cost of pesticide treatment by 34% when compared with pest control pratices used by commercial growers.

Previous investigations of mite distribution.

Successful mite management depends upon sampling and accurate estimation of mite population densities. Sampling cannot be organised without prior knowledge of the distribution of pest and predatory mites over apple trees. The distribution of mites differs from orchard to orchard and also differs between certain leaves and trees. Different sampling methods have been reported. For example, Dicker (1967) discussed the use of direct counts on leaves by microscope, the use of brushing machines and the mangling or imprint method. All these methods have advantages and disadvantages. Counting the numbers of mites directly on the leaves requires time but does permit all mite species to be identified. The brushing machine is a fast and less laborious method and one can count 90% of the mites but it is not possible to count the mites on leaf surfaces especially if the area of interest is to study the mite distribution on upper and lower leaf surfaces. The mangling or imprint method is also easy and quick, but it is difficult to differentiate between the imprint of adult mites and their eggs. Zacharda et al. (1988) used a " shake - and - wash " technique for sampling the predatory mites *Typhlodromus pyri* (Scheut) and *Amblyseius finlandicus* (Oudms) (Acarina: Phytoseiidae) and pest mites, *T. urticae, P. ulmi* and *A. schlechtendali*. Using this method, leaves, shoots and spurs are shaken or agitated in alcohol. By shaking and agitating leaves or shoots, mites are removed from leaves these are later removed from the alcohol using a separating funnel. This technique is very useful when only the mobile stages of mites are sampled. This technique, however, does not lend itself easily to the sampling of spider mite eggs.

The sampling methods described above cannot give sufficient or detailed knowledge about the distribution of mites on upper and lower leaf surfaces. They also fail to give information about the distribution of predators. A suitable sampling method should give enough information about both pest and predatory mite distribution. Little information is available about mite distribution on different leaf ages and tree positions and only a small amount of work has been reported on predator distribution. Hull et al. (1976) studied the distribution of *Stethorus punctum* (LeConte) (Coleoptera: Coccinellidae) in relation to the densities of red spider mites within an apple orchard and within individual trees. Solomon (1975 and 1982) discussed the effectiveness of mirids, *Blepharidoperus angulutus* (Fall), *Malacocoris chlorizans* (Pasnz) and Anthocorids, *Anthocoris nemorum* but did not report their distributions although (1981) the effects of windbreaks were studied as sources of pest and predatory insects and mites and the distribution and dispersal of these arthropods between orchards and windbreaks. Other predators of spider mites (Holdsworth, 1968) include *Leptothrips mali* (Fitch), *Orius insidios* (Say), *Plagiognathus politus* (Whler), *Chrysopa rufilabris* (Burmeister), *C. carnea* (Stephens) and *S. punctum.*

Gilliatt (1935) observed that in late autumn when the temperature is low, the female *P. ulmi* congregate on the upper surfaces of leaves where they remain for hours exposed to solar radiation. Baten and Hutson (1943) reported that 90 percent of the leaves counted had more mites on the lower than on the upper surface. Cagle (1946) has also reported similar results. He studied the distribution of each stage of red mite on upper and lower surfaces and found, of 607 quiescent larvae in 1944, 83.2% were on the lower surface and 16.8% on the upper; of 517 quiescent protonyphs, 83.8% were on the lower surface and 16.2% on the upper; and of 437 quiescent duetonyphs, 82.7% were on the lower surface and 17.3% on the upper. Kuenen (1949) also mentioned that mites live on the lower surfaces of leaves and only come to the upper surface when the temperature was high and bronzing occured when mites fed on the upper surface. He also collected leaves from the centre and periphery of the trees, from high and low and from long and short shoots. Chant (1959) studied the distribution of the pest mite *P. ulmi*, in sprayed orchards and the distribution of the phytoseiid predatory mites *T. pyri* and *Typhlodromus finlandicus* (Oudems) on unsprayed orchard leaf surfaces (upper and lower), and also their interleaf distribution and distribution on shoots and spurs. He found that *T. finlandicus* were uniformly distributed on the lower leaf surfaces and showed no preference for any part of the leaf; *T. pyri* were along the central ribs and large subsidiary veins and *P. ulmi* were uniformly distributed. *T. pyri* was found on few leaves in early and midsummer. Similar studies were carried out by Chant and Fleschner (1960) on citrus and avocado. Van De Vrie (1964) studied the distribution of prey and predatory mites over the leaves on annual shoots. Herbert and Butler (1973) worked on the distribution of three species of mite, *P. ulmi, A. schelechtentali* and *Zetzellia mali* (Ewing) (Acarina: Stigmaeidae) within the tree in different positions (upper and lower levels, inner and outer positions

) and in four quadrants (NW., SW., SE. and NE). They found significant differences among trees and for most species, between levels. For *P. ulmi* eggs, significant differences occured among trees and levels, when each generation was analysed separately a significant level - quardrant interaction was also found only for third generation of *P ulmi*. They also found significant differences between positions for *Z. mali* mites and its eggs, and for *A. schlechtendali* on one sampling date. Level - position interaction only for *Z. mali* was significant on two sampling dates. Similarly, Santos (1976) studied the distribution of *Z. mali* in unsprayed apple orchards. He found that 71 - 88% of *Z. mali* occured more frequently along the midrib, on the underside of the leaf, and this did not depend on the density of prey or time in the season. Its prey, *P. ulmi* and *A. schlechtendali*, occurred on both sides of the leaves. *Z. mali* were found on short branches or fruit spur growth whereas *A. schlechtendali* were found primarily at the tips of the branches containing terminal leaves. Therefore, some prey were always protected from this predator and adult *P. ulmi* were not attacked. He concluded that this predator alone could not maintain the population of prey below economic damage levels. Mowery et al (1980) studied within tree and between tree distributions of spider mites. To study mite distribution, they collected leaves from top and bottom levels and from N., S., E., and W. quadrants. Herbert and Butler (1975) also studied mite distribution and evaluated the influence of leaf cluster size and spur cluster on the distribution of *P. ulmi* in apple orchards. They found that the number of mites per cluster increased as the number of leaves per cluster increased. They also observed that *P. ulmi* tended to be distributed more evenly over the leaves in a cluster with increasing population density. At low population densities the numbers of mite per cluster was affected very little by cluster size, whereas, at higher population densities, the numbers of leaves in a cluster became important in determining which mites could inhabit that cluster. Dabrowski and Beilak (1977) studied the effects of nutrients in apple leaves on *P. ulmi*. Chemical analysis of leaves showed that young leaves contained more nitrogen and phosphorus than older leaves and that fecundity was lower on young leaves. The younger and older leaves contained similar amounts of potassium (K) but the young foliage had less manganese (Mg) and iron (Fe) than moderately old and older leaves. They concluded that the differences in these elements in young and older leaves have a direct effect on the biology of the red spider mite. Bielak (1986) studied the influence of apple leaf age on populations of *P. ulmi* and reported that on young leaves, the development of *P. ulmi* was markedly poorer than on mature (middle aged) leaves in his insectarium and orchard experiment. The population size of red mites was smaller on young leaves and female fecundity was limited. He related these findings to the nutrient content of different leaf ages. By chemical analysis of leaves he found that young leaves had a lower dry weight, contained more phosphorus and less calcium, sodium, manganese and the potassium : calcium ratio was smaller than in middle-aged leaves. Young leaves were also richer in inorganic forms of phosphorus. Post (1962) and, Van De Vrie and Boersma (1970) observed that increases in the density of red mites was related to leaf nitrogen content. Gilliatt

(1935) reported that early in the spring, the leaves at the base (older) of the current year's growth are preferred by mites. The mite counts indicated 140 adult females on older leaves and only 5 - 20 at or near the terminal growth, where the mites lay their eggs and build up their initial populations. The adults were frequently observed crawling from a leaf via petiole to adjoining foliage. Santos (1984) studied interrelated factors including leaf nutrients, soil moisture, leaf conditioning, predation and growth of the apple leaves to determine what factor(s) regulated predator - prey oscillations. He observed that prey (*P. ulmi, A. schlechtendali* and *T. urticae*) initially increased when the tree grew new leaves and that predators (*Z. mali*) also increased in numbers. The combined effect of predation and leaf conditions caused a decline in prey populations. Leaf nutrients, soil moisture and leaf conditioning affected the numbers of phytophagous mites on the trees but the overall predator-prey cycle was not affected.

P. ulmi overwinters as the egg stage and its predator *T. pyri* hibernates as adult females in the tree bark and branch crevices. Studies on the distribution of these species over leaves has been carried out by several workers but few of these have investigated the movement of *T. pyri* to and from hibernating places. Niemczyk (1964) reported that females of *T. pyri* which overwintered in protected positions on the trunk and main branches, resumed activity between bud - burst and the late green cluster stage. During this period the mites showed a marked preference for sheltered habitats and were found successively under loose bud scales and in crevices in developing fruit buds, between the floral pedicels, and in flower buds. From green cluster onwards increasing proportions were found on the undersides of leaves until, at the end of the blossom period, this became the only important habitat. McGroarty and Croft (1976) studied the distribution and movement of the predatory mite, *A. fallacis* in relation to the two spotted spider and red spider mite. They collected a six inch diameter orchard sod from the orchard floor, under the tree canopy and from the area between trees. 88.5% of the *A. fallacis* population was found under the trees. They were also found on ground-cover vegetation, grass and broad - leaved herbs. They have also related this predator population in the ground cover with populations of *P. ulmi* in the tree, observing low numbers of red mites in the tree during the early season. As the summer progressed, their numbers increased. The predators moved into the tree about the time when the red mite population began to increase and eventually limited the red mite population in late August. When the prey decreased in the tree, the predator returned to the ground cover where their numbers increased. Some pesticides such as pyrethroids have irritancy or repellency activity against spider mites which cause the spider mites to disperse. This was investigated by Penman and Chapman (1988). In their laboratory assays they observed repellent effects of pyrethroids against tetranychidae; *T. urticae* dispersed either to recolonize plants free of residues or to leave the treated habitat. Nachman (1988) mentioned that spider mites and their phytoseiid predators may avoid unfavourable local conditions either by dispersal (escape in space) or by entering diapuse (escape in time). He further explained that prey individuals may escape patches with many predators and establish new colonies on plants without predators. He termed this type of dispersal of prey and predators " hide and seek. " Similarly, Hussey and Parr (1963) worked on *T. urticae* and *Phytoseiulus persimilus* (Athias Henriot) (Acarina: Phytoseiidae) and reported that spider mites tend to depart from plants when the degree of leaf injury and predators increase.

Apple rust mite, *A. schlechtendali*, lives in the same habitat as *P. ulmi*. Although the numbers of rust mites are always higher than red mites these mites do not cause severe damage to apple trees, it serves however, as an alternate food for many predator species Herbert and Sanford (1969). Experimental work carried out by Hoying and Croft (1976) has shown that colonisation by the rust mite early in the season may affect the reproduction of *P. ulmi*. Laboratory results also supported these findings when the red mites were released onto leaves which had been fed upon by rust mites. The red mite oviposition fell when they fed on these leaves. Similar studies were carried out by Croft and Hoying (1977). Their field and laboratory experiments provided evidence that previous feeding of the rust mite population of up to 500 - 1000 / leaf and even intermediate levels within economic threshold densities, of 100 - 500 / leaf, reduced the potential of *P. ulmi* to increase on apple trees. Croft and McGoarty (1977) reported that management of this species by different pesticides provided several benefits in particular as an alternate food for *A. fallacis*. The presence of rust mite may, therefore, greatly improve the possiblities for biological control of red mites and also suppress the reproductive potential of *P. ulmi*.

Recent studies conducted in England suggest that rust mites are reaching pest status. Easterbrook and Solomon (1983) found that rust mites fed on the flower receptacle and young fruitlets from bloom to early July and they found that the epidermal cells of fruitlets were damaged leading to russet formation on the fruit. Fruit on treated clusters had less russet than untreated. They concluded that these russets were due to high numbers of rust mites feeding on fruit. Easterbrook (1984) evaluated different pesticides applied at the most suitable time, for rust mite control and their effects on *T.pyri*. He also studied the role of this predator as a natural control against rust mites. He found that the application of pesticides at the green cluster stage was the most favourable time to prevent russets caused by rust mites. Among other pesticides and acaricides, Clofentezine suppressed rust mites and had no effect on *T. pyri*. Easterbrook and Fuller (1986) reported significant correlation between the numbers of rust mites and the amount of russet on the calyx-end and cheek of apples at harvest. Their histological studies showed that feeding by mites on flower receptacles/fruitlets in May and June damaged epidermal cells, resulting in russet formation. They also found less russet on the fruits collected from trees where the rust mites were controlled by acaricide applications. Similarly, apple rust mites were also found damaging apples in Denmark, Matakowski and Schadegg (1988). Herbert (1974) also found rust mite damaging apple foliage in Canada. He observed that injury to apple foliage by this mite becomes noticeable early in July. The underside of the leaves become brown or bronzed, whereas the dorsal (upper) surface remained green. He concluded that these mites feed mainly on the ventral (lower) surface of the leaves and in heavy infestation the leaves become leathery and silvery in appearance. Based on peak numbers of eggs on 28th May, 22nd June and 10th July in the conditions of Nova Scotia he has reported that this mite has three generation . He observed that on 28th May the eggs were on the ventral surface only, whereas on 22nd June and 10th July they were generaly distributed on the dorsal and ventral surfaces.

Various methods of integrated mite management have been developed and reported. One of the most important factors in mite management is the sampling and estimation of mite populations on apple trees. The distribution of mites reported to date, have been carried out on the complete range of leaf position and physiological ages. Less work has been done on spider mite distribution on defined leaf ages (eg. young, middle aged and older) on annual shoots in different tree positions (eg. inner and outer zones of trees). The size and appearance of apple leaves are different, for example young leaves are smaller and more hairy than middle aged and older leaves. Spider mites seem to have preferances for different kinds of leaves, at different times of the year. In spring, mites colonise older leaves (Gilliatt, 1935), where their numbers increase and they move towards the tips of shoots. This could be another reason among others (eg. leaf nutrient) for different numbers of mites on different leaf ages. The present study was designed to investigate the distribution of spider mites on leaf ages on annual shoots in the inner and outer positions (position of leaf ages on annual shoots and inner/outer positions of trees are explained in the materials and methods section) of apple trees in commercial apple orchards.

The distribution of the red spider mite has been investigated by numerous scientists but the distribution or dispersal of the rust mite, *A. schlechtendali* has not been previously studied. This species serves as an alternative food for predators and also has an effect on *P. ulmi* development (Hoying and Croft, 1976) and reproduction (Croft and Hoying, 1977). Mite predator distribution on apple leaves follows red spider mite distribution and apple rust mite distribution. It is therefore important to study the distribution of both species in order to understand the system.

The red spider mite has a preferance for laying winter eggs on apple trees. The preferred site as reported by Metcalf et al. (1962) is on twigs and small branches. It also lays eggs in cracks and on roughened areas of branches rather than on smooth areas (Holdsworth, 1968), while Anonymous (1983) reported that it lays eggs on the underside of the spur and smaller branches, but to a lesser extent around the buds on young shoots.

The distribution of winter eggs on different sites is known from the above studies but the distribution is still not known on twig ages in the inner and outer positions of trees. Goonewarden and Kwolek (1975) selected a total linear length of 395.4 cm twig which included 309.5 cm new wood, 5cm bud scale scar and 80 cm old wood to determine the winter egg population of red spider mites. Th eggs were divided into two groups, coloured (viable) and colourless (nonviable) and the nodes on each twig were also numbered. The egg numbers increased as counts proceeded from new wood to old wood and a significant interaction was found between the location of eggs on the twigs and selection. When egg counts were expressed as numbers of egg / cm of the twig it was found that the bud scale scar counts increased 3 times whereas old wood and new wood counts decreased by 9 times. The terms old and new wood were used but were not defined. Similarly, in Switzerland, Zahne et al. (1985) reported the distribution of winter egg of *P. ulmi* on various age classes of wood and observed that about 40% of the eggs occurred on 2 year old wood. They proposed 2 year old wood for absolute estimation of winter eggs of red mites. The distribution of eggs in the inner and outer positions is still not known. Considering these questions, studies on the distribution of winter eggs of *P. ulmi* were started on twig ages (one and two years old and tree positions, inner and outer). Studies on the distribution of winter eggs can help in determining the egg population which will later on help in determining/predicting the mite population in spring and summer.

MATERIALS AND METHODS.

Studies of the distribution of spider mite were started in mid June, 1988. In the beginning, leaves were sampled from inner and outer positions of the trees. In order to study the distribution of mites in detail, therefore, the trees were divided into two positions, inner and outer. The leaves which were within one to two feet around the tree trunk were considered to be in the inner position and leaves on the tree periphery were in the outer position (Fig. 1). Then the leaves were divided into three age groups (young, middle aged and older) on annual shoots in both positions. The leaves which were at the base, in the middle and at the top of the shoots were considered as older, middle-aged and younger leaves, respectively (Fig. 2). Sampling of the spider mite on young and middle aged leaves has been reported by various authors but sampling of mites on these two leaf ages in different positions (eg. inner and outer) has not been reported so far. Bielak and Dabrowski (1986) also sampled middle-aged leaves but they did not record the positions of their leaves on shoots or branches. Similarly, Bielak (1986) studied the populations of *P. ulmi* on medium-aged and young leaves. He collected medium-aged leaves from the central parts of shoots and he classified young leaves as light green with smaller areas. Van De Vrie (1964) studied the distribution of prey and predatory mites on annual shoots but with slightly different aims. He numbered the leaves from 1 to 20. Leaf number 1 was at the base and leaf number 20 was at the top of the shoots. These were the oldest and youngest leaves, respectively. He found many mites on

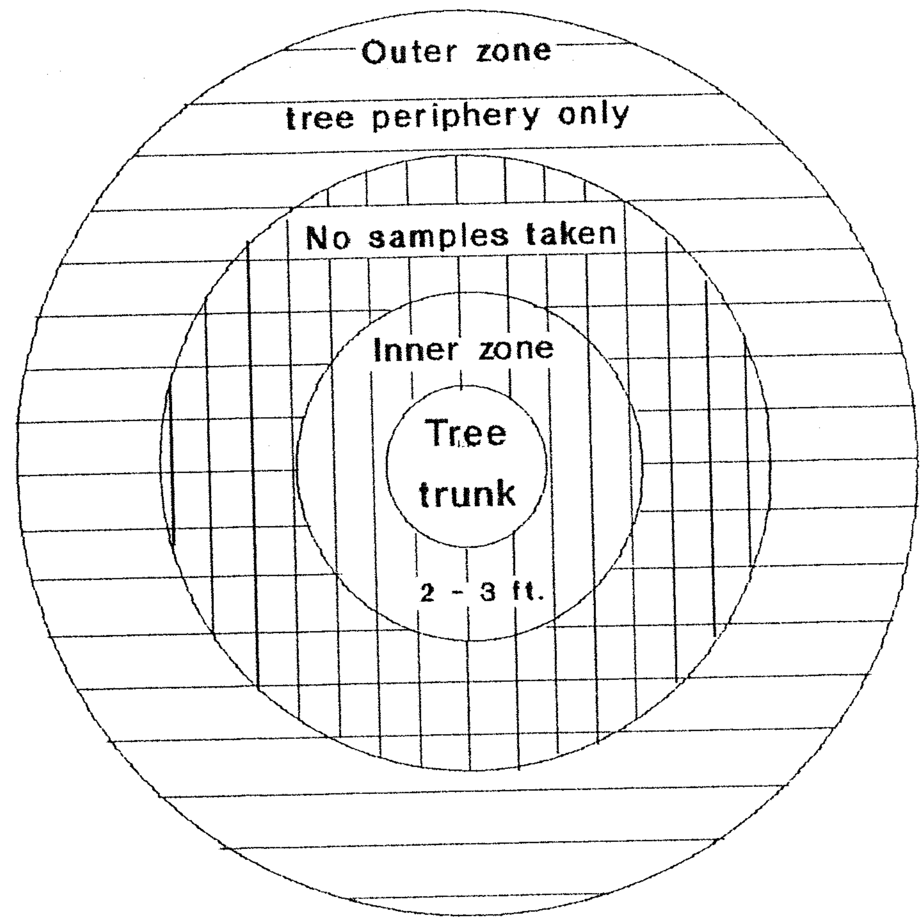


Figure 1. Different sampling zones of an apple tree.

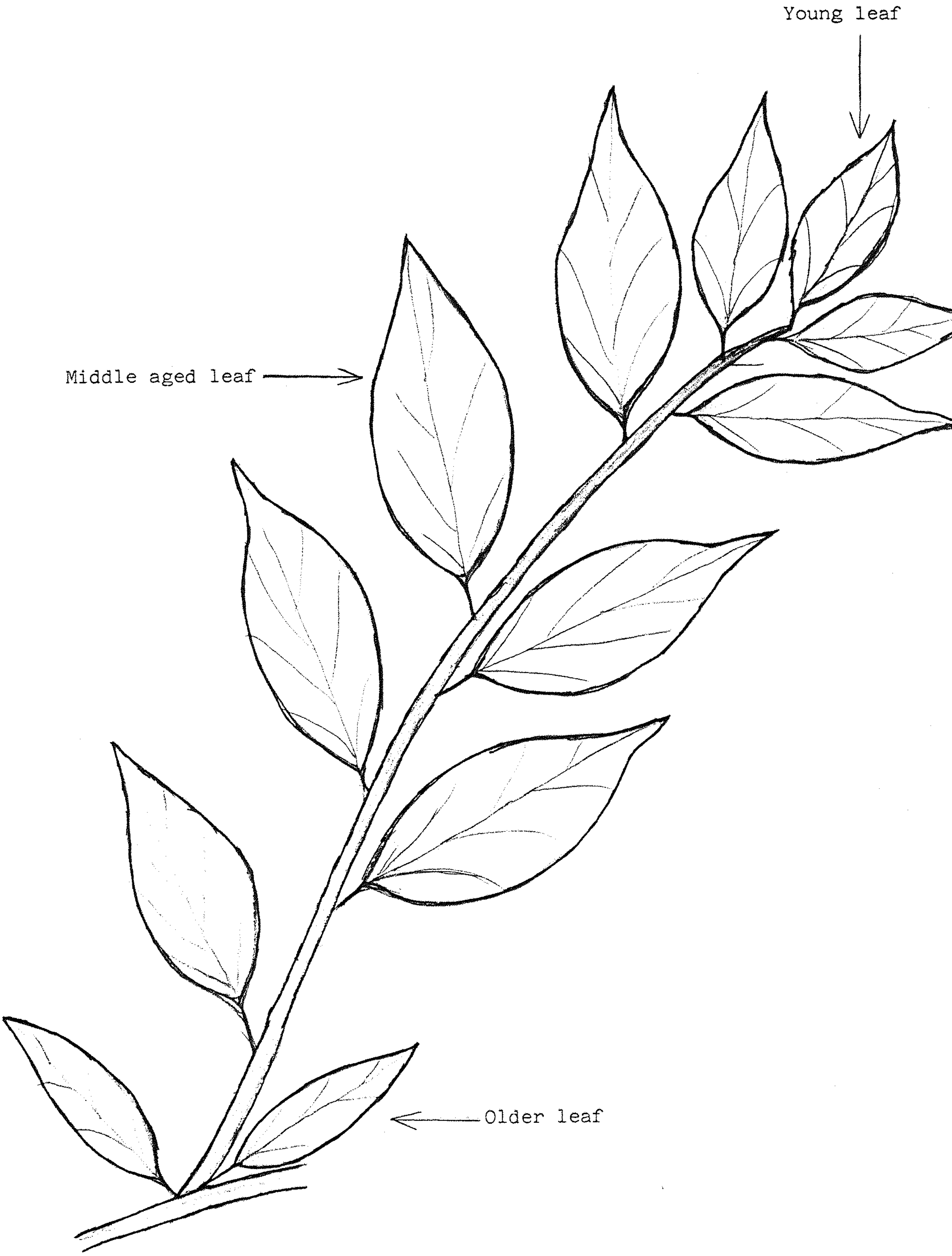


Figure 2. Different leaf ages on an annual shoot of apple.

leaves number 11 and 12 which were in the middle of the shoots and these two were equivalent to the middle aged leaves. Nyrop (1988) used two sampling techniques to quantify the numbers of *T. Pyri* and *P. ulmi* on apple trees. In his first sampling method, he collected five branch spurs from the mid-crown of each sample tree and recorded the numbers of predators and prey on each leaf and on each spur. However, the numbers of leaves per spur ranged from 5 - 13. In his second sampling procedure, he collected 20 intermediate-aged leaves, randomly from each sample tree. He was of the opinion that intermediate-aged leaves gave the best estimate of red spider mite population density.

The present study was carried out in four commercial orchards in the same locality (Leckford); four trees per orchard were sampled. Five leaves of each age from each position (inner and outer) and from each tree were collected which gave a total of 20 leaves of each age from each position and from each orchard. The reason for collecting leaves from four orchards was to find out which of these orchards had predatory mites in order to study their distribution. Unfortunately no predatory mites were found in any of these orchards. Because no predators were found in any of these orchards and the data from all orchards gave no evidence of predators and since our aim also was not to study the spider mite population/distribution in four commercial orchards in the same locality; the data of only one orchard was analysed and reported here. Large numbers of apple rust mite, *A. schlechtendali* were found. and their numbers were also counted to study their distribution.

In 1988, the leaves were initially collected at weekly intervals but later on the orchards were sampled at bi-weekly interval. The mites were counted in the laboratory under a binocular microscope. In the case of *P. ulmi*, eggs and motile stages were counted; in the case of *A. schlechtendali* only active stages were counted.

Sampling procedures during the 1989 season were slightly changed. In this year the leaves were collected only from one orchard and from two rows. Three trees from the central row and three trees from the edge of the orchard (Fig. 3, Site 2). This gave a total of six trees for this experiment. Five leaves of each age (young, middle aged and older leaves) from both zones (inner and outer) were sampled on each sampling occasion. This gave a total of 30 leaves of young, 30 leaves of middle aged and 30 older leaves from the inner and outer positions. The sampling was started on 23rd May and terminated on 22nd August. Counting procedures for the numbers of eggs and motile stages of *P. ulmi* and *A. schlechtendali* were similar to 1988.

Since the numbers of adult mites and eggs aggregated on some leaves and some leaves had no mite. To normalise the spatially aggregated data,the log(x + 1) was used to transform the data. Williams (1937), Bartlett (1947), Oakland (1953) and, Daum and Dewey (1960) have suggested that if the mean and standard deviation are proportional to each other then log(x + 1) would be a suitable transformation. The same log transformation was used for statistical analysis of all experiments carried out during 1989 season including caged/uncaged and covered/uncovered branches for field experiments.

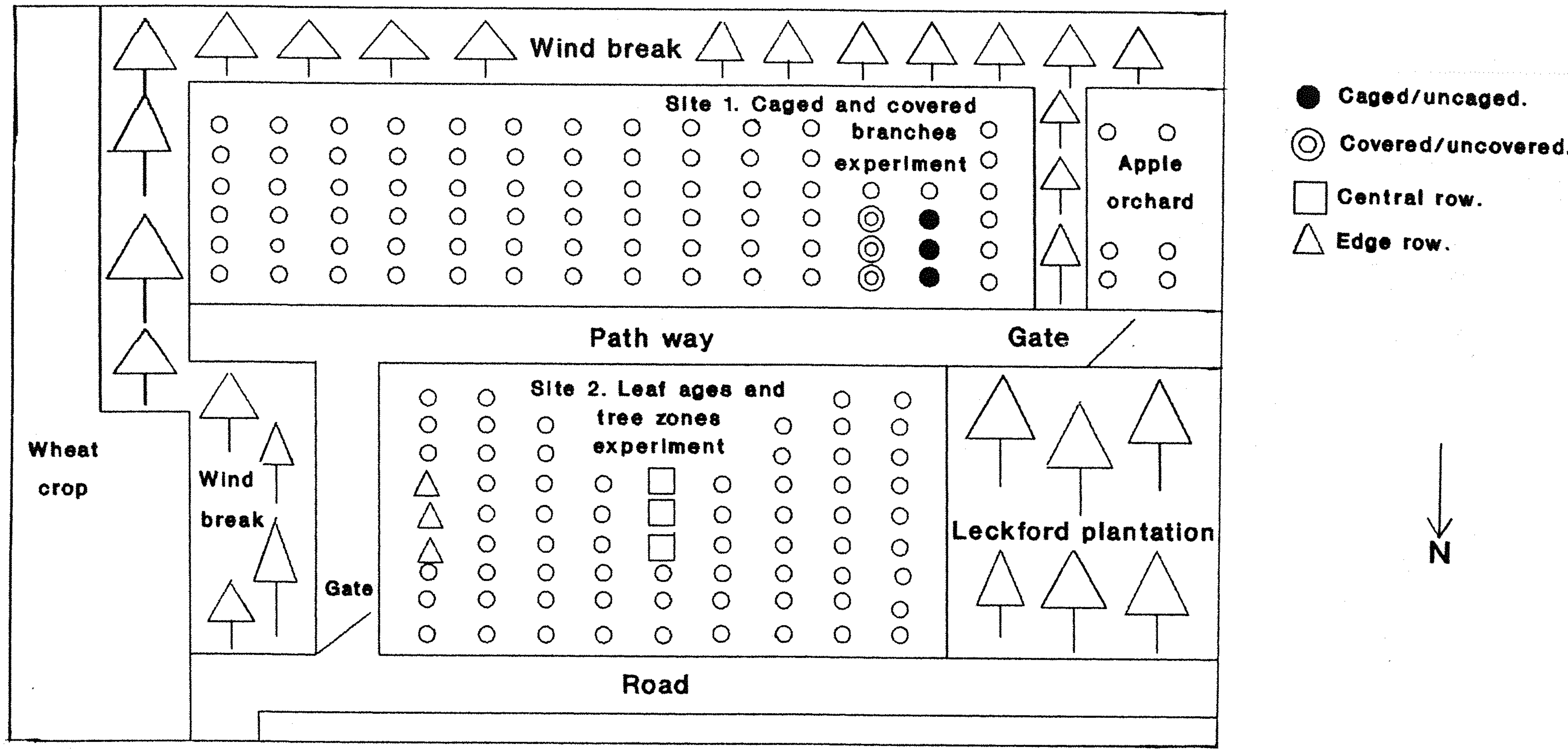


Figure 3. Experimental sites for caged/uncaged and covered/uncovered branches and, leaf ages and tree zones experiment.

Studies of the winter egg distribution were started in October, 88. The twigs were sampled on 7th and 28th October, and on 10th and 21st November from inner and outer positions of the trees. The twigs which were within 1 to 2 feet around the tree trunk were considered to be in the inner and the twigs on the tree periphery were in the outer position.

After four samplings from the inner and outer positions, a sampling procedure was designed to study the distribution of winter egg in detail. In this new method the twigs were divided into two groups, one and two year old twigs in the inner and outer positions. The twigs which were at the top of branches (above first bud scale scar) were 1 year old. The twigs below the first bud scale scar up to second bud scale scar were 2 years old. The numbers of egg present on bud scale scar between 1 year and 2 years old twigs were included in the 2 year old twigs. The twigs were collected on 9th December, 1988; and 11th and 20th January and 16th February, 1989. Two twigs of each age from each position were collected from twelve trees which made a total of twenty four twigs of each age from each position. In 1989 - 90 the sampling method was similar to 1988 and the twigs were sampled on two dates, 5th December, 1989 and 9th January, 1990.

The numbers of winter egg were also transformed to log numbers by log(x + 1) and the data was analysed using multifactor analyses of variance on log transformed numbers.

RESULTS AND DISCUSSION.

Distribution of spider mites during 1988.

Studies of the distribution of the *P. ulmi* and *A. schlechtendali* were started on 22nd July, 88; on different leaf ages and in different tree positions. Figures 4 and 6a show that the distribution of both species was different on each leaf age. The overall mean numbers of adults were higher on middle aged leaves and the numbers of eggs were at similar levels on middle aged and older leaves but were higher on younger leaves (Fig. 4). In the case of *A. schlechtendali* (Fig. 6) the overall mean numbers of mites were higher on younger leaves compared with middle aged and older leaves. When the numbers of both species were compared between positions, the overall mean numbers of both species of mites were higher in the inner position than the outer (Figs. 5 and 6). Analyses of variance for the numbers of both mites indicate significant differences ($p < 0.01$) between dates, leaf ages and positions (Tables 3 and 4, Apppendix 1). Significant ($p < 0.01$) dates X leaf age, dates X position and leaf age X position interactions are also evident.

When the log mean numbers of mites per leaf on each sampling occassion were plotted (Figs. 7 and 8), the figures show that the numbers of mites were changing between leaf ages and positions. For example, in the inner position on the first sampling day (22nd July) many adult mites were on young and middle aged leaves but on the second sampling occasion (29th July) the numbers decreased on young and

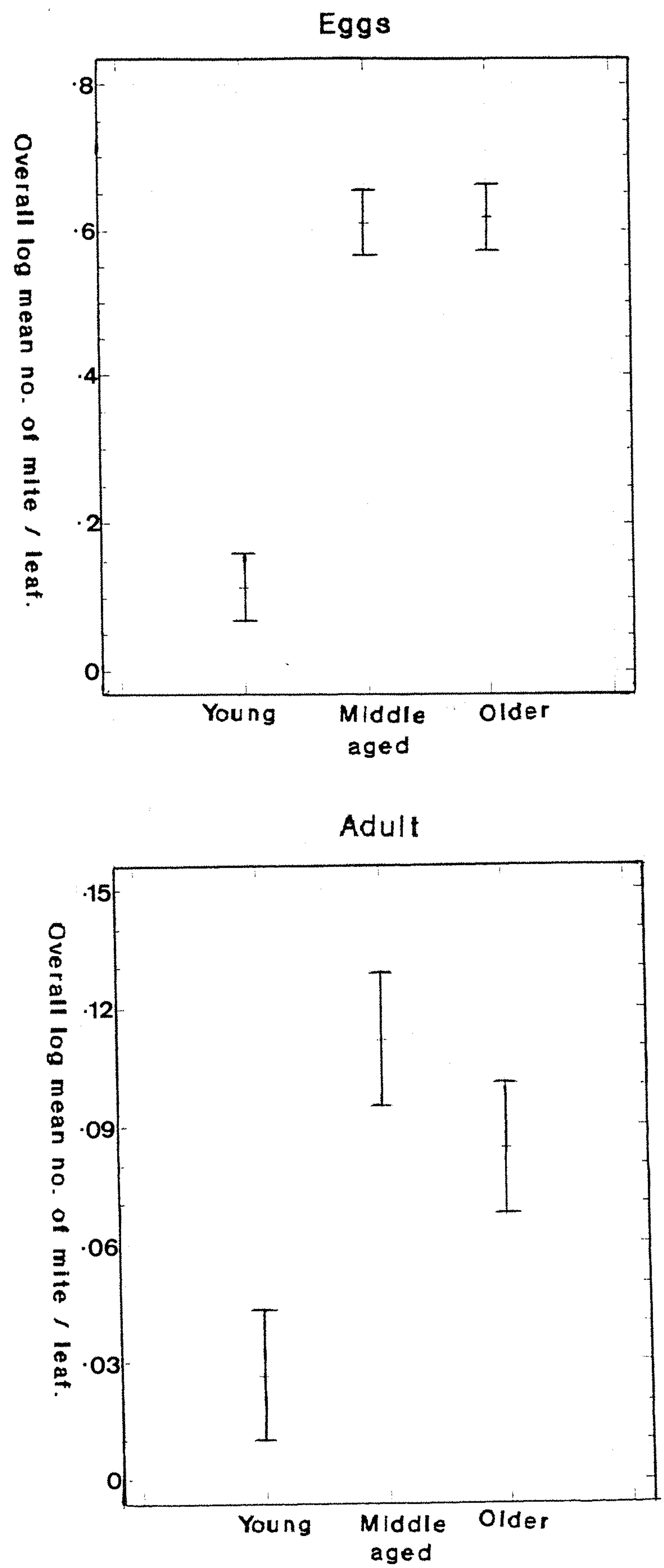


Figure 4. Overall log mean numbers of P. ulmi with 95% confidence interval on different leaf ages.

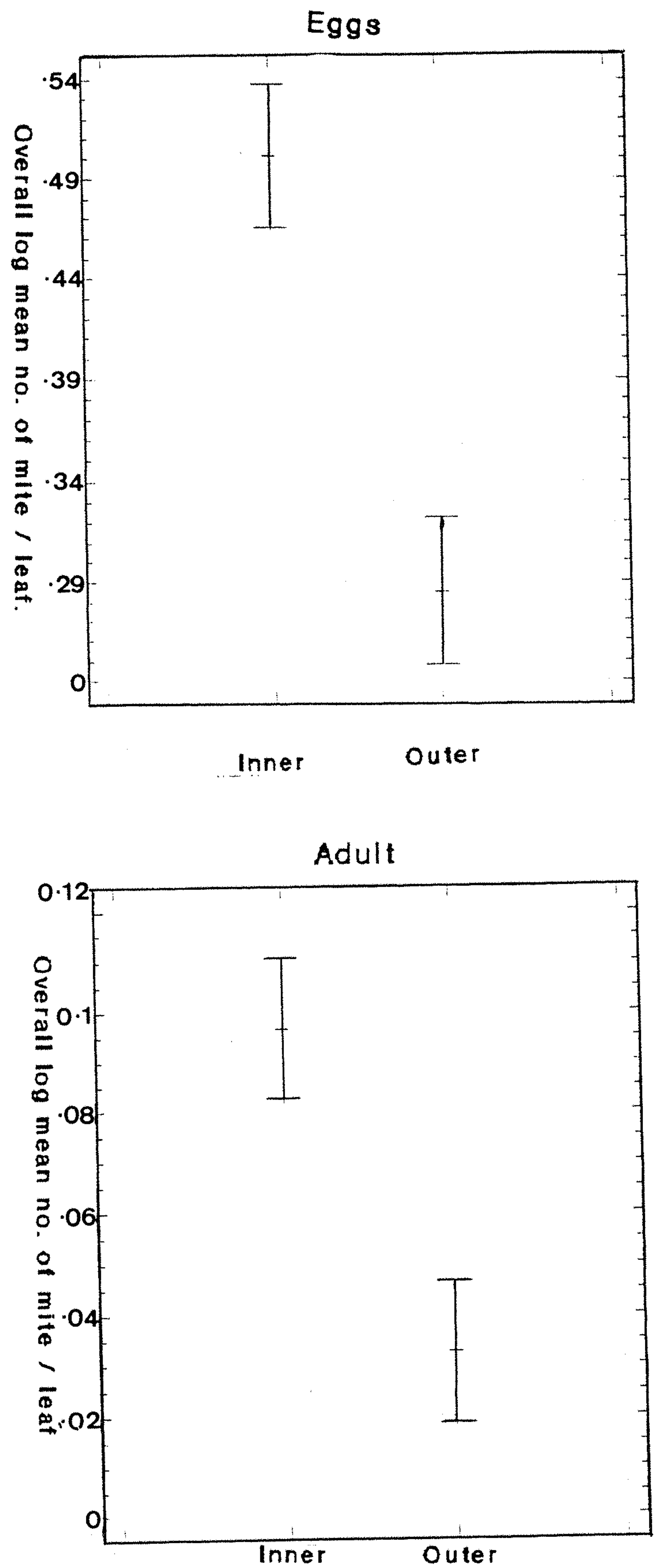
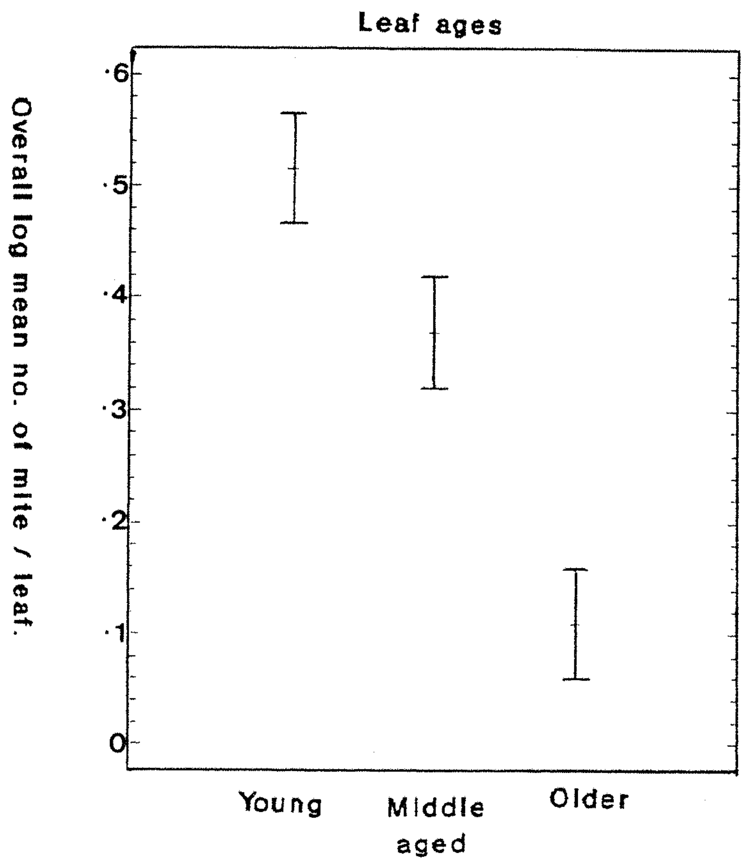


Figure 5. Overall log mean numbers of P. ulmi with 95% confidence interval on different positions



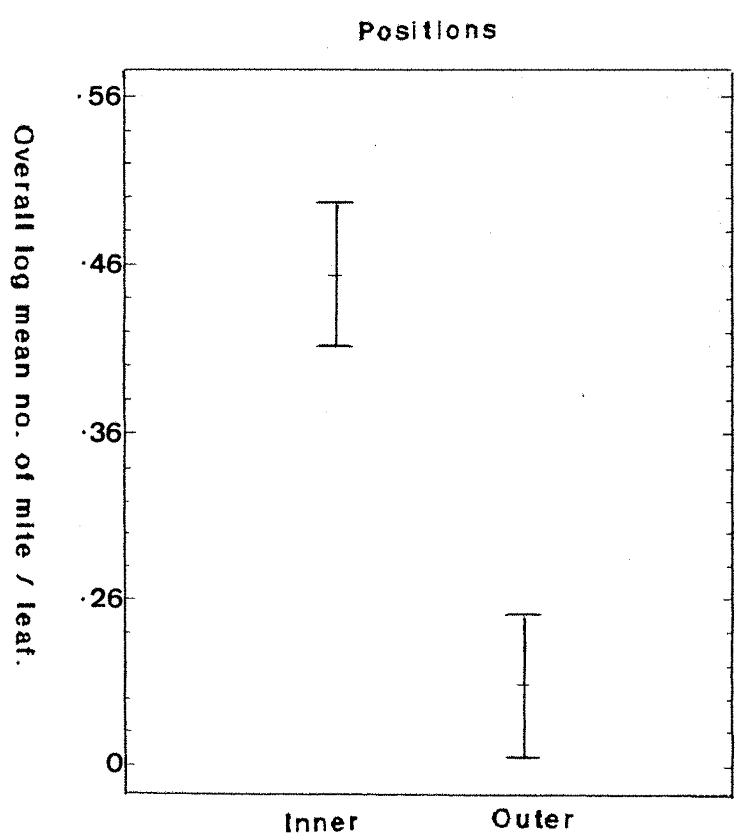


Figure 6. Overall log mean numbers of A. schlectendali with 95% confidence interval on different leaf ages and positions

Figure 7. Distribution of *P. ulmi* on different leaf ages in the inner position of the trees.

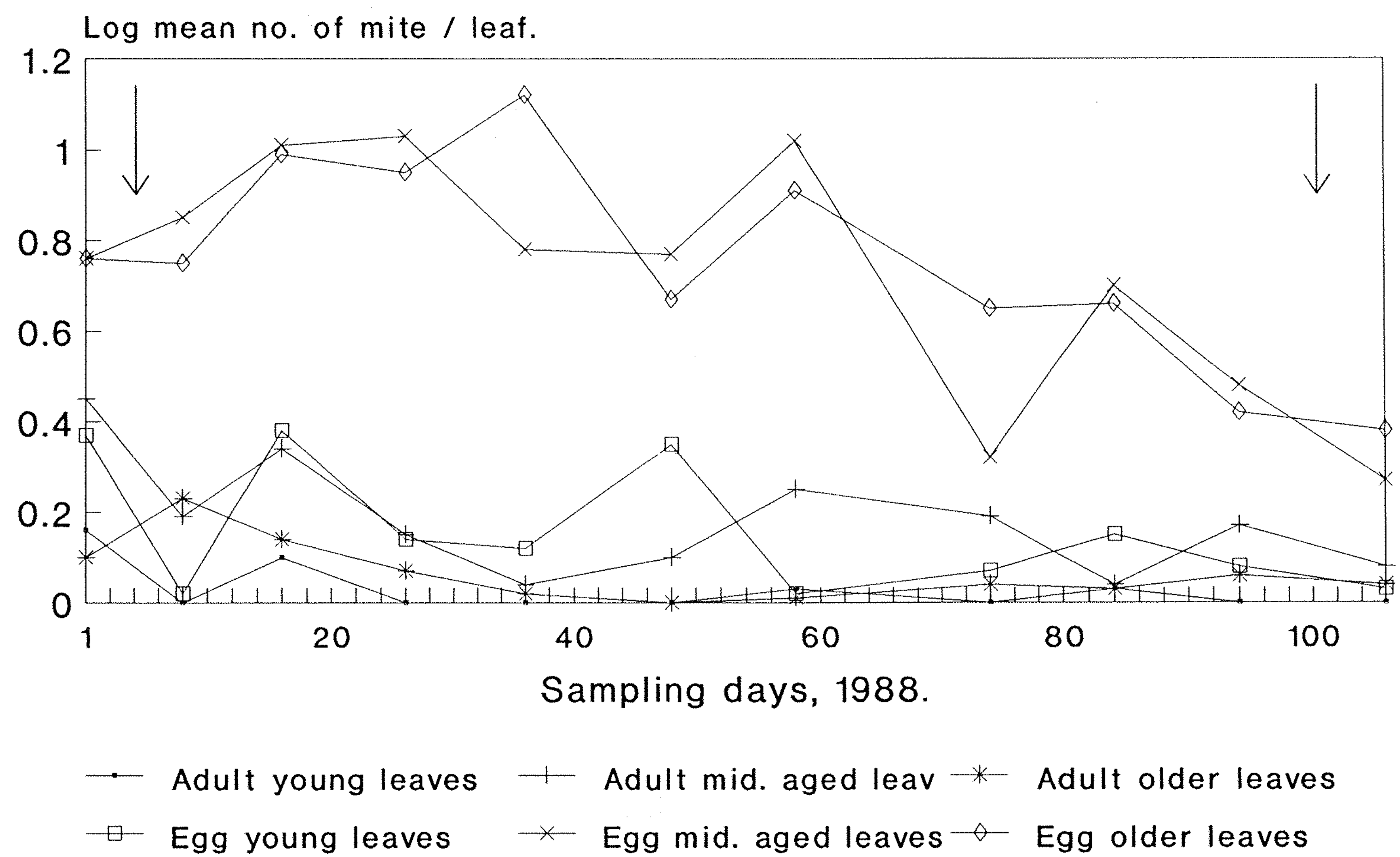


Figure 8. Distribution of *P. ulmi* on different leaf ages in the outer position of the trees.

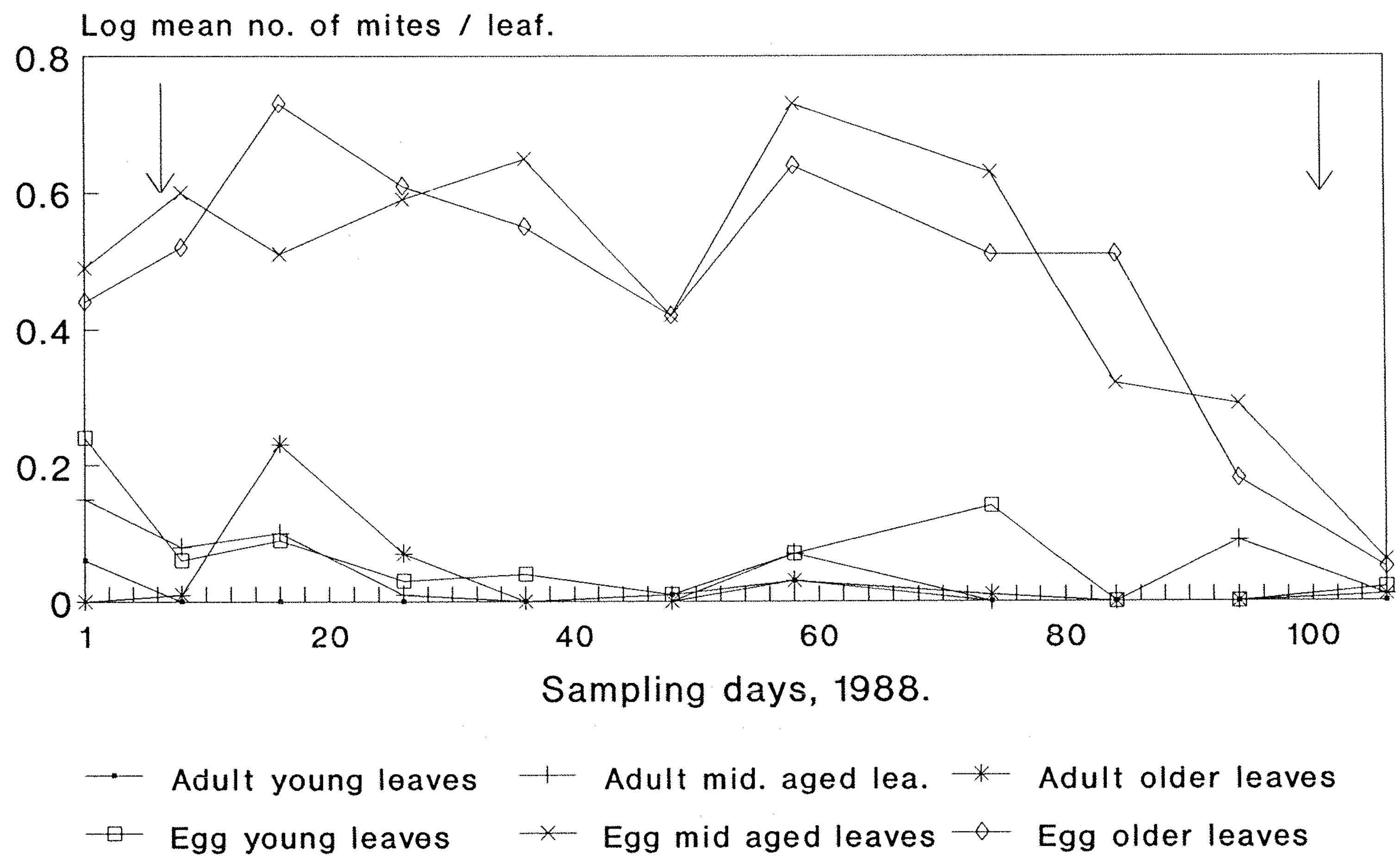


Table 1. Mean and ± 95% confidence interval of the numbers of *P. ulmi* on different leaf ages in the inner position.

Dates, 1988.	leaf ages	Adult			Egg		
		Mean	95% conf. int.		Mean	95% conf. int.	
22/7	Young	0.16	0.00	0.32	0.37	-0.00	0.75
	Middle aged	0.45	0.29	0.61	0.767	0.39	1.14
	Older	0.10	0.05	0.26	0.760	0.38	1.13
29/7	Young	0.0	0.0		0.02	-0.35	0.39
	Middle aged	0.19	0.03	0.35	0.85	0.47	1.22
	Older	0.23	0.07	0.39	0.75	0.38	1.13
5/8	Young	0.10	-0.06	0.26	0.38	0.00	0.75
	Middle aged	0.34	0.17	0.50	1.01	0.63	1.38
	Older	0.14	-0.01	0.30	0.99	0.61	1.36
15/8	Young	0.0	0.0		0.14	-0.23	0.52
	Middle aged	0.15	-0.01	0.31	1.03	0.65	1.40
	Older	0.07	0.08	0.23	0.95	0.57	1.32
25/8	Young	0.0	0.0		0.12	-0.25	0.50
	Middle aged	0.04	-0.11	0.20	0.78	0.40	1.15
	Older	0.02	-0.13	0.18	1.12	0.75	1.50
6/9	Young	0.0	0.0		0.35	-0.02	0.72
	Middle aged	0.10	-0.06	0.26	0.77	0.39	1.14
	Older	0.0	0.0		0.67	0.29	1.04
16/9	Young	0.03	-0.13	0.19	0.02	-0.35	0.39
	Middle aged	0.25	0.09	0.41	1.02	0.64	1.40
	Older	0.01	-0.14	0.17	0.91	0.53	1.28

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29/9	Young	0.0	0.0		0.07	-0.30	0.44
	Middle aged	0.19	0.03	0.35	0.32	-0.04	0.70
	Older	0.04	-0.11	0.20	0.65	0.27	1.02
7/10	Young	0.03	-0.13	0.19	0.15	-0.22	0.52
	Middle aged	0.04	-0.11	0.20	0.70	0.32	1.07
	Older	0.03	-0.12	0.19	0.66	0.28	1.03
17/10	Young	0.0	0.0		0.08	-0.29	0.45
	Middle aged	0.17	0.01	0.33	0.48	0.11	0.86
	Older	0.06	-0.10	0.22	0.42	0.04	0.79
28/10	Young	0.0	0.0		0.03	-0.34	0.40
	Middle aged	0.08	-0.07	0.24	0.27	-0.10	0.64
	Older	0.04	-0.11	0.20	0.38	0.00	0.75

middle aged leaves but increased on older leaves (Fig 7). Similar trends were also observed in outer position (Fig. 8). The decrease in the numbers on young and middle aged leaves may be because of the spray application on 26th July. The numbers of adult mites increased again on young and middle aged leaves but decreased on older leaves on the third sampling day (5th August) while in the outer zone mites were still on older leaves and numbers did not increase on young and middle aged leaves. This type of trend remained up until the last sampling day. Similar trends were also observed in the case of *A. schlechtendali*. On the first sampling day although ± 95% confidence intervals overlapped

Table 2. Mean and ± 95% confidence interval of the numbers of *P. ulmi* on different leaf ages in the outer position.

Dates, 1988.	leaf ages	Adult			Egg		
		Mean	95% conf. int.		Mean	95% conf. int.	
22/7	Young	0.06	-0.00	0.14	0.24	-0.05	0.53
	Middle aged	0.15	0.08	0.22	0.49	0.19	0.78
	Older	0.0	0.0		0.44	0.14	0.73
29/7	Young	0.0	0.0		0.06	-0.23	0.35
	Middle aged	0.08	0.00	0.15	0.60	0.30	0.89
	Older	0.01	-0.05	0.08	0.52	0.23	0.82
5/8	Young	0.0	0.0		0.09	-0.19	0.39
	Middle aged	0.10	0.03	0.18	0.51	0.22	0.81
	Older	0.23	0.16	0.32	0.73	0.44	1.03
15/8	Young	0.0	0.0		0.03	-0.25	0.33
	Middle aged	0.01	-0.05	0.08	0.59	0.29	0.88
	Older	0.07	0.00	0.14	0.61	0.31	0.90
25/8	Young	0.0	0.0		0.04	-0.24	0.34
	Middle aged	0.0	0.0		0.65	0.35	0.95
	Older	0.0	0.0		0.55	0.25	0.85
6/9	Young	0.01	-0.05	0.08	0.01	-0.28	0.31
	Middle aged	0.0	0.0		0.42	0.12	0.71
	Older	0.0	0.0		0.42	0.12	0.72
16/9	Young	0.03	-0.03	0.11	0.07	-0.22	0.36
	Middle aged	0.07	0.0	0.15	0.73	0.43	1.03
	Older	0.03	-0.03	0.11	0.64	0.34	0.94

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29/9	Young	0.0	0.0		0.14	-0.15	0.43
	Middle aged	0.0	0.0		0.63	0.33	0.92
	Older	0.01	-0.05	0.08	0.51	0.22	0.81
7/10	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.0	0.0		0.32	0.02	0.61
	Older	0.0	0.0		0.51	0.21	0.80
17/10	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.09	0.02	0.17	0.29	-0.00	0.58
	Older	0.0	0.0		0.18	-0.11	0.47
28/10	Young	0.0	0.0		0.02	-0.27	0.31
	Middle aged	0.01	-0.05	0.08	0.06	-0.23	0.35
	Older	0.01	-0.05	0.08	0.05	-0.24	0.34

each other (Table 3), the numerical trend in Figures 9 and 10 show that, initially, many mites were on middle aged leaves but towards the end of sampling period the numbers of rust mites increased on young leaves in both positions, inner and outer.

Correlation analyses were also carried out between the numbers of eggs and adult *P. ulmi* on all leaf ages i.e. young, middle aged and older leaves in both positions, inner and outer (Table 4). On all leaf ages and positions, correlation coefficients were positive and significantly different $P < 0.01$ but $P < 0.05$ for older leaves in the outer position. The correlation coefficient (r) on young leaves in the inner ($r = 0.4246$) and outer (0.5616) were higher than other

Figure 9. Distribution of *A. schlechtendali* on different leaf ages inner position of the trees.

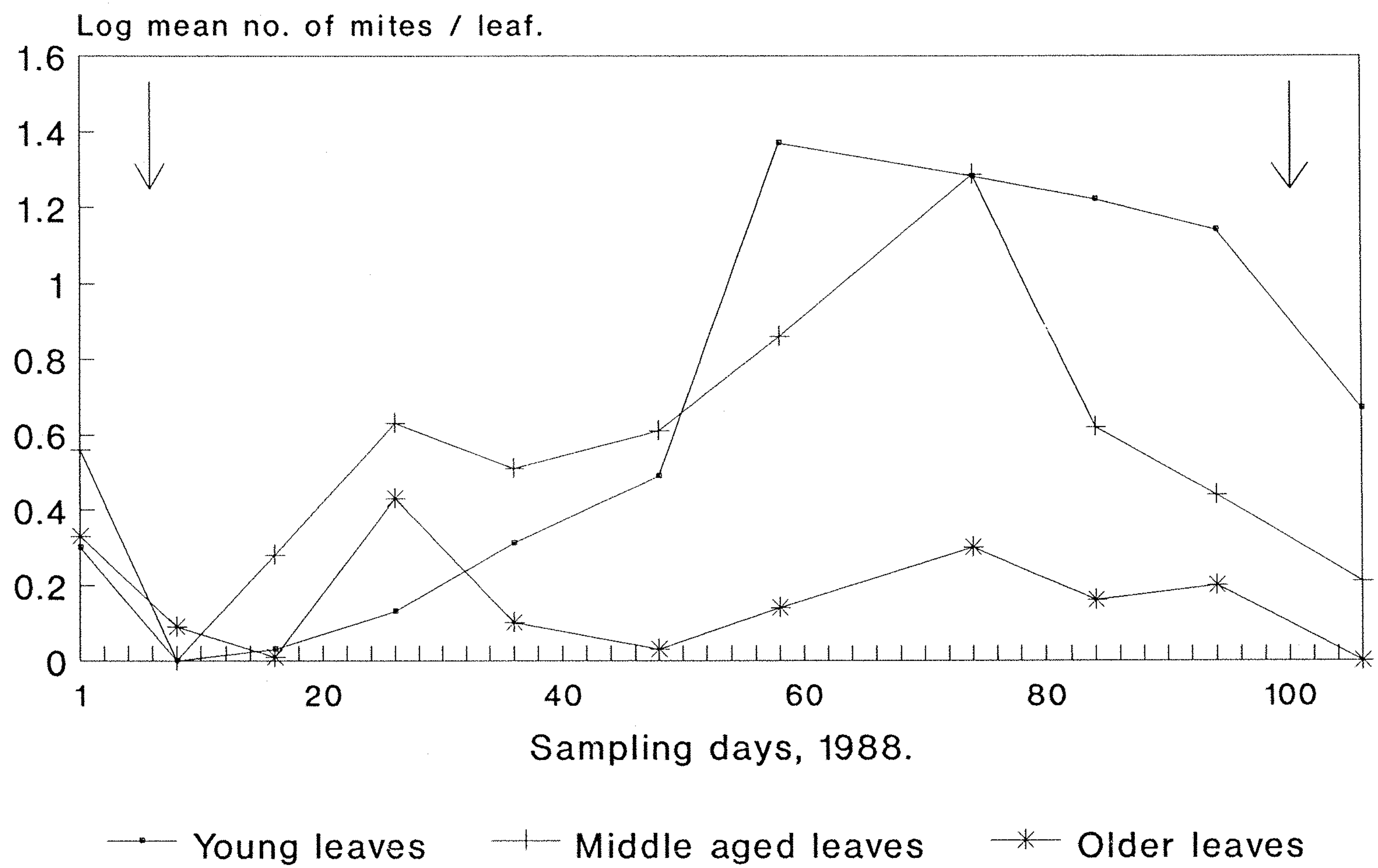

Figure 10. Distribution of *A. schlechtendali* on different leaf ages in the outer position of the trees.

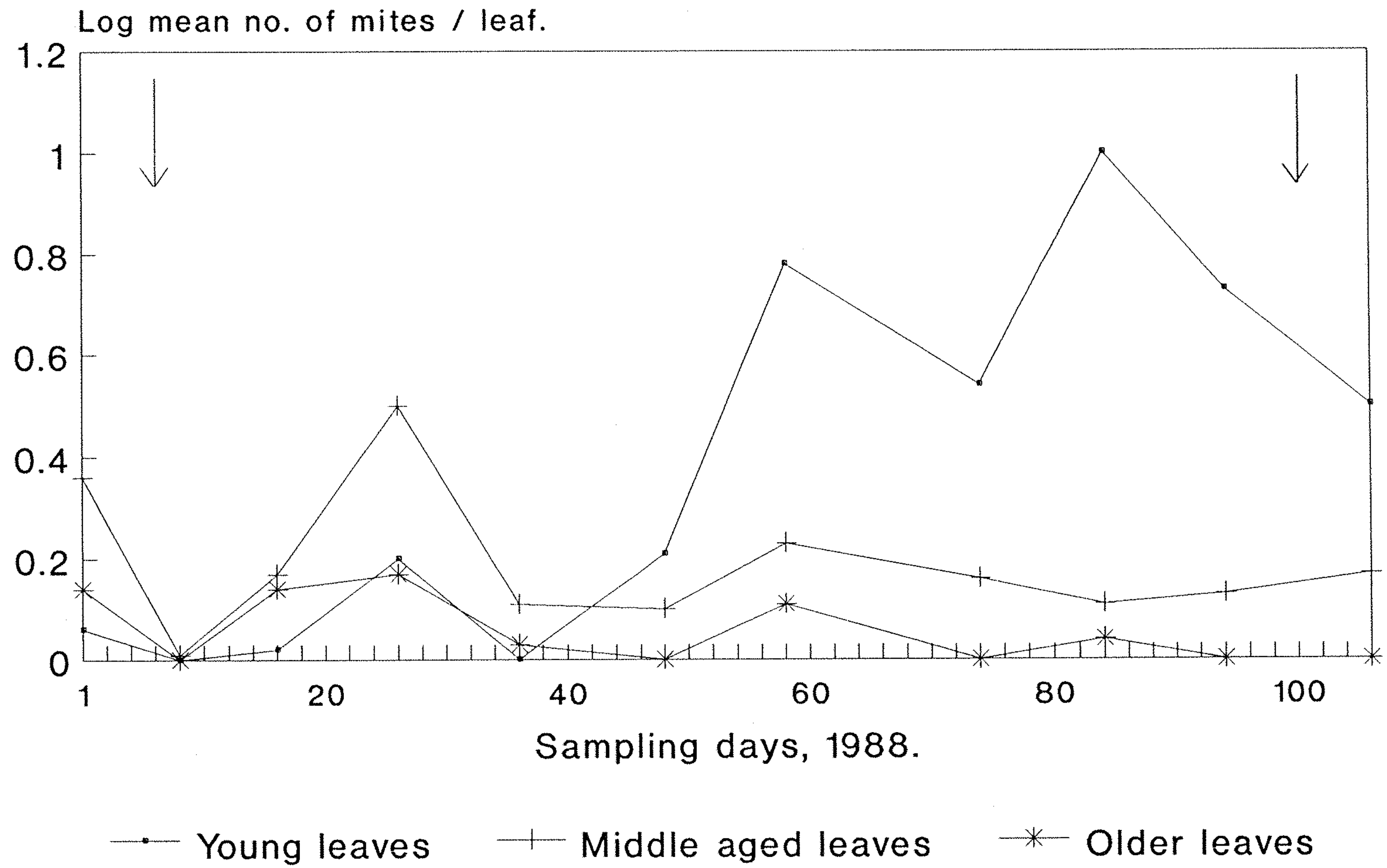

Table 3. Mean and ± 95% confidence interval of the numbers of *A. schlechtendali* on different leaf ages and positions.

Dates, 1988.	leaf ages	Inner			Outer		
		Mean	95% conf. int.		Mean	95% conf. int.	
22/7	Young	0.30	-0.10	0.70	0.06	-0.17	0.30
	Middle aged	0.56	0.16	0.96	0.36	0.12	0.60
	Older	0.33	-0.06	0.73	0.14	-0.09	0.38
29/7	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.0	0.0		0.01	-0.22	0.25
	Older	0.09	-0.31	0.49	0.0	0.0	
5/8	Young	0.03	-0.36	0.43	0.02	-0.21	0.26
	Middle aged	0.28	-0.11	0.68	0.17	-0.06	0.41
	Older	0.01	-0.38	0.41	0.14	-0.09	0.38
15/8	Young	0.13	-0.26	0.53	0.20	-0.03	0.44
	Middle aged	0.63	0.22	1.03	0.50	0.26	0.73
	Older	0.43	0.03	0.83	0.17	-0.06	0.41
25/8	Young	0.31	-0.08	0.71	0.0	0.0	
	Middle aged	0.51	-0.11	0.91	0.11	-0.12	0.34
	Older	0.10	-0.30	0.40	0.03	-0.20	0.26
6/9	Young	0.49	0.09	0.89	0.21	-0.02	0.45
	Middle aged	0.61	0.20	1.01	0.10	-0.13	0.34
	Older	0.03	-0.37	0.43	0.0	0.0	
16/9	Young	1.37	0.97	1.77	0.78	0.54	1.02
	Middle aged	0.86	0.46	1.26	0.23	-0.00	0.47
	Older	0.14	-0.25	0.54	0.11	-0.12	0.35

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29/9	Young	1.28	0.88	1.68	0.54	0.30	0.77
	Middle aged	1.28	0.88	1.68	0.16	-0.07	0.40
	Older	0.30	-0.09	0.70	0.0	0.0	
7/10	Young	1.22	0.82	1.62	1.00	-0.76	1.24
	Middle aged	0.62	0.22	1.02	0.11	-0.12	0.35
	Older	0.16	-0.24	0.56	0.04	-0.19	0.28
17/10	Young	1.14	0.73	1.54	0.73	-0.49	0.96
	Middle aged	0.44	0.03	0.84	0.13	-0.10	0.37
	Older	0.20	-0.19	0.60	0.0	0.0	
28/10	Young	0.67	0.26	1.07	0.50	-0.26	0.74
	Middle aged	0.21	-0.18	0.61	0.17	-0.06	0.41
	Older	0.0	0.0		0.0	0.0	

leaf ages.

Table 4. Correlation analyse between the numbers of egg and adult *P . ulmi* on different leaf ages and positions.

Positions	Leaf ages	correlation between egg and adult	significant level
Inner	Young	0.4246	0.00
	Middle aged	0.3608	0.00
	Older	0.2716	0.00
Outer	Young	0.5616	0.00
	Middle aged	0.3835	0.00
	Older	0.1769	0.00

Distribution of spider mites during 1989.

European red spider mite, *P. ulmi*.

Studies of the distribution of spider mites were carried out in a similar fashion i. e. leaf ages and tree positions. During this year the numbers of mite (egg and adult) were also significantly different $p < 0.01$ between positions and leaf ages (Table 5, Appendix 1) The overall mean plot (Fig. 11) of the numbers of mites shows that they were higher on middle aged and older leaves than younger leaves. In case of eggs, the highest numbers were found on older leaves followed by middle aged and younger leaves (Fig. 11). The overall mean numbers of egg and adult, *P. ulmi* were higher in the inner position than in the outer position (Fig. 12). Although ± 95% confidence intervals of the numbers of mites overlapped, the numerical trend in Figures 13 and 14 indicate that the mean numbers of eggs and adults were higher on older leaves than the other two leaf ages in the inner position on the first sampling day (23rd May) with no adults on other leaf ages on this date. The reason for no adults on this date is that the orchard received a pesticide application on 18th May (Table 2, Appendix 1). The numbers of mites started increasing after this date and reached maximum numbers on all leaf ages between the 40th and 60th (22nd June and 11th July) sampling days, although ± 95% confidence interval of the numbers of mites on each leaf age on each sampling date overlapped each other. After this period the numbers of mites started decreasing on all leaf ages and both positions may be because of the season.

Correlation analyses between the numbers of eggs and adults on

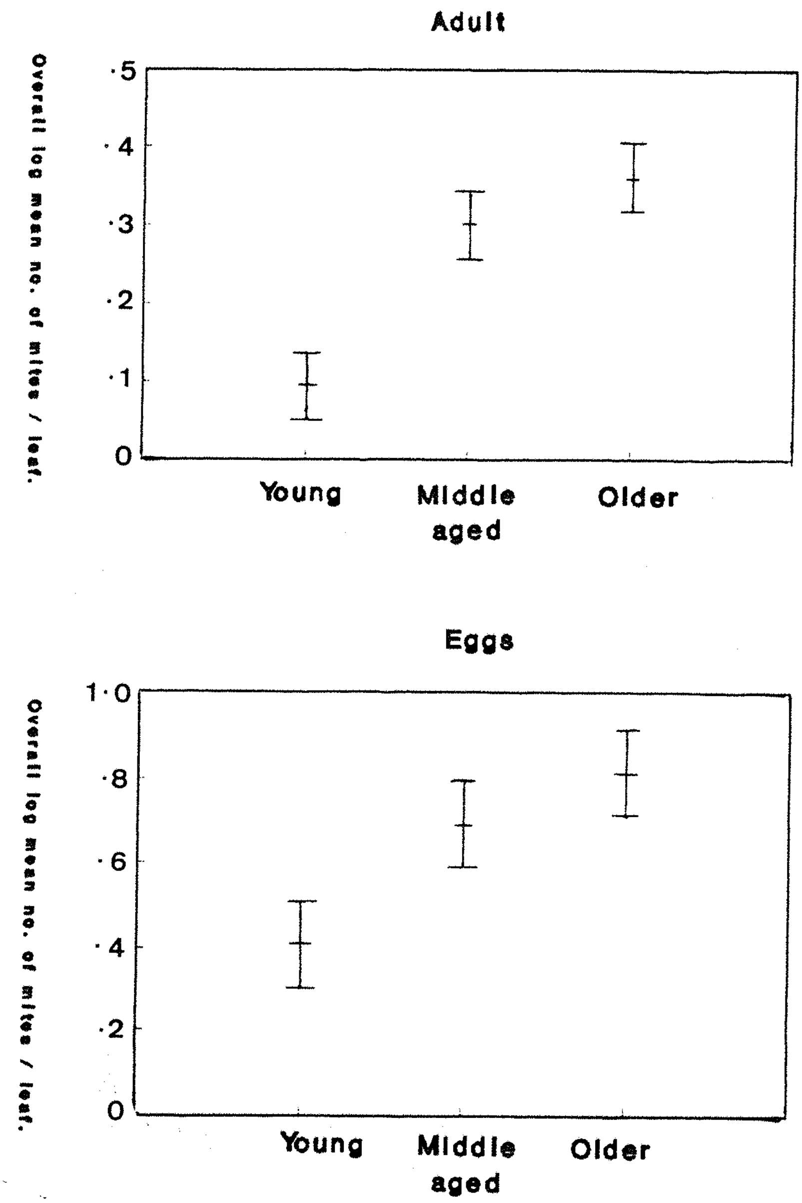
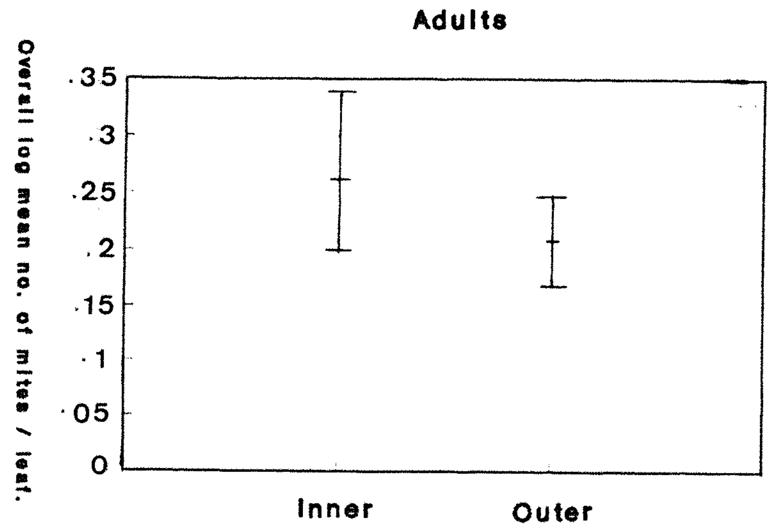


Figure 11. Overall log mean numbers of P. ulmi with 95% confidence interval on different leaf ages.



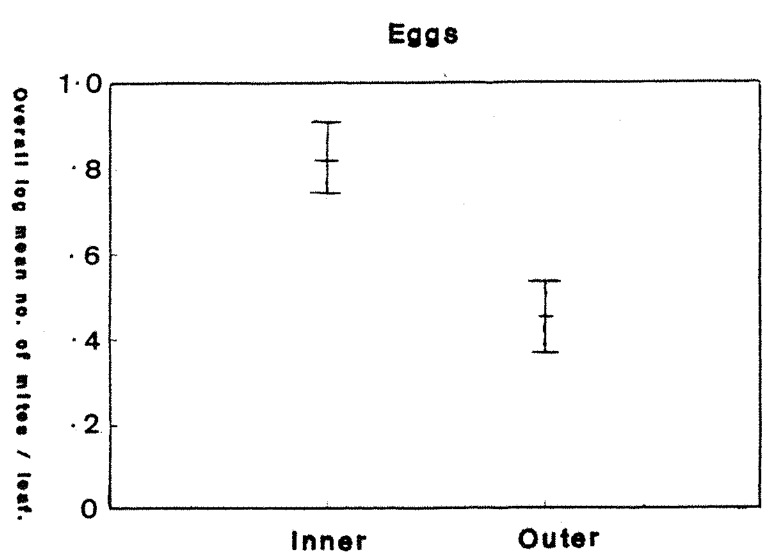


Figure 12. Overall log mean numbers of P. ulmi with 95% confidence interval in different positions.

Figure 13. Distribution of *P. ulmi* on different leaf ages in the inner position of the trees.

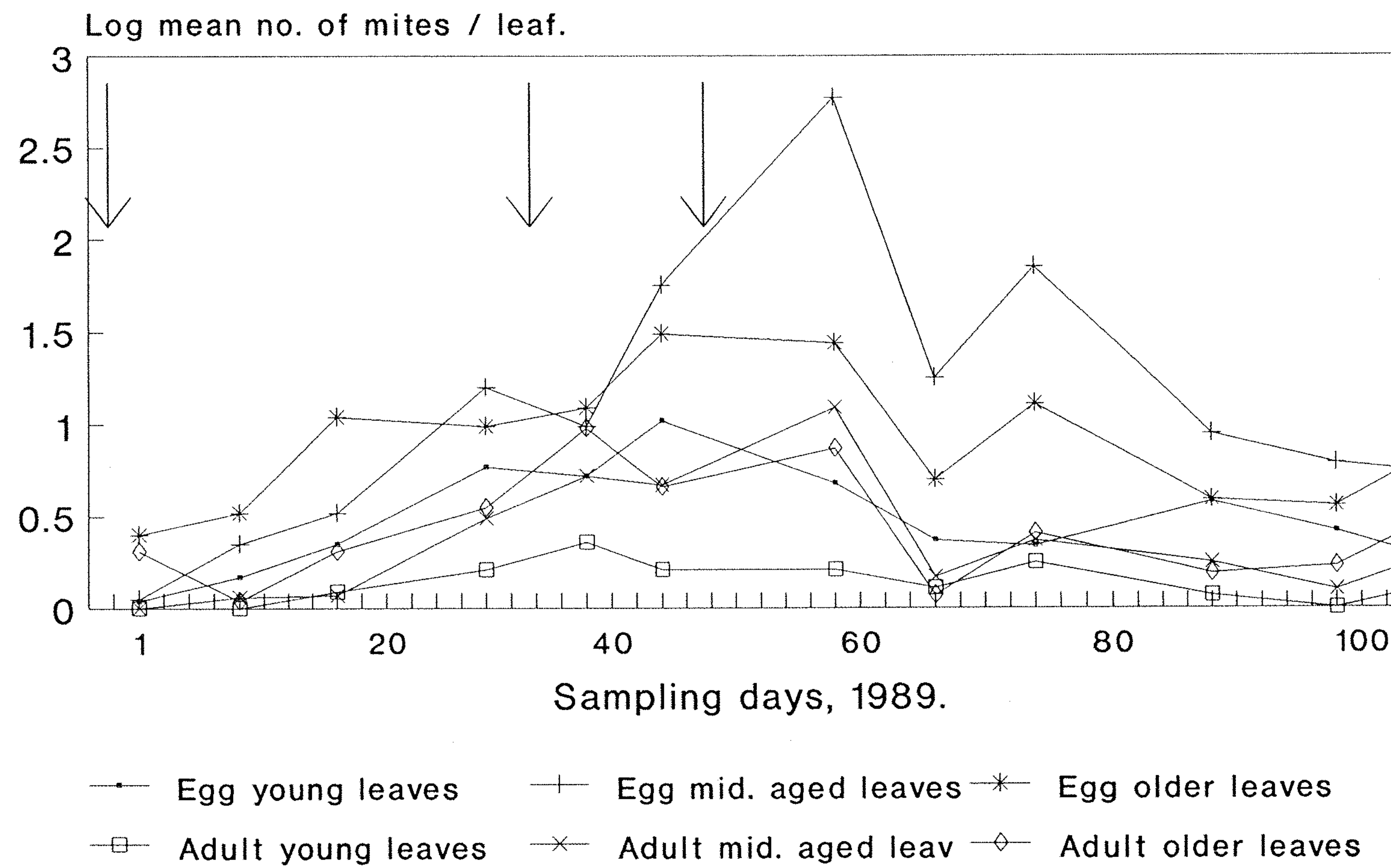


Figure 14. Distribution of *P. ulmi* on different leaf ages in the outer position of the trees.

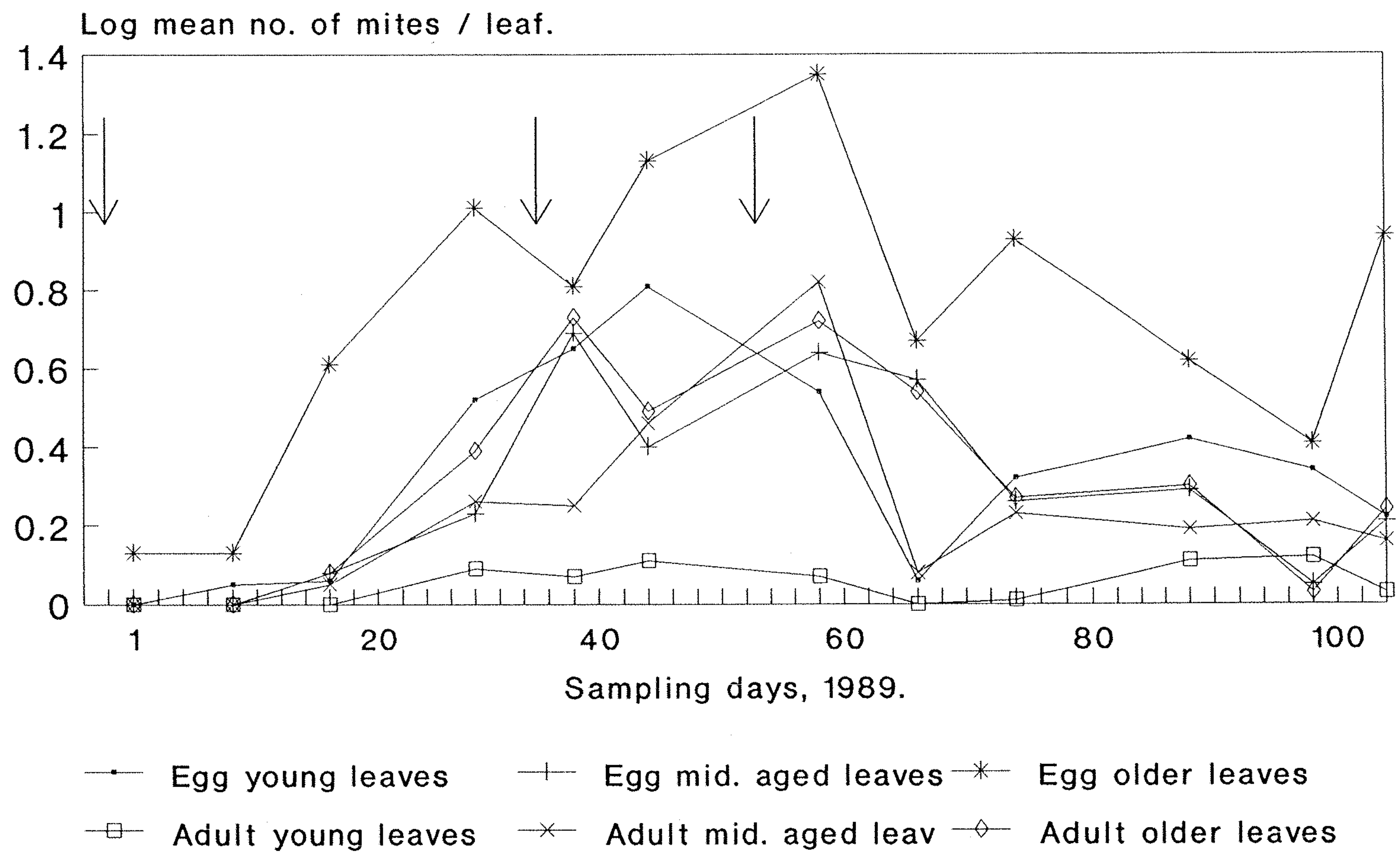


Table 5. Mean and ± 95% confidence interval of the numbers of *P. ulmi* on different leaf ages in the inner position.

Dates, 1989.	leaf ages	Adult			Egg		
		Mean	95% conf. int.		Mean	95% conf. int.	
23/5	Young	0.0	0.0		0.04	-0.43	0.52
	Middle aged	0.0	0.0		0.05	-0.43	0.53
	Older	0.03	-0.18	0.24	0.40	-0.08	0.88
30/5	Young	0.0	0.0		0.17	-0.31	0.65
	Middle aged	0.06	-0.14	0.27	0.35	-0.12	0.84
	Older	0.04	-0.17	0.25	0.52	0.03	1.00
6/6	Young	0.09	-0.11	0.31	0.35	-0.13	0.83
	Middle aged	0.07	-0.13	0.28	0.52	0.03	1.00
	Older	0.31	0.09	0.52	1.04	0.55	1.52
15/6	Young	0.21	0.0	0.42	0.77	0.29	1.25
	Middle aged	0.49	0.28	0.70	1.20	0.71	1.68
	Older	0.55	0.33	0.76	0.99	0.50	1.47
22/6	Young	0.36	0.15	0.57	0.72	0.24	1.21
	Middle aged	0.72	0.51	0.93	0.99	0.50	1.47
	Older	0.98	0.77	1.19	1.09	0.60	1.57
27/6	Young	0.21	0.0	0.42	1.03	0.55	1.51
	Middle aged	0.67	0.45	0.88	1.75	1.26	2.23
	Older	0.66	0.44	0.87	1.49	1.00	1.97
11/7	Young	0.21	0.0	0.42	0.68	0.20	1.17
	Middle aged	1.09	0.88	1.31	2.77	2.28	3.25
	Older	0.87	0.66	1.08	1.44	0.96	1.93

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18/7	Young	0.11	-0.10	0.32	0.37	-0.11	0.85
	Middle aged	0.17	-0.03	0.39	1.25	0.76	1.73
	Older	0.07	-0.13	0.29	0.70	0.21	1.18
25/7	Young	0.25	0.03	0.46	0.34	-0.14	0.82
	Middle aged	0.37	0.16	0.58	1.85	1.36	2.33
	Older	0.41	0.20	0.62	1.11	0.62	1.59
8/8	Young	0.07	-0.13	0.29	0.58	0.09	1.06
	Middle aged	0.25	0.04	0.46	0.95	0.46	1.43
	Older	0.19	-0.01	0.41	0.59	0.10	1.07
17/8	Young	0.00	0.0		0.42	-0.06	0.90
	Middle aged	0.10	-0.10	0.31	0.79	0.30	1.27
	Older	0.23	0.02	0.44	0.56	0.08	1.05
22/8	Young	0.09	-0.11	0.30	0.30	-0.18	0.78
	Middle aged	0.24	0.03	0.46	0.75	0.26	1.23
	Older	0.43	0.21	0.64	0.78	0.30	1.26

all leaf ages in both zones were carried out. It showed that on all leaf ages and positions egg and adult positively correlated with each other and were significantly different P < 0.01 (Table 7).

Apple rust mite, *Aculus schlechtendali*.

During 1989, the distribution of rust mites on different leaf ages differed slightly from the 1988 season. In this year the overall log mean numbers of mites were higher on young and older leaves than on

Table 6. Mean and ± 95% confidence interval of the numbers of *P. ulmi* on different leaf ages in the outer position.

Dates, 1989.	leaf ages	Adult			Egg		
		Mean	95% conf. int.		Mean	95% conf. int.	
23/5	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.0	0.0		0.0	0.0	
	Older	0.0	0.0		0.13	-0.19	0.47
30/5	Young	0.0	0.0		0.05	-0.28	0.39
	Middle aged	0.0	0.0		0.0	0.0	
	Older	0.0	0.0		0.13	-0.19	0.47
6/6	Young	0.0	0.0		0.06	-0.27	0.39
	Middle aged	0.05	-0.13	0.24	0.08	-0.25	0.41
	Older	0.08	-0.10	0.27	0.61	0.27	0.94
15/6	Young	0.09	-0.09	0.27	0.52	0.18	0.85
	Middle aged	0.26	0.07	0.45	0.23	-0.09	0.57
	Older	0.39	0.20	0.58	1.01	0.67	1.34
22/6	Young	0.07	-0.11	0.26	0.65	0.31	0.98
	Middle aged	0.25	0.06	0.44	0.69	0.35	1.02
	Older	0.73	0.54	0.92	0.813	0.47	1.14
27/6	Young	0.11	-0.07	0.29	0.810	0.47	1.14
	Middle aged	0.46	0.25	0.67	0.40	0.06	0.74
	Older	0.49	0.30	0.68	1.13	0.79	1.46
11/7	Young	0.07	-0.11	0.26	0.54	0.21	0.88
	Middle aged	0.82	0.61	1.03	0.64	0.30	0.97
	Older	0.72	0.53	0.91	1.35	1.01	1.68

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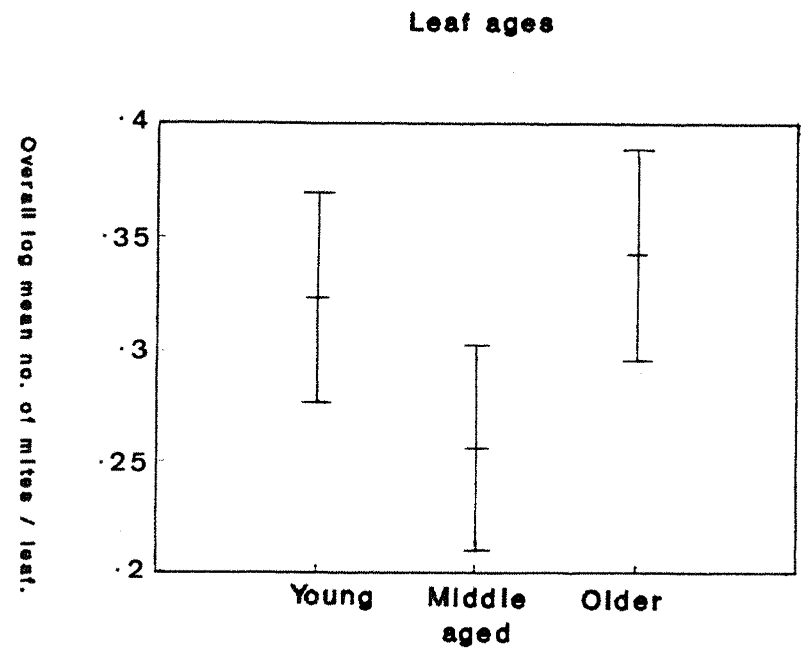
18/7	Young	0.0	0.0		0.06	-0.27	0.39
	Middle aged	0.08	-0.10	0.27	0.57	0.23	0.90
	Older	0.54	0.35	0.73	0.67	0.33	1.00
25/7	Young	0.01	-0.17	0.19	0.32	-0.00	0.66
	Middle aged	0.23	0.04	0.42	0.26	-0.06	0.60
	Older	0.27	0.08	0.46	0.93	0.59	1.27
8/8	Young	0.11	-0.07	0.30	0.42	0.08	0.75
	Middle aged	0.19	0.0	0.38	0.29	-0.04	0.62
	Older	0.30	0.11	0.49	0.62	0.28	0.95
17/8	Young	0.12	-0.06	0.31	0.34	0.00	0.67
	Middle aged	0.21	0.02	0.40	0.05	-0.28	0.39
	Older	0.03	-0.15	0.22	0.41	0.07	0.74
22/8	Young	0.03	-0.15	0.22	0.22	-0.11	0.55
	Middle aged	0.16	0.02	0.35	0.21	-0.12	0.54
	Older	0.24	0.05	0.43	0.94	0.60	1.27

middle aged but there was not much difference between young and older leaves (Fig. 15). The reason for this is that, in 1988, sampling was started on 22nd July and by that time there were few mites on older leaves and many mites were on young and middle aged leaves (Figs. 9 and 10); while, in 1989, sampling was started on 23rd May and at that time of the year there were more mites on older leaves compared with young and middle aged leaves. The numbers of mites on young leaves increased towards the end of the season (Figs. 16 and 17), which



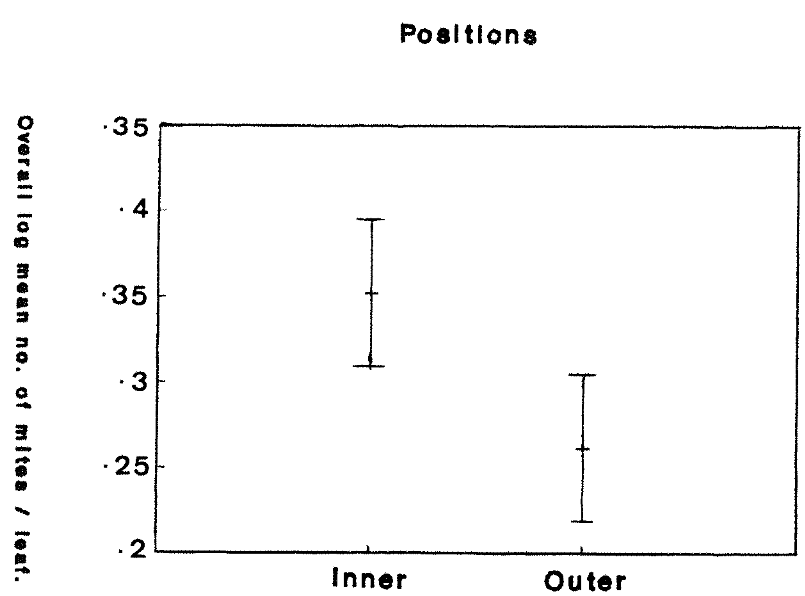


Figure 15. Overall log mean numbers of rust mite with 95% confidence interval on different leaf ages and positions

Figure 16. Distribution of *Aculus schlechtendali* on different leaf ages in the inner position.

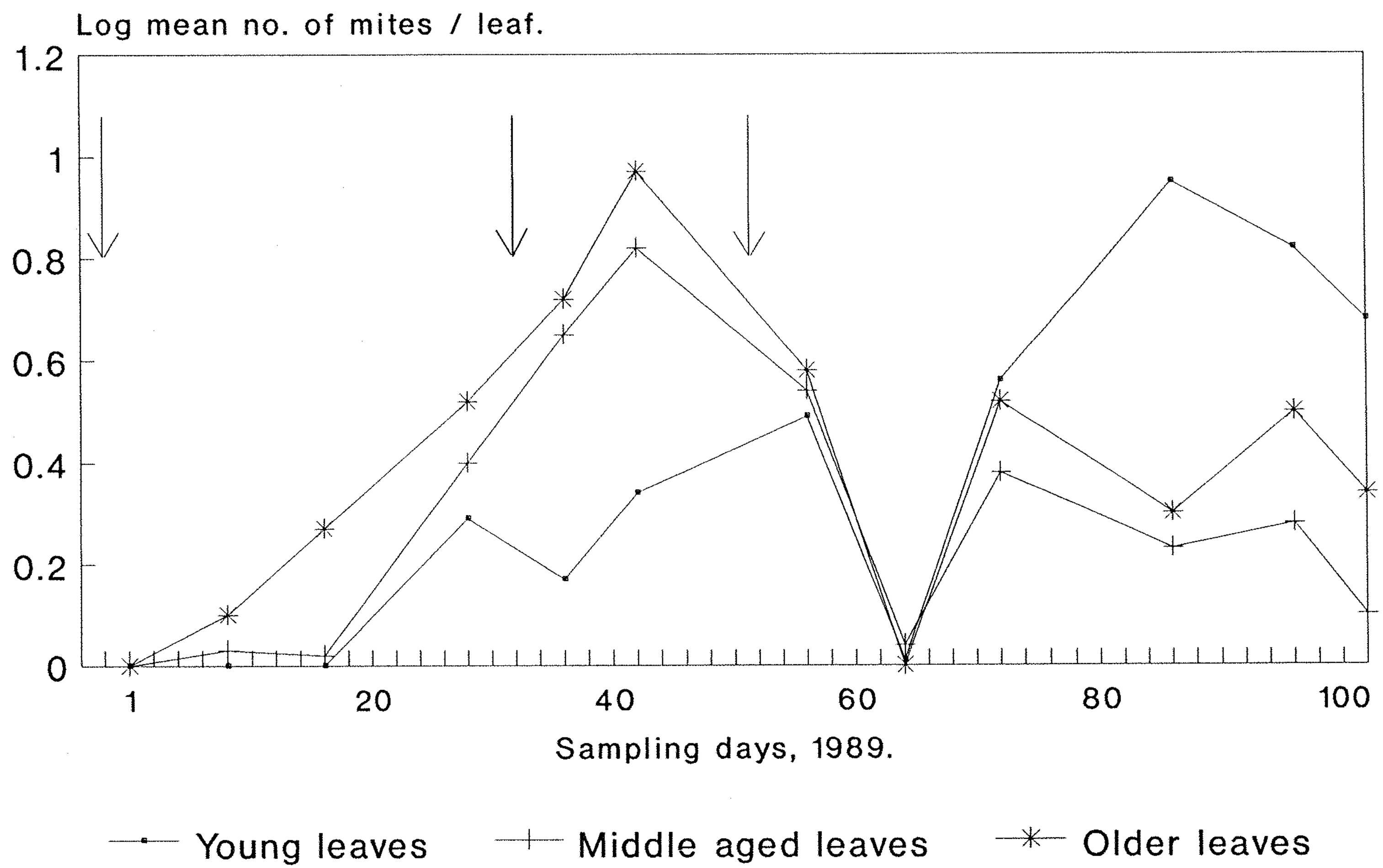
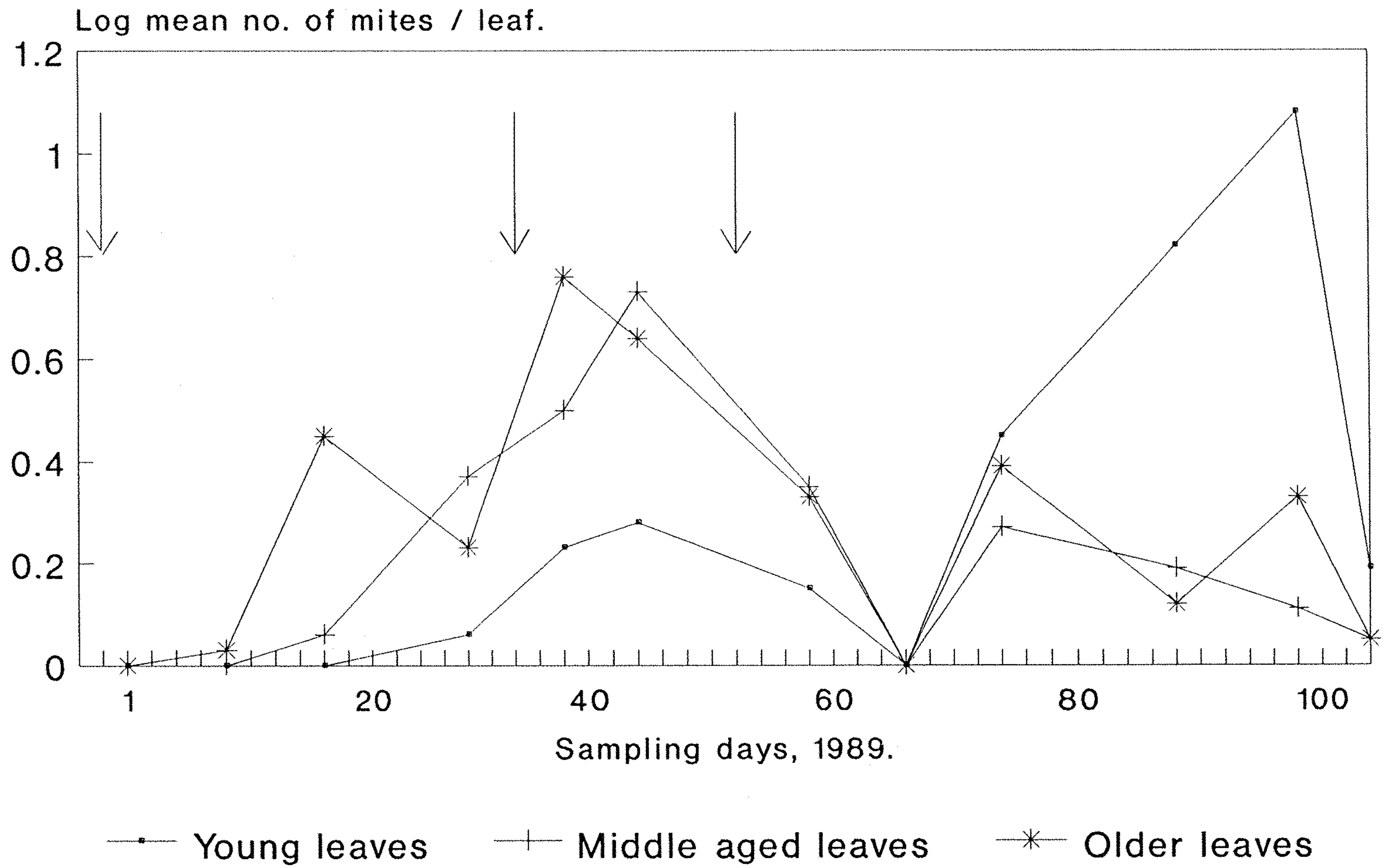


Figure 17. Distribution of *Aculus schlechtendali* on different leaf ages in the outer position.



increased the overall means on young and older leaves (Fig. 15). The

Table 7. Correlation analyses between the numbers of egg and adult *P. ulmi* on different leaf ages and positions.

Positions	Leaf ages	Correlation between egg and adult	Significant level
Inner	Young	0.3896	0.00
	Middle aged	0.6253	0.00
	Older	0.3391	0.00
Outer	Young	0.5178	0.00
	Middle aged	0.3626	0.00
	Older	0.5843	0.00

distribution of *A. schlechtendali* in inner and outer position did not differ from the 1988 results. The numbers of mites were higher in the inner position, compared with the outer position (Fig. 15). Analyses of variance of the numbers of rust mites showed significant differences ($p < 0.01$) between dates, positions and leaf ages. The interactions, dates X positions and dates X leaf ages were significantly different ($p < 0.01$) but the leaf ages X positions interaction was not significantly different ($p < 0.05$). Figures 16 and 17 indicate that rust mites appeared first on older leaves followed by middle aged and young leaves. The numbers of rust mites reached a maximum on the 6th sampling day (27th June) on older and middle aged leaves, although their ± 95% confidence intervals overlapped each other

Table 8. Mean and ± 95% confidence interval of the numbers of *A. schlechtendali* on different leaf ages and positions.

Dates, 1989.	leaf ages	Inner			Outer		
		Mean	95% conf. int.		Mean	95% conf. int.	
23/5	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.0	0.0		0.0	0.0	
	Older	0.0	0.0		0.0	0.0	
30/5	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.03	-0.20	0.27	0.0	0.0	
	Older	0.10	-0.13	0.33	0.03	-0.17	0.24
6/6	Young	0.0	0.0		0.0	0.0	
	Middle aged	0.02	-0.21	0.25	0.06	-0.14	0.27
	Older	0.27	0.03	0.50	0.45	0.24	0.65
15/6	Young	0.29	0.05	0.53	0.06	-0.14	0.27
	Middle aged	0.40	0.16	0.63	0.37	0.16	0.58
	Older	0.52	0.28	0.76	0.23	0.02	0.44
22/6	Young	0.17	-0.06	0.40	0.23	0.02	0.44
	Middle aged	0.65	0.41	0.89	0.50	0.29	0.71
	Older	0.72	0.49	0.96	0.76	0.55	0.97
27/6	Young	0.34	0.11	0.58	0.28	0.07	0.49
	Middle aged	0.82	0.59	1.06	0.73	0.52	0.94
	Older	0.97	0.73	1.20	0.64	0.43	0.85
11/7	Young	0.49	0.25	0.72	0.15	-0.05	0.36
	Middle aged	0.54	0.31	0.78	0.35	0.14	0.55
	Older	0.58	0.35	0.82	0.33	0.12	0.54

Table contd. on next page.

18/7	Young	0.01	-0.22	0.24	0.0	0.0	
	Middle aged	0.04	-0.19	0.27	0.0	0.0	
	Older	0.0	0.0		0.0	0.0	
25/7	Young	0.56	0.32	0.80	0.45	0.24	0.66
	Middle aged	0.38	0.14	0.61	0.27	0.06	0.48
	Older	0.52	0.28	0.75	0.39	0.18	0.60
8/8	Young	0.95	0.72	1.19	0.82	0.61	1.03
	Middle aged	0.23	0.0	0.47	0.19	-0.01	0.39
	Older	0.30	0.06	0.53	0.12	-0.08	0.33
17/8	Young	0.82	0.58	1.06	1.08	0.86	1.28
	Middle aged	0.24	0.01	0.48	0.11	0.09	0.32
	Older	0.50	0.26	0.74	0.33	0.12	0.54
22/8	Young	0.68	0.44	0.92	0.19	-0.01	0.40
	Middle aged	0.10	-0.13	0.33	0.05	0.15	0.25
	Older	0.34	0.10	0.58	0.05	-0.15	0.25

(Table 8), while the numbers increased on younger leaves and reached a maximum on the 10th sampling day (8th August).

Winter eggs.

Winter egg counts on the twigs collected from the inner and outer positions of trees during 1988 - 89, showed that when the numbers of winter eggs were analysed between dates and positions. Significant differences ($P < 0.01$) were found (Table 7, Appendix 1) but their interactions were not however, significantly different ($P > 0.05$).

In the second sampling method during the same years the winter egg distribution was significantly different ($P < 0.01$) between dates, positions and twig ages (Tables 8, Appendix 1). The interactions, dates x twig ages, dates x positions and positions x twig ages were not significantly different ($P > 0.05$). In 1989 - 90, the distributuion of winter eggs were significantly different between positions ($P < 0.05$) between twig ages ($P < 0.01$) but no significant differences ($P > 0.05$) were found between dates.

Overall mean plots with ± 95% confidence interval (Figs. 18, 19 and 20) for the numbers of winter egg by both sampling methods and both years also indicates that the numbers of winter egg were higher in the inner position than the outer, it was also higher on two year old twigs as compared with one year old twigs. This may be posibly because two years old twigs have more roughened areas or crevices while one year old twigs have smoother surfaces.

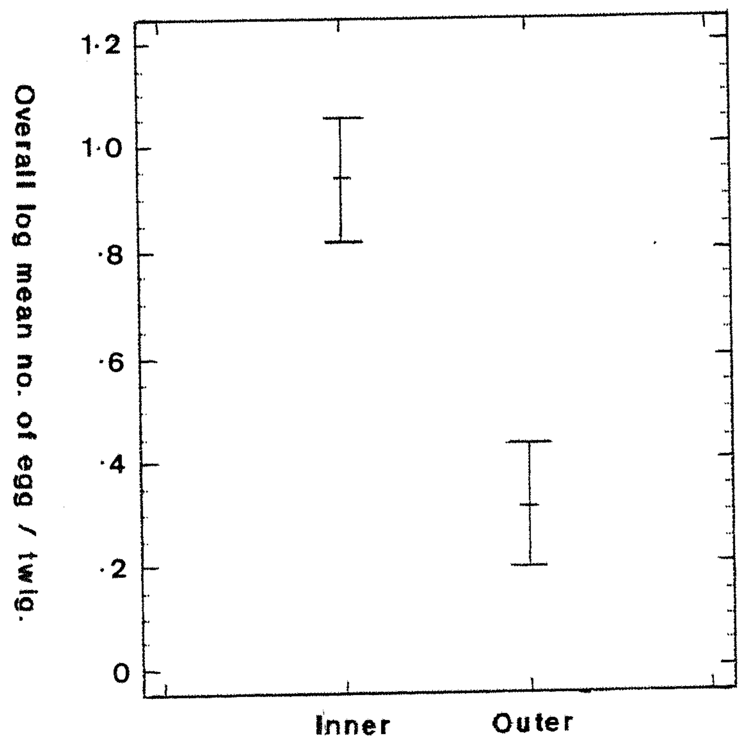
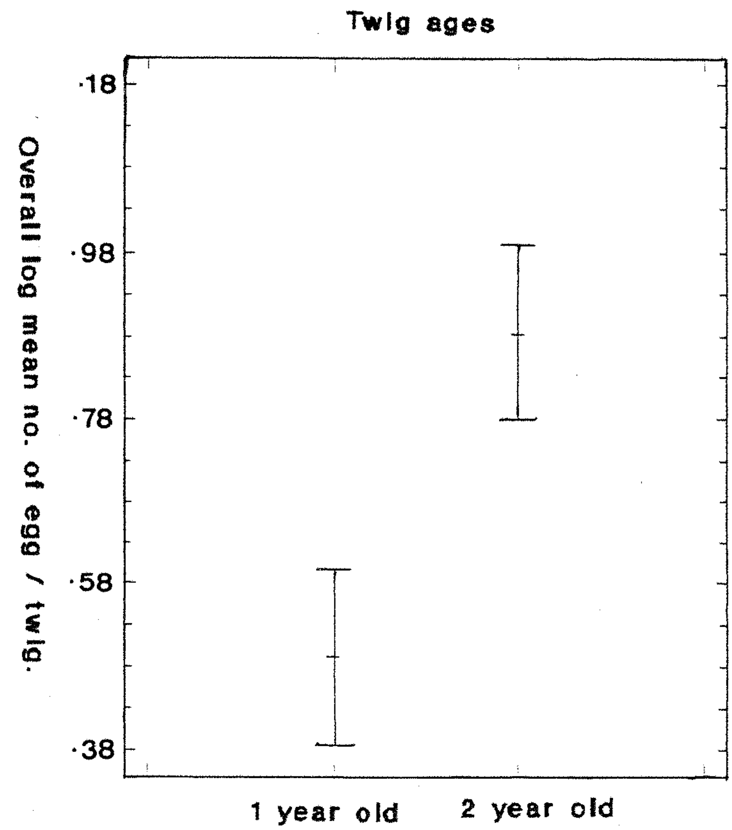


Figure 18. Overall log mean numbers of winter egg of P. ulmi with 95% confidence interval on different positions of trees during 1988 - 89.



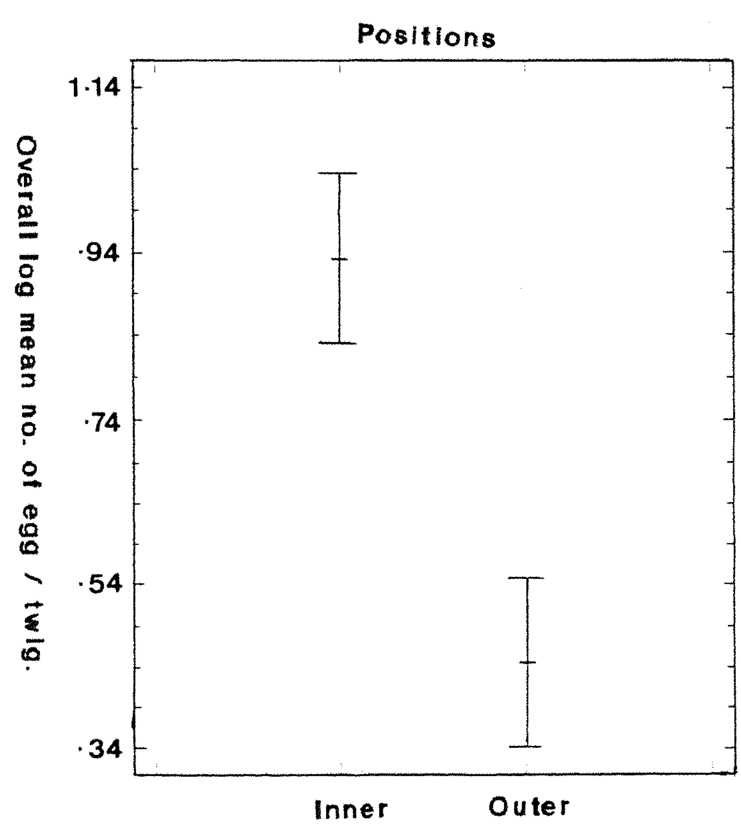


Figure 19. Overall log mean numbers of winter egg of P. ulmi with 95% confidence interval on different twig ages and positions during 1988 - 89.

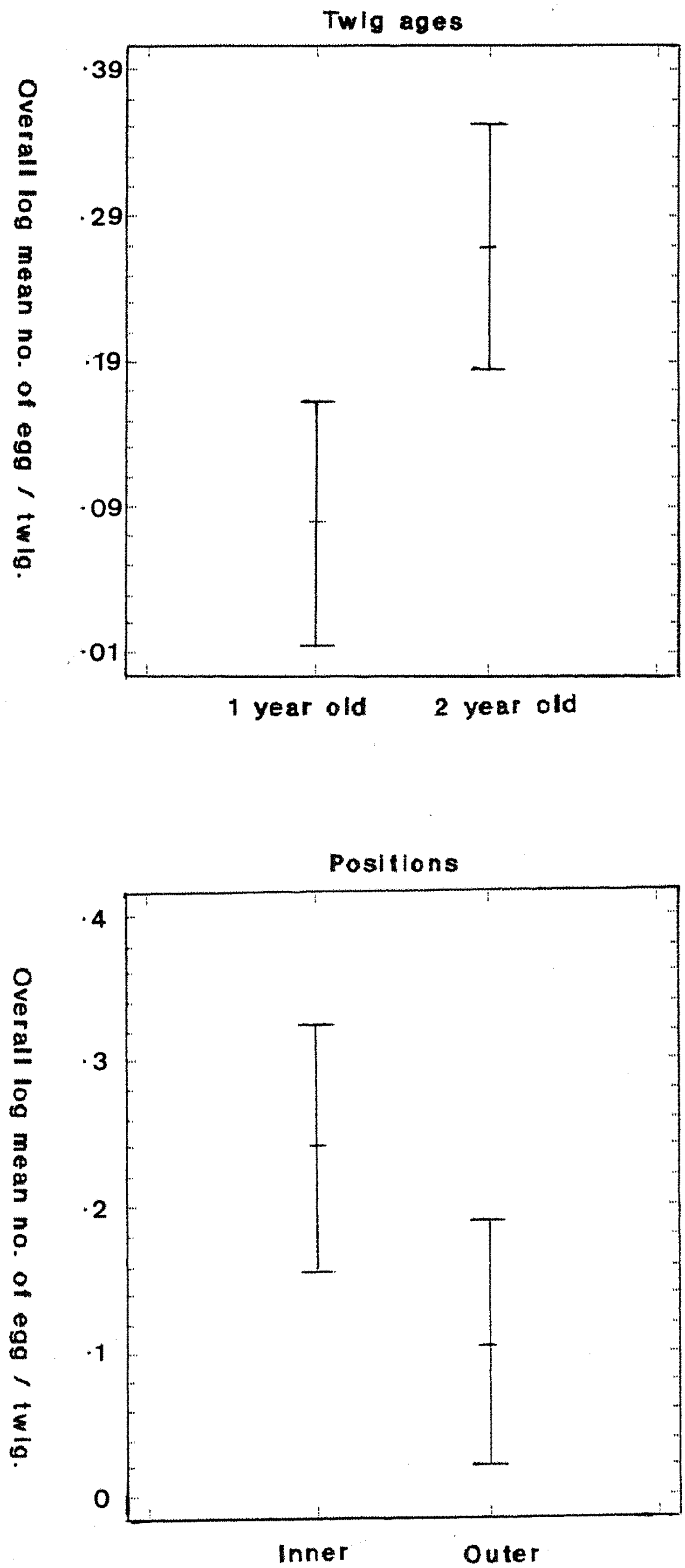


Figure 20. Overall log mean numbers of winter egg of P. ulmi with 95% confidence interval on different twig ages and positions during 1989 - 90.

Chapter 2

GLASSHOUSE EXPERIMENT.

INTRODUCTION.

During the studies of spider mite distribution in the 1988 season, some trends in the distribution patterns of numbers of *P. ulmi* on different leaf ages (young, middle aged and older leaves) and in the two sampling zones (inner and outer) varied. The numbers of *P. umli* were highest on middle aged leaves and the numbers of *A. schlechtendali* were highest on young leaves. The numbers of both species were also higher in the inner zone of the trees compared with the outer zone. Following spray application, the numbers of mites decreased. These reductions were higher in the outer tree zone, compared with the inner zone, although, after a delay, the numbers increased again in this position. It was postulated that the inner zone of the tree may have received less pesticide than the outer zone and that it could act as a reservoir of reinvading mites once toxic pesticide deposits had declined in the outer zone.

On the basis of these results, experiments were designed, during the 1989 season, in the glasshouse and in a commercial orchard to follow mite movement and to determine whether mites disperse from untreated to treated branches following treatment. These experiments were designed to establish whether or not the hypothesis that parts of the tree acted as a reservoir for the recolonisation of sprayed areas could be accepted.

MATERIALS AND METHODS

Twelve apple trees, six each of the varieties Cox orange and Exquisitte, were obtained from a private nursery. Both varieties were budded onto M 27 root stock. The plants were potted in plastic pots (30 cm diameter) in John Innes No. 2 compost (7 parts sterilized loam, 4 parts peat, 3 parts fine grit with 226.8 g / bushel of Vitax Q4 fertilizer). The plants were then pruned to leave four branches on each tree. Each pruned branch was examined under binocular microscope for the presence of winter eggs, which were detected but not counted. These plants were then kept until sprouting, in a glasshouse with an average temperature of 15 °C and variable relative humidity. Daylength was controlled by supplementary lighting to 16 hours. The trees started sprouting and were in flower within ten to twelve days. They were then transfered to another glasshouse at an average temperature of 20 °C and variable relative humidity. Ventilation was given above 20 °C, although precise temperature control was not possible in hot weather. The supplementary lighting was provided by mercury vapour lamp from 1st March to 1st May, with no extra lighting between 1st May and 1st September.

Before the start of the experiment, aphids colonised the trees. Pirmicarb (Pirimor; 50% WP) at the rate of 2.8 gram / 5 l. of water was applied, to run-off, on 20th April as a control measure.

To investigate the dispersal of mites from untreated to treated branches, three trees of each variety, were selected. To isolate mites on treated or untreated foliage, one branch per tree was caged. A sticky barrier was put around the base of each caged branch to avoid dispersal of mites from these to uncaged branches. These branches will be referred as " caged " and " uncaged " branches in the text. The cages were cylindrical and prepared using aluminium wire and " Tubegauze " . The cages were approximatly 0.79 m long and 0.34 m wide. To avoid any spray drift into the cages, they were covered with tubular polythene before spraying. The bags were removed following spraying.

An alternative treatment was devised to permit mites to disperse from covered (untreated) to uncovered (treated) branches; three Cox orange trees were used in this study. Shortage of space in the glasshouse prevented use of the second variety. The branches will be termed " covered and uncovered " in the text in this case. One branch per tree was tagged and covered with a polythene bag before spraying as above. Since the mites were allowed to disperse from covered (untreated) to uncovered (treated) branches, no cages or sticky barriers were used.

In order to avoid the dispersal of spider mites from apple trees to other plants in the glasshouse, a large cage measuring 1.78 m X 4.86 m X 0.78 m was constructed of bamboo canes and fine - meshed cotton gauze. This cage was divided into three equal parts, separated by gauze. Three trees of each variety with caged and uncaged branches, were kept separately in two parts of the large cage and the three trees with covered and uncovered branch were kept in the third part of the large cage. *P. ulmi* were released on 14th May on both caged and covered branches. The mites were from an insectary culture and were transferred by stapling the infested Prunus leaves onto apple leaves selected at random. The mites were not however, released onto uncaged and uncovered branches. During the experiment, the mites which were found on the leaves of the latter branch types were from winter eggs. Since the Prunus leaves had no *A. schlechtendali* none of this species were released on these branches but some of this species may have been present on twigs which were observed later during the experiment.

During the mite distribution studies in the 1988 season, it was hypothesised that mites moved from untreated to treated foliage or branches after a delay, when pesticide residues had declined. To make the experiment in the glasshouse similar to the orchard these trees were also sprayed with an acaricide to investigate effects on mite distribution and to examine whether they move from untreated to treated branches. The uncaged and uncovered branches of the trees in the glasshouse were sprayed with Torque (fenbutatin oxide; 50% WP) acaricide at a rate of 3 g / 6 l. of water on 25th May, 21st June and 10th July. The trees were sprayed evenly to run - off.

To determine the numbers of eggs and active stages of *P. ulmi* and of *A. schlechtendali*, assessments were made of excised leaves under binocular microscope. Three trees for each of the cage and covered branch studies were sampled on each occasion. Two leaves were collected from each caged and uncaged branch of each tree, giving a total of six leaves per treatment in each experiment.

RESULTS AND DISCUSSION.

Caged branches VS uncaged branches.

European red spider mite, *P. ulmi*.

Sampling in the glasshouse experiment was started on 23rd May. The overall mean plot in Figures 21a and 21b and Table 9 show that the numbers of eggs and adults on caged branches of both varieties were higher than on uncaged branches. Thus mites on the caged branches did not disperse in large numbers to the uncaged branches. The differences between the numbers of *P. ulmi* on caged and uncaged branches of both varieties were analysed statistically and found to be significantly different $p < 0.01$ (Tables 10a and 10b, Appendix 2). The most likly explanation for this difference is that the mites were prevented from moving between caged and uncaged branches due to sticky barriers. Another possible reason is that few mites on the uncaged areas could not escape from pesticide applications to protected branches and they were thus killed by the acaricide spray (dates of spray are indicated by downward arrows in each Figure and by " * " in each Table). The differences between the numbers of mites, before and after spraying, were not significantly different on some occasions (Tables 11 & 12, Appendix 2). Figures 22 & 23 demonstrate that on Cox orange the eggs of *P.ulmi* reached a peak on 16th June (26th sampling day) followed by peak numbers of adults on 23rd June (34th sampling day). On Exquisitte, both eggs and adults reached a peak on the 34th sampling day. Following these peaks, there was a decline in numbers of both eggs

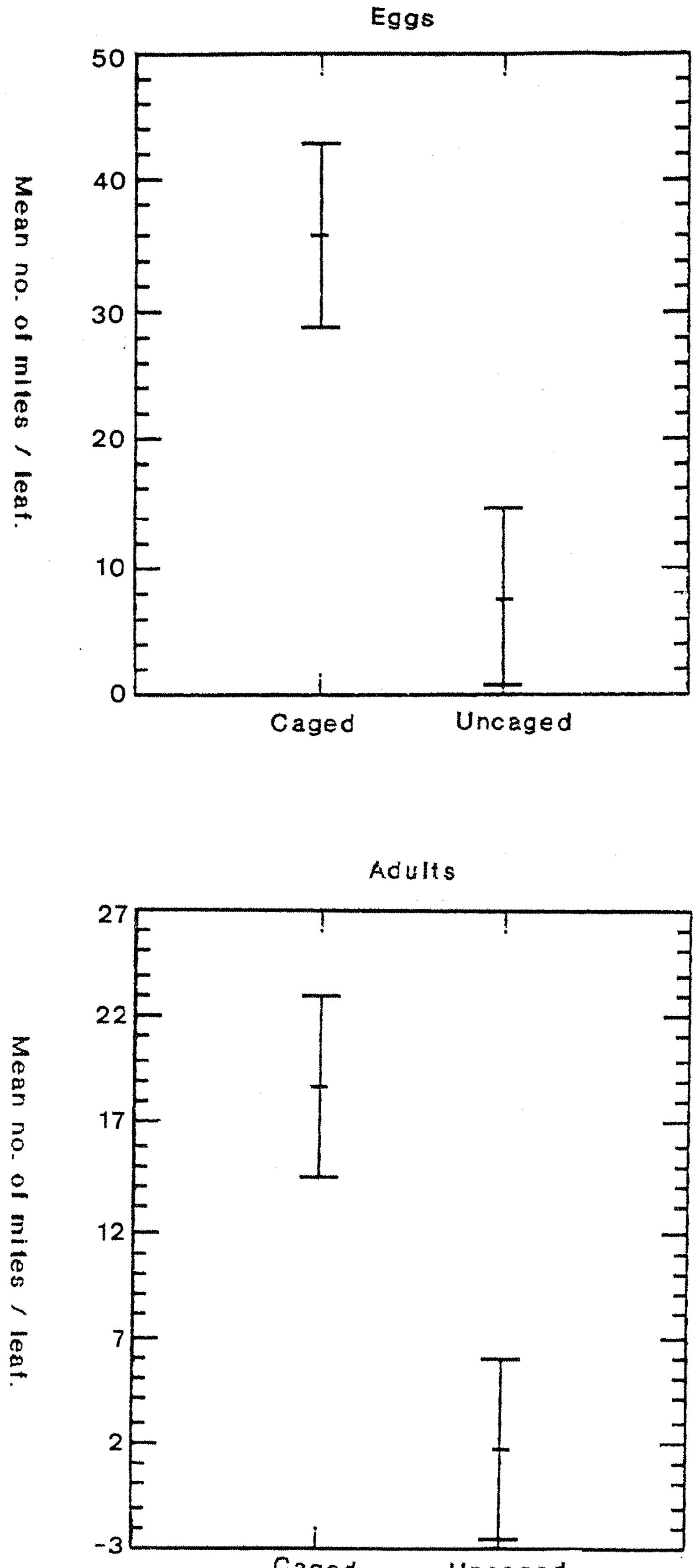
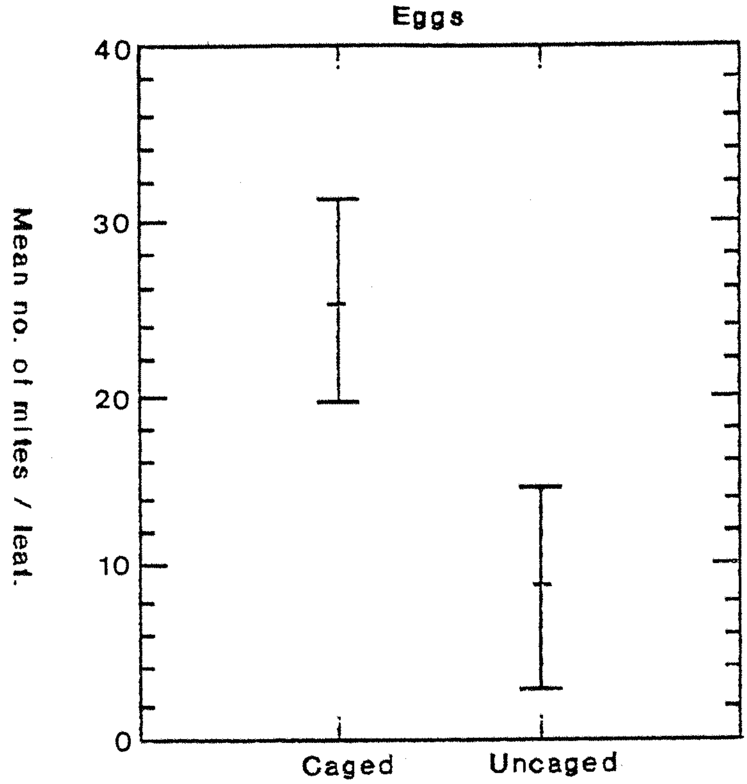


Figure 21a. Overall mean numbers of mite / leaf with 95% confidence interval on different branches of the Cox orange.



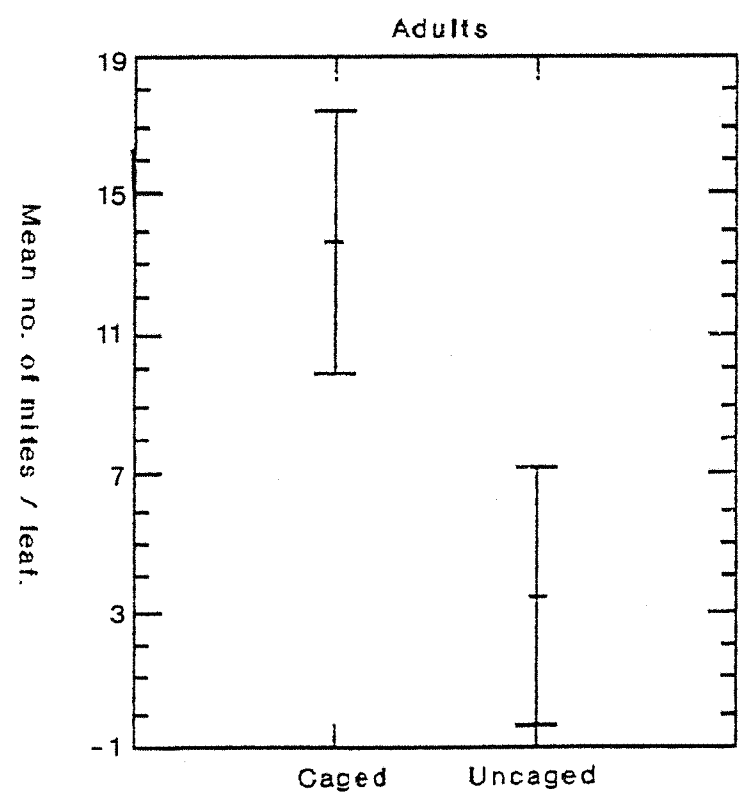


Figure 21b. Overall mean numbers of mites / leaf with 95% confidence interval on differnt branches of the Exquisitte.

Figure 22. Distribution of *P. ulmi* on the Cox orange apple variety.

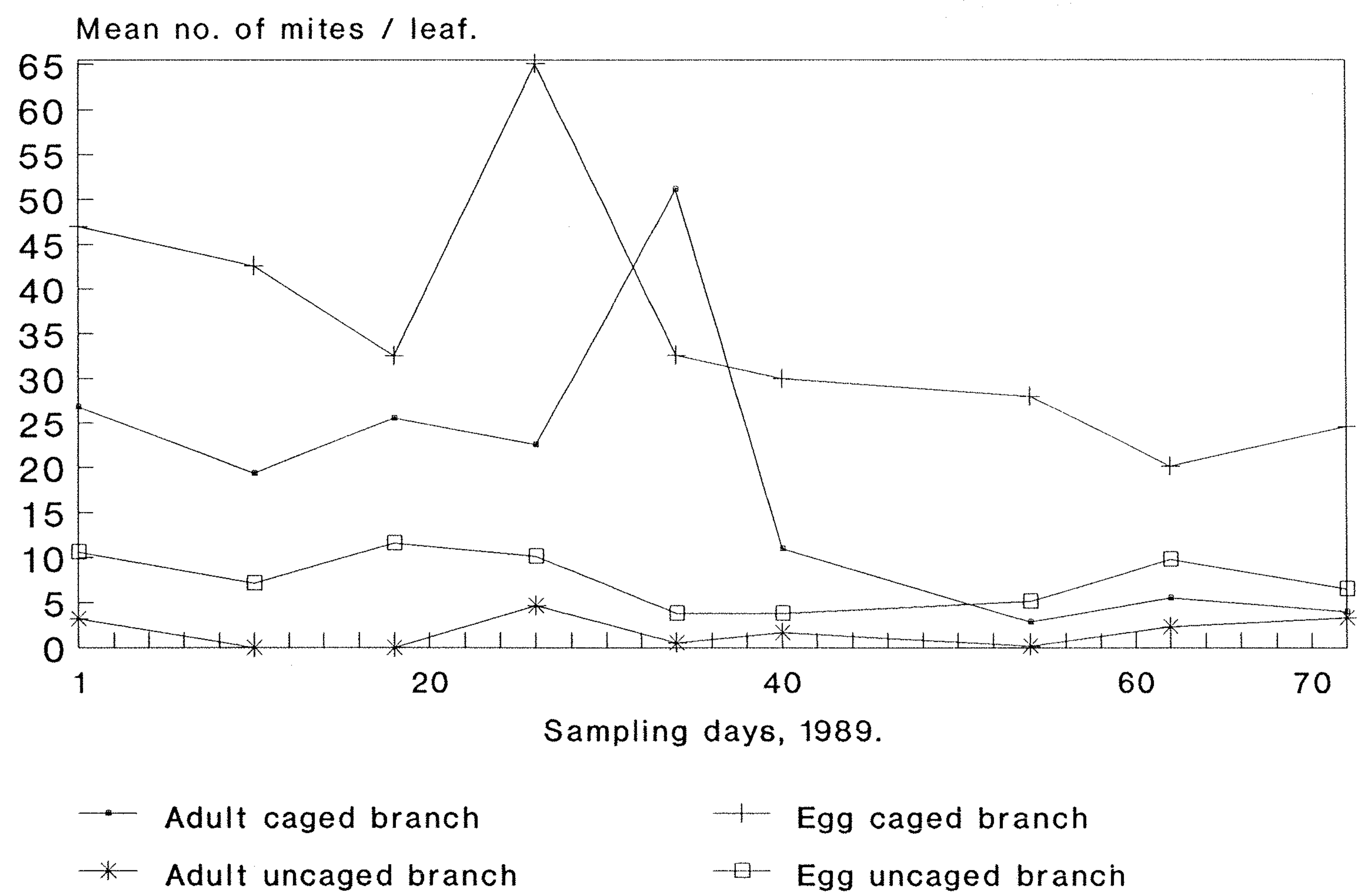


Figure 23. Distribution of *P. ulmi* on the exquisitte apple variety.

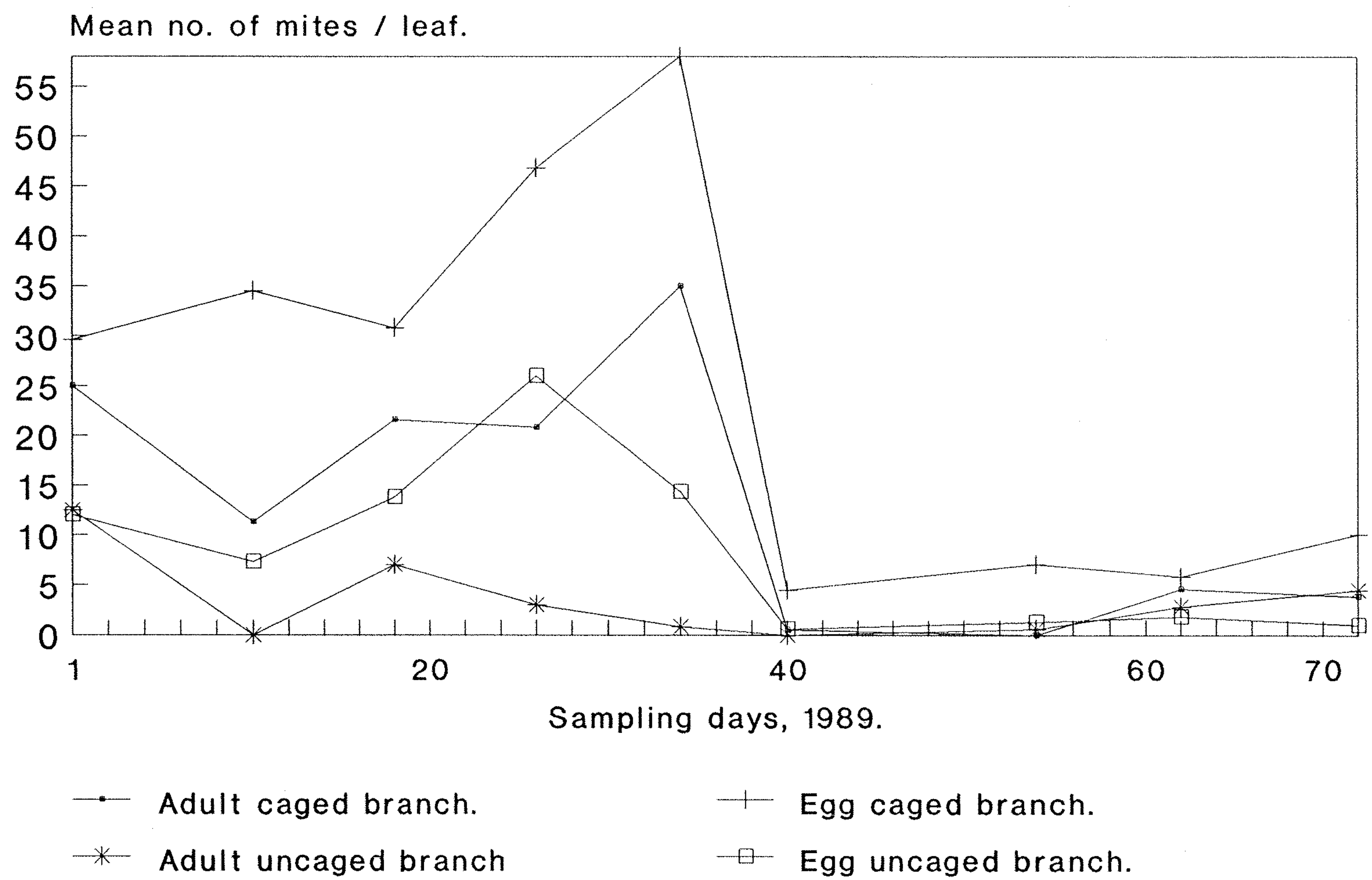


Table 9. Mean ± standard deviation of the numbers of *P. ulmi* and *A. schlechtendali* per leaf over the whole experiment.

9a Cox orange.

Statistics	*P. ulmi*				*A. schlechtendali*	
	Adult		Egg			
	Caged	Uncaged	Caged	Uncaged	Caged	uncaged
Mean	18.74	1.75	35.87	7.64	35.46	14.50
Standard deviation	24.83	2.95	34.76	9.55	85.00	27.72

9b Exquisitte.

Statistics	*P. ulmi*				*A. schlechtendali*	
	Adult		Egg			
	Caged	Uncaged	Caged	Uncaged	Caged	uncaged
Mean	13.64	3.48	25.27	8.70	34.37	16.37
Standard deviation	20.98	6.94	31.88	13.19	59.78	29.73

and adults of *P. ulmi* on both varieties. This may have been because leaf condition declined and the mites were unable to feed or disperse to new foliage because of the sticky barriers and cages. The numbers of egg and adult *P. ulmi* on uncaged branches of Cox orange did not reach any noticeable peak (Fig. 22) while on uncaged branches of Exquisitte there was a peak in the numbers of eggs on 26th sampling day (16th June) (Fig. 23), although ± 95% confidence interval overlapped each other on some dates as summary statistics of both branches caged and uncaged indicate in Tables 10a/10b and 11a/11b.

Correlation analysis was carried between the numbers of eggs and adults of *P. ulmi* on individual leaves on caged and uncaged branches of

Table 10. Mean, standard deviation and ± 95% conf. Interval of the numbers of *P. ulmi* per leaf on uncaged branches.

10a Cox orange.

Dates 1989.	Adult				Egg			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf. interval	
23/5	3.16	3.3	-9.4	15.7	10.6	9.3	-10.1	31.5
2/6*	0.0	0.0	0.0		7.1	9.2	-13.6	28.0
9/6	0.0	0.0	0.0		11.6	17.0	-9.1	32.5
16/6	4.66	5.8	-7.9	17.2	10.1	9.5	-10.6	31.0
23/6*	0.5	0.8	-12.0	13.0	3.8	6.0	-17.0	24.6
29/6	1.66	1.6	-10.9	14.2	3.8	6.4	-17.0	24.6
12/7*	0.16	0.4	-12.4	12.7	5.1	6.0	-15.6	26.0
19/7	2.33	2.5	-10.2	14.9	9.8	13.0	-11.0	30.6
27/7	3.33	3.0	-9.2	15.9	6.5	6.2	-14.3	27.3

10b Exquisitte bush.

Dates 1989	Adult				Egg			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf. interval	
23/5	12.5	16.0	1.1	23.8	12.0	11.4	-5.3	29.3
2/6*	0.0	0.0	0.0		7.3	6.1	-10.0	24.7
9/6	7.0	6.5	-4.3	18.3	13.8	13.2	-3.5	31.2
16/6	3.0	3.0	-8.3	14.3	26.0	26.4	8.6	43.3
23/6*	0.8	0.9	-10.5	12.1	14.3	8.8	-3.0	31.7
29/6	0.0	0.0	0.0		0.6	1.6	-16.7	18.0
12/7*	0.6	0.8	-10.6	12.0	1.3	1.2	-16.0	18.7
19/7	2.8	2.5	-8.5	14.1	1.8	2.3	-15.5	19.2
27/7	4.5	5.6	-6.8	15.8	1.0	1.2	-16.3	18.3

* indicates the sampling dates after spray applications.

Table 11. Mean, standard deviation and ± 95% conf. interval of the numbers of *P. ulmi* per leaf on caged branches.

11a Cox orange.

Dates 1989	Adult				Egg			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf. interval	
23/5	26.8	15.5	14.2	39.4	47.0	64.2	26.1	67.8
2/6	19.3	14.7	6.7	31.9	42.6	25.1	21.8	63.5
9/6	25.5	8.0	12.9	38.0	32.5	27.7	11.6	53.3
16/6	22.5	34.7	9.9	35.0	65.1	55.5	44.3	86.0
23/6	51.1	46.6	38.5	63.7	32.6	29.6	11.8	53.5
29/6	11.0	17.0	-1.5	23.5	30.0	28.7	9.1	50.8
12/7	2.83	2.1	-9.7	15.4	28.0	17.6	7.1	48.8
19/7	5.5	8.0	-7.0	18.0	20.1	8.8	-0.6	41.0
27/7	4.0	3.0	-8.5	16.5	24.6	16.8	3.8	45.5

11b Exquisitte bush.

Dates 1989	Adult				Egg			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf. interval	
23/5	25.0	27.1	13.6	36.3	29.6	20.92	12.2	47.0
2/6	11.3	9.2	-0.0	22.6	34.5	26.23	17.1	51.8
9/6	21.6	39.2	10.3	33.0	30.8	37.14	13.4	48.2
16/6	20.8	17.4	9.4	32.1	46.8	47.34	29.4	64.2
23/6	35.0	22.0	23.6	48.3	58.0	44.27	40.6	75.3
29/6	0.5	0.8	-10.8	11.8	4.5	4.59	-12.8	21.8
12/7	0.0	0.0	0.0		7.1	14.64	-10.2	24.5
19/7	4.6	3.6	-6.6	16.0	5.8	4.30	-11.5	23.2
27/7	3.8	2.8	-7.5	15.1	10.1	13.01	-7.2	27.5

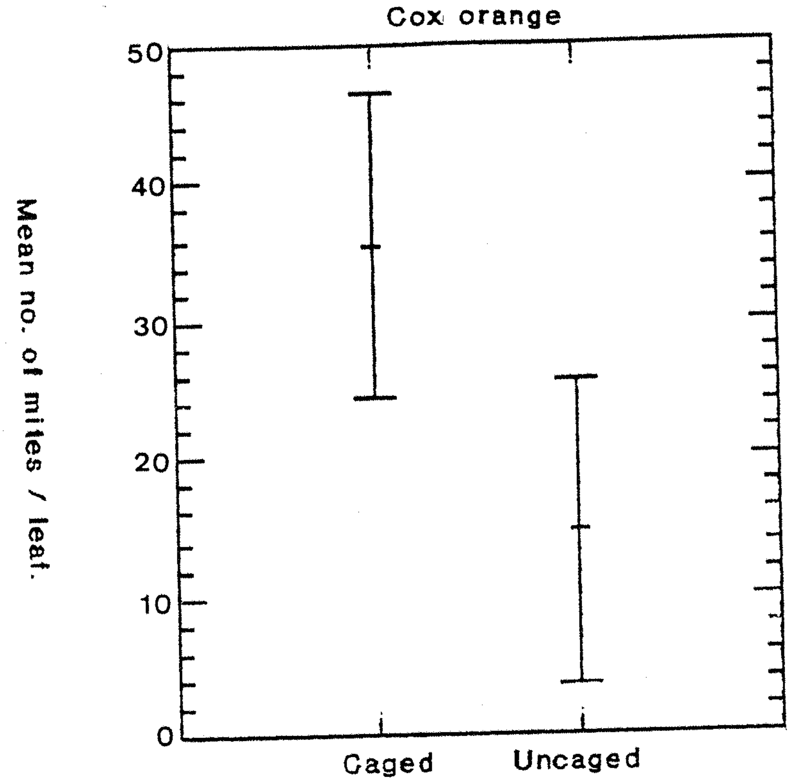
both varieties and also for covered and uncovered branches. Table 12 reveals a weak positive correlation between the numbers of eggs and adults of *P. ulmi*. The correlation was higher on caged and covered branches compared with uncaged and uncovered branches.

Table 12. Correlation analysis of the numbers of eggs and adult of *P. ulmi*.

Branches	Correlation between egg and adult	Significancet level (p)
Caged Cox orange	+ 0.2324	0.09
Uncaged Cox orange	+ 0.1354	0.32
Caged Exquisitte	+ 0.4649	0.00
Uncaged Exquisitte	+ 0.0700	0.61
Covered	+ 0.1182	0.39
Uncovered	+ 0.0807	0.56

Apple rust mite, *A. schlechtendali*.

The numbers of rust mites on caged and uncaged branches were analysed in the same way as the numbers of red mites and significant differences were again found between caged and uncaged branches of Cox orange $p < 0.01$ and Exquisitte $p < 0.05$ (Figs. 24 & Table 9 and Tables 10a & 10b in Appendix 2). Figures 25 and 26 show that the numbers of rust mites reached a peak on the 26th sampling day (16th June) on caged and uncaged branches of Exquisitte but their ± 95%



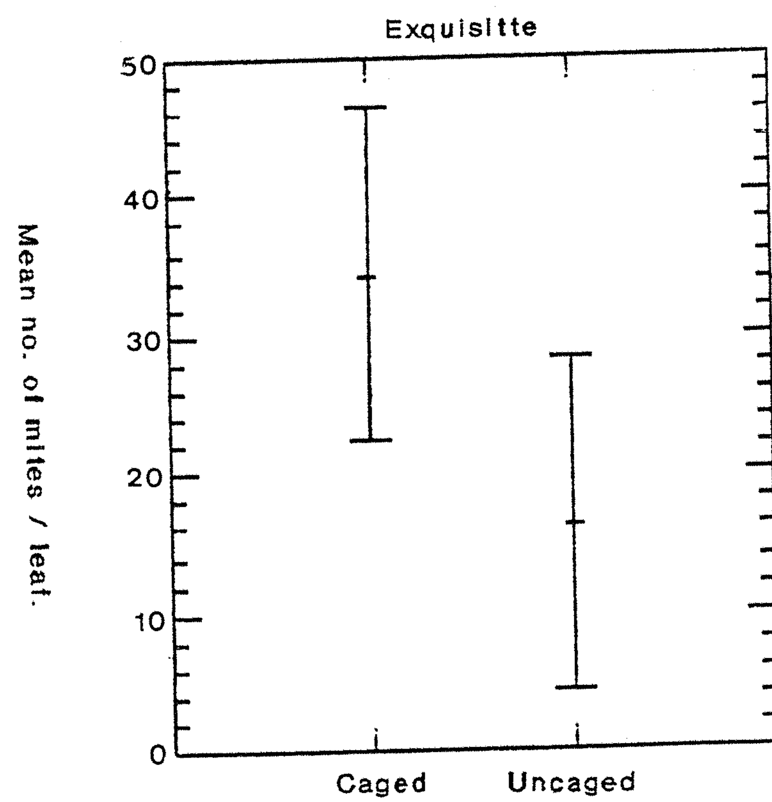


Figure 24. Overall mean numbers of rust mite / leaf with 95% confidence interval on differnt branches and varieties.

Figure 25. Distribution of *A. schlechtendali* on the Cox orange apple variety.

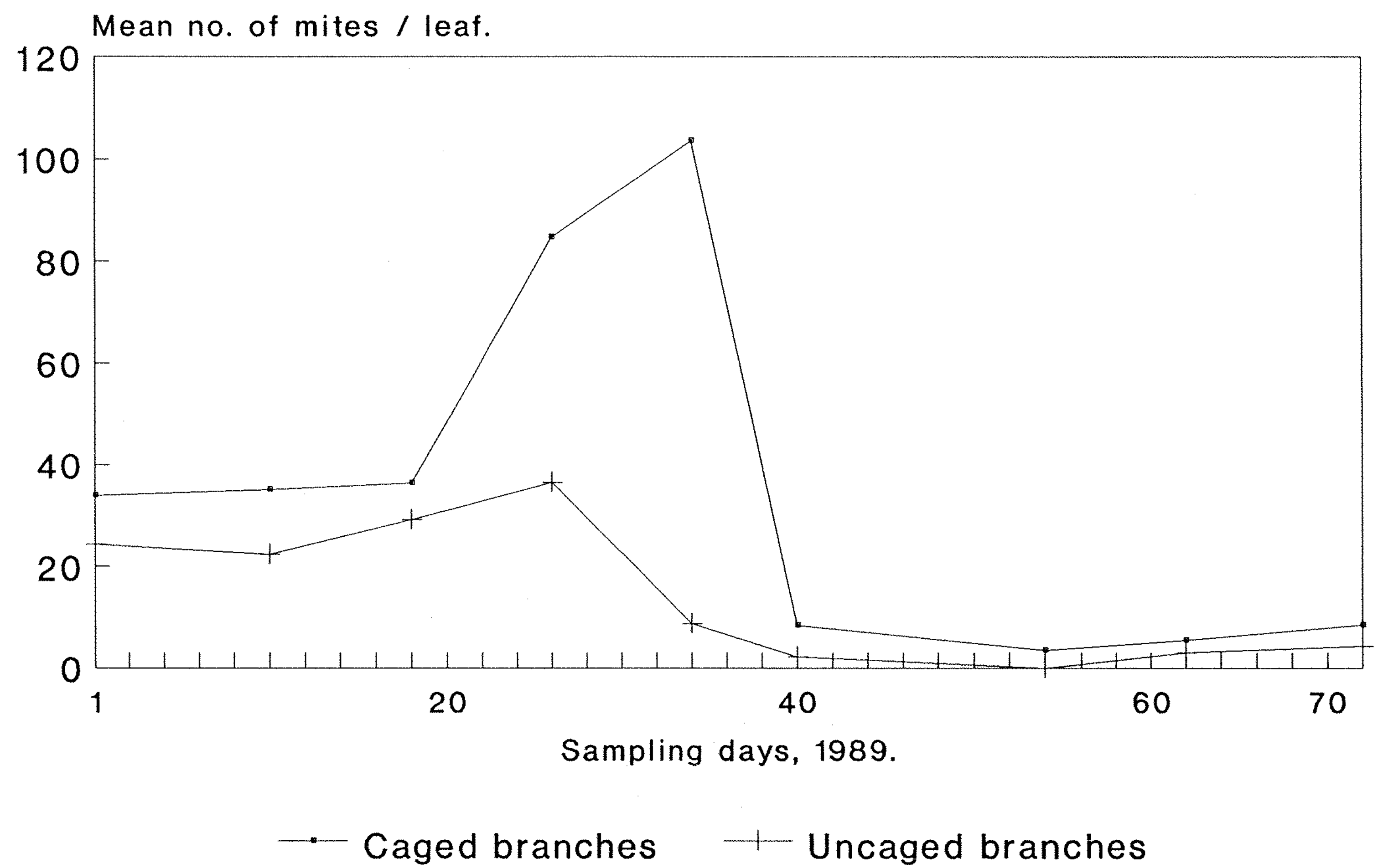


Figure 26. Distribution of *A. schlechtendali* on the Exquisitte apple variety.

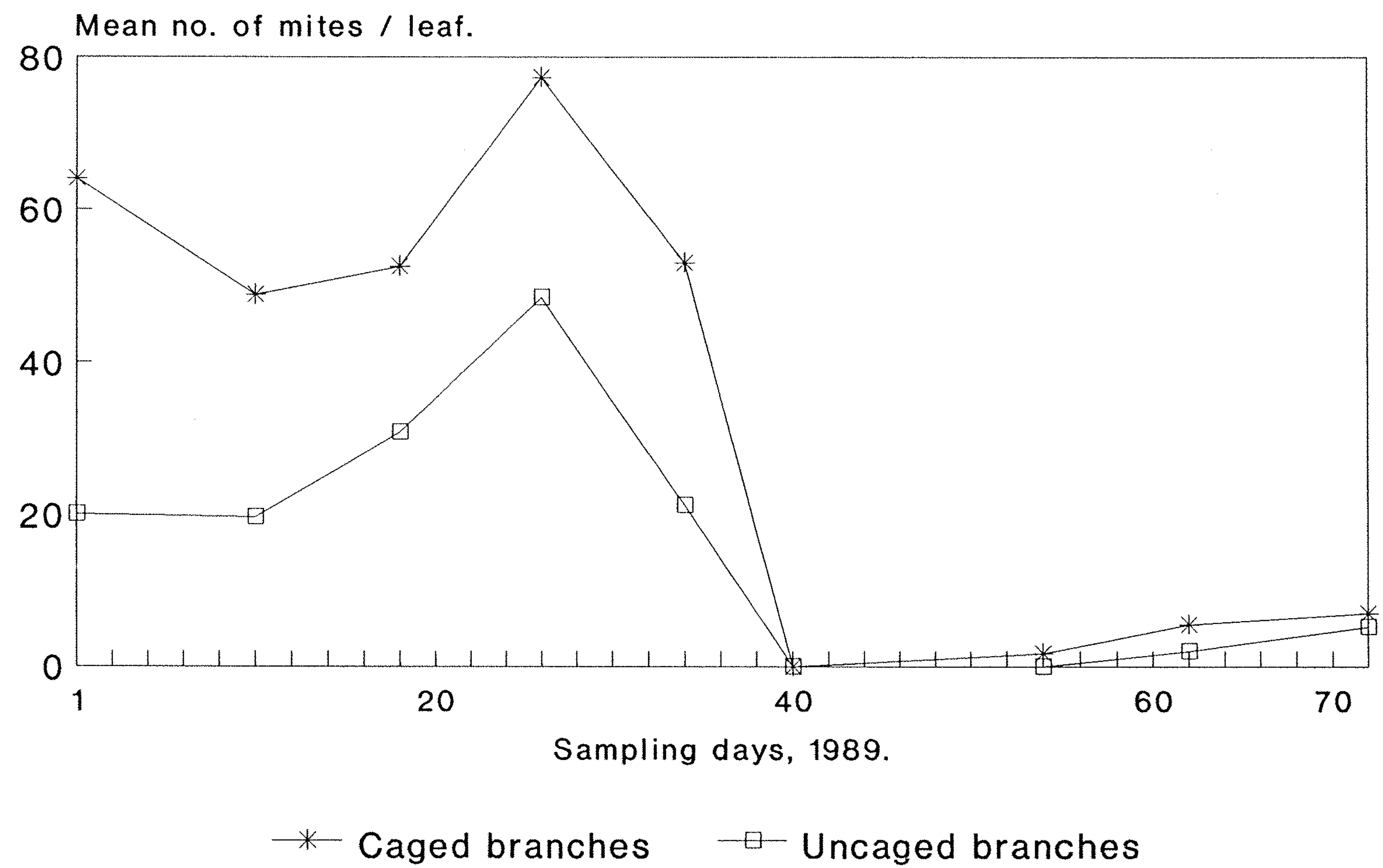


Table 13. Mean, standard deviation and ± 95% conf. interval of the numbers of *A. schlechtendali* per leaf on uncaged branches.

Dates 1989	Cox orange				Exquisitte			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf. interval	
23/5	24.33	46.13	-8.5	57.1	20.00	32.90	-16.1	56.1
2/6*	22.33	14.73	-2.1	67.8	19.66	20.07	-16.4	55.7
9/6	29.16	26.68	-3.6	62.0	30.83	32.98	-5.2	66.9
16/6	36.50	56.29	3.6	69.3	48.50	61.60	12.3	84.6
23/6*	8.66	8.14	-24.1	41.5	21.16	18.82	-14.9	57.2
29/6	2.16	2.13	-30.6	35.0	0.0	0.0	0.0	
12/7*	0.0	0.0	0.0		0.0	0.0	0.0	
19/7	3.0	2.68	-29.8	35.8	2.0	1.41	-34.1	38.1
27/7	4.33	7.33	-28.5	37.1	5.16	7.80	-30.9	41.2

* indicates sampling dates following spray application.

confidence interval overlapped each other (Tables 13 and 14). On the 34th sampling day (23rd June) of caged branches on the variety Cox orange (Fig. 25) and ± 95% confidence interval of caged and uncaged branches on this date did not overla each other. After these peaks the numbers decreased on both varieties which may again have been due to leaf condition as noted above. Table 13 indicates that after each spray the mean numbers of rust mites decreased, although the differences were not significant ($P > 0.05$) on certain occasions (Tables 11 & 12 in Appendix 2). Statistics for the numbers of rust mite on caged branches were also calculated and are given in Table 14.

Table 14. Mean, standard deviation and ± 95% conf. interval of the numbers of *A. schlechtendali* per leaf on caged branches.

Dates 1989	Cox orange.				Exquisitte			
	Mean	Std. dev.	95% conf. interval		Mean	Std.	95% conf.	
23/5	33.83	69.22	0.9	66.6	64.0	117.83	27.8	100.1
2/6	35.0	25.66	2.1	67.8	48.83	36.85	12.7	84.9
9/6	36.33	43.71	3.4	69.1	52.5	55.02	16.3	88.6
16/6	84.66	72.56	51.8	117.5	77.33	60.26	41.2	113.4
23/6	103.56	101.49	70.6	136.3	53.0	83.24	16.8	89.1
29/6	8.33	9.41	-24.5	41.1	0.0	0.0	0.0	
12/7	3.5	1.87	-29.3	36.3	1.66	0.83	-34.9	37.2
19/7	5.5	6.25	-27.3	38.3	5.5	1.87	-30.6	41.6
27/7	8.5	9.24	-24.3	41.3	7.0	3.20	-29.1	43.1

Covered branches VS uncovered branches.

European red spider mite, *P. ulmi*.

In the second treatment the spider mites were allowed to disperse from covered (untreated) to uncovered (treated) branches. Because the overall mean and ± 95% confidence interval line in Figure 27 overlapped and analysis of variance also showed that the differences between the numbers of eggs and adults *P. ulmi* on covered and uncovered branches were not significant $p > 0.05$ (Table 13 in Appendix 2) probably because the mites were allowed to disperse. It is also interesting to note that red spider mites were released on caged and covered branches on 14th May but when the leaves were sampled after 10 days on 23rd May, the mean numbers of eggs were 47.0 and adults were

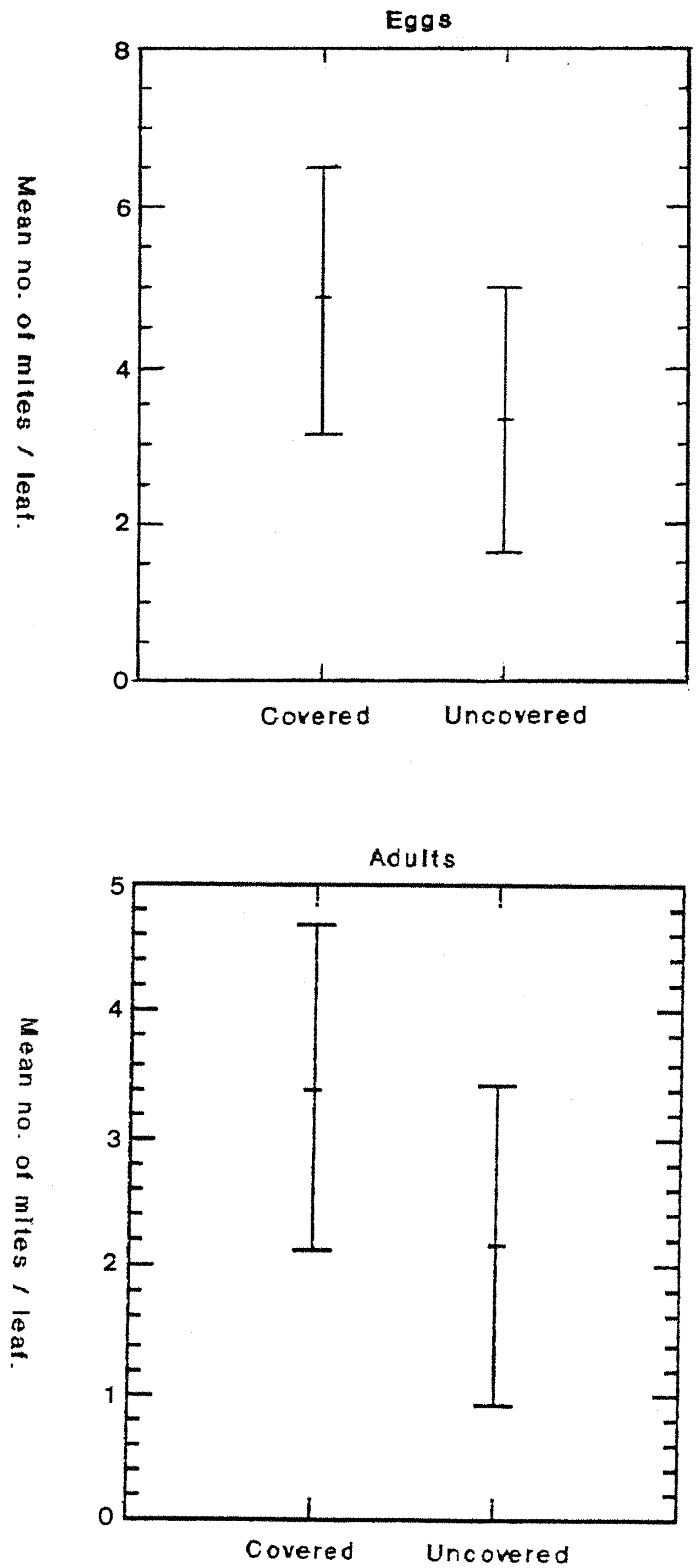


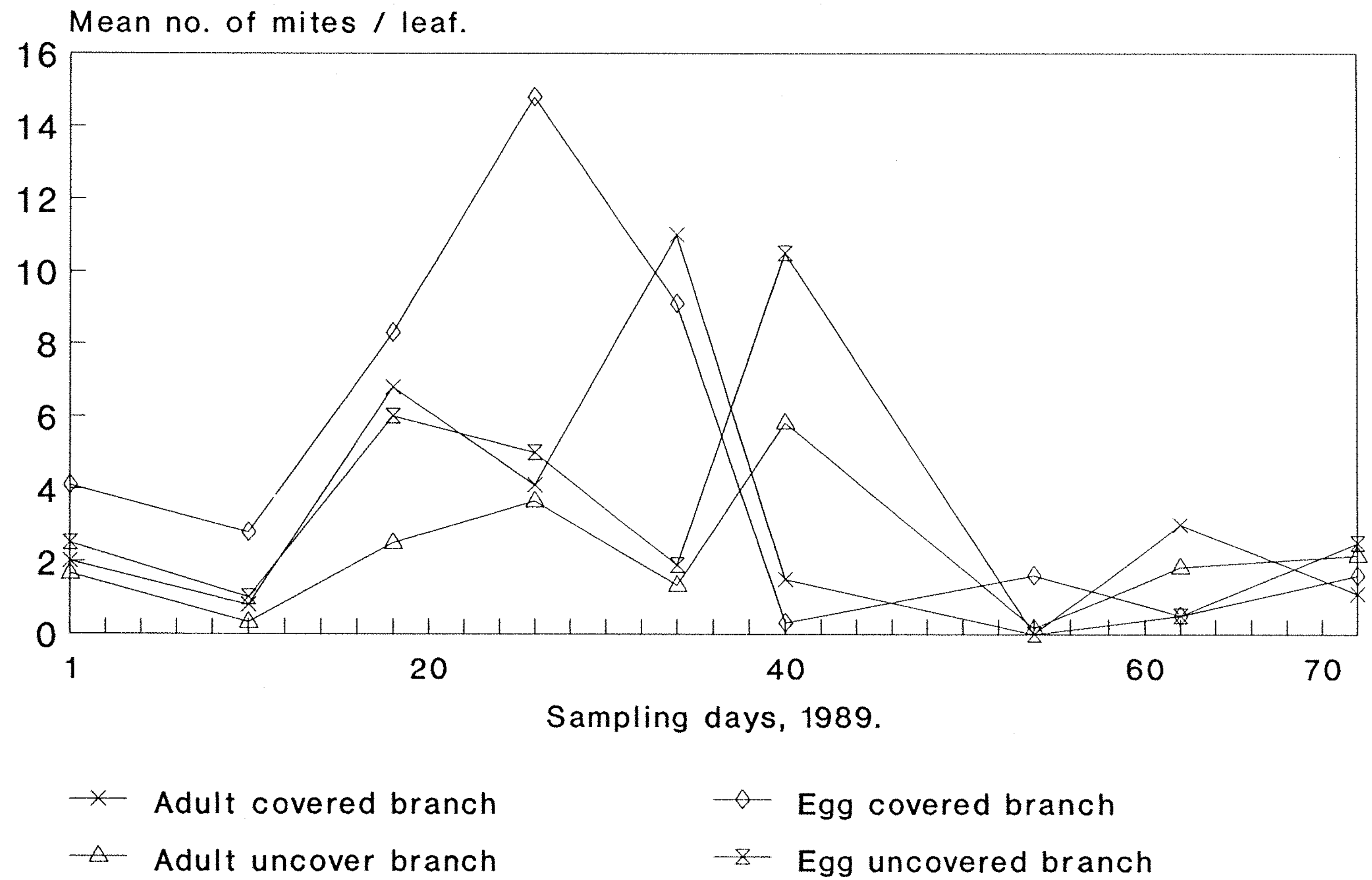
Figure 27. Overal mean numbers of mites / leaf with 95% confidence interval on different branches.

26.8 on caged branches of Cox orange (Table 11a, Fig. 22) and the mean numbers of eggs were 29.6 and adults were 25.0 on caged branches of Exqusitte (Table 11b, Fig. 23) while on covered branches the mean numbers of eggs and adults were 4.1 and 2.0 (Table 17, Fig. 28), respectively. This confirms the basic hypothesis that mites moved to uncovered branches within 10 days while on caged branches the mites did not move and many mites were found on this branch. The covered branches did not receive any spray at any time during the experiment. Figure 28 shows that many eggs and adults of *P. ulmi* were observed during the early part of the experiment on covered branches, where they were not exposed to residues. The numbers of egg on these branches reached a peak on the 26th sampling day (16th June) followed by peak numbers of adult on 34th sampling day (23rd June). The numbers of eggs and adults on uncovered branches reached peaks during the later part of the experiment on 29th June (40th sampling day), although ± 95% confidence interval of the numbers of mites on these two dates overlapped each other. Thus, during the early part of experiment,

Table 15. Mean and ± standard deviation of the numbers of *P. ulmi* and *A. schlechtendali* per leaf over the whole experiment.

Statistics	*P. ulmi*				*A. schlechtendali*	
	Adult		Egg			
	Covered	uncovered	covered	uncovered	covered	uncovered
Mean	3.38	2.16	4.83	3.31	9.40	6.25
Standard deviation	6.39	3.28	8.50	4.98	17.86	10.36

Figure 28. Distribution of *P. ulmi* on different branches of apple.



the leaves on covered branches, which were also in good condition, were unsprayed. The possible explanation for the decline on covered branches later in the experiment may be that leaves were damaged by continuous feeding. Mite numbers reached a peak during the latter part of the

Table 16. Mean, standard deviation and ± 95% conf. interval of the numbers *P. ulmi* per leaf on uncovered branches.

Dates 1989	Adult				Egg			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf. interval	
23/5	1.66	2.25	-2.1	5.4	2.5	1.8	-2.5	7.5
2/6*	0.33	0.51	-3.4	4.1	1.0	1.0	-4.0	6.0
9/6	2.5	2.73	-1.3	6.3	6.0	3.7	0.9	11.0
16/6	3.66	4.58	-0.1	7.4	5.0	3.8	-0.0	10.0
23/6*	1.33	1.50	-2.4	5.1	1.8	1.4	-3.1	6.8
29/6	5.83	4.83	2.0	9.6	10.5	10.5	5.4	15.5
12/7*	0.16	0.40	-3.6	3.9	0.0	0.0	0.0	
19/7	1.83	3.25	-1.9	5.6	0.5	0.8	-4.5	5.5
27/7	2.16	3.92	-1.6	5.9	2.5	2.8	-2.5	7.5

* indicates the sampling dates after spray applications.

experiment on uncovered branches on 29th June, but the numbers decreased again by 12th July (54th sampling day) after acaricide had been applied on 10th July. The summary statistics (Table 15) shows that there were few differences between the covered and uncovered branches. There were apparent differences in population variance estimates in the two treatments. However, when the numbers of mites on uncovered branches were compared for each date separately, it was found that after each spray the numbers decreased (Table 16). Statistical analysis showed that the differences between the numbers of mites after first and second sprays were not significantly different, however, there was a significant difference after the third spray (Table 14 in Appendix 2).

Mean, standard deviation and ± 95% confidence intervals for the numbers of mites on covered branches were also calculated and are given in Table 17.

Table 17. Mean, standard deviation and ± 95% confidence interval of the numbers *P. ulmi* per leaf covered branches.

Dates 1989.	Adult				Egg			
	Mean	Std. dev.	95% conf. interval		Mean	Std. dev.	95% conf . interval	
23/5	2.0	1.6	-1.8	5.8	4.1	3.0	-0.8	9.1
2/6	0.8	0.9	-2.9	4.6	2.8	1.8	-2.1	7.8
9/6	6.8	6.9	3.0	10.6	8.3	47.6	3.3	13.3
16/6	4.1	5.0	0.3	7.9	14.8	18.9	9.8	19.8
23/6	11.0	14.9	7.1	14.8	9.1	11.4	4.1	14.1
29/6	1.5	1.5	-2.3	5.3	0.3	0.8	-4.6	5.3
12/7	0.0	0.0	0.0		1.6	1.3	-3.3	6.6
19/7	3.0	2.8	-0.8	6.8	0.5	0.8	-4.5	5.5
27/7	1.1	1.6	-2.6	4.9	1.6	1.2	-3.3	6.6

Positive correlations between the numbers of eggs and adults of *P. ulmi* on covered and uncovered branches were evident (Table 12).

Apple rust mite, *A. schlechtendali*.

Figure 29 reveals that the increase in numbers of rust mites on covered and uncovered branches was paralleled from the first to 26th sampling day (23rd May to 16th June) with slightly lower numbers on uncovered branches. On 21st June the uncovered branches received an acaricide spray and the population on uncovered branches decreased by

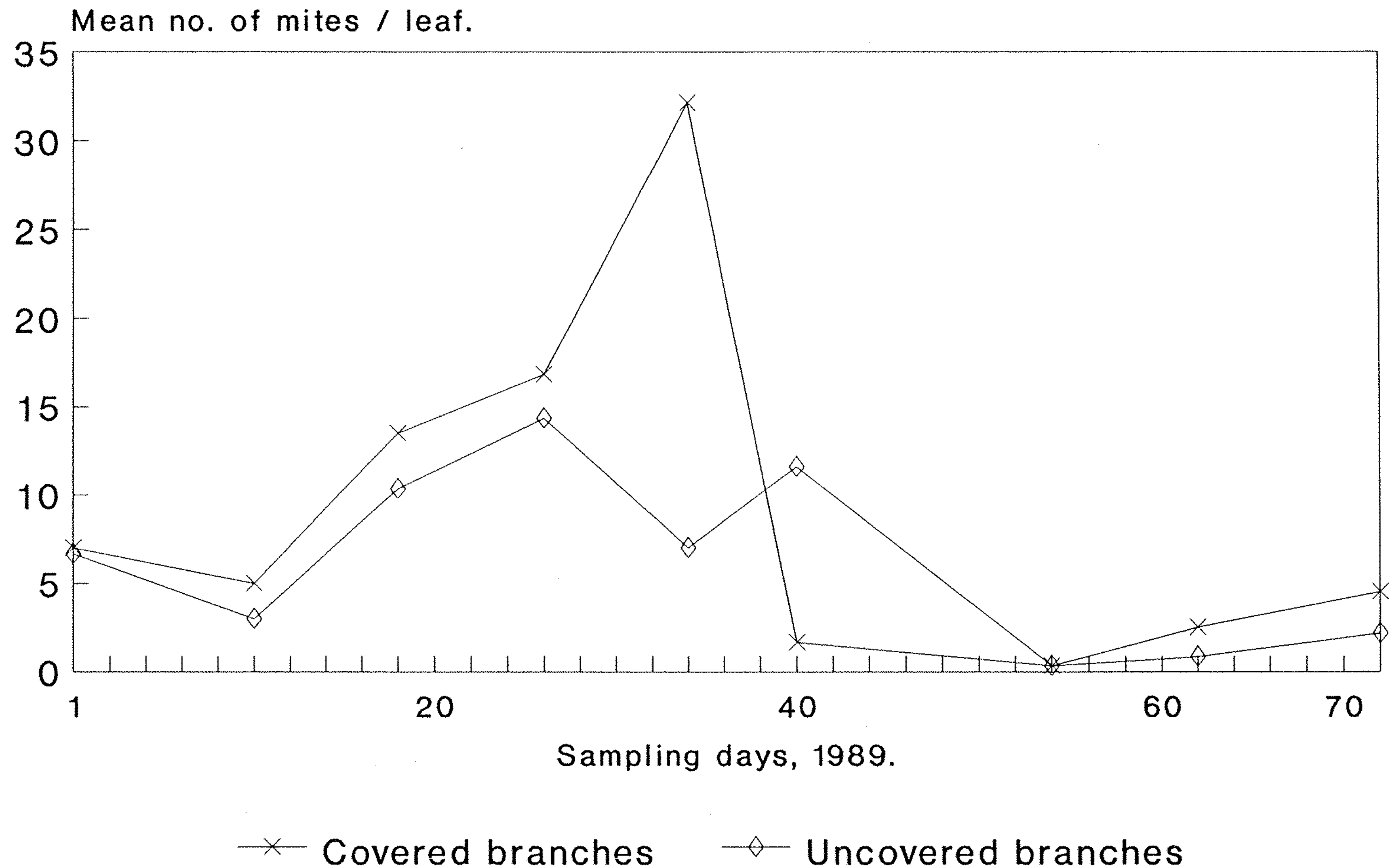
Table 18. Mean, standard deviation and ± 95% conf. interval of the numbers of *A. schlechtendali* per leaf on uncovered branches.

Dates 1989	Mean	Std. dev.	95% conf. interval	
23/5	6.66	8.43	-4.3	17.6
2/6*	3.00	1.67	-7.9	13.9
9/6	10.33	10.05	-0.5	21.2
16/6	14.33	23.25	3.4	25.2
23/6*	7.00	7.87	-3.9	17.9
29/6	11.66	10.36	0.7	22.5
12/7*	0.33	0.81	-10.5	11.2
19/7	0.83	0.98	-10.0	11.7
27/7	2.16	2.71	-8.7	13.0

* indicates the sampling dates after spray applications.

the 34th sampling day (23rd June). This difference was not significant $p > 0.05$ (Table 14, Appendix 2). The numbers eventually decreased on the covered branches possibly due to the worsening condition of the leaves and the mites may have died because of starvation, or some of them may have dispersed to uncovered branches

Figure 29. Distribution of *A. schlechtendali* on different branches of apple.



due to overcrowding oncovered branches or may be because the uncovered branches received three acaricide applications and the numbers of mites did not increase to such an extent and the leaves were in slightly better condition than the covered branches. This may be the reason why numbers increased on uncovered branches by 29th June (40th sampling day). The numbers of rust mites on covered and uncovered branches were compared statistically and were not significantly different $p > 0.05$ (Table 13, Appendix 2). The overall mean plot of the numbers of rust mites for the whole experiment gave the same trend (Fig. 30). The

Table 19. Mean, standard deviation and ± 95% conf. interval of the numbers of *A. schlechtendali* per leaf on covered branches.

Dates 1989	Mean	Std. dev.	95% conf. interval	
23/5	7.83	4.79	3.0	18.7
2/6*	5.0	3.22	-5.9	15.9
9/6	13.5	17.80	2.5	24.4
16/6	16.83	28.63	5.9	27.7
23/6*	32.1	34.30	21.2	43.0
29/6	1.66	1.21	-9.2	12.5
12/7*	0.33	0.51	-10.5	11.2
19/7	2.50	2.58	-8.4	13.4
27/7	4.5	5.46	-6.4	15.4

* indicates the sampling dates after spray applications.

sample statistics for rust mites are given in Table 15. Although the numbers on covered branches were higher than on the uncovered branches, the difference between them was not significant, $p > 0.05$. The mean

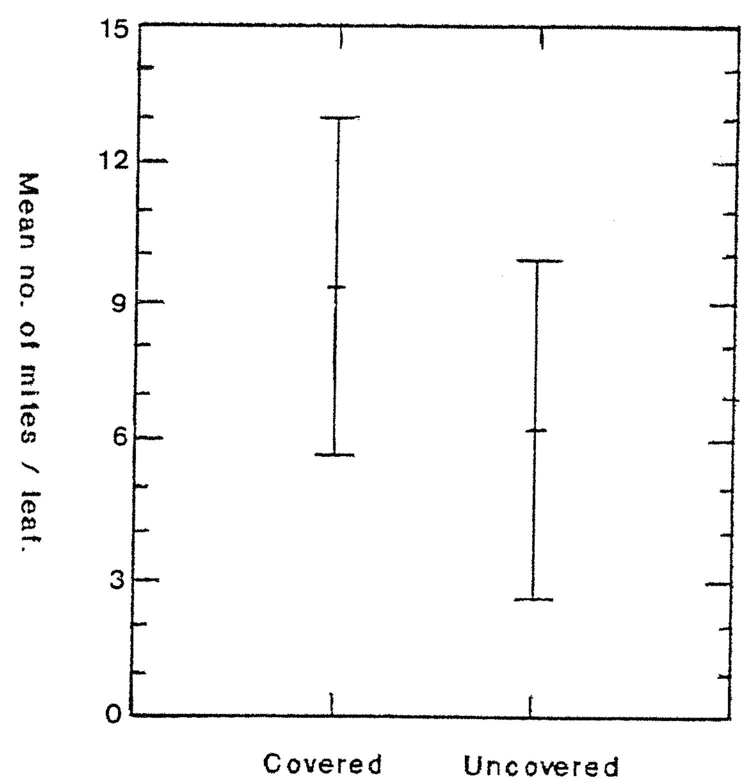


Figure 30. Overal mean numbers of rust mite / leaf with 95% confidence interval on different branches.

numbers of rust mites on uncovered branches also decreased each time after spraying (Table 18). The differences after the first and second sprays were not significant, however, the difference was significant after the third spray (Table 14, Appendix 2). Summary statistics of the numbers of rust mites on covered branches are also given in Table 19.

Caged branches VS covered branches.

European red spider mite, *P. ulmi.*

P. ulmi were released onto caged and covered branches on 14th May but after 10 days more mites were found on the caged branches of both varieties than on the covered ones in the first sampling on 23rd May. This suggests that mites did not move to uncaged branches due to the sticky barriers, while they moved from covered to uncovered branches which had no sticky barriers. This trend is also evident in Figures 22, 23 and 28. The overall mean plot with ± 95% confidence interval in figures 31a and 31b also shows significant differences between the two branches since their lines did not overlap. The numbers of eggs and adults on the caged branches of Cox orange (Fig. 22) reached a peak numbers on the 26th and 34th sampling day (16th and 23rd June), respectively. While they reached a peak on 23rd June on Exquisitte (Fig. 23). Although the numbers on covered branches also reached peaks, they were less than on the caged branches (Fig. 28). The numbers of eggs and adults on covered branches decreased by 29th June (40th sampling day) and they did not increase until the end of the experiment. The numbers of eggs and adults on uncovered branches

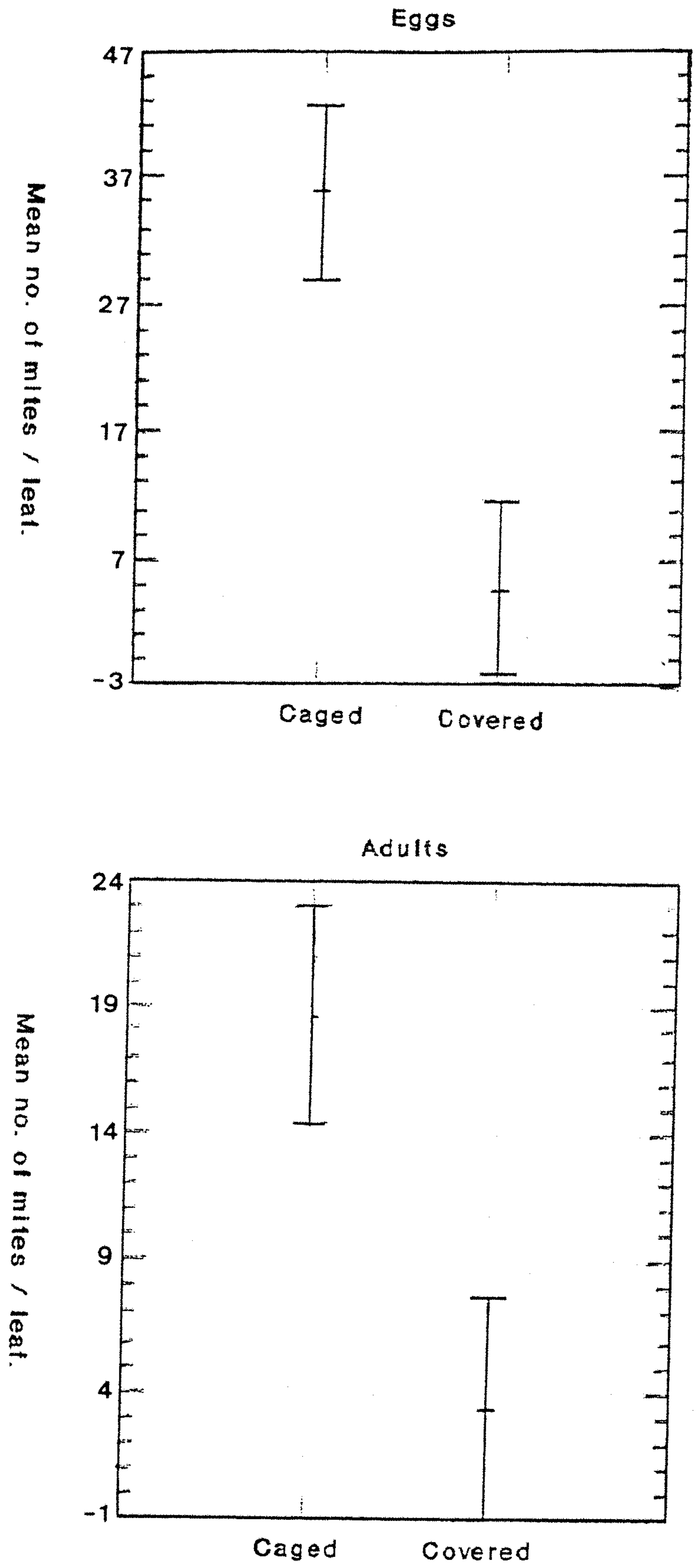
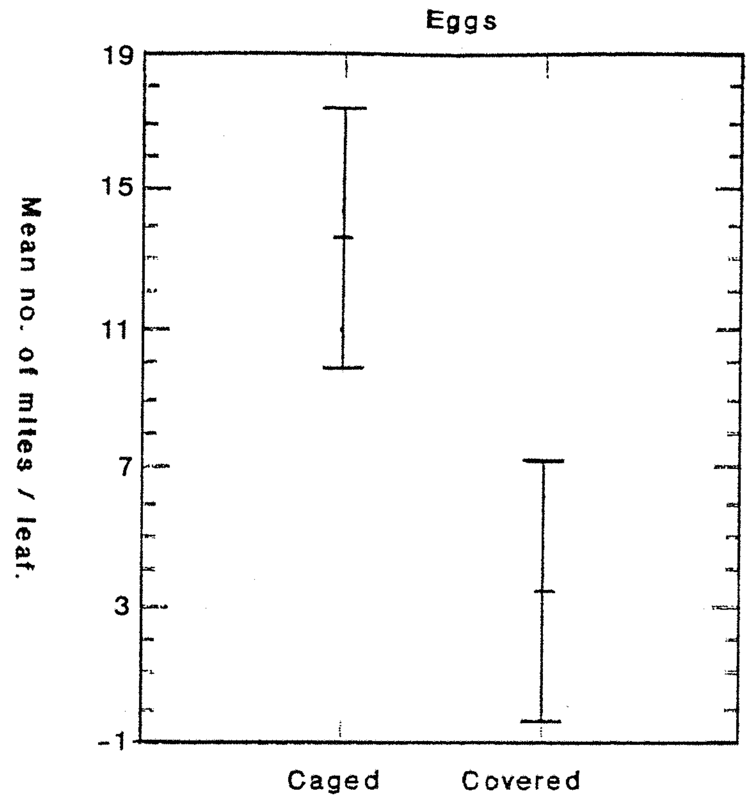


Figure 31a. Overall mean numbers of mites / leaf with 95% confidence interval on different branches.



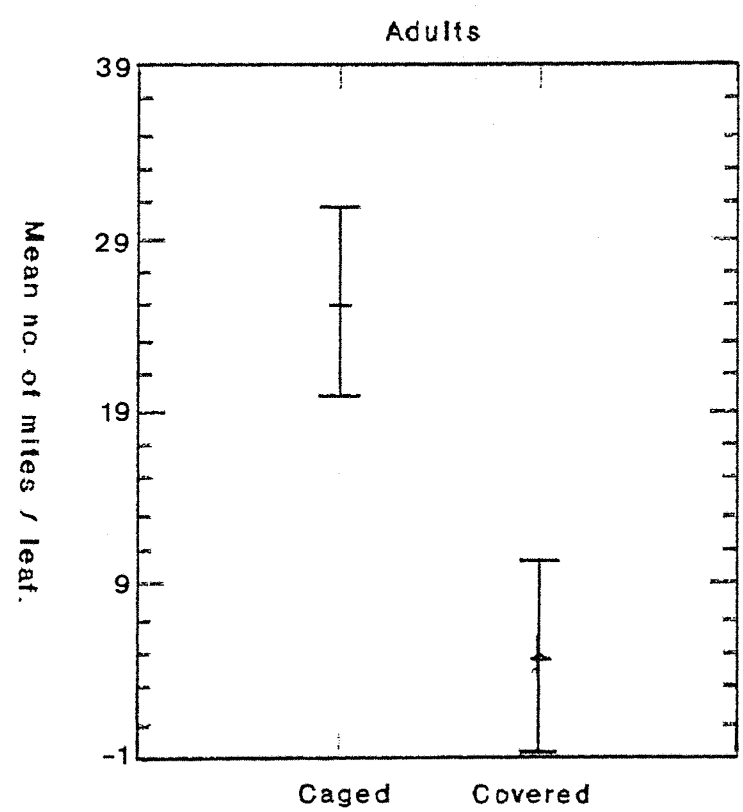


Figure 31b. Overall mean numbers of mites / leaf with 95% confidence interval on different branches.

increased in the period upto 29th June (Fig. 28). This trend suggests that mites may have moved onto uncovered branches from covered ones. The comparison between caged and covered branches confirms the potential importance of redistribution from reservoirs. However, the drastic overall decline in numbers in the " covered " experiment

Table 20. Mean and standard deviation of the numbers of *P. ulmi* and *A. schlechtendali* per leaf on different branches over the whole experiment.

Cox orange.

Statistics	*P. ulmi*				*A. schlectendali*	
	Adult		Egg			
	Caged	Covered	Caged	Covered	Caged	Covered
Mean	18.74	3.38	35.87	4.83	35.46	9.40
Standard deviation	24.83	6.39	34.76	8.50	54.00	17.86

Exquisitte

Statistics	*P. ulmi*				*A. schlectendali*	
	Adult		Egg			
	Caged	Covered	Caged	Covered	Caged	Covered
Mean	13.64	3.38	25.27	4.83	34.37	9.40
Standard deviation	20.98	6.39	31.88	8.50	59.74	17.86

suggests that mites are not repelled by residues and may be killed when they disperse. The differences between caged and covered branches were compared and found to be significant $p < 0.01$ (Table 15, Appendix 2). Table 20 shows the sample statistics of the numbers of mite on caged and covered branches.

Apple rust mite, *A. schlechtendali*.

The numbers of rust mites on caged and covered branches showed similar results to the eggs and adults of *P. ulmi*. Since the mites were not permitted to disperse from the caged areas, the numbers of rust mites were higher on the caged branches of both varieties (Fig. 32). Mites were therefore dispersing from covered to uncovered branches where they were not confined on covered branches by cages and sticky barriers. The numbers of rust mite decreased by 29th June (40th sampling day) (Figs. 24, 25 & 29). The possible reason for this was the worsening condition of leaves due to the continuous feeding by mites on covered branches. Although the numbers of mites decreased on caged branches, the numbers were still higher than on covered branches (Figs. 24, 25 & 29). Significant differences ($p < 0.01$) were found when the numbers of mites were compared between caged and covered branches (Tables 15a & 15b, Appendix 2). The statistics of the numbers of mites on caged and covered branches are given in Table 20.

Uncaged branches VS uncovered branches.

European red spider mite, *P. ulmi*.

For the purposes of comparison, the numbers of eggs and adults of *P. ulmi* on uncaged branches of Cox orange and Exqusitte were compared with uncovered branches. The numbers of eggs of *P. ulmi* on uncaged branches of both varieties were significantly higher ($P < 0.01$) than uncovered branches but numbers of adults were not significantly different $P > 0.05$ (Figs. 33a & 33b). The numbers of adults on uncaged and uncovered branches were similar, with slight changes on some occasions from the 1st sampling day to the 34th sampling day

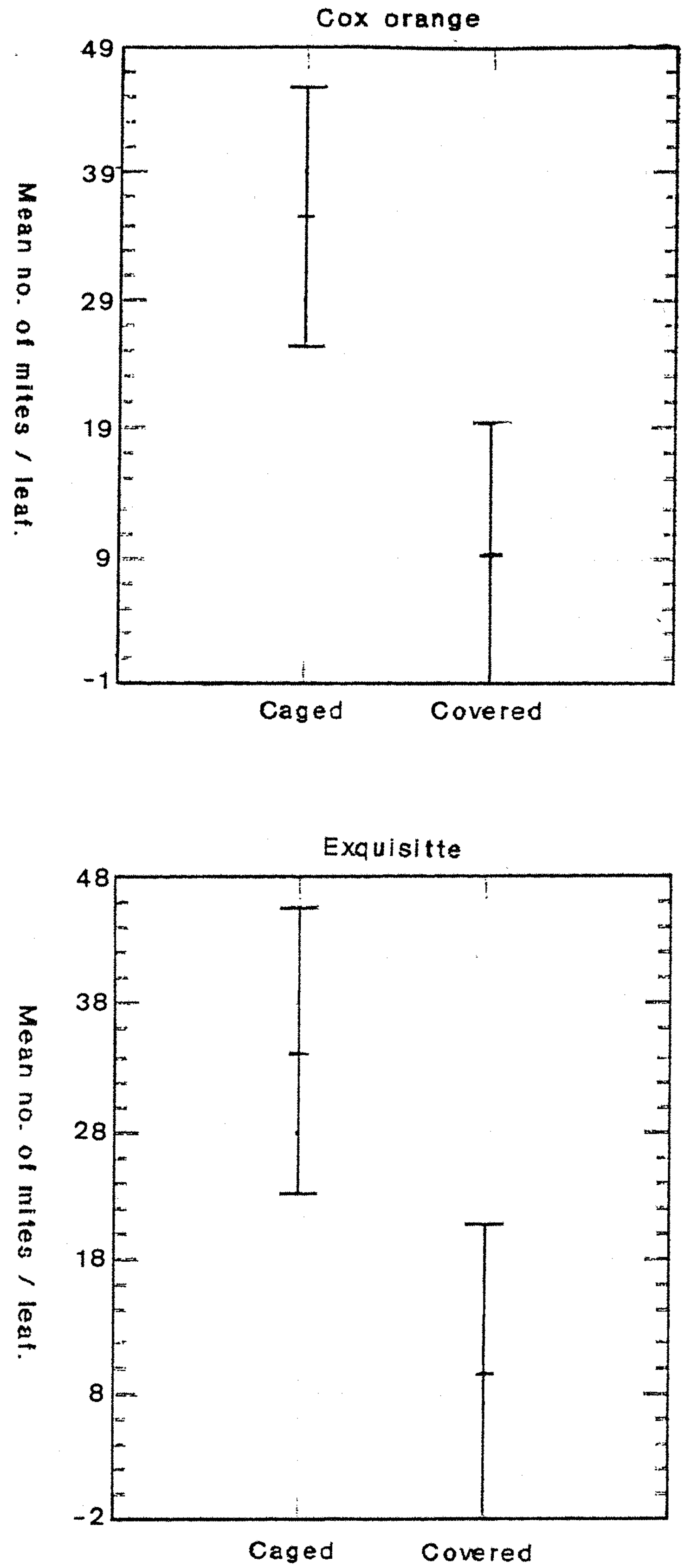
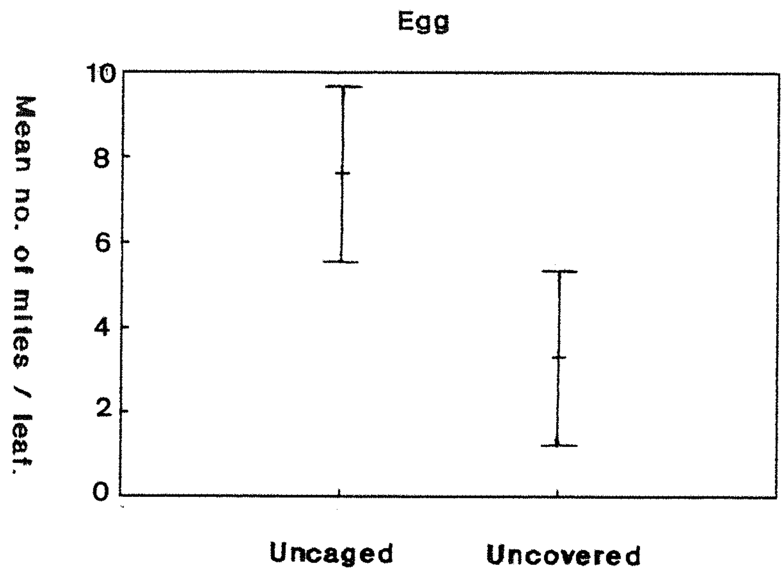


Figure 32. Overall mean numbers of rust mite / leaf with 95% confidence interval on different branches and varieties.

Cox orange



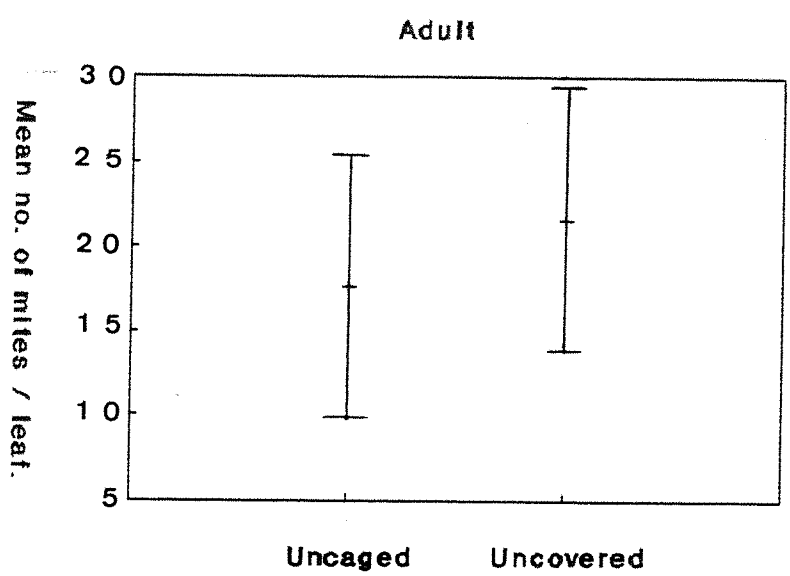


Figure 33a. Overall mean numbers of mites / leaf with 95% confidence interval on different branches.

Exquisitte

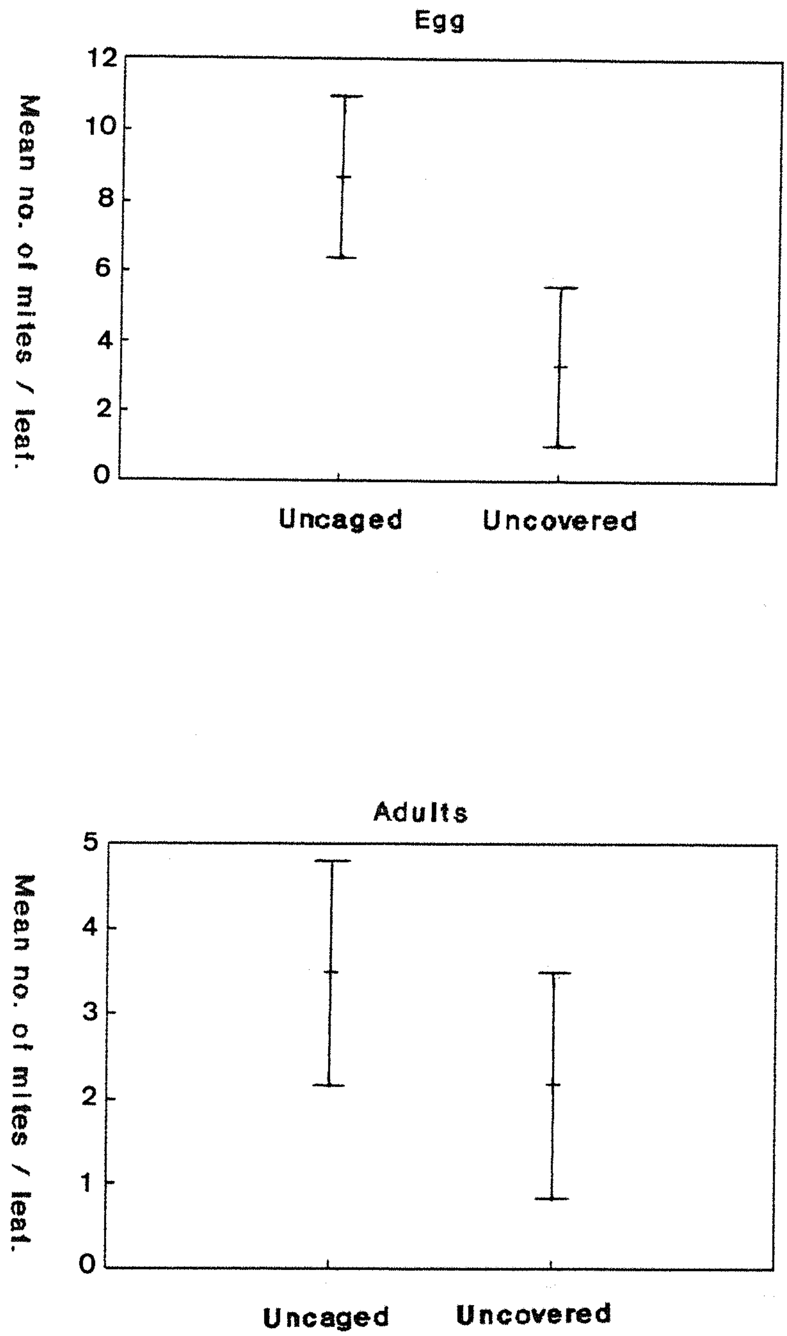


Figure 33b. Overall mean numbers of mites / leaf with 95% confidence interval on different branches.

(23rd May to 23rd June) and from 12th July to 27th July (54th sampling day to last sampling day) (Fig. 34 & 35). These Figures also indicate that the numbers of egg and adult of *P. ulmi* increased on uncovered branches on 40th sampling day (29th June). The possible reason is the dispersal of mites from covered to uncovered branches (Fig. 28). At the end of the experiment on the last sampling date (27th July) the numbers of adults increased on uncaged branches, although eggs decreased; this suggests that on these branches many mites were in the adult stage. The numbers of mites on uncovered branches showed the opposite response. On these branches more mites were in the egg stage than the adult stage.

Apple rust mite, *A. schlechtendali*.

The numbers of *A. schlechtendali* on uncaged and uncovered branches were also compared. There were many mites found on uncaged branches of both varieties from the 1st sampling day to the 26th sampling day (23rd May to 16th June) (Figs. 25, 26 and 29). The numbers decreased on both branches on the 23rd June due to an acaricide application on the 21st June. On the 40th sampling day (29th June) the numbers increased on uncovered branches but not on uncaged ones. The posible reason for this is that mites moved from covered to uncovered but they did not move from caged to uncaged branches. Statistical analysis of the numbers of rust mites on uncaged and uncovered showed that the numbers were significantly different $p < 0.05$ on Cox orange and on Exquisitte $p < 0.01$ (Tables 16 and 17, Appendix 2). Mean and ± 95% confidence interval also reveals the same trend (Fig. 36).

Figure 34. Distribution of P. ulmi on different branches of apple (Cox orange).

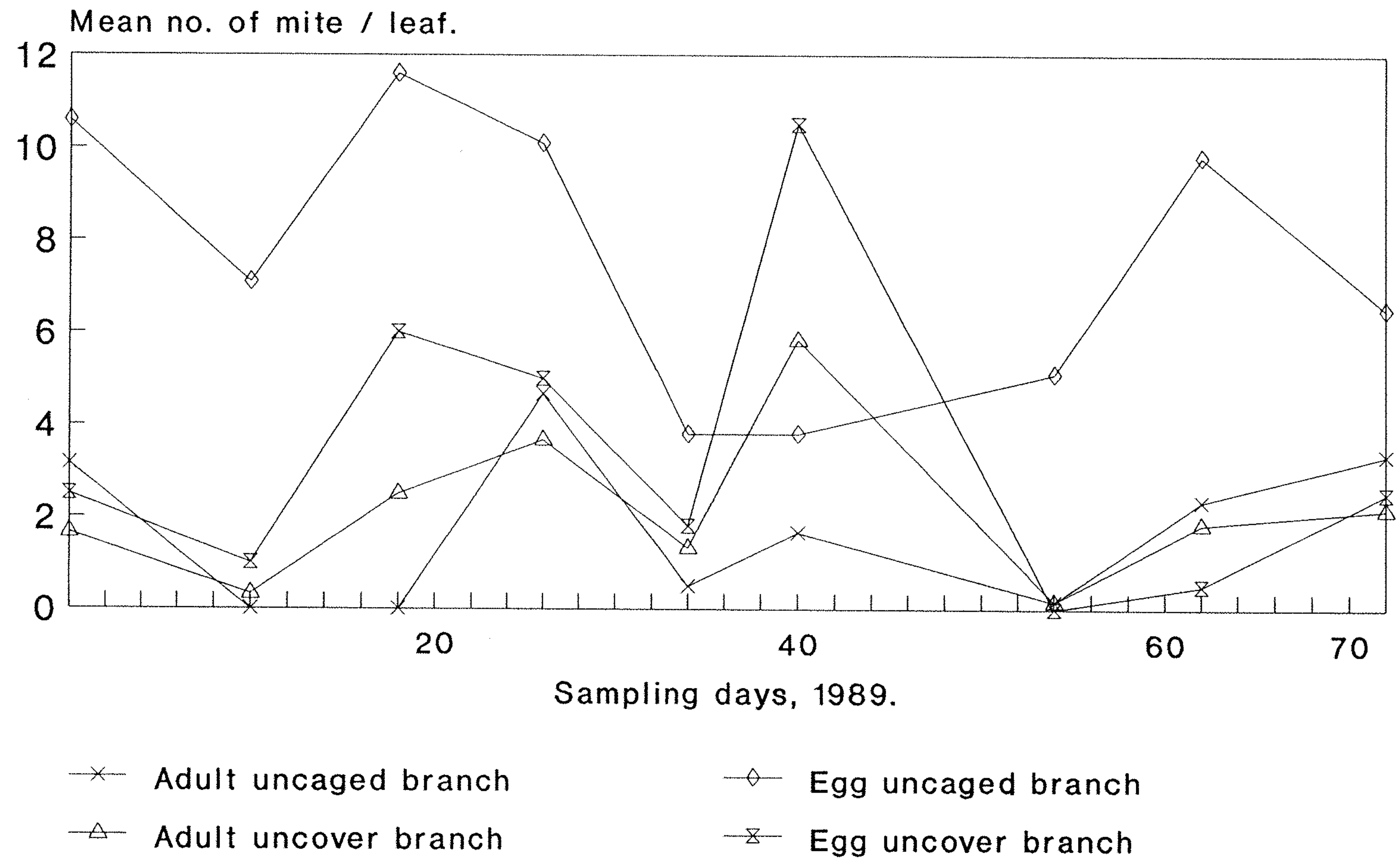
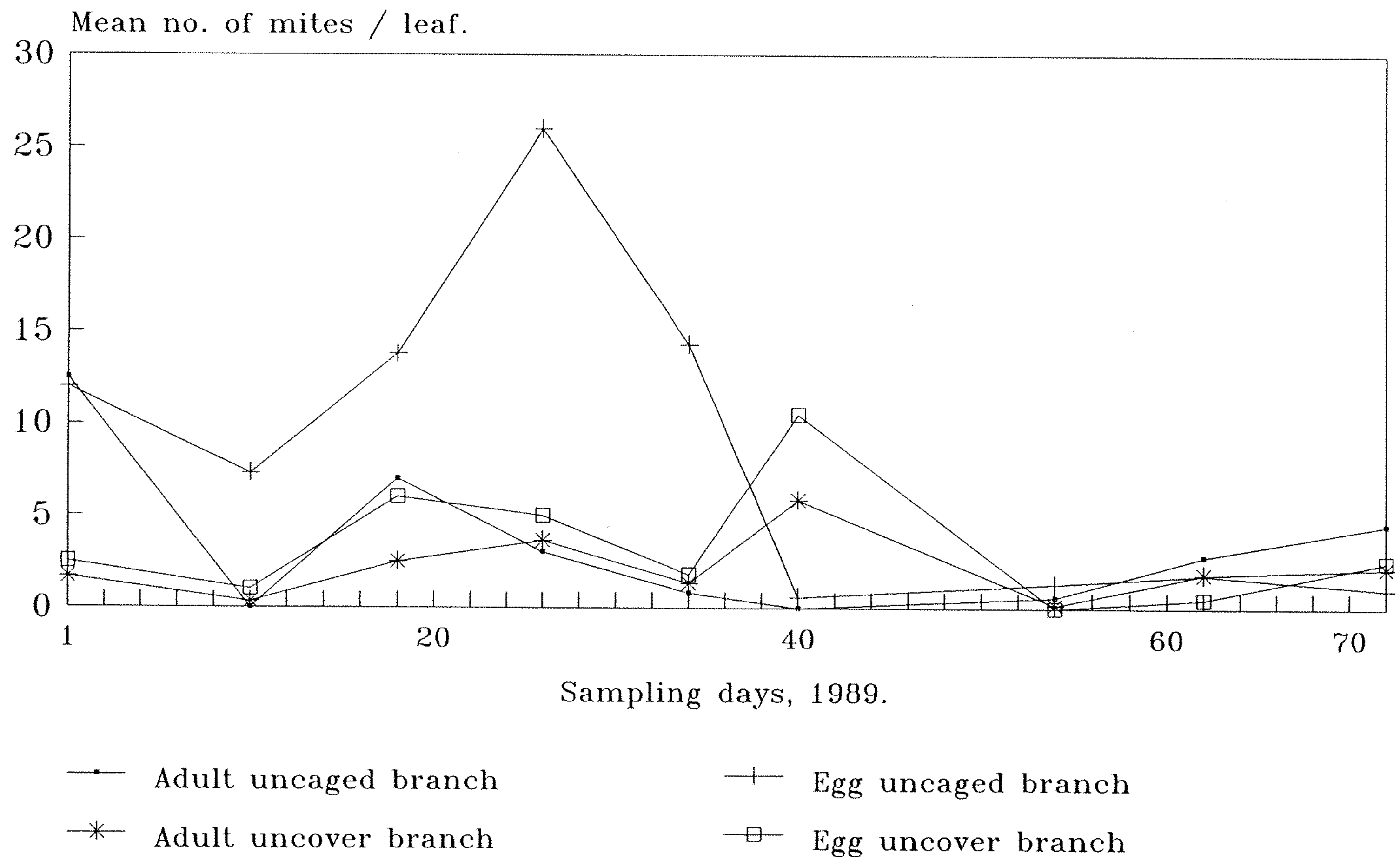


Figure 35. Distribution of *P. ulmi* on different branches of apple (Exquisitte).



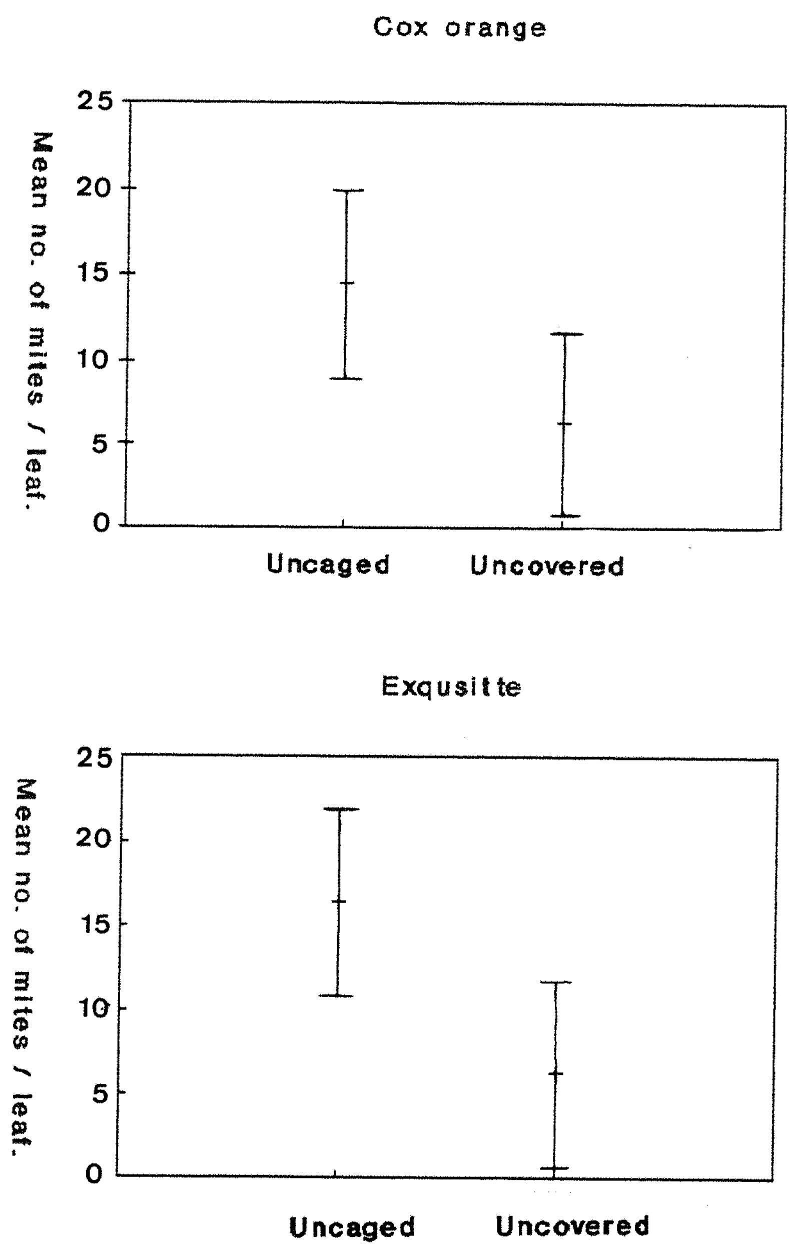


Figure 36. Overall mean numbers of rust mite / leaf with 95% confodence interval on different branches.

This questions the significance of the recolonisation of sprayed areas from the unsprayed reservoir; if this phenomenon was significant, the numbers of mites on the uncovered branches should have been higher than numbers on the uncaged branches.

CONCLUSIONS

Experiments on the movement or dispersal of mites from untreated to treated branches in the glasshouse showed that when the movement of mites were restricted on branches with cages and sticky barriers the mites did not disperse or move and their numbers were significantly higher than on uncaged branches. When the mites were allowed to disperse from branches which were covered (untreated) without cages or sticky barriers they moved and the numbers of mites were not significantly different between the different branch areas.

The above results from the glasshouse experiment only lend limited support to our studies of mite distribution on leaf ages and positions during the 1988 season, when it was suggested that mites moved or dispersed from untreated to treated branches or foliage and that those, less treated rather than untreated branches, acted as reservoirs. Untreated branches or foliage may be in the inner or outer positions of the trees but the most probable site is in the inner position. It is not neccesary for adult mites to survive these sprays. Eggs can also survive on treated or less treated branches or foliage and hatch after spraying allowing the next generation to disperse.

From the results of this experiment it is concluded that (1) limited movement occurs between branches or foliage, (2) many mites move and die if the leaf on a certain branches or foliage has some toxic residue of pesticides. (3) Along with the mite movement from untreated branches or foliage to treated ones, limited additional survival especially as eggs on treated branches, may occur. In future, a control group of trees which are fully sprayed will be used, to provide a second comparison. This would permit the overall importance of reservoir areas on the tree to be determined. Limited doses could also be applied to the caged/covered areas to simulate agricultural practice.

Chapter 3

FIELD EXPERIMENT

INTRODUCTION.

To investigate the dispersal of spider mites from untreated to treated branches, similar studies were designed in a commercial orchard with old trees which were planted in 1965.

MATERIALS AND METHODS.

The basic materials and methods of this experiment were similar to the glasshouse experiment.

This experiment was carried out on 24 year old Cox orange trees budded on M9, planted in rows of 4.2 m X 3 m. The tree height was approximately 3.5 metres. To manipulate spider mite dispersal from untreated to treated branches, three trees were selected for the establishment of caged (untreated) and uncaged (treated) branches. One branch per tree was chosen and a sticky barrier was put around the base of each caged branch. The cages were made of " Tube gauze ". The branches were then caged in the first week of April, just before the second pesticide spray on 7th April (Table 2 in Appendix 1). The size (length and diamter) of the cages and the materials used were the same as for the glasshouse experiment. In order to avoid spray drift into the cages, they were covered by tubular polythene. Since it was not convenient to cover the branches each time before spraying, the branches remained covered throughout the experiment. The base of each cage was open all the time and a few small holes were made in the tubular polythene at the top of each cage for aeration.

To permit the spider mites to disperse from covered (untreated) to uncovered (treated) branches, three trees were selected and one branch per tree was chosen. The tubular polythene was placed on a cylindrical frame but without tube gauze, the bottom end was open and no sticky barrier was put around the base of these branches. The mites were thus permitted to move to the uncovered (treated) branches.

The orchard was sprayed with different pesticides according to the grower's own spray schedule (Table 2, Appendix 1).

The assessments of numbers of spider mites were similar to those for the glasshouse experiment but the numbers of leaves per sample were increased from 2 to 3 leaves / branch from each of three trees. The numbers of mites on each leaf were transformed by log(x + 1) and all statistical analyses were carried out on these numbers.

RESULTS AND DISCUSSIONS

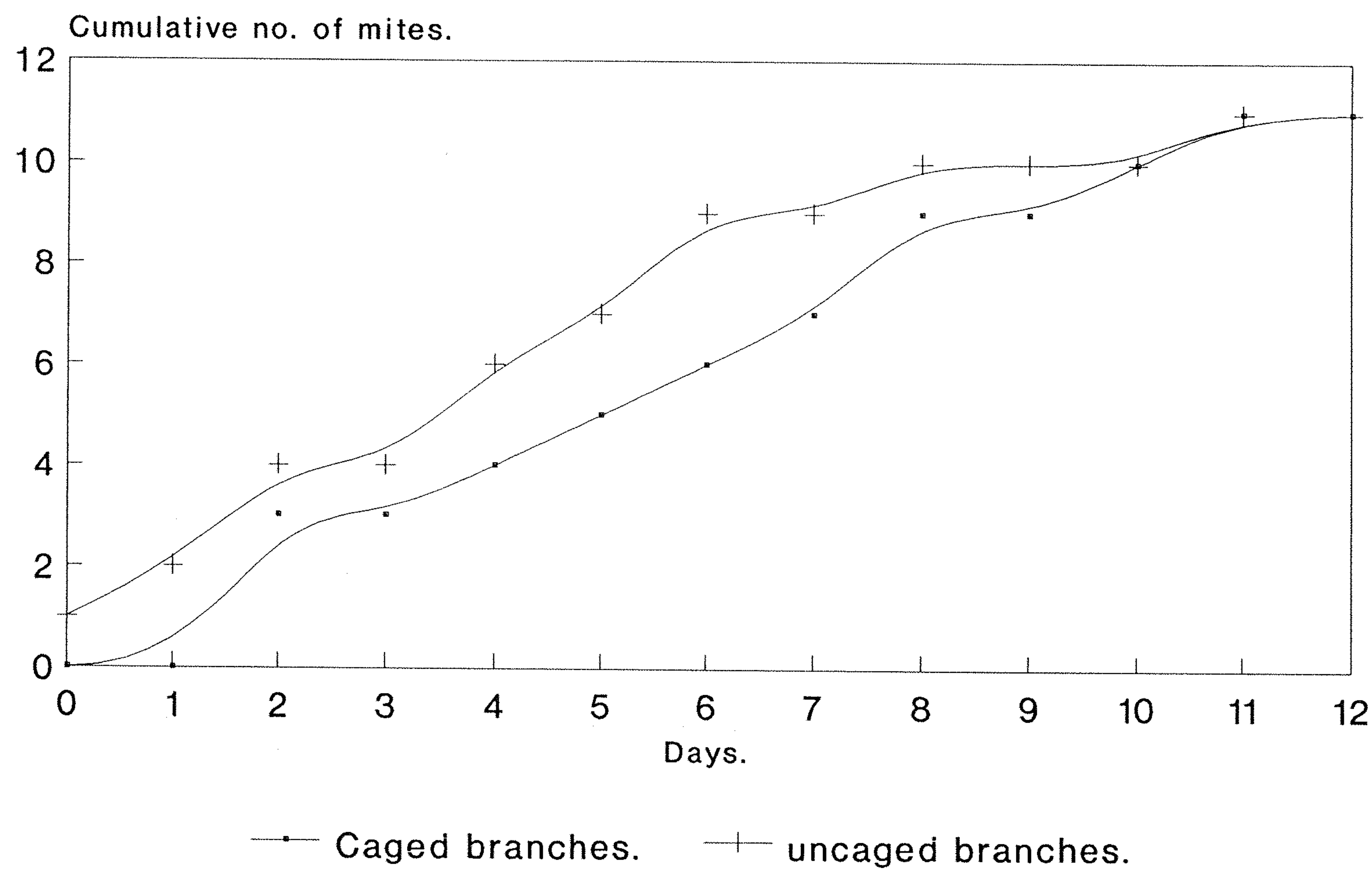
European red spider mite, *P. ulmi*.

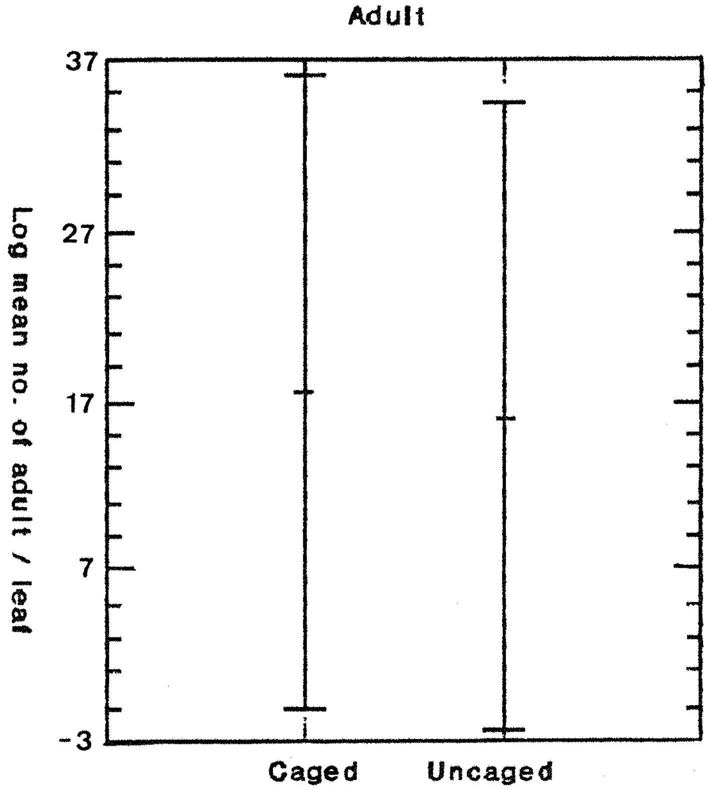
In the field experiment there was no significant difference $P > 0.05$ (Table 18, Appendix 3) in the numbers of mites on caged and uncaged branches and the cumulative numbers of mites were also almost equal (Fig. 37). The overall mean plots of the numbers of mites (Fig. 38) show similar trends. It is also important to note that on caged branches, predatory mites (*Typhlodromus pyri*) were found, while on uncaged branches no predators were found. This is may be a possible

Table 21. Mean and ± 95% confidance interval of the numbers of *P. ulmi* on caged branches.

Sampling dates 1989.	Adult			Eggs		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.0	0.0		0.22	0.06	0.39
6/6	0.0	0.0		0.033	-0.13	0.20
15/6	0.0	0.0		0.033	-0.13	0.20
22/6	0.093	0.03	0.15	0.16	-0.00	0.32
27/6	0.033	-0.02	0.09	0.13	-0.02	0.30
11/6	0.0	0.0		0.08	-0.08	0.25
18/7	0.0	0.0		0.13	-0.03	0.30
25/7	0.033	-0.02	0.09	0.11	-0.05	0.27
8/8	0.033	0.02	0.94	0.13	-0.03	0.30
17/8	0.0	0.0		0.033	-0.13	0.20
22/8	0.0	-0.06	0.06	0.10	-0.06	0.26

Figure 37. Cumulative trend in population of *P. ulmi* on different branches in a commercial orchard.





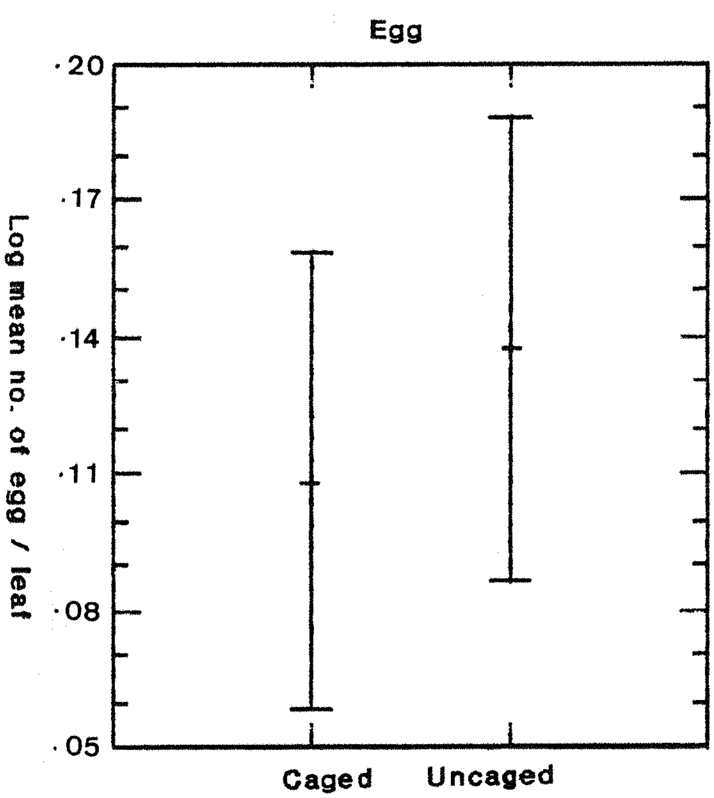


Figure 38. Overall mean numbers of P. ulmi / leaf with 95% confidence interval on different branches.

Table 22. Mean and ± 95% confidance interval of the numbers of *P. ulmi* on uncaged branches.

Sampling dates 1989	Adult			Eggs		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.0	0.0		0.20	0.03	0.37
6/6 *	0.0	0.0		0.0	0.0	
15/6	0.0	0.0		0.19	0.02	0.35
22/6 *	0.033	-0.02	0.09	0.1	-0.06	0.26
27/6	0.0	0.0		0.16	-0.00	0.32
11/7 *	0.033	-0.02	0.09	0.11	-0.05	0.27
18/7	0.0	0.0		0.033	-0.13	0.20
25/7	0.0	0.0		0.066	-0.10	0.23
8/8	0.076	0.01	0.13	0.198	0.03	0.36
17/8	0.033	-0.02	0.09	0.371	0.20	0.53
22/8	0.0	0.0		0.076	-0.09	0.24

* sampling dates following spray applications.

explanation for non significant results between the numbers of mites on these two branches, because, on uncaged branches, the pest and predatory mites were probably affected by pesticide application, whereas on caged branches, predatory mites, *T. pyri* were observed and the spider mites may thus have been affected by predation (Fig. 39). The numbers of mites on uncaged branches without predators are given in Figure 40. Strikler et al. (1987) also observed, a shift in predator species took place rapidly over a single season when an orchard was not sprayed. Pest mites did not show any change as did the predators when spraying ceased. A

Figure 39. Relation between the numbers of *Panonychus ulmi* and *Typhlodromus pyri* on caged branches.

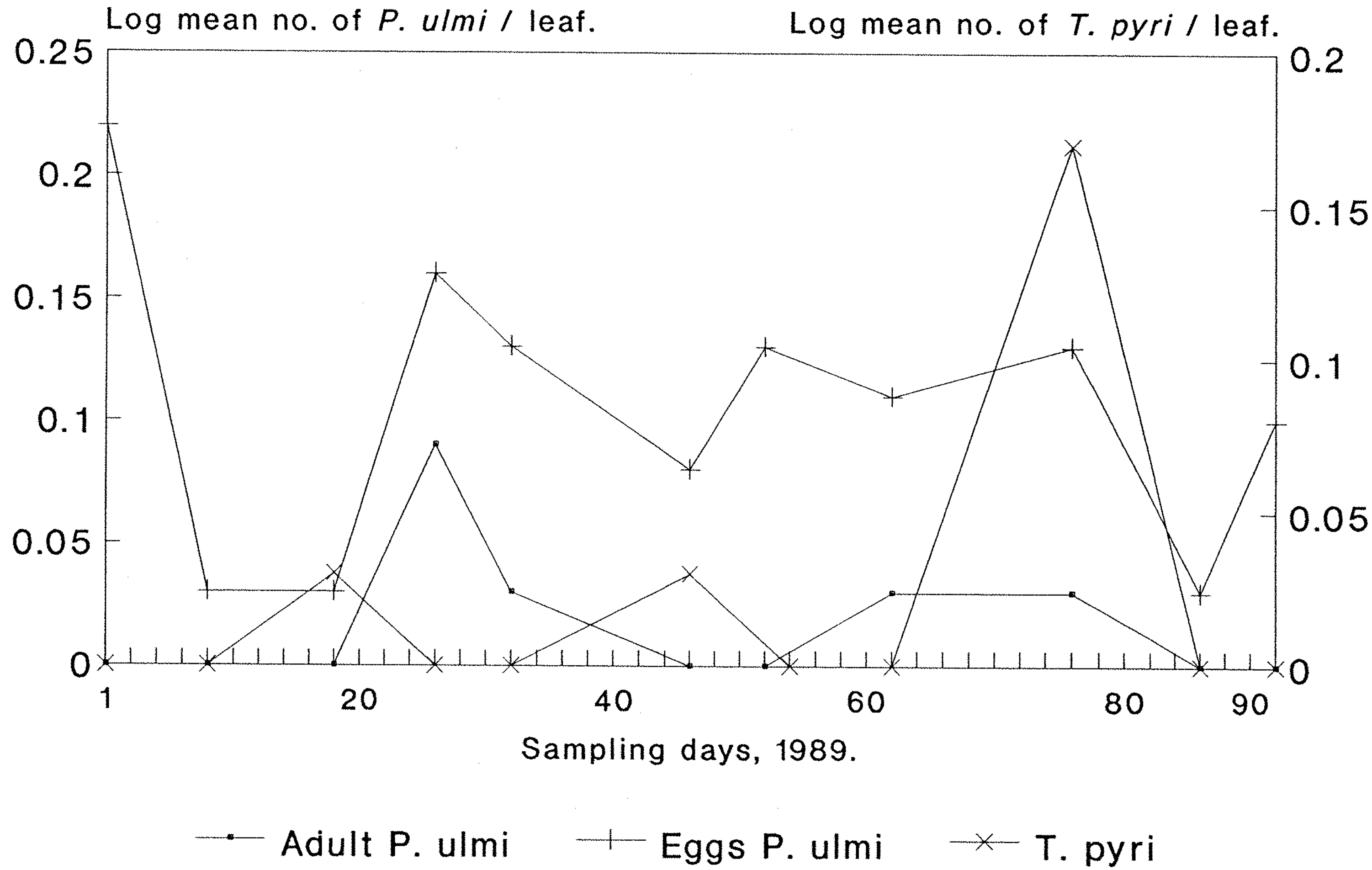
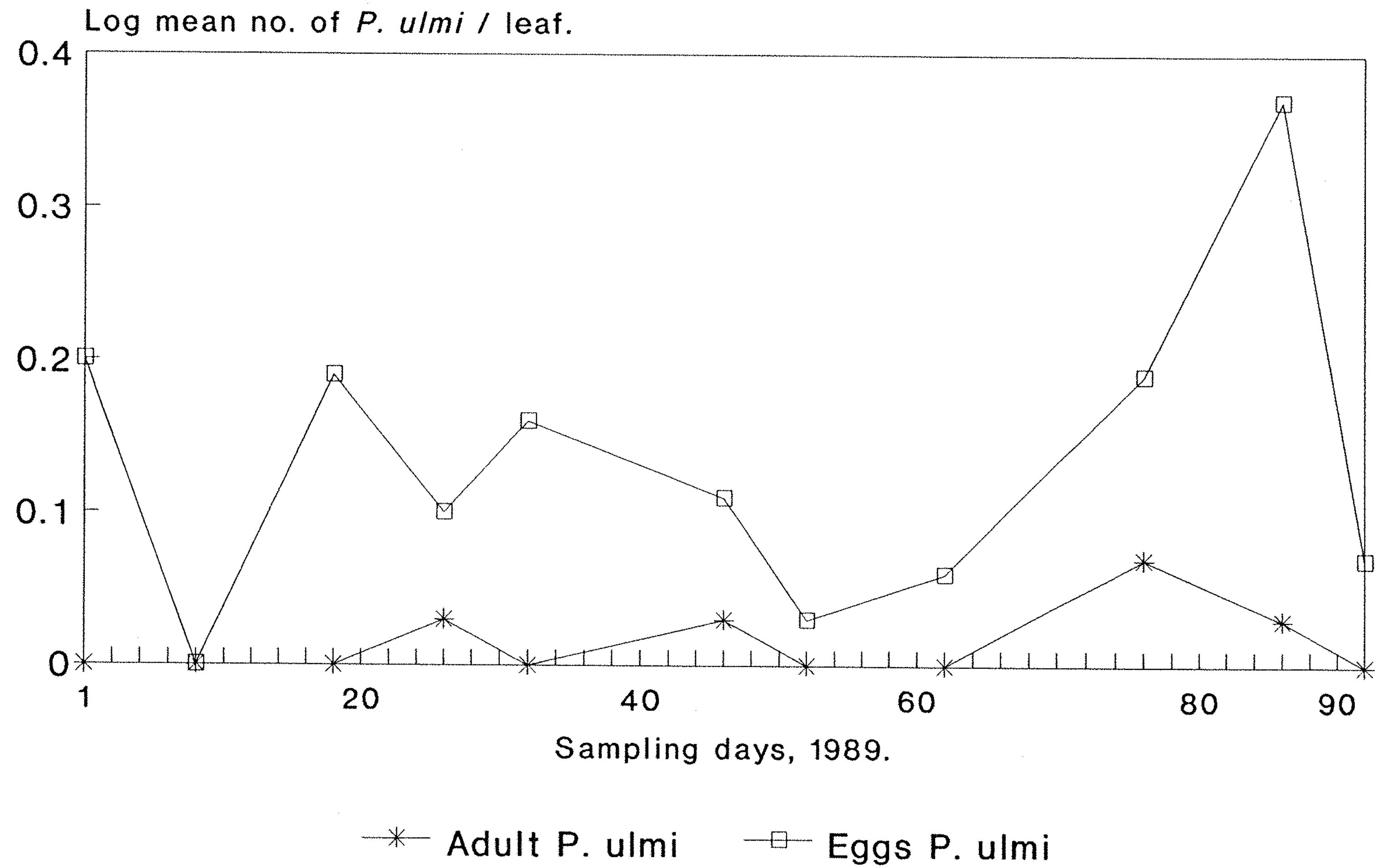


Figure 40. *Distribution of Panonychus ulmi* uncaged branches without *Typhlodromus pyri* in commercial orchard



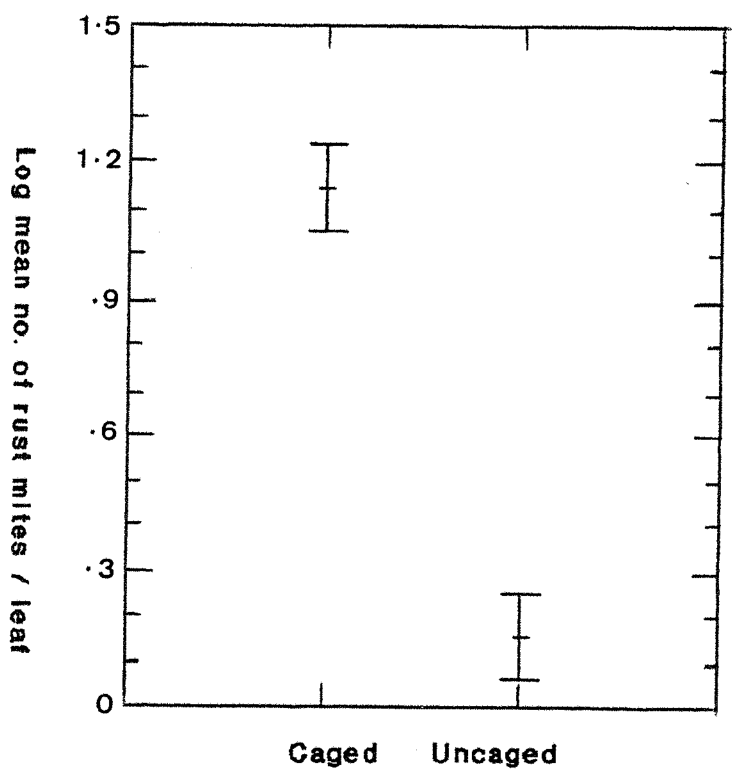
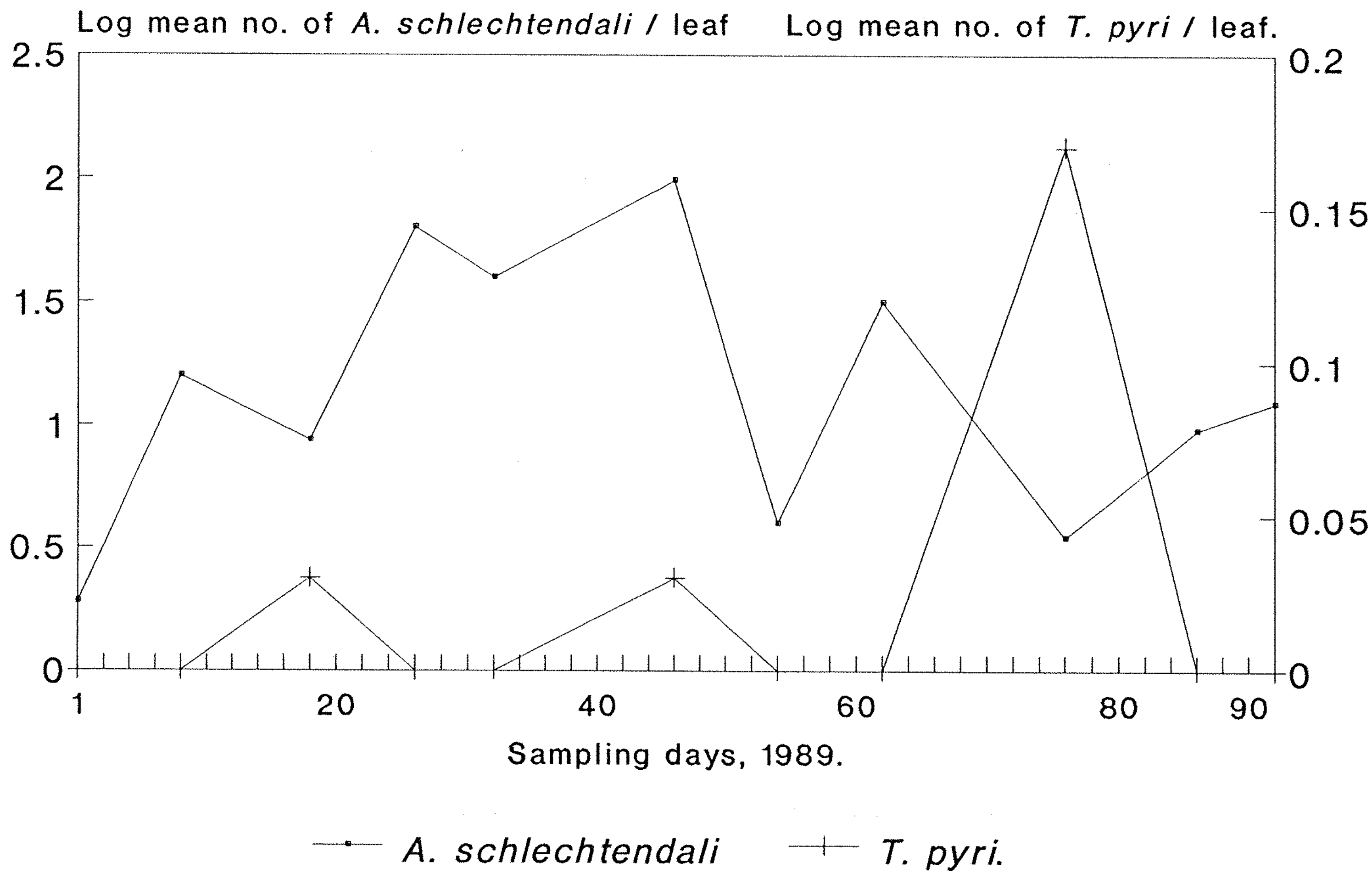


Figure 46. Overall mean numbers of A. schlechtendali / leaf with 95% confidence interval on different branches.

Figure 47. Relation between the numbers of *A. schlechtendali* and *T. pyri* on caged branches in a commercial orchard.



similar situation may have arisen in this experiment when the branches were caged (untreated) for one season. Summary statistics of the numbers of eggs and adults *p. ulmi* on caged and uncaged branches for each date were calculated and are given in Tables 21 and 22.

The numbers of red mites on covered and uncovered branches were not significantly different p > 0.05 (Table 21, Appendix 3) as on caged and uncaged branches. The overall mean plot with ± 95% confidence interval showed similar results (Fig. 41). Figure 42 shows that the numbers of

Table 23. Mean and ± 95% confidance interval of the numbers of *P. ulmi* on covered branches.

Dates, 1989	Adult			Eggs		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.0	0.0		0.066	-0.17	0.30
6/6	0.0	0.0		0.0	0.0	
15/6	0.0	0.0		0.033	-0.20	0.27
22/6	0.0	0.0		0.085	-0.15	0.32
27/6	0.033	-0.08	0.14	0.0	0.0	
11/7	0.0	0.0		0.033	-0.20	0.27
18/7	0.0	0.0		0.033	-0.20	0.27
25/7	0.085	-0.03	0.20	1.275	1.03	1.51
8/8	0.204	0.08	0.32	0.446	0.20	0.68
17/8	0.264	0.14	0.38	0.445	0.20	0.68
22/8	0.185	0.06	0.30	0.542	0.30	0.78

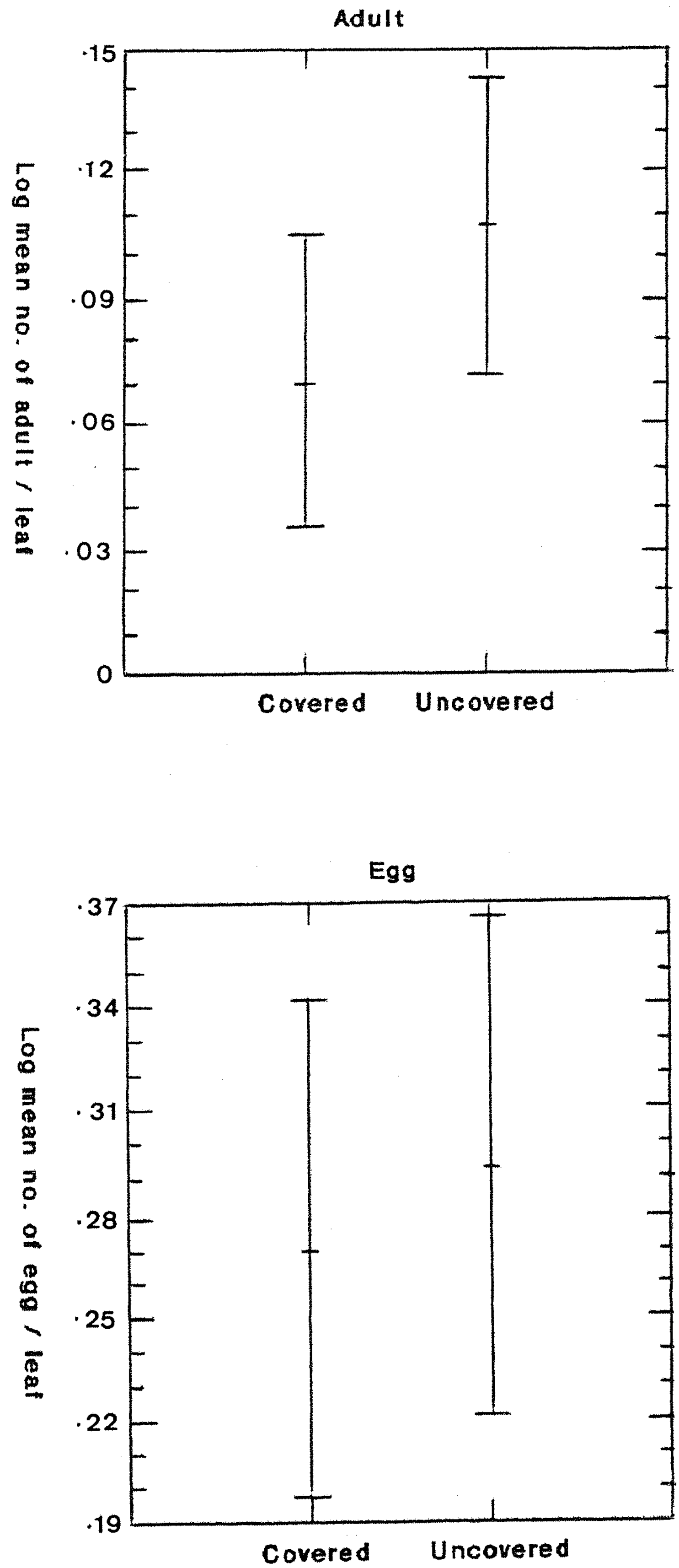
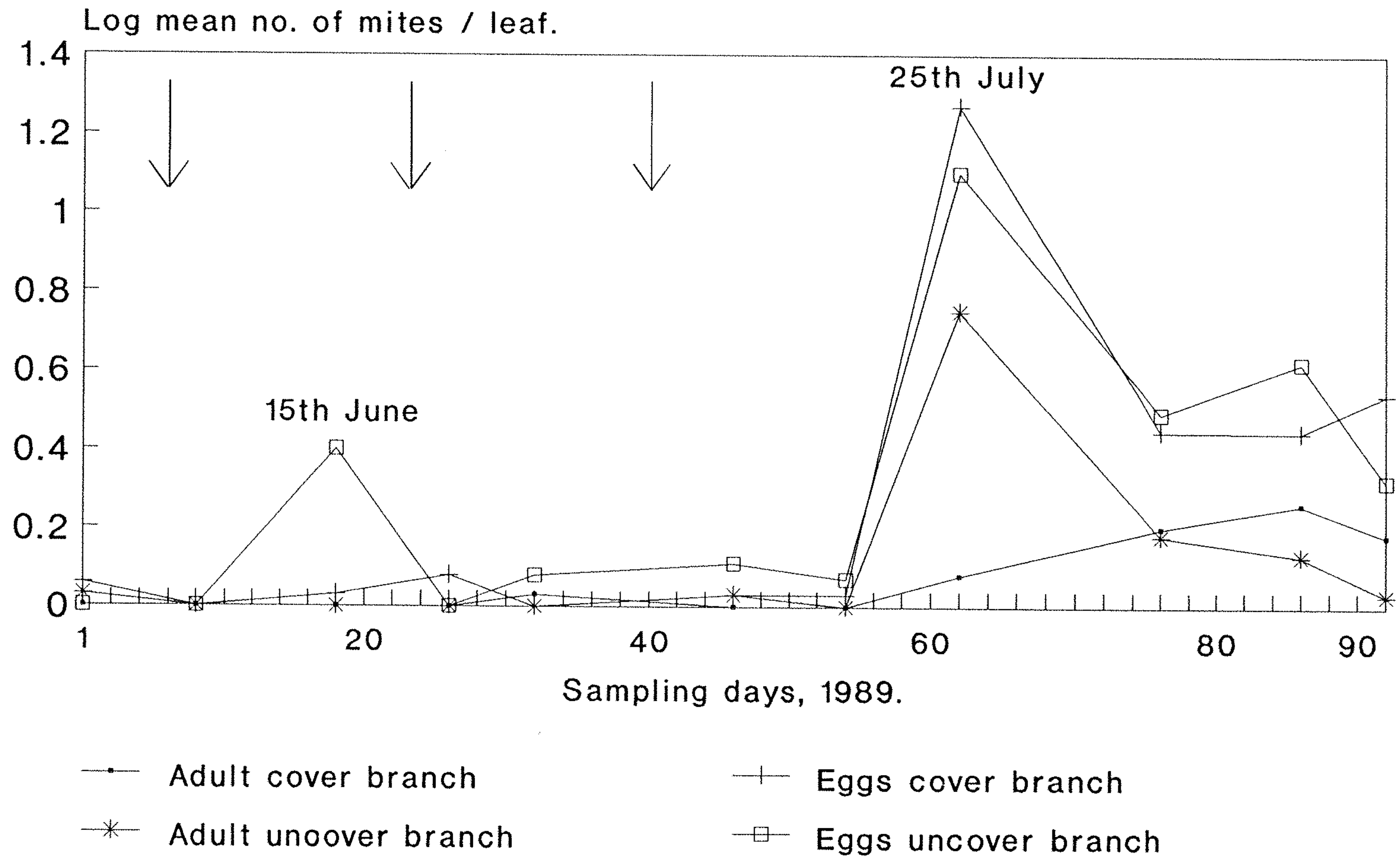


Figure 41. Overall mean numbers of P. ulmi / leaf with 95% confidence interval on different branches.

Figure 42. Distribution of *Panonychus ulmi* on different branches in a commercial orchard.



mites on these two branches during the early part of the experiment were lower from the first (30th May) to the 54th (18th July) sampling day except on 15th June when the numbers of eggs were higher on the uncovered branches. The numbers on both branches increased during the later part of the experiment. The most probable reason for this is that pesticides

Table 24. Mean and ± 95% confidance interval of the numbers of *P. ulmi* on uncovered branches.

Dates, 1989.	Adult			Eggs		
	Mean	95% con. interval		Mean	95% con. interval	
30/6	0.033	-0.08	0.14	0.0	0.0	
6/6 *	0.0	0.0		0.0	0.0	
15/6	0.0	0.0		0.405	0.16	0.64
22/6 *	0.0	0.0		0.0	0.0	
27/6	0.0	0.0		0.085	-0.15	0.32
11/7 *	0.033	-0.08	0.14	0.118	-0.12	0.35
18/7	0.0	0.0		0.076	-0.16	0.31
25/7	0.755	0.63	0.87	1.100	0.85	1.34
8/8	0.185	0.06	0.30	0.496	0.25	0.73
17/8	0.137	0.02	0.25	0.623	0.38	0.86
22/8	0.033	-0.08	0.14	0.320	0.07	0.56

* sampling dates following spray applications.

were not sprayed during this period (Table 2, Appendix 1). The numbers of egg and adult *P. ulmi* reached a peak on 25th July on uncovered branches and the numbers of eggs on covered branches were also at maximum numbers on this date, while adults were lower. The possible reason may be that mites after hatching moved to uncovered branches. On uncaged branches only the eggs were at maximum numbers on 17th August. Statistics of these two branches are given in Tables 23 and 24.

For the purpose of comparison caged and covered branches were compared (Fig. 39 & 42). The numbers of mites on these two branches were significantly different $p < 0.01$ (Table 23, Appendix 3). The overall plot of mean numbers of mites indicated similar results to the

Table 25. Mean and ± 95% confidence interval of the numbers of *P. ulmi* on different branches.

Dates 1989.	Adult				Egg			
	Caged		Covered		Caged		Covered	
	Mean	95% con. interval	Mean	95% con. interval	Mean	95% con. interval	Mean	95% con. interval
30/5	0.0	0.0	0.0	0.0	0.22	0.04 0.40	0.06	-0.11 0.24
6/6	0.0	0.0	0.0	0.0	0.03	-0.14 0.21	0.0	0.0
15/6	0.0	0.0	0.0	0.0	0.03	-0.14 0.21	0.03	-0.14 0.21
22/6	0.09	-0.00 0.18	0.0	0.0	0.16	-0.01 0.34	0.08	-0.09 0.26
27/6	0.03	-0.06 0.12	0.03	-0.06 0.12	0.13	-0.04 0.31	0.0	0.0
11/7	0.0	0.0	0.0	0.0	0.08	-0.09 0.26	0.03	-0.14 0.21
18/7	0.0	0.0	0.0	0.0	0.13	-0.04 0.31	0.03	-0.14 0.21
25/7	0.03	-0.06 0.12	0.08	-0.00 0.17	0.11	-0.06 0.29	1.27	1.09 1.45
8/8	0.03	-0.06 0.12	0.20	0.11 0.29	0.13	-0.04 0.31	0.44	0.26 0.62
17/8	0.0	0.0	0.26	0.17 0.35	0.03	-0.14 0.21	0.44	0.26 0.62
22/8	0.0	0.0	0.18	0.09 0.27	0.10	-0.07 0.27	0.54	0.36 0.72

analyses of variance, but it indicated higher numbers on covered branches as compared with caged ones (Fig. 43). This may be because in caged branches the mites were not dispersing out or into cages due to sticky barriers. Predatory mites, *(T. pyri)* were also observed on these branches and might have affected the red mite (Fig. 39), whereas, on covered branches, no predators were found. Summary statistics of these two branches are given in Table 25.

Table 26. Mean and ± 95% confidence interval of the numbers of *P. ulmi* on different branches.

Dates 1989.	Adult				Egg			
	Uncaged		Uncovered		Uncaged		Uncovered	
	Mean	95% con. interval	Mean	95% con. interval	Mean	95% con. interval	Mean	95% con. interval
30/5	0.0	0.0	0.03	-0.05 0.12	0.20	-0.02 0.43	0.0	0.0
6/6*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15/6	0.0	0.0	0.0	0.0	0.19	-0.03 0.42	0.40	0.17 0.63
22/6*	0.03	-0.05 0.12	0.0	0.0	0.10	-0.13 0.33	0.0	0.0
27/6	0.0	0.0	0.0	0.0	0.16	-0.07 0.39	0.08	-0.14 0.31
11/7*	0.03	-0.05 0.12	0.03	-0.05 0.12	0.11	-0.12 0.34	0.11	-0.11 0.34
18/7	0.0	0.0	0.0	0.0	0.03	-0.19 0.26	0.07	-0.15 0.30
25/7	0.0	0.0	0.75	0.66 0.84	0.06	-0.16 0.29	1.10	0.86 1.33
8/8	0.07	-0.01 0.16	0.18	0.09 0.27	0.19	-0.03 0.42	0.49	0.26 0.72
17/8	0.03	-0.05 0.12	0.13	0.04 0.22	0.37	0.14 0.60	0.62	0.39 0.85
22/8	0.0	0.0	0.03	-0.05 0.12	0.07	-0.15 0.30	0.32	0.08 0.55

* sampling dates following spray applications.

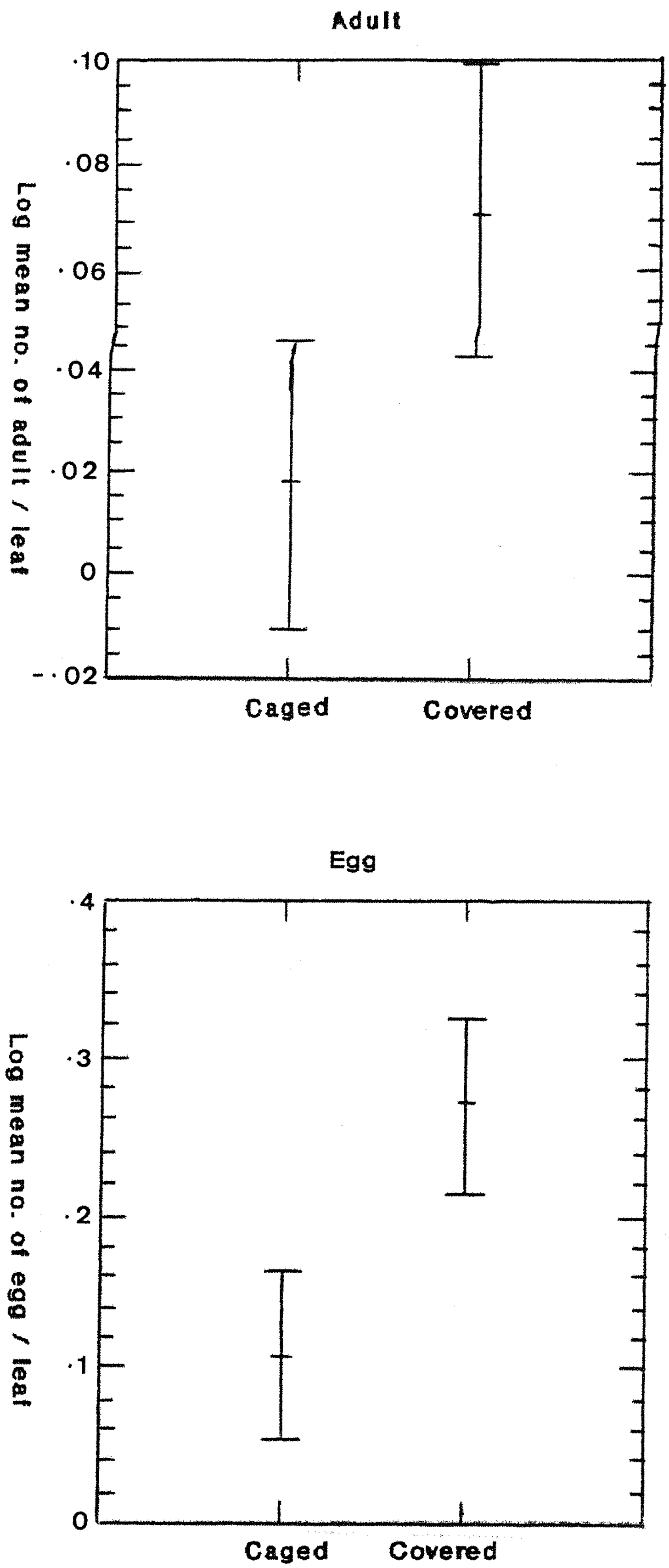


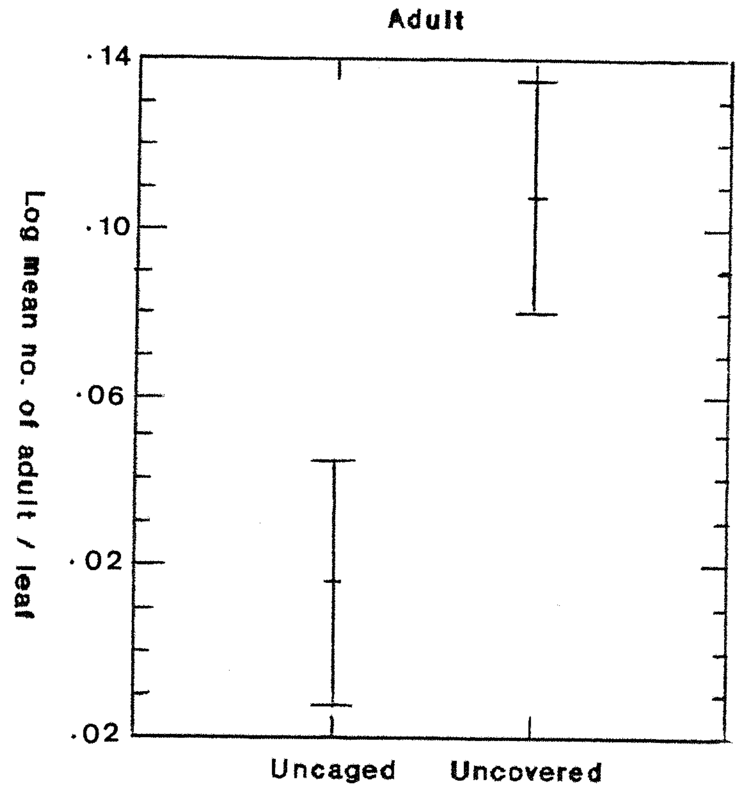
Figure 43. Overall mean numbers of P. ulmi / leaf with 95% confidence interval on different branches.

The two treated branches i.e. uncaged and uncovered branches were compared (Fig. 40 & 42). The numbers of eggs and adult on these two branches were significantly different $p < 0.01$ (Table 25 in Appendix 3). The overall mean plot with ± 95% confidence interval produced similar results with higher numbers of eggs and adults on uncovered branches (Fig. 44) probably because the mites were moving from covered to uncovered areas. Mean and ± 95% confidence intervals are given in Table 26.

Correlation analyses were carried out on the numbers of eggs and adults on caged/uncaged and covered/uncovered branches. Since predatory mites, *T. pyri* were only found on caged branches, correlation analyses were only carried out on the numbers of adult *P. ulmi* and adult *T. pyri* on these branches. The results are given in Table 27. Significant ($p < 0.05$ for caged and $p < 0.01$ for uncaged) positive correlations between the numbers of eggs and adults were found on these branches. This table indicates that the correlation coefficient $r = 0.2170$ for caged branches was lower than for uncaged branches $r = 0.3912$. This indicates

Table 27. Correlation ananlysis of the numbers of eggs and adults *P. ulmi* on different branches.

Branches	Correlation between eggs and adults *P. ulmi*	Sig. level	Correlation between adult *P. ulmi* and adult *T. pyri*	Sig. level
Caged	+ 0.2170	0.03	− 0.1013	0.318
Uncaged	+ 0.3912	0.00		
Covered	+ 0.2753	0.00		
Uncovered	+ 0.6135	0.00		



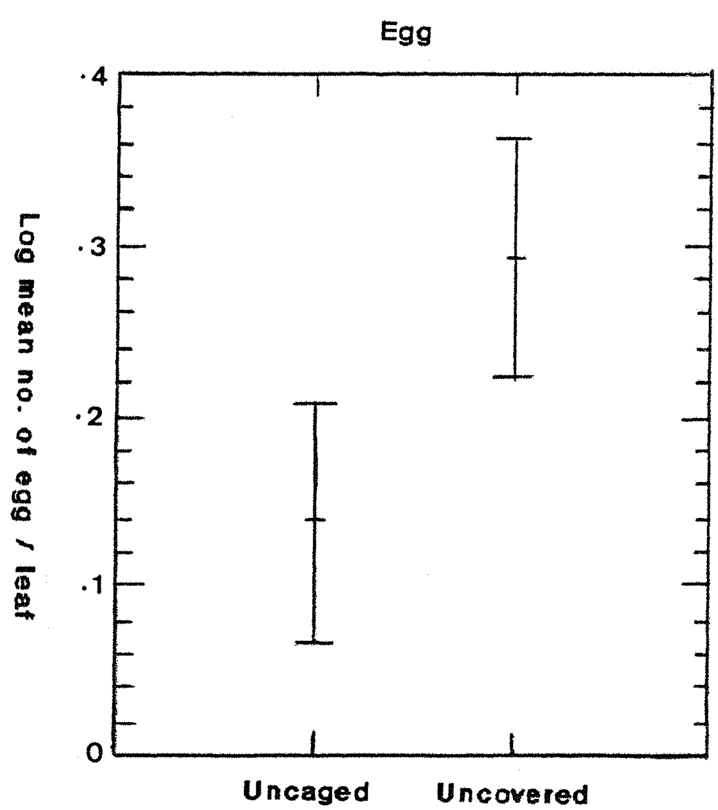


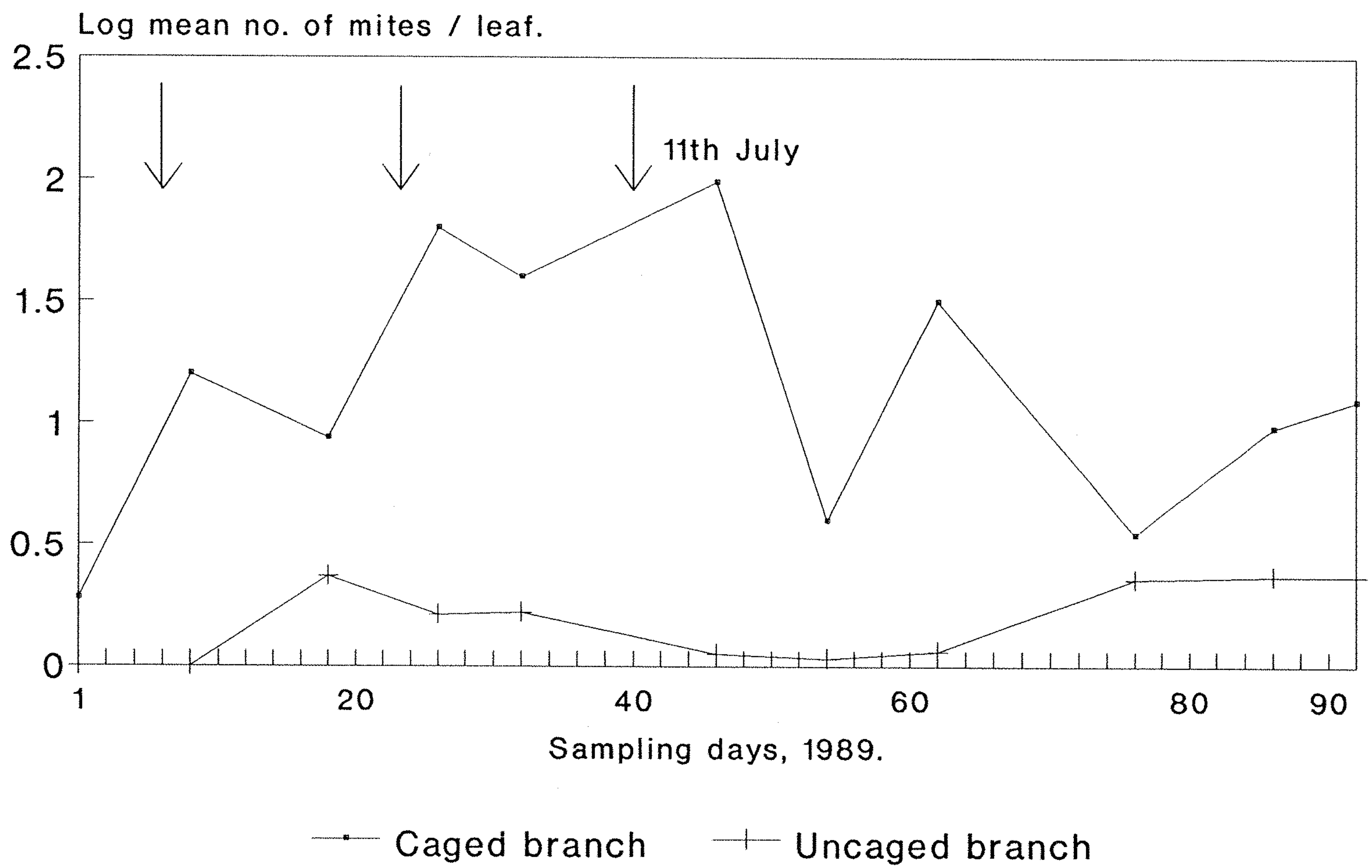
Figure 44. Overall mean numbers of P. ulmi / leaf with 95% confidence interval on different branches.

that the increase in adult numbers on caged branches was lower than for uncaged branches which is probably because of predation by *T. pyri* in caged branches. The correlation between the numbers of *P. ulmi* and *T. pyri* was negative $r = -0.101$ but it was not significantly different $p > 0.05$. Nyrop (1988) observed in his field experiment that significant negative correlations between the numbers of *P. ulmi* and *T. pyri* occurred at *P. ulmi* densities above five / leaf and a non-significant correlation was observed at red mite densities of less than five / leaf. He concluded that this relation was a result of *T. pyri* predation on *P. ulmi*. A weak positive significant correlation coefficient $r = 0.2753$, $p < 0.01$ between the numbers of eggs and adult on covered branches was observed. Similar results were found on uncovered branches with slightly higher r value 0.6135, $p < 0.01$.

Apple rust mite, *A. schlechtendali*.

Figure 45 gives the numbers of rust mites on caged and uncaged branches and reveals that the numbers of mites were higher on caged branches from the first day of sampling (30th May) until the last sampling day (22nd August). This figure also indicates that the numbers were increasing (with fluctuations) from the beginning and reached a peak on 11th July on the caged branches while on the uncaged branches, the mite numbers did not reach a peak. The differences between these two branches were analysed and significant differences were found $p < 0.01$ between branches and dates (Table 20, Appendix 3). These results indicated that mites remained on caged branches and did not move to uncaged branches probably because of the sticky barriers. The overall

Figure 45. Distribution of *Aculus schlechtendali* on different branches in a commercial orchard.



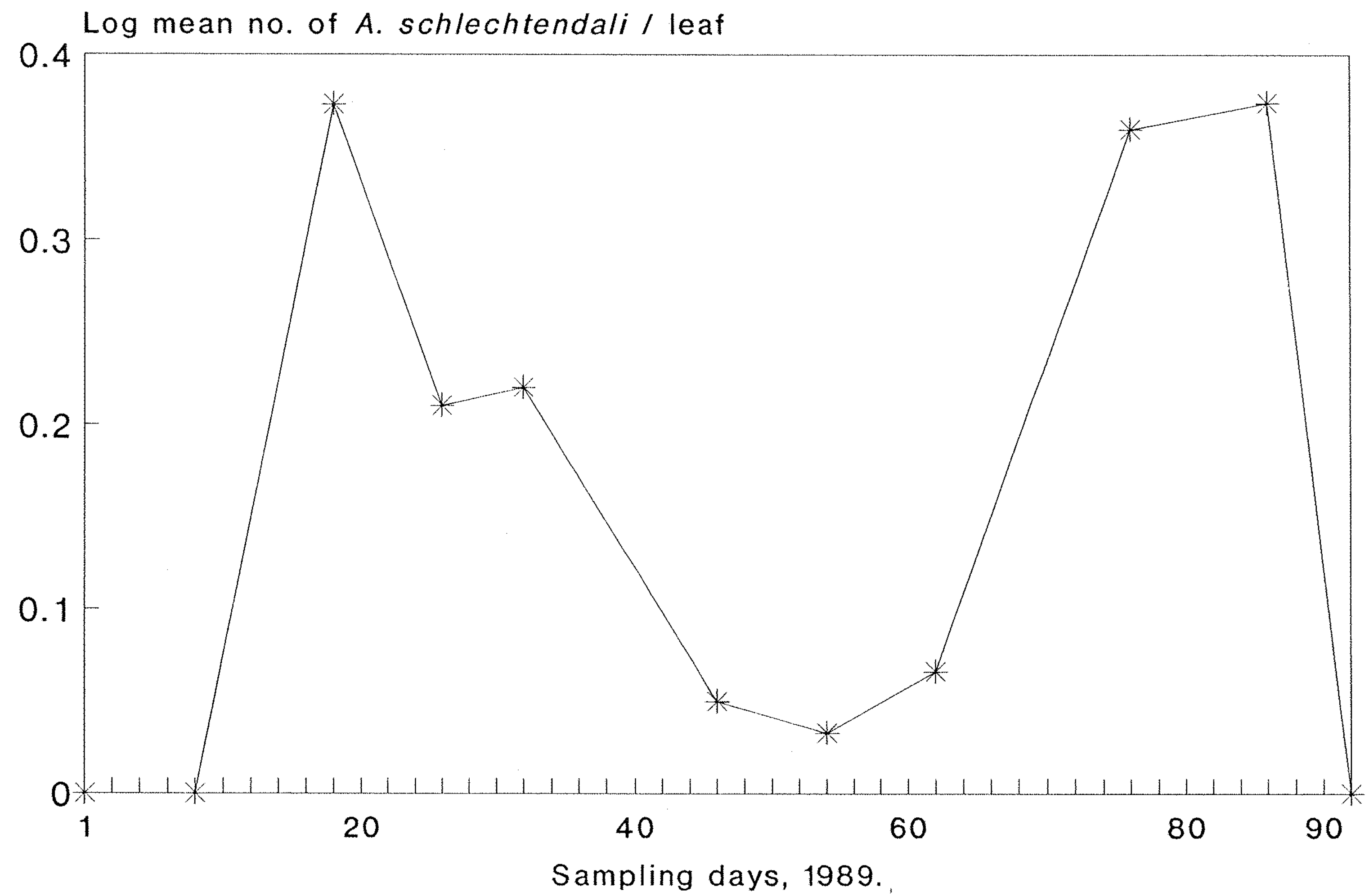
mean plots of the numbers of rust mites gave similar results (Fig. 46). When the numbers of rust mites were plotted with and without the numbers of predatory mites, *T. pyri* (Figs. 47 and 48), rust mite numbers remained higher in the presence of predatory mites. This indicates that predators may have avoided rust mites early in the season but towards the end rust mite decreased and *T. pyri* increased on 17th August. Mean and ± 95% confidence intervals of these branches are given in Table 28.

Table 28. Mean and ± 95% confidence interval of the numbers of *A. schlechtendali* on different branches.

Dates, 1989	Caged			Uncaged		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.282	-0.02	0.58	0.0	0.0	
6/6 *	1.20	-0.90	1.50	0.0	0.0	
15/6	0.94	0.64	1.25	0.373	0.06	0.67
22/6 *	1.80	1.49	0.09	0.21	-0.09	0.52
27/6	1.60	1.29	1.91	0.22	-0.07	0.53
11/7 *	1.99	1.69	2.30	0.05	-0.25	0.35
18/7	0.60	0.29	0.90	0.033	-0.30	0.30
25/7	1.50	1.19	1.80	0.066	-0.23	0.37
8/8	0.54	0.23	0.85	0.360	0.05	0.66
17/8	0.98	0.67	1.29	0.374	0.06	0.68
22/8	1.09	0.78	1.39	0.0	-0.30	0.30

* sampling dates following spray applications.

Figure 48. Numbers of *A. schlechtendali* on uncaged branches without *T. pyri* in a Commercial orchard.



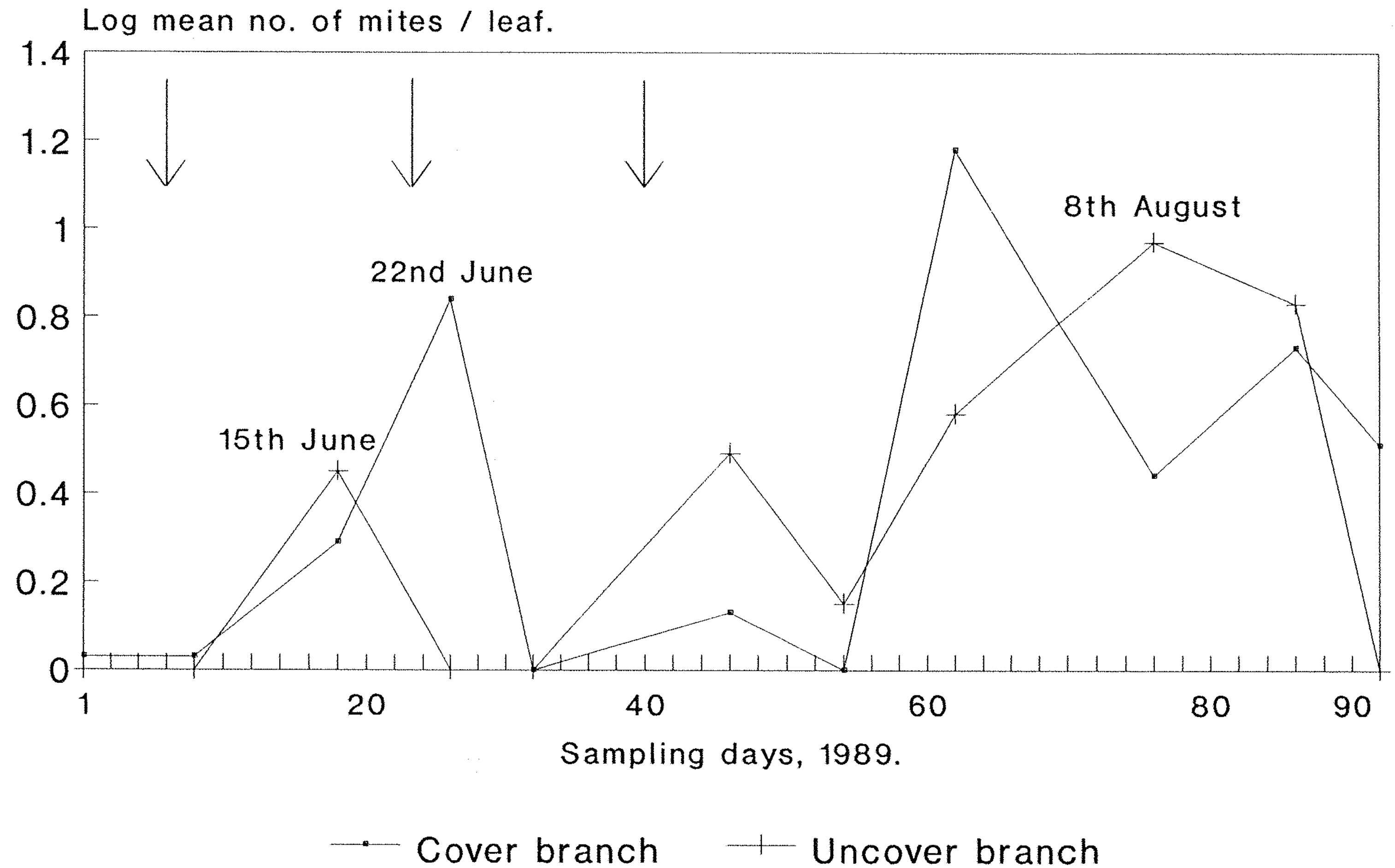
Apple rust mites on covered and uncovered branches produced similar results to egg and adult *P. ulmi* on the same branches (Fig. 49). The numbers of mites on covered and uncovered branches were similar on the first (30th May) to the eighth (6th June) sampling days but increased and reached a peak on 15th June on uncovered branches. The numbers decreased on the 26th sampling day (22nd June) because of the spray application on 19th June (Table 2, Appendix 1). The population on covered branches gradually increased and reached maximum numbers on 22nd June. The numbers of rust mites on these two branches were compared and

Table 29. Mean and ± 95% confidence interval of the numbers of *A. schlechtendali* on different branches.

Dates, 1989	Covered			Uncovered		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.033	-0.18	0.24	0.0	0.0	
6/6 *	0.033	-0.18	0.24	0.0	0.0	
15/6	0.295	0.08	0.50	0.45	0.24	0.67
22/6 *	0.845	0.63	1.05	0.0	0.0	
27/6	0.0	0.0		0.0	0.0	
11/7 *	0.13	-0.07	0.35	0.49	0.28	0.71
18/7	0.0	0.0		0.15	0.05	0.37
25/7	1.18	0.96	1.39	0.58	0.37	0.80
8/8	0.44	0.23	0.65	0.97	0.75	1.18
17/8	0.73	0.52	0.95	0.83	0.61	1.04
22/8	0.51	0.30	0.72	0.0	0.0	

* sampling date following spray applications

Figure 49. Distribution of *Aculus schlechtendali* on different branches in a commercial orchard.



were not significantly different $p > 0.05$ (Table 22 in Appendix 3). The overall mean plot of the numbers of mites indicates the same results (Fig. 50). Summary statistics of rust mites for each date are given in Table 29.

When the numbers of rust mites were compared on caged and covered branches, statistical analyses showed significantly higher numbers on caged branches $p < 0.01$ (Table 24, Appendix 3). The overall mean plots of the numbers on these branches produced simiar results (Fig. 51).

Table 30. Mean and ± 95% confidence interval of the numbers of *A. schlechtendali* on different branches.

Dates, 1989	Caged			Covered		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.282	-0.03	0.60	0.033	-0.28	0.35
6/6	1.206	0.88	1.52	0.033	-0.28	0.35
15/6	0.947	0.62	1.26	0.295	-0.02	0.61
22/6	1.802	1.48	2.12	0.845	0.52	1.16
27/6	1.605	1.28	1.92	0.0	0.0	
11/7	1.998	1.67	2.31	0.137	-0.18	0.45
18/7	0.600	0.27	0.92	0.0	0.0	
25/7	1.503	1.18	1.82	1.180	0.85	1.50
8/8	0.544	0.22	0.86	0.44	0.12	0.76
17/8	0.985	0.66	1.30	0.73	0.41	1.05
22/8	1.092	0.77	1.41	0.51	0.19	0.83

Mean and ± 95% confidence intervals for each date are given in Table 30.

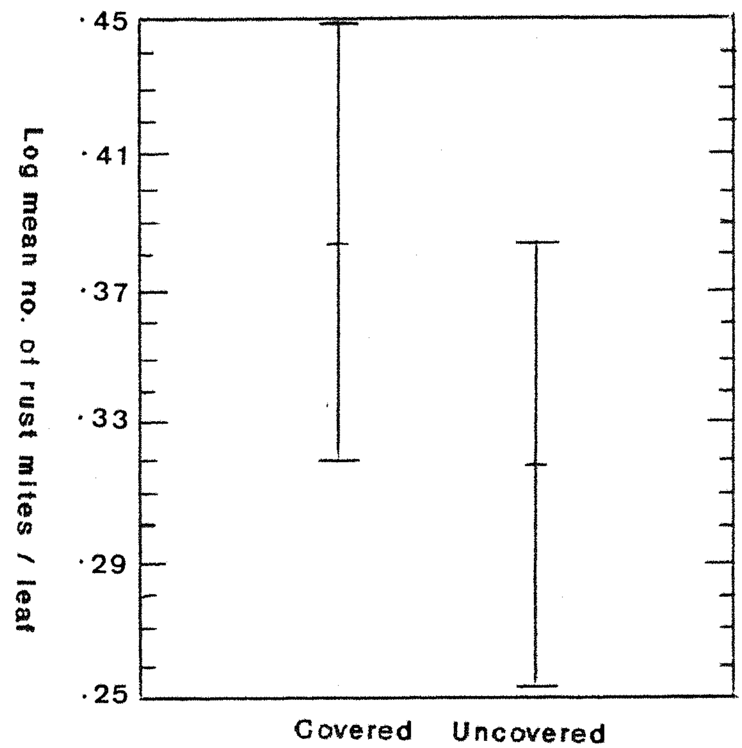


Figure 50. Overall mean numbers of A. schlechtendali / leaf with 95% confidence interval on different branches.

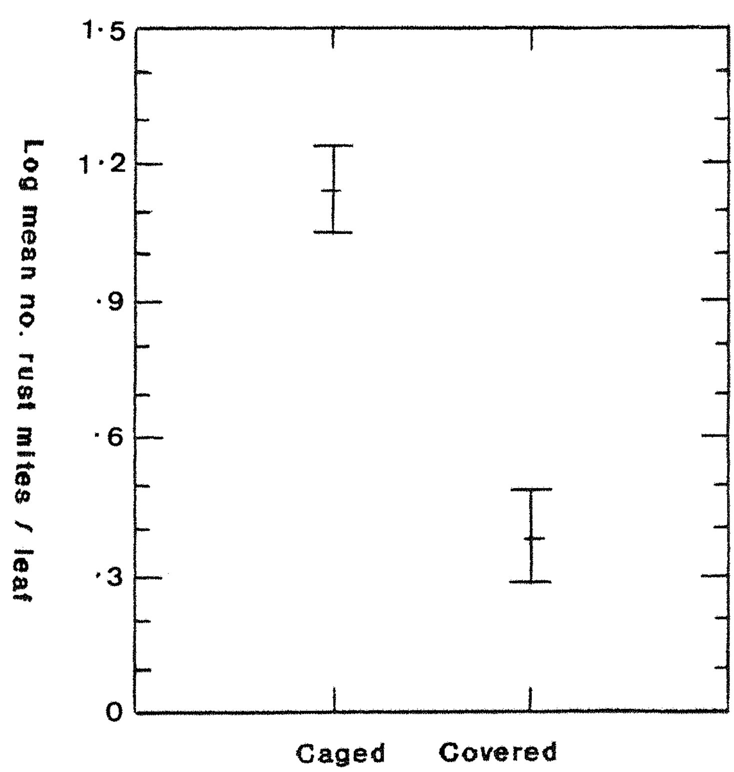


Figure 51. Overall mean numbers of A. schlechtendali / leaf with 95% confidence interval on different branches.

The numerical trend in Figures 45 and 49 indicate that during the whole experiment the numbers of mites were higher on uncovered branches on most of the sampling occasions. This might be due to the movement of mites from covered to uncovered branches. The difference on these branches were also analysed and significant results $p < 0.01$ (Table 26, Appendix 3) were found. The overall mean plot of the numbers of mites also showed similar results but higher numbers on uncovered branches (Fig. 52). Mean and ± 95% confidence intervals are given in Table 31.

Table 31. Mean and ± 95% confidence interval of the numbers of *A. schlechtendali* on different branches.

Dates, 1989	Uncaged			Uncovered		
	Mean	95% con. interval		Mean	95% con. interval	
30/5	0.0	0.0		0.0	0.0	
6/6 *	0.0	0.0		0.0	0.0	
15/6	0.37	0.18	0.56	0.45	0.26	0.65
22/6 *	0.21	0.02	0.40	0.0	-0.19	0.19
27/6	0.22	0.03	0.42	0.0	-0.19	0.19
11/7 *	0.05	-0.14	0.24	0.49	0.30	0.69
18/7	0.0	0.0		0.15	-0.03	0.35
25/7	0.06	-0.12	0.25	0.58	0.39	0.77
8/8	0.36	0.16	0.55	0.97	0.77	1.16
17/8	0.37	0.18	0.56	0.83	0.63	1.02
22/8	0.0	0.0		0.0	0.0	

* sampling dates following spray applications.

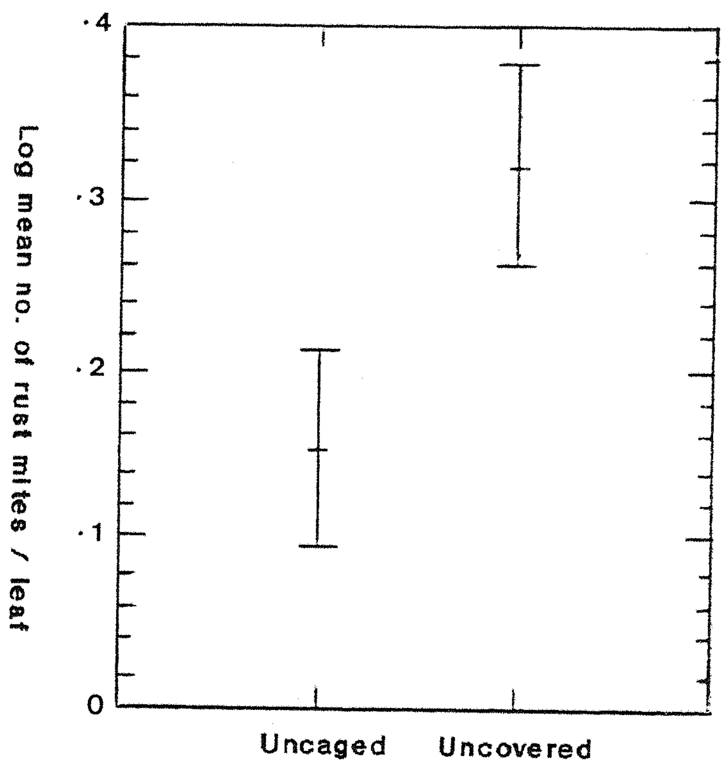


Figure 52. Overall mean numbers of A. schlechtendali / leaf with 95% confidence interval on different branches.

CONCLUSIONS.

An experimant was carried out to investigate the movement or dispersal of spider mites from untreated (caged or covered) to treated (uncaged or uncovered) branches of apple trees in a commercial orchard at Leckford.

In this experiment the numbers of mites on caged and uncaged branches were almost equal and were not significantly different. The reason for this may have been that on uncaged branches, spider mites and predators particularly *T. pyri*, were killed by pesticide application, whereas, on caged branches the predatory mites *T. pyri* survived and reduced numbers of *P. ulmi* to a level equal to those on uncaged branches (Fig. 37).

The numbers of rust mites on these two branch categories were significantly different, with higher numbers on the caged branches.

The numbers of *P. ulmi* on covered and uncovered branches were not significantly different. The possible reason may be that the spider mites were dispersing. Slightly higher numbers of eggs on 22nd June on covered branches shows this difference. The possible explanation for this difference is that the eggs which were on covered branches hatched and adult or immature stages of mites moved to uncovered branches and laid eggs there. Therefore, the numbers of eggs on uncovered branches increased on 27th June and 11th July. The numbers of rust mites on these branches were not significantly different which is possibly due to the last few samplings when the numbers on the uncovered were higher than on covered branches, although their ± 95% confidence interval overlapped each other.

Chapter 4

SPRAY DISTRIBUTION.

INTRODUCTION

One of the most important reasons for the failure of spider mite control on apple trees is likly to be the uneven distribution of pesticide spray between the inner and outer canopies of apple trees. This has been of interest to various workers who have studied spray distribution over apple and other fruit trees. Various types of spray equipment and spray application methods have been tried; each test has produced a different spray distribution pattern. An uneven spray distribution is likly to have an influence on pest and disease control. Cooke et al. (1975) used four sprayers to control pests and diseases of apple. In three years of experimentation, two experimental sprayers (an overhead boom applying 1125 l/ha and an overhead mist - blower, applying 562 l/ha) were compared with two conventional sprayers (an automatic mast spraying 2250 l/ha and a conventional mist - blower applying 562 l/ha). Application of demeton - s -methyl (0.0036% a.i.) with azinphos methyl (0.0165% a.i.) or application of fenitrothion (0.031% a.i.) by both the overhead boom and conventional methods gave good control of the apple-grass aphid, *Rhopalosiphum insertum* at the green cluster stage. The overhead boom method and coventional sprayer gave equal control of scab in a dodine / captan (0.03% a.i. and

0.094% a.i. and benomyl (0.025%) application programme. When scab incidence was heveir, the overhead sprayer was again equal to the conventional method with the benomyl programme but was less effective with the dodine / captan pragramme. The overhead mist application equipment gave control when the scab incidence was light. Repeated applications of dinocap emulsion (0.025% a.i.) in fungicide programmes gave as good control of the active stages of fruit tree red spider mite, *P. ulmi* when applied by the overhead methods as by conventional spraying but application of the benomyl programme gave poor control. Cooke et al. (1975) also assessed and compared spray coverage and fungicide distribution on leaf surfaces in the top, middle and base zones of apple trees by three orchard sprayers (conventional large - volume automatic methods applying 2250 l./ha, fast overhead methods with nozzle booms applying 1125 l./ha). They found that conventional methods gave heavy coverage on the upper and lower surfaces on all zones and the two overhead methods gave heavier cover on the upper surfaces than on the lower. A proportion of the lower surfaces especially in the base zones of the trees sprayed by the overhead mist - blower had no flourescent deposit. They also observed greater spray deposits of copper on the upper leaf surfaces of the trees sprayed from overhead. Their monitoring studies of captan spray deposition, before and after each fungicide application, showed that in the three zones the residual and cumulative deposits from the conventional automatic application were heavier and more uniform than those from overhead methods, which gave lighter deposits on the middle and base zones. Cooke et al. (1976) also studied spray deposition and fungicide distribution on leaf surfaces in the top, middle and base zones of apple trees by a conventional high-volume automatic mast method applying 2250 l/ha, and by low and ultra low volume tractor mist blowers applying 225 l/ha at normal dilution at 45 l/ha, at five times normal concentration and a modified hand directed, fan - disc sprayer applying 225 or 22.5 l/ha. A fluorescent tracer method revealed heavy but uneven coverage on the upper and lower surfaces of the leaves in all zones, the tractor mist method gave lighter but uniform cover. The fan - disc sprayer gave poor cover on the upper surfaces at the top and on the lower surfaces at the base zones. Their studies of fungicide distribution showed that conventional high volume spraying gave consistently high copper deposits on both surfaces in all three zones. Hand directed low and ultra low volume methods, applying one tenth the amounts of copper fungicide / ha, gave deposit levels 5 - 30% of those of the high volume method and tractor mist applications gave levels equivalent to 0.8 - 5.2%. The corresponding captan deposits from conventional high volume spraying gave much higher cumulative deposit levels than low and ultra low volume methods and also gave higher residual deposits. The fan - disc application, especially at the rate of 22.5 l/ha, generally gave higher cumulative deposits than the tractor mist sprayer. The above findings suggest that the upper leaf surfaces receive more spray deposits than lower, contradicting results which were obtained by Pielou et al. (1962). They applied Sevin 50% wetteable powder to cherry trees at the rate of 1 lb/100 imperial gallons (0.0998 Kg/100 l.) until run - off. Immediately after drying, 100 leaves were analysed. Seventy five of these leaves had a higher deposit on the lower surfaces than upper. The mean deposits on the upper and lower surfaces were 1.65 microgram/cm and 2.38 micrograms/cm, repectively. They also sprayed dwarf apple trees in the same way and found 130 leaves out of 144 had heavier deposits on their undersides. The mean deposit on lower surfaces was 1.84 times that of the upper surface. Similar ratios of lower to upper surface deposits were obtained with concentrate air-blast spraying in which run - off does occur. They were of the opinion that these differences were not because small apple trees were sprayed as much from above as from below. It was more likely that the increased deposit on the lower surfaces was the outcome of some difference in structure between the two leaf surfaces. The difference may be related to the ultra - structure of wax on leaves, revealed by electron microscopy of carbon replicas. Similar results were obtained by Sharp (1973), who studied spray distribution with two spray machines. He divided apple trees into six regions and the two leaf surfaces. The six regions were, (1) foliage at lowest portions in the centre of tree, (2) outer foliage at mid - height, (3) foliage in the center of the tree at mid - hight, (4) outer foliage at mid -hight on the opposite side of the tree to region 2, (5) foliage in the lower regions where adjacent trees meet and (6) upper-most foliage above region 5. He found higher mean spray deposits ($\mu l / cm^2$) on the undersides of leaves in all regions after spraying by both machines.

The numbers and size of droplets are also important in control of pests and diseases, especially for smaller pests like thrips, aphids and spider mites. This is because, as the numbers of droplets increase, the probability of contacting the pest also increases. Similar studies were carried out by Fisher and Menzies (1973). They studied the behaviour of adult female European red mite, *P. ulmi* on peach leaf discs. In their first test they treated five leaf discs using nigrosine black dye with 11, 19, 28, 50 and 71 droplets. In their second test the numbers of droplets were 11, 22, 52, 75 and 75 per leaf discs. They used 0.1% Carzol as an acaricide with 0.5% nigrosine tracer. In their third test, two concentrations of Dicofol at field strength (2 gm./1.) and 70X field strength (140 gm./1.) were used with 0.5% nigrosine. In this test the numbers of droplets / leaf disc were 26, 45, 89 and 118 for field strength and 55, 60, 93 and 105 for 70X field strength. In all these tests the sizes of the droplets remained similar at 200 microns. They found that with nigrosine alone the numbers of contacts increased with the numbers of droplets of stain and the relationship was linear. When carzol (acaricide) was added with nigrosine the numbers of contacts with droplets decreased. The response of mites to both rates of dicofol was intermediate between nigrosine alone and carzol + nigrosine.

The speed of the tractor during spraying and the use of different application pressures also has some influence on spray distribution. Mc Mechan et al. (1960) studied spray distribution by two sprayers. Sprayer A was a single-sided sprayer delivering 7000 cubic feet of air per minute at an average velocity of 115 m.p.h. Sprayer B was a double -sided sprayer that delivered 10,300 cubic feet of air per minute per side at an average velocity of 87 m.p.h. The sprayers operated at one and two miles per hour. They divided the trees into two parts, the top 15 feet above ground level and the bottom 6 feet above ground level. They collected 50 leaves from each part. They observed that when DDT was applied at 300 p.s.i. by sprayer A at one and two miles / hour, the deposits were higher on both parts (top and bottom) of the tree at two m.p.h. They also sprayed the trees with both sprayers at two pressures, 75 p.s.i. and 300 p.s.i. and two speeds, one and two m.p.h. They found that the insecticide deposits by sprayer A at 75 p.s.i. were slightly higher on both parts (top and bottom) of the tree when they were applied by either speed but when the same insecticide was sprayed by sprayer B they found higher deposits in both parts of the trees by 300 p.s.i. at one m.p.h.

Studies of spray distribution carried out on other fruit trees such as citrus and peach by various worker are summarised in Table 32. These fruit trees are similar to apple trees and the methods developed for these trees could therefore be useful.

In the Studies of spray distribution carried out on apple trees and other fruit trees (Table 32) workers used different sprayers, methods, pressures, speeds and various meterials for collecting and recording the spray droplets. They also divided the trees into different zones or regions to study the spray distribution.

None of these methods agree with each other. There is still scope to study the spray distribution on fruit trees such as apple trees, to find out a suitable method by which spray droplets could be distributed equally or evenly on all parts of tree and leaf ages and to relate it

Table **32**. Summary of the results of spray distribution on different fruit trees carried out by various workers.

Authors	Fruit trees	Sprayers	Materials	Sampling surfaces	Sampling areas	Results
Carman and Jeppson (1974)	Citrus	RSM - 4 Spout	Fluorescent dye and Cherry red cards	Leaves	Top and bottom portions of trees	Uniform distribution on lower.
		Kinkelder Royal				Uniform distribution on top.
		Span sprayer				Unsuitable droplet size.
		Turbo - mist 38 CD				Other sprayers were good and effective.
		Windmil 500				
		Air - O - Fan				
Chiba (1974)	Peach	Hand gun and air blast	Carbaryl	Leaves	Inner, outer, top and bottom portions	Large quantities on outer bottom than other portions.
Dean et al (1961)	Citrus	not mentioned	Fluorescent dye and oil. Surfactant (Sponto 200)	Fruits	not mention-ed	Accmulation of drops around bottom and styler end of fruits.
				Leaves		More dye around the midrib and larger veins. Accumulation of dye at downward position of leaves.
				Twigs and smaller branches		Larger drops on green twigs. Uniform radiation on the smaller branches than green twigs.

with pest distribution (eg. spider mites). Although spray distribution has been measured in different positions of tree, it has not been related to leaf age and tree positions togather. Considering this question, studies of spray distribution were designed to study leaf age (young, middle aged and older) and tree zones (inner and outer) at different application pressures.

During studies of spider mite distribution on apple trees in a commercial orchard during the 1988 season, it was found that the numbers of spider mites varied between leaf ages in the inner and outer positions of the tree. The numbers of mites were higher in the inner position. It was hypothesised that the variation in mite numbers may be related to uneven spray distribution between these leaves and positions. Differences in mite distribution on leaf ages and tree positions also led me to study spray distribution.

MATERIALS AND METHOD.

Various materials have been used for collecting and recording the spray droplets. Johnstone (1961) used glazed photographic paper and MgO slides to collect and record spray droplets and he used croceine scarlet dye and crystal violet dye; fluorescent dye with oil on citrus trees was used by Dean et al. (1961); droplets of Saturn yellow and black dye were collected on Petridishes containing petrolum jelly / medicinal paraffin mixture by Patterson (1963). Fisher and Dougan (1970) collected water droplets on glass slides coated with silicone fluid and a butylene polymer. Sharp (1973) used a 0.4% (W:V) suspension of MT-grade Saturn yellow fluorescent dye in water and collected droplets on leaf surfaces. Cherry red cards were used by Carman and Jeppson (1974) to collect droplets of fluorescent dye. Leaf surfaces were used to collect and record droplets of Saturn yellow fluorescent dye by Cooke et al. (1975).

The present study was carried out on apple trees in a commercial orchard. The trees were divided into two positions and the leaves were divided into the three age groups identical to thise that they were divided into for the mite distribution study. The two positions of the trees were inner (one to two feet around the tree trunk) and the outer position was the tree periphery (Fig. 1). The leaf which was at the top, in the middle and at the base on an annual shoot were considered to be the young, middle aged and older leaves, respectively (Fig. 2). The experiment was conducted on 22 year old Cox orange trees budded on M 9, planted in rows of 4.2 X 3 meters. The heights of the trees was 3.5 m and their circumference was 2.9 m approximately. Two sprays were carried out in the same orchard and on the same trees. The tractor speed was 4 m.p.h. approximately, for both sprays. The first spray was done on 20th June. On this date the weather was clear with no clouds, the minimum temperature was 13.8 °C and maximum 28.4 °C, wind speed was 2 m.p.h. and the direction was north east.

In this study white glazed photographic paper and red dye were used to detect deposits. The photographic papers were cut into small pieces of 8 X 2.5 cm. Before spraying ten photographic papers were stuck onto the upper surfaces of each leaf age (ten on young, ten on middle aged and ten on older leaves) in the inner position. Similarly, ten photographic papers were stuck on the upper surfaces of each leaf age in the outer position of the tree. In the first spray the trees were sprayed at the normal pressure used by the grower. This was replicated three times (1 tree / replication). After spraying the photographic papers were collected, stuck onto a paper, labeled and brought to the laboratory. The numbers of droplets / cm^2 (of any size) were counted. Ten leaves of each age (ten young, ten middle aged and ten older leaves) from inner and outer positions were collected and shaken in 10 ml distilled water for one minute. After shaking the leaves in 10 ml distilled water, they were taken out and were stuck onto paper. The leaves were then photocopied. The photocopies of leaves were cut from the paper and were weighed to calculate the leaf area. Using the leaf area and readings obtained from a spectrophotometer the total volume of dye per cm^2 was calculated.

The second spray was carried out on 1st August, 1989. On this date the weather was clear with two hours of cloud only. The minimum temperature was 8 °C and the maximum was 21.7 °C. The wind speed was 3 m.p.h. and the direction was north west. In order to study the spray distribution on different leaf ages in the inner and outer positions of the trees, the trees were sprayed at three pressures; 50 p.s.i., 100 p.s.i. and 150 p.s.i. Each pressure was replicated three times (1 tree per replication). Other methods were similar to the first spray.

RESULTS AND DISCUSSION.

Studies of the distribution of spray over apple trees in a commercial orchard were carried out twice.

First spray.

In the first spray the trees were sprayed at pressure usually used by grower and the tractor speed was 4 m.p.h.

Distribution of droplets.

The numbers of dye droplets of any size were counted per cm^2 under a hand lens. The numbers of droplets were compared among the leaf ages (young, middle aged and older leaves) and between positions (inner and outer) of trees. It was found that the numbers of droplets on different leaf ages were not significantly different $p > 0.05$ but significant differences $p < 0.01$ were found between the numbers of droplets in the inner and outer positions (Table 27, Appendix 4). Figure 53 shows that the mean numbers of droplets were higher on young leaves than other leaf ages in both positions but their ± 95% confidence intervals were overlapping each other. The overall mean plot of the numbers of droplets / cm^2 shows the same results (Figs. 54 & 55). Figure 55 reveals that the numbers of droplets were higher in the outer position of the trees compared with the inner position. Mean, standard deviation and ± 95% confidance interval are given in Table 33. Statistics of the numbers of droplets / cm^2 on all leaf ages in the inner and outer position are given in Table 34.

Figure 53. Distribution of dye droplets on different leaf ages and different tree positions.

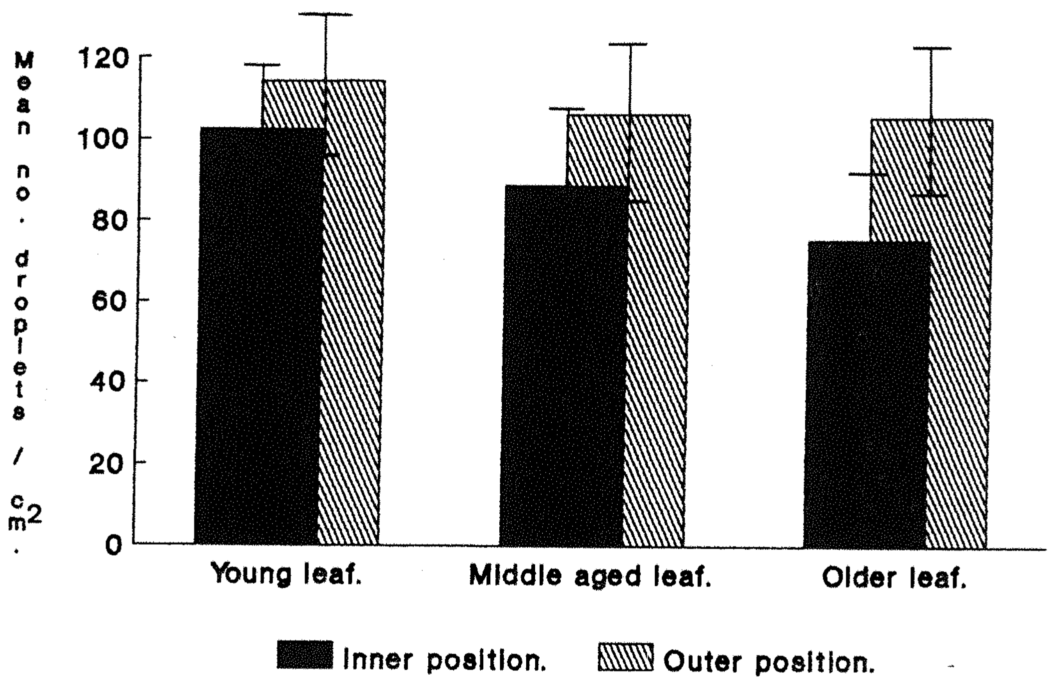
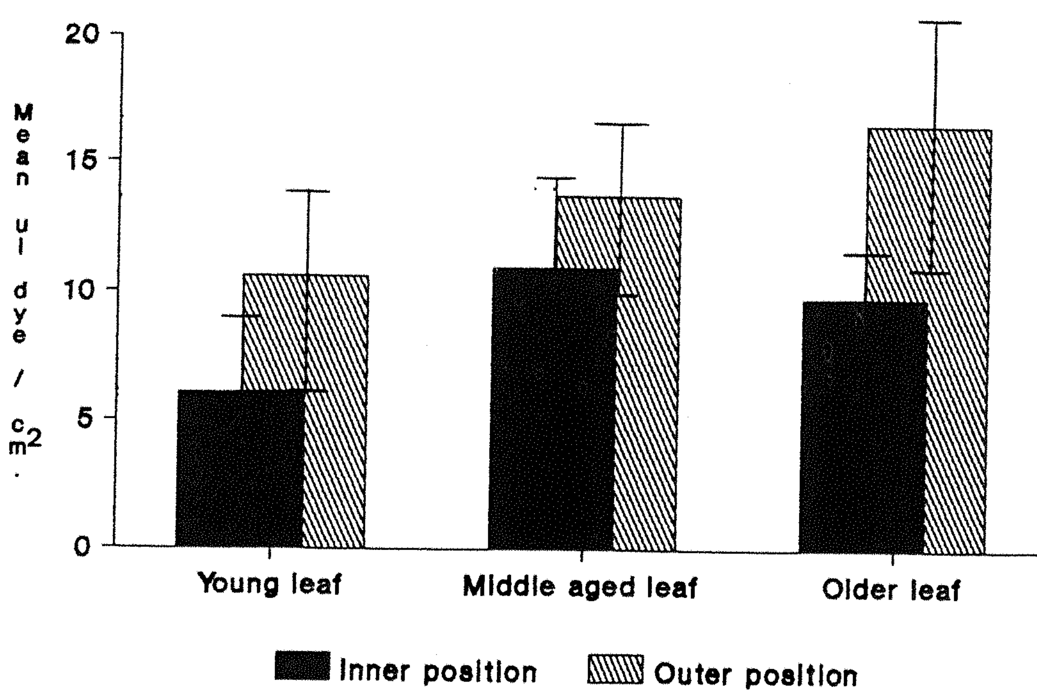


Figure 56. Distribution of dye on different leaf ages and positions.



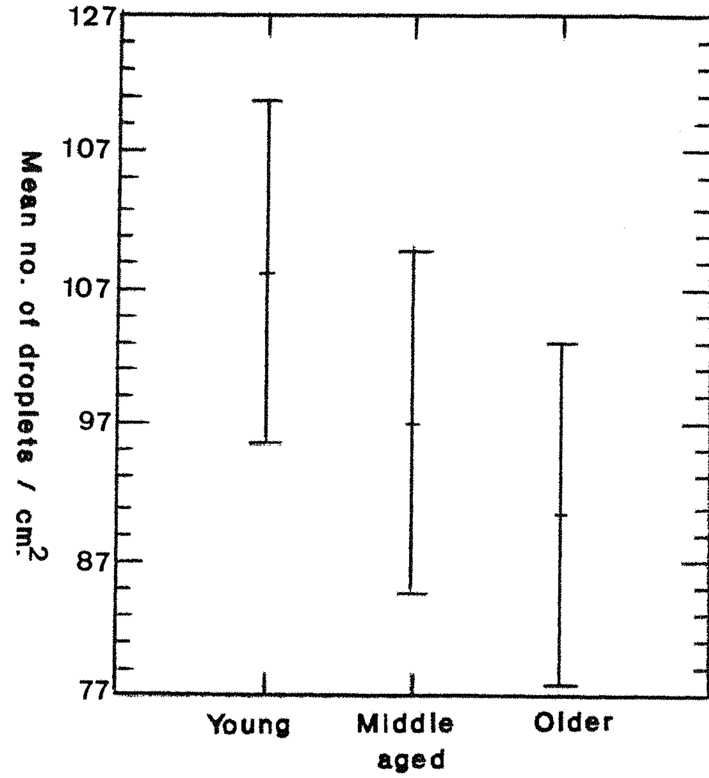


Figure 54. Mean numbers of droplets / cm^2 with 95% confidence interval on different leaf ages.

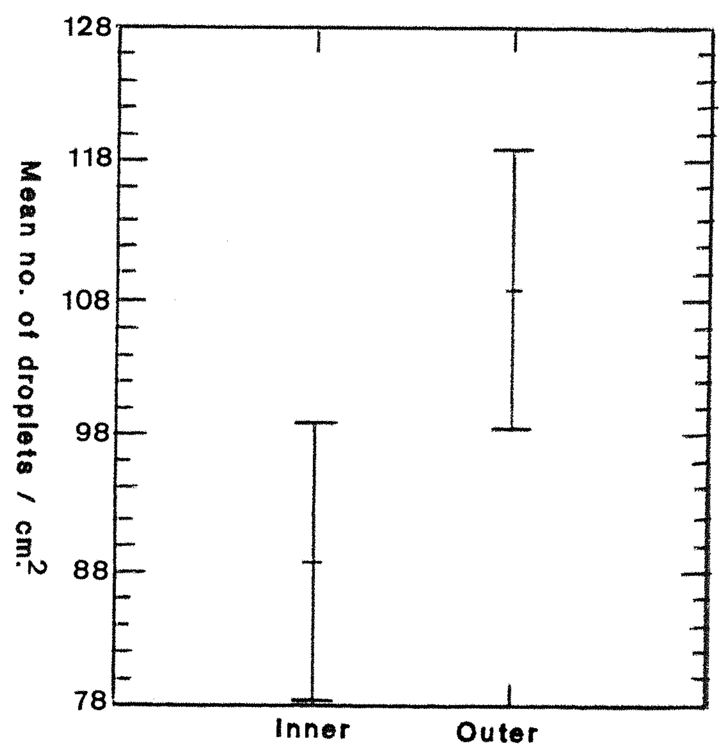


Figure 55. Mean numbers of droplets / cm^2 with 95% confidence in different positions of apple trees.

Table 33. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on leaf ages and tree positions.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	102.23	88.43	75.1	114.1	106.03	105.46
St. dev.	57.90	51.26	55.11	44.53	40.00	43.17
95% conf. interval	84.53-119.93	70.73-106.13	57.40-92.79	96.40-131.79	88.33-123.73	87.78-123.16

Table 34. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on all leaf ages in different tree positions.

Statistics	Inner position	Outer position
Mean	88.58	108.53
St. dev.	55.34	42.31
95% conf. interval	78.37 - 98.80	98.31 - 118.75

Distribution of dye.

Figure 58 shows the mean in microliters (μl) dye / cm^2 was higher in the outer position as compared with the inner position. Figure 56 reveals that mean microliter dye / cm^2 was higher on middle aged leaves in the inner position but it was higher on older leaves in the outer position. Futher observation of Figure 56 also indicates that the amount of dye was lower on young leaves than other leaves. The amount

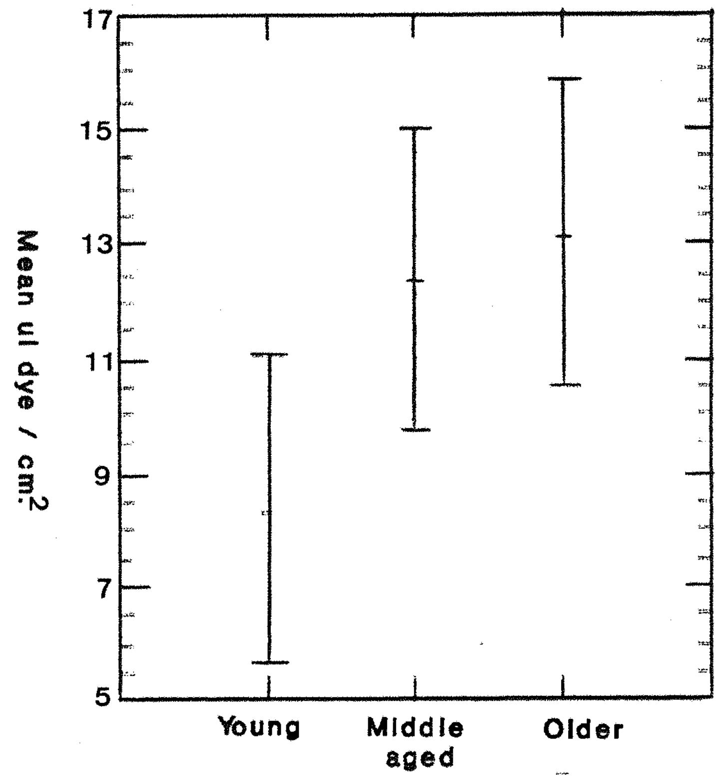


Figure 57. Mean microliter (ul) of dye / cm^2 with 95% confidence interval on different leaf ages.

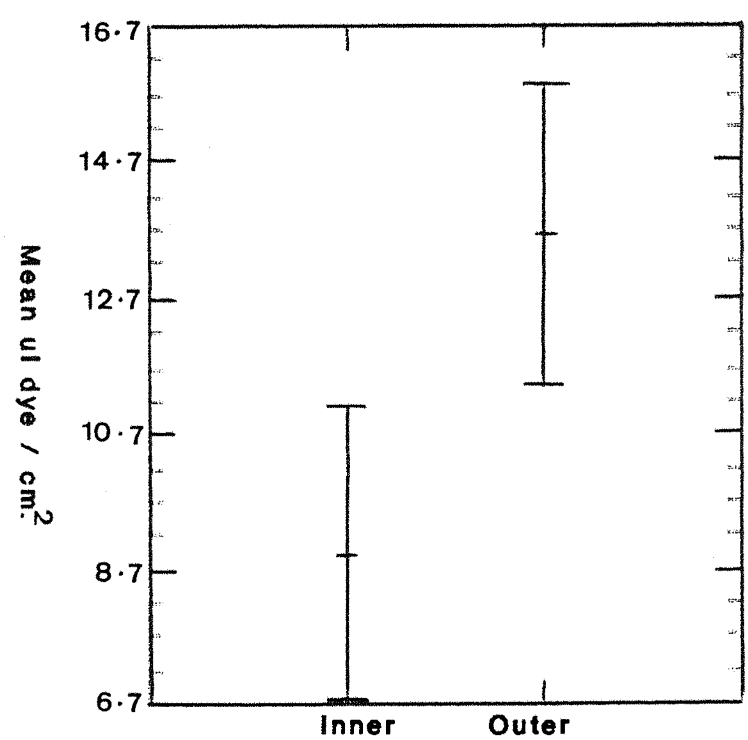


Figure 58. Mean microliter (ul) of dye / cm^2 with 95% confidence interval in different positions of apple tree

of dye in microliter / cm^2 on leaf ages in the inner and outer positions were compared and significant differences were found on leaf

Table 35. Mean, standard deviation and ± 95% confidence interval for the amount of dye in μl / cm^2 on leaf ages and tree positions.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	6.09	10.96	9.76	10.61	13.72	16.54
St. dev.	5.19	13.58	10.33	7.95	8.15	14.28
95% conf. interval	2.33-9.85	7.20-14.72	6.00-13.52	6.85-14.37	9.96-17.48	12.79-20.30
l. per ha.	60.9	109.6	97.6	106.1	137.2	165.4

ages $p < 0.05$ and tree positions $p < 0.01$ (Table 28, Appendix 4). Similar result were obtained when the overall mean of the amount of μl dye were plotted (Figs 57 & 58). Other statistical analysis such as mean, standard deviation and ± 95% confidence interval of the amount of μl dye / cm^2 on leaf ages in both positions were calculated and given in Table 35.

Similarly statistics of the dye distribution on all leaf ages in the inner and outer positions were calculated and are present in Table 36.

Table 36. Mean, variance, standard deviation and ± 95% confidence interval for the amount of dye in µl / cm² on all leaf ages in different tree positions.

Statistics	Inner position	Outer position
Mean	8.94	13.62
St. dev.	10.39	10.71
95% conf. interval	6.77 - 11.10	11.46 - 15.79
l. per ha.	89.4	136.2

Second spray.

In second spray the trees were sprayed with different pressures 50 p.s.i., 100 p.s.i. and 150 p.s.i. The speed of the tractor was similar as in the first spray.

Distribution of droplets at 50 p.s.i.

Distribution of dye droplets on leaf ages and tree positions were measured after application at this pressure. The numbers of droplets produced by this pressure on leaf ages and positions were compared statistically. Significant differences $p < 0.01$ were found between the numbers of droplets in the inner and outer positions but it was not significantly different $p > 0.05$ on leaf ages (Table 29, Appendix 4). The overall plot of the mean numbers of droplets indicates the same results (Figs. 61 & 62). When the mean numbers of droplets on each leaf age in both positions were plotted in Figure 59, it indicates that there was not much difference in the mean numbers of droplets on all leaf ages in both positions. However, the mean numbers of droplets were

Figure 59. Distribution of dye droplet on different leaf ages and tree position by 50 P.S.I pressure.

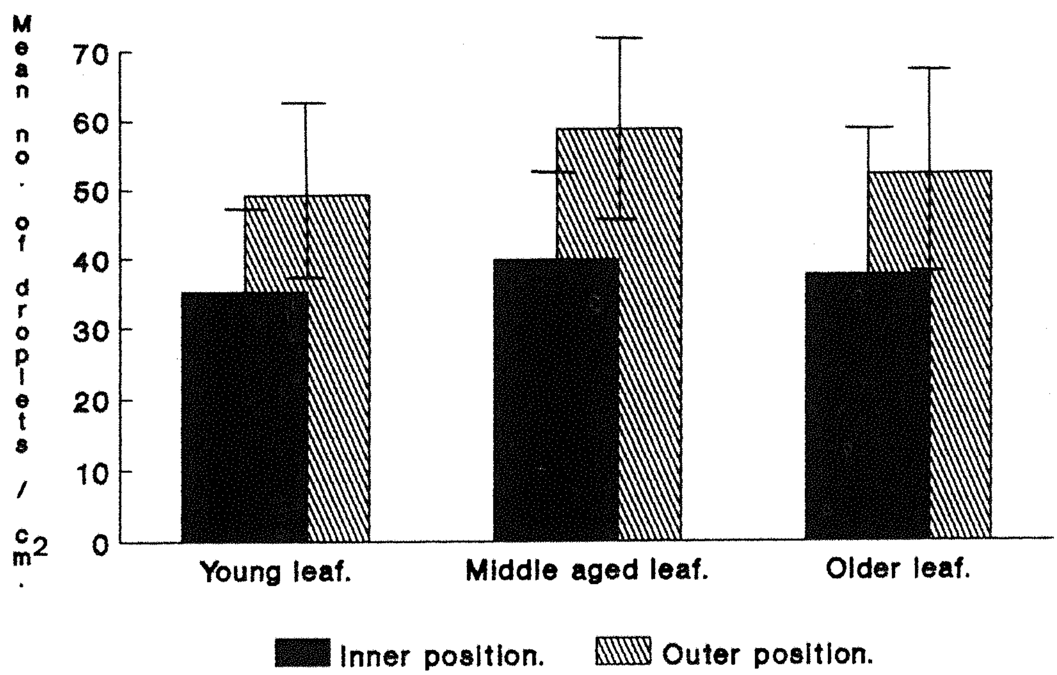
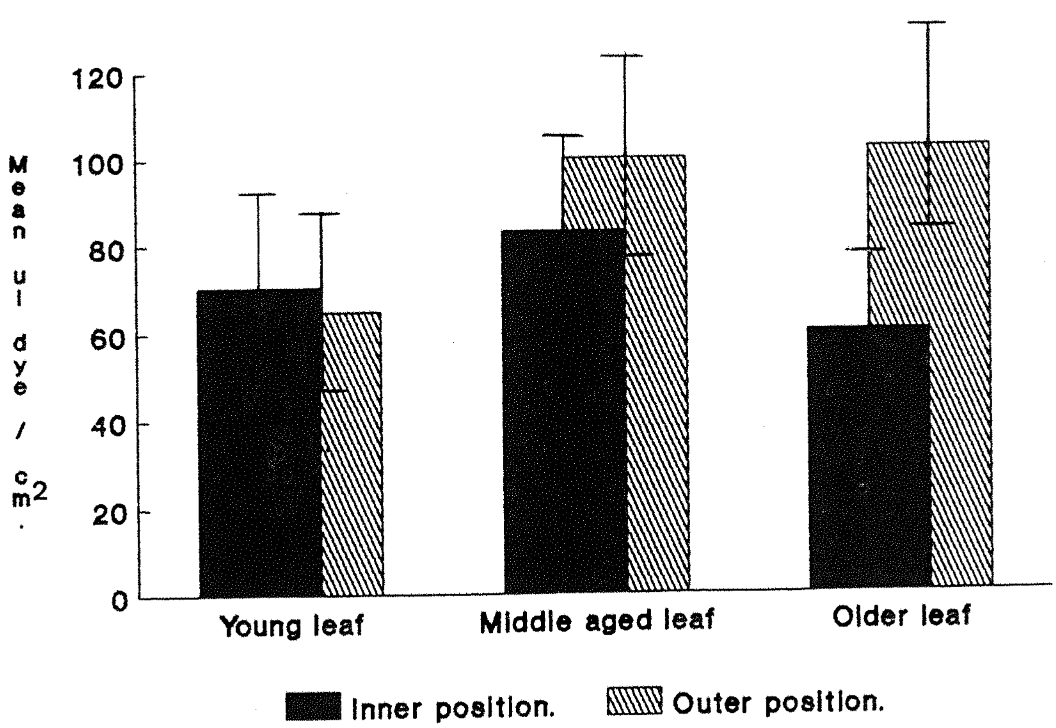


Figure 60. Distribution of dye by 50 p.s.i. pressure.



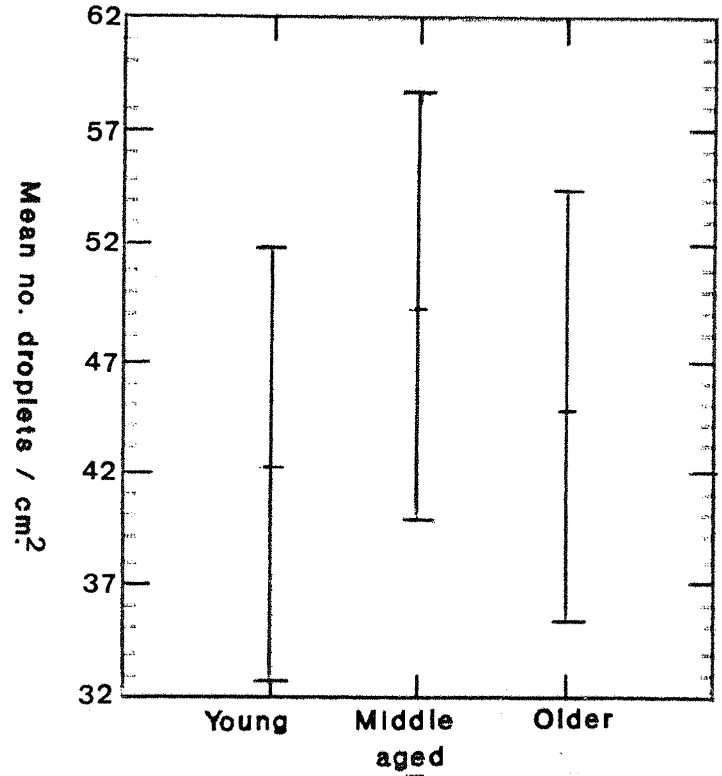


Figure 61. Mean numbers of droplets / cm^2 with 95% confidence interval by 50 p.s.i. on different leaf ages.

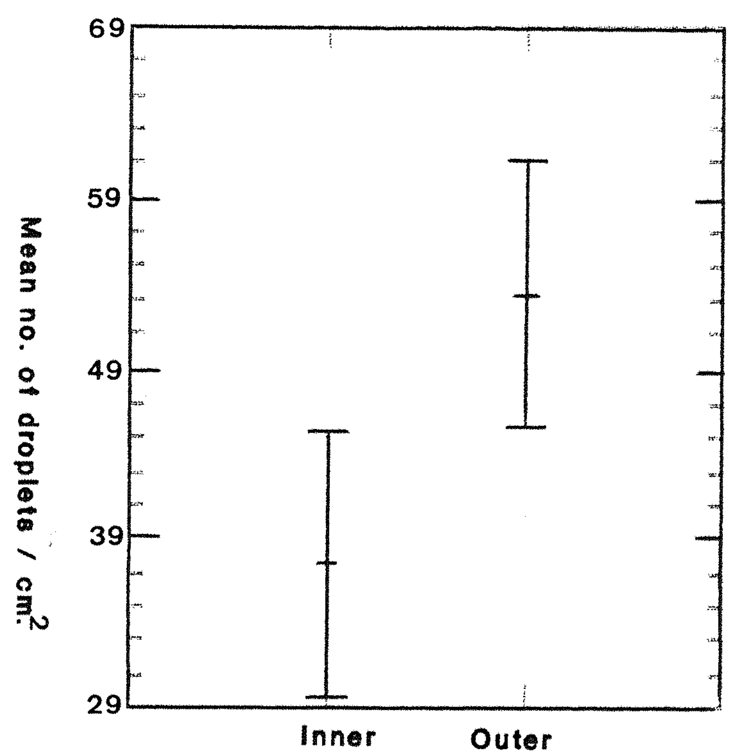


Figure 62. Mean numbers of droplets / cm^2 with 95% confidence by 50 p.s.i. in different positions of apple trees

slightly higher on middle aged leaves in both positions. Sample statistics of this pressure also reveals same results (Table 37).

Table 37. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on leaf ages and tree positions by 50 p.s.i..

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	35.20	39.76	37.56	49.26	58.70	52.20
St. dev.	47.09	49.55	18.21	15.52	41.21	37.18
95% conf. interval	21.77-48.62	26.33-53.19	24.13-50.99	35.83-62.69	45.27-72.12	38.77-65.62

Summery statistics of the numbers of droplets on all leaf ages in the inner and outer positions were also calculated and is present in Table 38.

Table 38. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on all leaf ages in different tree positions by 50 p.s.i.

Statistics	Inner position	Outer position
Mean	37.51	53.38
St. dev.	40.42	33.14
95% conf. interval	29.75 - 45.26	45.63 - 61.14

Distribution of dye by 50 p.s.i.

Figure 60 indicates that the amount of dye in microliter (μl) / cm^2 was similar as dye droplet distribution. In the inner position the amount of dye was slightly higher on middle aged leaves than other leaf ages. The amount of dye was almost equal on middle aged and older leaves in the outer position. Summery statistics of these leaves including mean, standard deviation and ± 95% confidence interval of the amount of dye on leaf ages and tree positions are given in Table 39. The differences in the amount of dye were compared and significant differences were found between the positions $p < 0.05$ but it was not

Table 39. Mean, standard deviation and ± 95% confidence interval for the amount of dye in μl / cm^2 on leaf ages and tree positions 50 p.s.i.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	70.39	82.96	59.98	64.91	99.82	102.01
St. dev.	40.43	63.08	21.44	37.92	89.34	75.54
95% conf. interval	48.97-91.81	61.47-104.31	36.54-79.38	43.49-86.33	78.40-121.24	80.59-123.43
l. per ha.	703.9	829.6	599.8	649.1	998.2	1020.1

significantly different on leaf ages $p > 0.05$ (Table 30, Appendix 4). The overal mean plot of the amount of dye with ± 95% confidence interval gave similar results (Figs. 63 & 64).

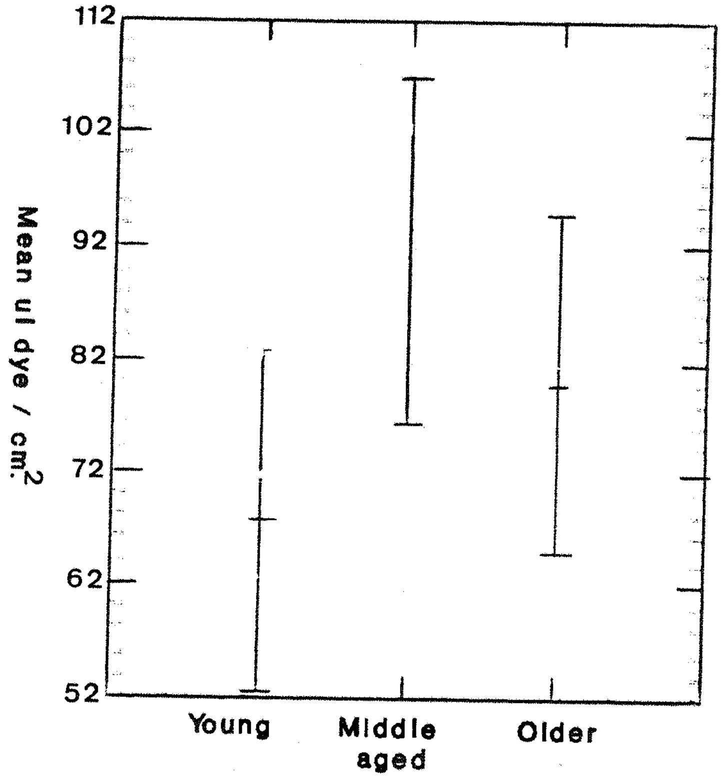


Figure 63. Mean microliter (ul) of dye / cm^2 with 95% confidence interval by 50 p.s.i. on different leaf ages

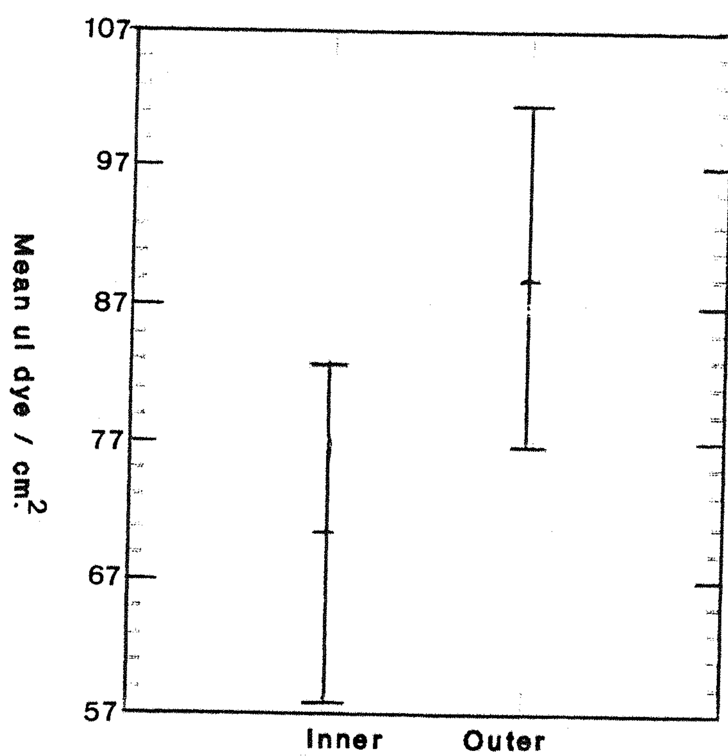


Figure 64. Mean microliter (ul) of dye / cm^2 with 95% confidence interval in different positions of apple trees.

Table 40. Mean, standard deviation and ± 95% confidence interval for the amount of dye in µl / cm^2 on all leaf ages in different tree positions 50 p.s.i.

Statistics	Inner position	Outer position
Mean	70.44	88.91
St. dev.	45.61	72.25
95% conf. interval	58.05 - 82.78	76.55 - 101.28
l. per ha.	704.4	889.1

Sample statistics of the amount of dye on all leaf ages in the inner and outer positions were also calculated and made it available in Table 40.

Distribution of droplets at 100 p.s.i.

The bars in Figure 65 and overall mean plot (Figure 67) reveal that the mean numbers of droplets / cm^2 was almost equal on all leaf ages in the inner and outer positions as their ± 95% confidence

Table 41. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on leaf ages and tree positions 100 p.s.i.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	32.60	31.36	25.33	48.30	48.96	51.23
St. dev.	21.35	19.37	15.90	43.32	41.08	37.46
95% conf. interval	21.15-44.04	19.91-42.81	13.88-36.78	36.85-59.74	37.51-60.41	39.78-62.68

Figure 65. Distribution of dye droplets on different leaf ages and tree position by 100 P.S.I. pressure.

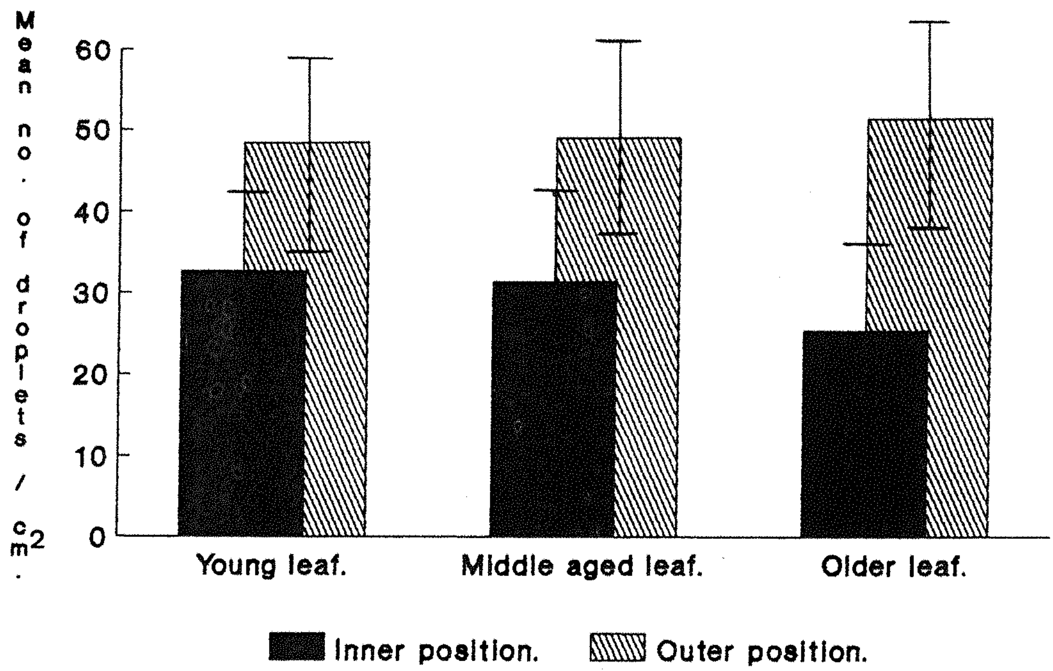
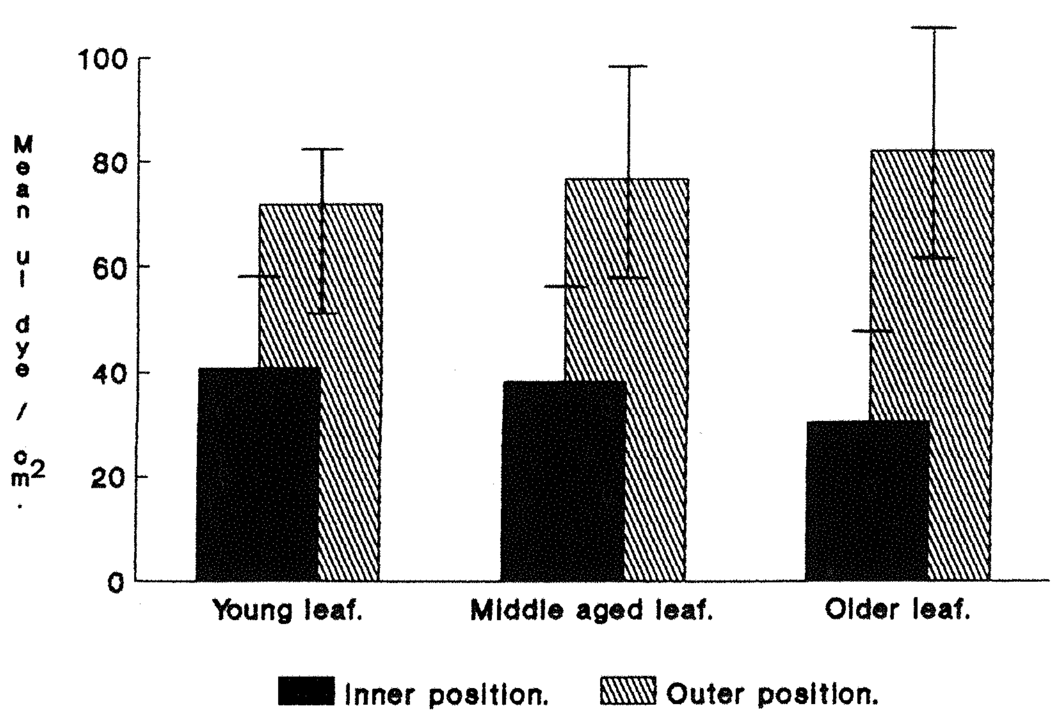


Figure 66. Distribution of dye by 100 p.s.i. pressure.



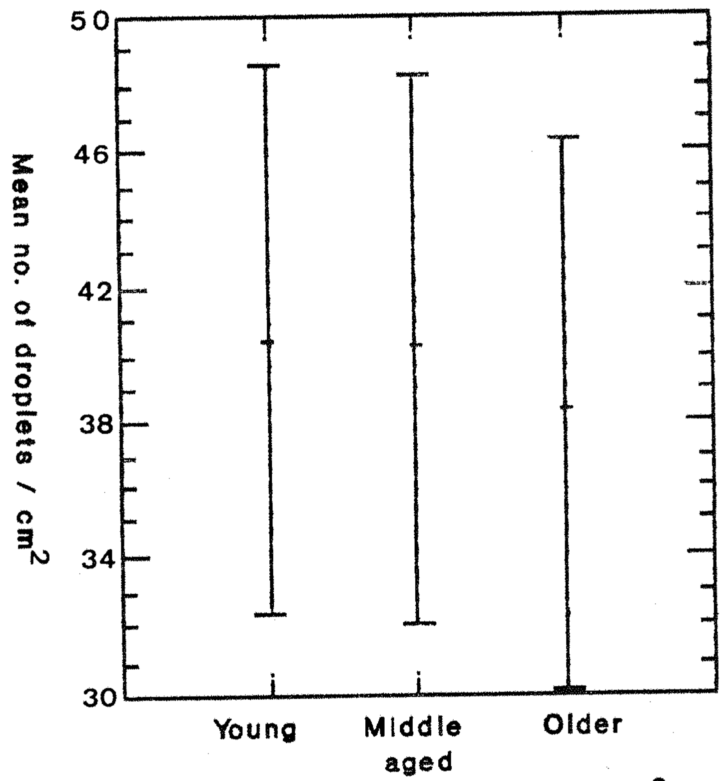


Figure 67. Mean numbers of droplets / cm^2 with 95% confidence by 100 p.s.i. in different positions of apple trees

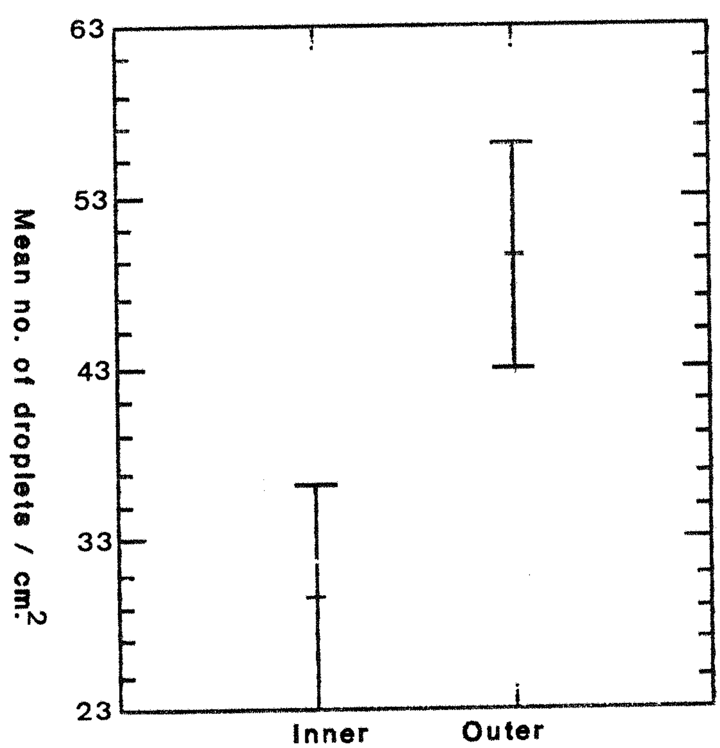


Figure 68. Mean microliter (ul) of dye / cm^2 with 95% confidence interval in different positions of apple trees.

interval (Table 41) indicates but the mean numbers of droplets was higher in the outer position than inner (Fig. 68 and Table 42). The numbers of droplets on these leaf ages and positions were analysed and significant differences were found between positions $p < 0.01$ and

Table 42. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on all leaf ages in different tree positions by 100 p.s.i.

Statistics	Inner position	Outer position
Mean	29.76	49.50
St. dev.	19.06	40.25
95% conf. interval	23.15 - 36.36	42.89 - 56.10

between leaf ages were not significantly different $p > 0.05$ (Table 31, Appendix 4).

Distribution of dye at 100 p.s.i.

Figure 66 and Table 43 are for the distribution of dye on leaf ages and tree positions. They show that the amount of dye in microliter / cm^2 were higher on all leaf ages in the outer position than inner but slight differences were found between leaf ages in both positions. The difference in the amount of dye in the inner and outer positions were highly significant $p < 0.01$ but it was not significantly different on leaf ages $p > 0.05$ (Table 32, Appendix 4). The overal plot of mean of the amount of dye on leaf ages and tree positions reveals the same results (Figs. 69 & 70).

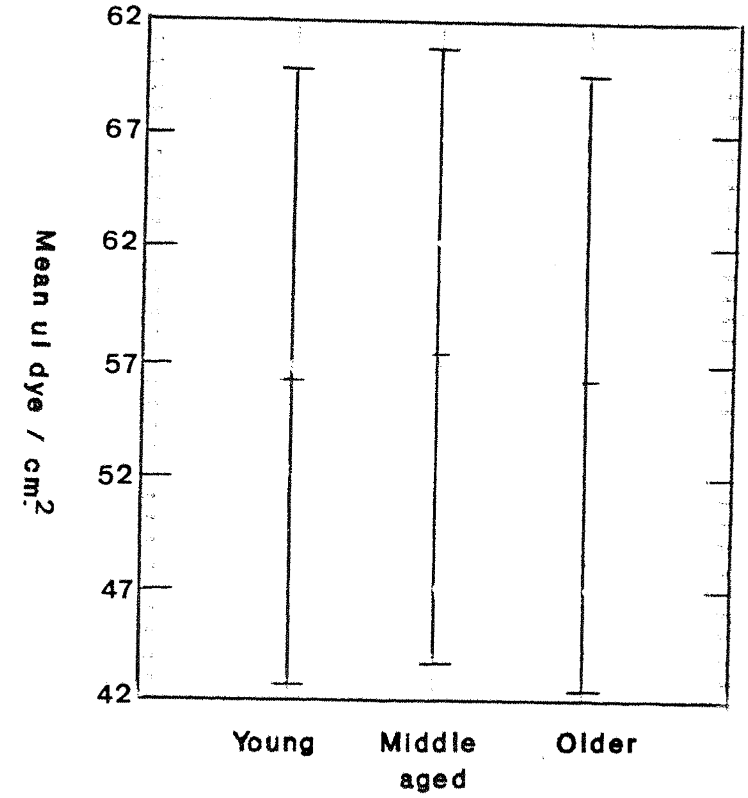


Figure 69. Mean microliter (ul) of dye / cm^{2}with 95% confidence interval by 100 p.s.i. on different leaf ages

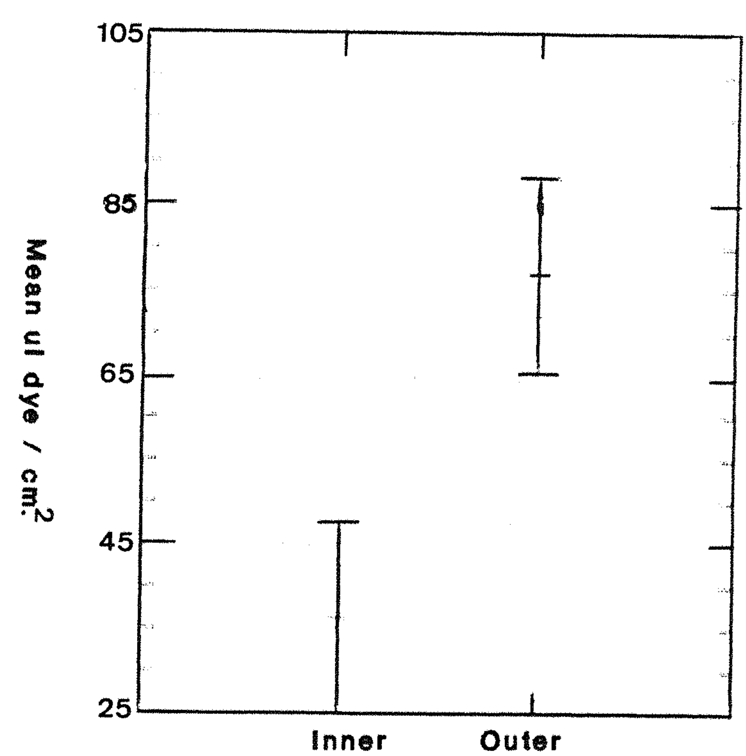


Figure 70. Mean microliter (ul) of dye / cm^{2}with 96% confidence interval in different positions of apple trees.

Similarly statistics of the amount of dye distributed on all leaf ages in the inner and outer positions were also calculated and given in Table 44.

Table 43. Mean, standard deviation and ± 95% confidence interval for the amount of dye in µl / cm^2 on leaf ages and tree positions by 100 p.s.i.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	40.89	38.04	30.40	71.64	76.46	81.79
St. dev.	17.85	30.13	17.11	33.43	55.53	105.53
95% conf. interval	21.78-59.99	18.93-57.14	11.30-49.51	52.53-90.74	57.36-95.57	62.69-100.90
l. per ha.	408.9	380.4	304.0	716.4	764.6	817.9

Table 44. Mean, standard deviation and ± 95% confidence interval for the amount of dye in µl / cm^2 on all leaf ages in different tree positions by 100 p.s.i.

Statistics	Inner position	Outer position
Mean	36.44	76.63
St. dev.	45.61	72.25
95% conf. interval	25.41 - 47.47	65.60 - 87.66
l. per ha.	364.4	766.3

Distribution of droplets by 150 p.s.i.

Numbers of droplets / cm^2 produced by 150 p.s.i. on leaf ages and tree positions were compared. Significant differences were found $p < 0.01$ on leaf ages and tree positions (Table 33, Appendix 4). The overal plot of mean of the numbers of droplets on leaf ages and tree positions showed similar trends (Figs. 71 & 72). The bars in Figure 73 suggests that the older leaves in the inner and outer positions received more droplets than other leaf ages and also all leaf ages in the outer position received higher numbers of droplets compared with leaf ages in the inner position, although the differences on individual leaf age in both positions were not significantly different as their ± 95% confidence interval indicates (Fig. 73 and Table 45).

Similarly, sample statistics of the numbers of droplets on all leaf ages in the inner and outer positions were calculated and given in Table 46. This Table also reveals the difference between inner and outer position.

Table 45. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on leaf ages and tree positions by 150 p.s.i.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	24.93	34.16	37.23	34.60	39.20	53.83
St. dev.	17.30	24.72	33.49	25.31	22.40	30.10
95% conf. interval	15.00-34.86	24.23-44.09	27.30-47.16	24.67-44.52	29.27-49.12	43.90-63.76

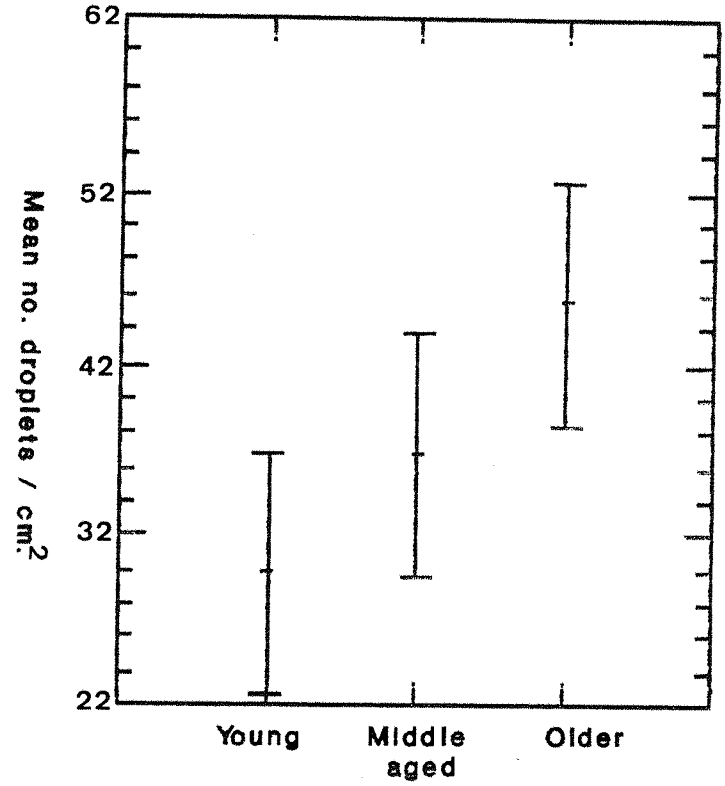


Figure 71. Mean numbers of droplets / cm^2 with 95% confidence interval by 150p.s.i. on different leaf ages.

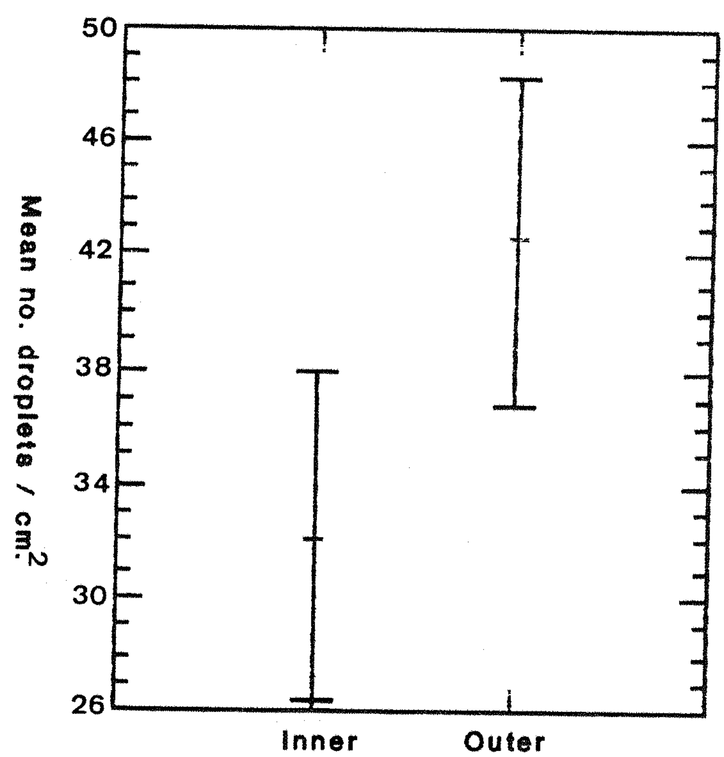


Figure 72. Mean microliter (ul) of dye / cm^2 with 95% confidence interval in different

Figure 73. Distribution of dye droplets on different leaf ages and tree position by 150 P.S.I. pressure.

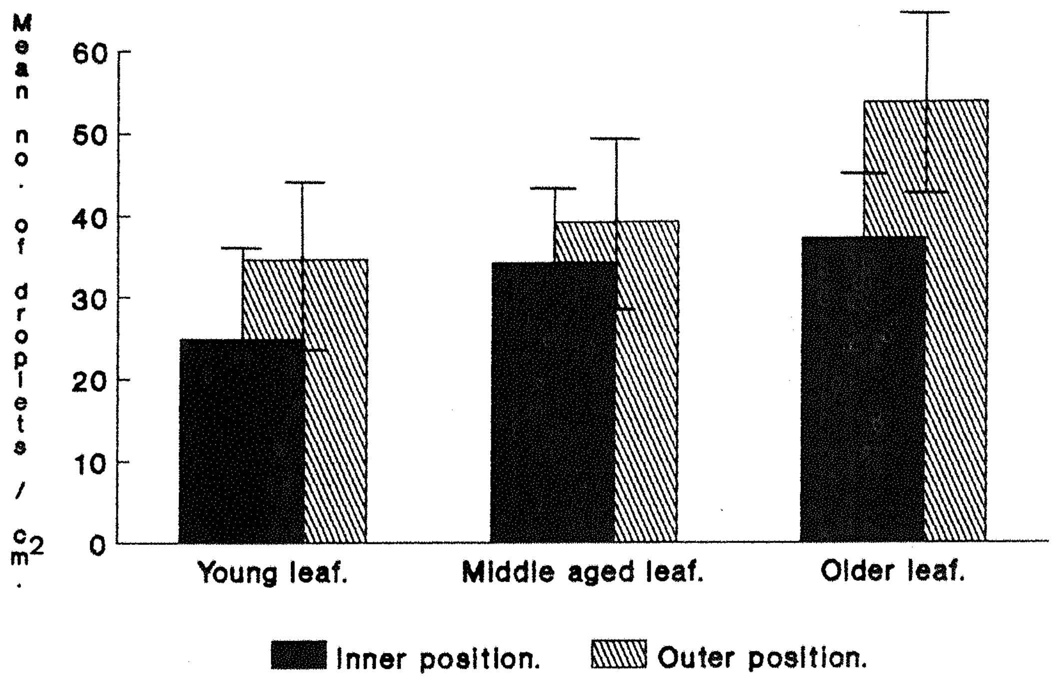


Figure 74. Distribution of dye by 150 p. s. i. pressure.

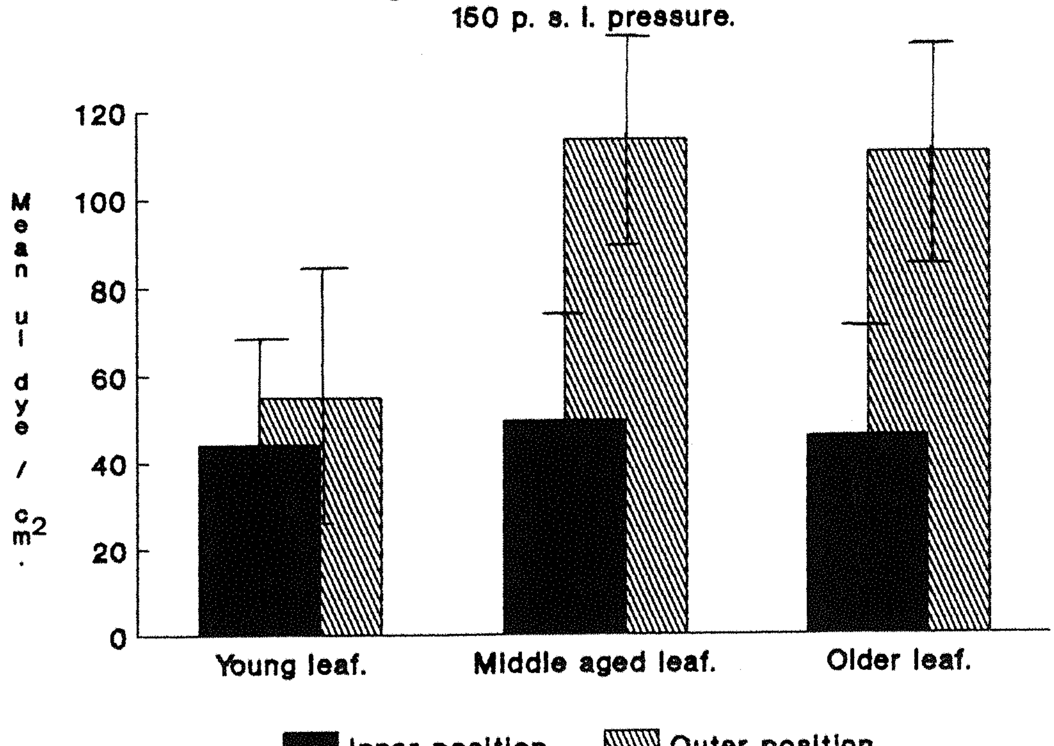


Table 46. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 on all leaf ages in different tree positions 150 p.s.i.

Statistics	Inner position	Outer position
Mean	32.11	42.57
St. dev.	26.26	29.83
95% conf. interval	26.37 - 37.84	36.81 - 48.27

Distribution of dye at 150 p.s.i.

The bar chart in Figure 74 and Table 47 indicate that the middle aged and older leaves in the outer position received higher amount dye compared with same leaf ages in the inner position but it was almost equal on middle aged and older leaves in the outer position while

Table 47. Mean, standard deviation and ± 95% confidence interval for the amount of dye in µl / cm^2 on leaf ages and positions 150 p.s.i.

Statistics	Inner position			Outer position		
	Leaf ages					
	Young	Middle aged	Older	Young	Middle aged	Older
Mean	43.88	49.59	45.88	55.00	113.54	110.53
St. dev.	34.19	41.15	53.04	29.28	108.94	127.84
95% conf. interval	16.45-71.31	22.16-77.02	18.46-73.31	27.58-82.43	86.11-140.97	83.10-137.95
l. per ha.	438.8	495.9	458.8	550.0	1135.4	1105.3

younger leaves received less amount of dye in the same position. The distribution of dye on all leaf ages in the inner position were almost equal however, the middle aged leaves received slightly more dye than other leaf ages. The difference in the amount of dye produced by this pressure were highly significant between inner and outer positions $p < 0.01$ and on leaf ages $p < 0.05$ (Table 34, Appendix 4). The overal plot of mean of the amount of dye gave similar results (Figs. 75, 76 and Table 48).

Table 48. Mean, standard deviation and ± 95% confidence interval for the amount of dye in µl / cm^2 on all leaf ages in different tree positions by 150 p.s.i.

Statistics	Inner position	Outer position
Mean	46.45	93.02
St. dev.	43.07	101.01
95% conf. interval	30.62 - 62.29	77.10 - 108.86
l. per ha.	464.5	930.2

Distribution of dye droplets at different pressures.

By looking at the Figures 77 & 78 it seems that the when all pressures were compared, there was not much difference in droplet distribution, although the pressure 50 p.s.i. produced slightly more droplets on young and middle aged leaves in both positions. The differences between pressures, leaf ages and positions were compared and significant differences were found between pressures $p < 0.05$, between positions $p < 0.01$ and the differences between leaf ages were not significantly different $p > 0.05$ (Table 35, Appendix 4). Figures

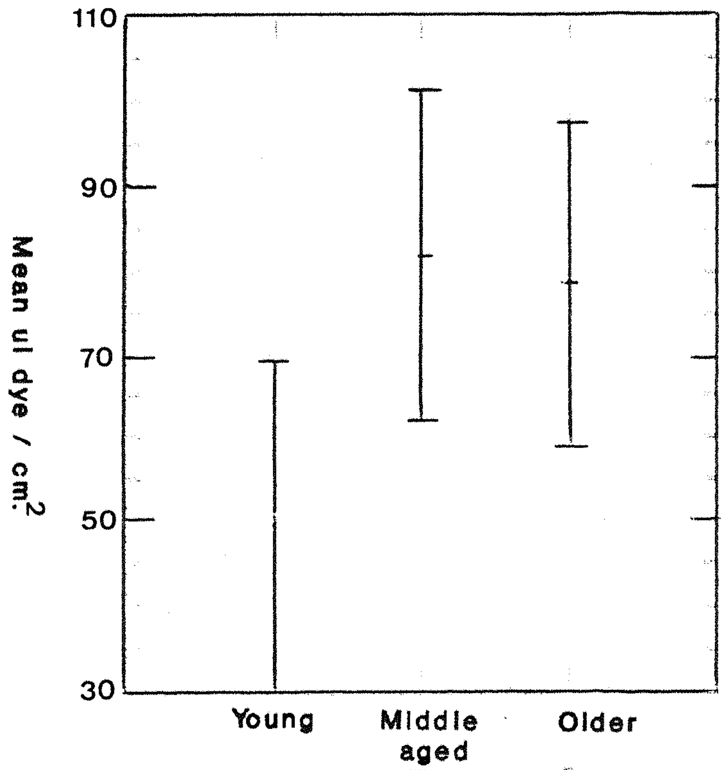


Figure 75. Mean microliter (ul) of dye / cm^2 with 95% confidence interval by 150 p.s.i. on different leaf ages

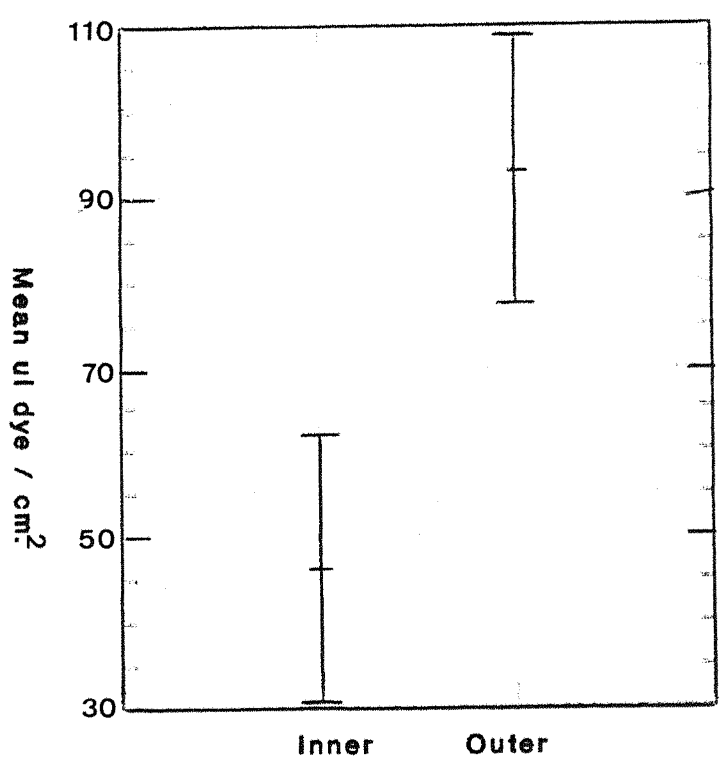


Figure 76. Mean microliter (ul) of dye / cm^2 with 95% confidence interval in different positions of apple trees.

Figure 77. Distribution of dye droplets
on leaf ages by different presures
in the inner position of trees.

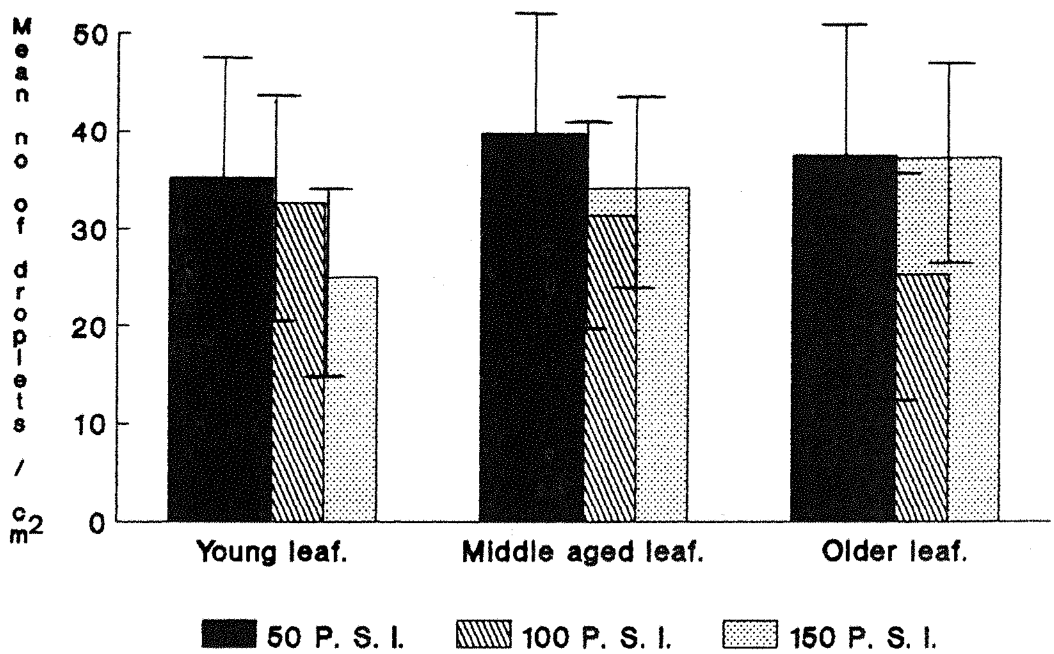
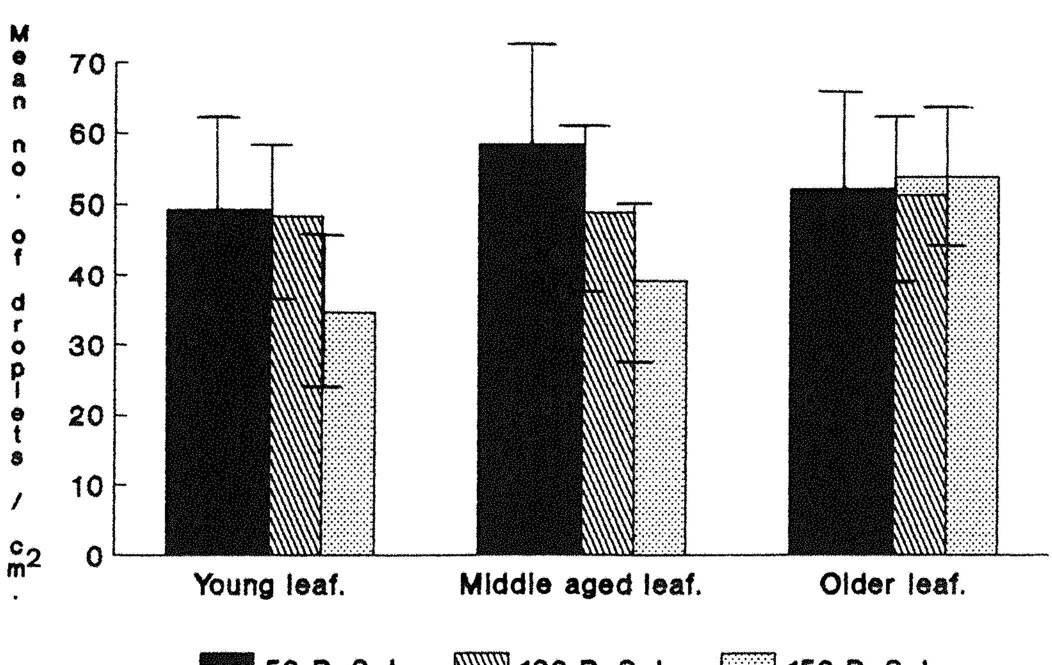


Figure 78. Distribution of dye droplets
on leaf ages by different pressures
in the outer position of trees.



81 and 82 are for the overall plot of mean of the numbers of dye droplets which indicate the same results.

Distribution of dye at different pressures.

The distribution of dye on leaf ages in the inner and outer positions were slightly different. The pressure 50 p.s.i. produced slightly higher amount of dye on all leaf ages in the inner position compared with other pressures (Fig. 79) while in the outer position middle aged and older leaves received higher amount of dye by 150 p.s.i. and young leaves received more dye by 100 p.s.i. (Fig. 80),

Table 49. Mean, standard deviation and ± 95% confidence interval for the numbers of droplets / cm^2 produced by different pressure on all leaf ages and tree positions.

Statistics	Pressures		
	50 p.s.i.	100 p.s.i.	150 p.s.i.
Mean	54.45	39.63	37.32
Standard deviation	37.71	32.93	28.50
95% conf. interval	40.71-50.19	34.89-44.37	32.95-42.06

although these differences on individual leaf ages are not significantly different. The distribution of dye were analysed and significant differences were found between all variables i.e. leaf ages, positions and pressures $p < 0.01$ (Table 36, Appendix 4). Similer results were obtaind when overall mean plot of the amount of dye were plotted (Fig. 83 & 84).

Figure 79. Distribution of dye on leaf ages in the inner position by different pressures.

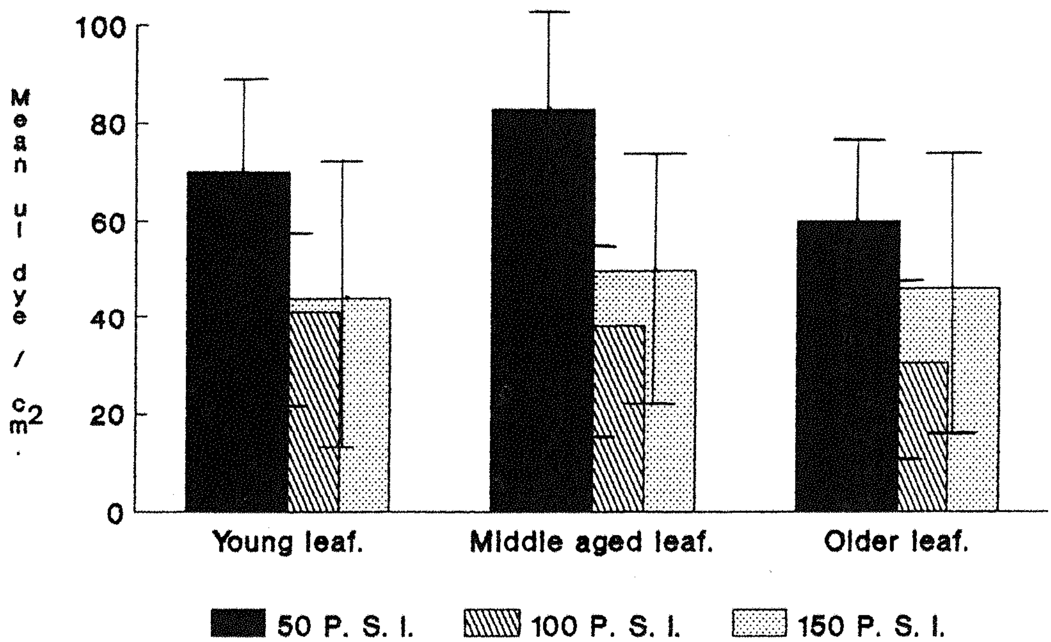
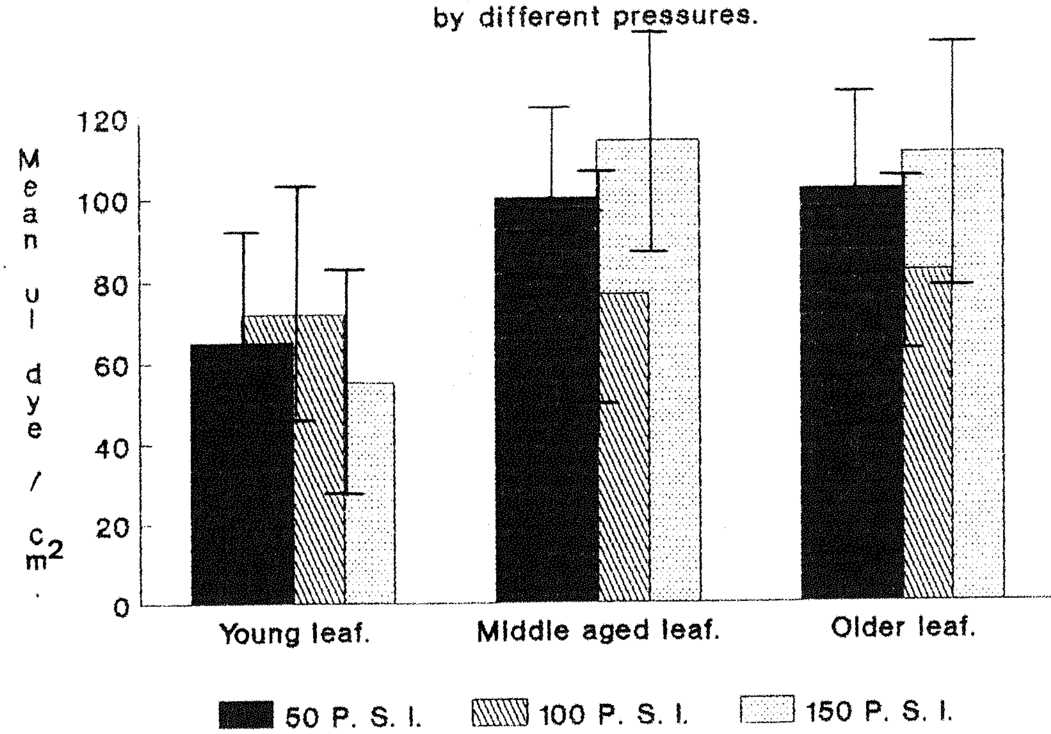
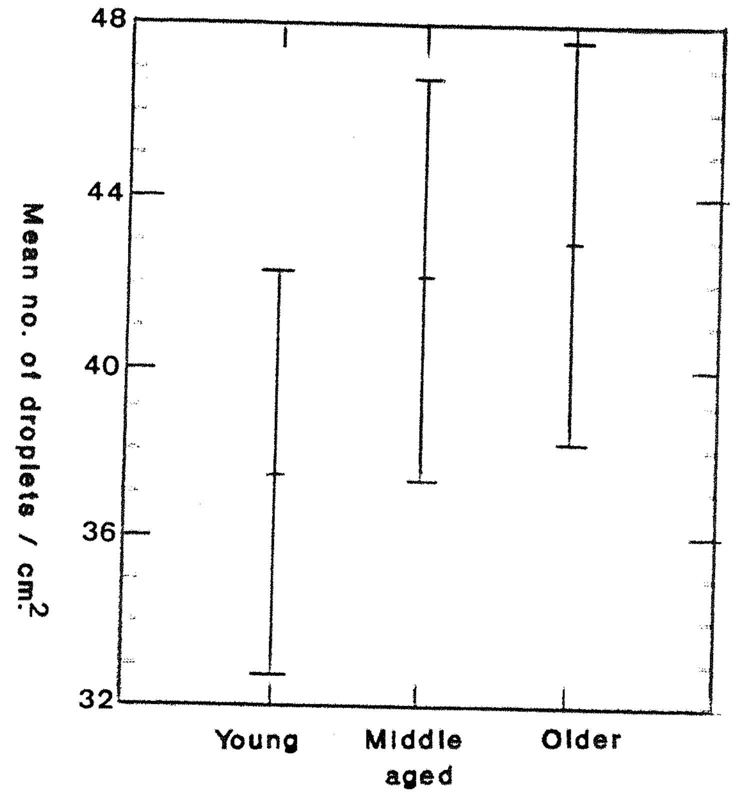


Figure 80. Distribution of dye on different leaf ages in the outer position by different pressures.





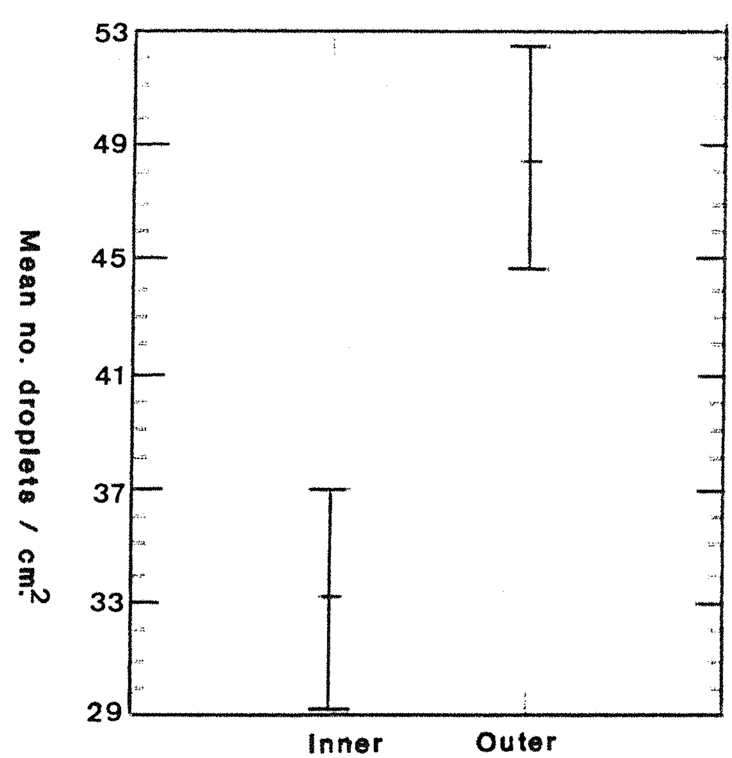


Figure 81. Mean numbers of droplets / cm^2 with 95% confidence interval on different leaf ages and positions by different pressures.

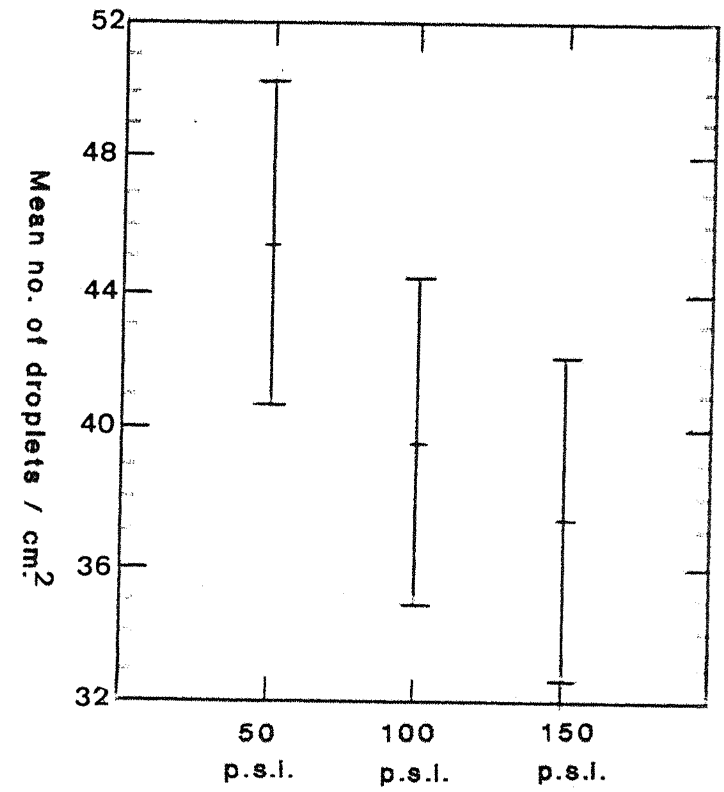


Figure 82. Mean numbers of droplets / cm with 95% confidenc interval by different pressures.

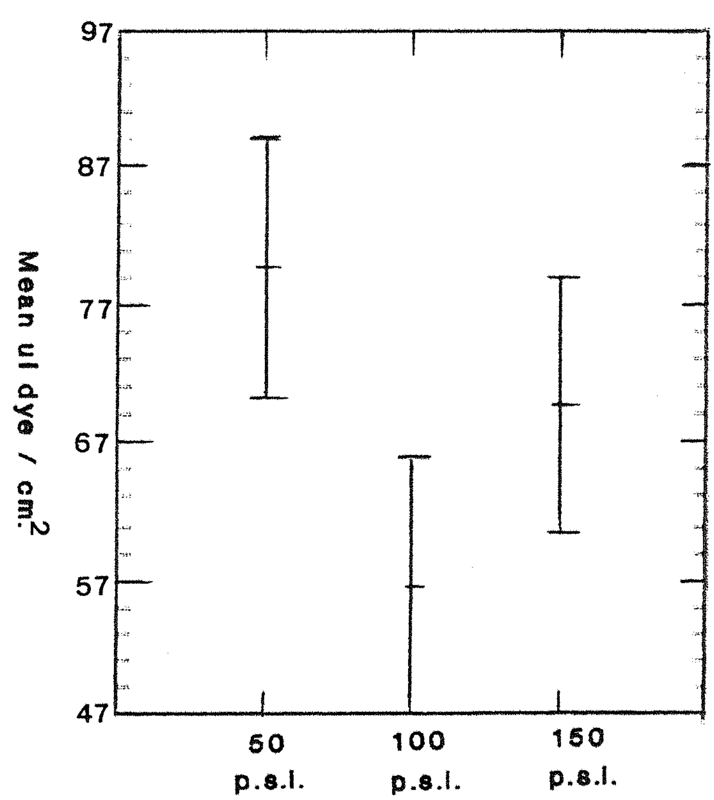
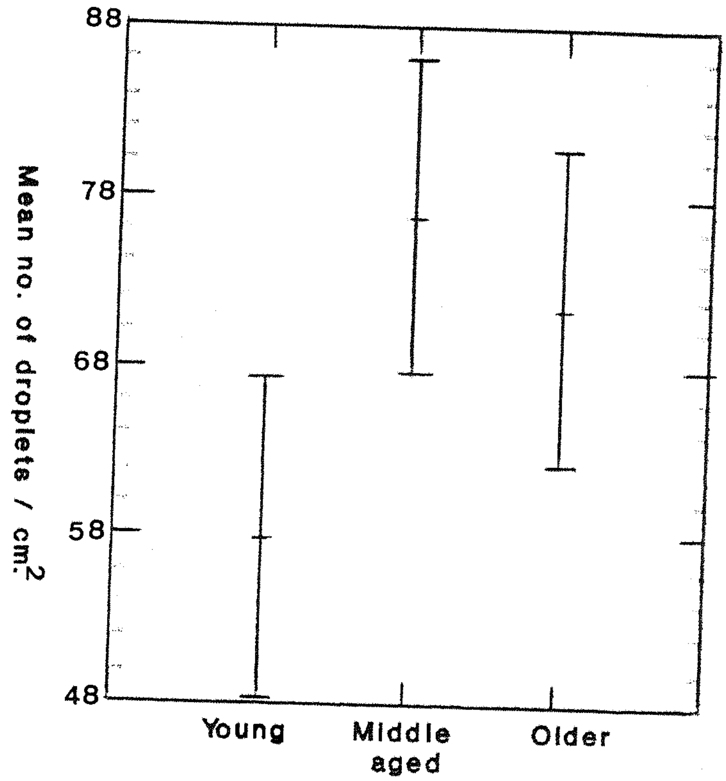


Figure 84. Mean ul dye / cm^2 with 95% confidence interval by different pressures.



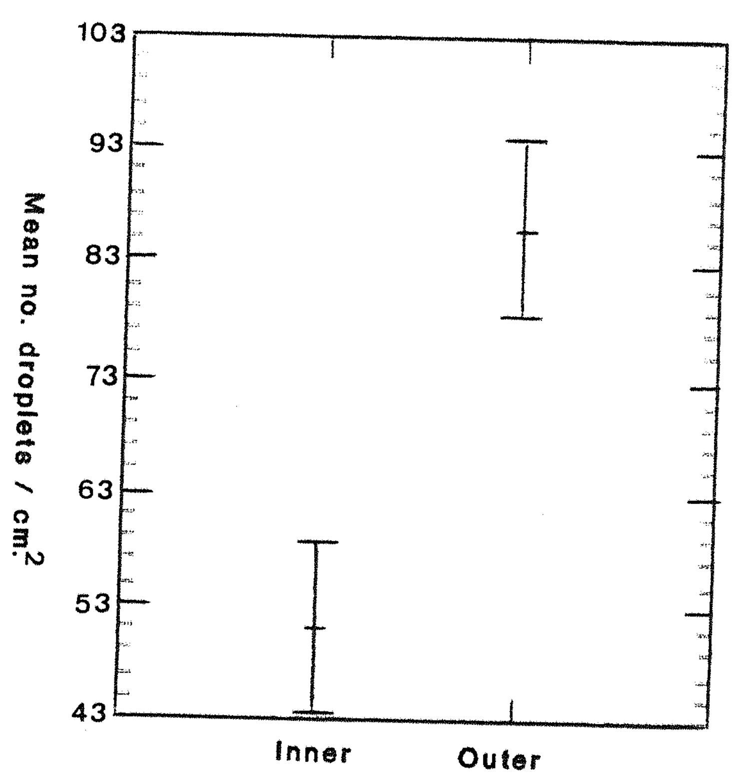


Figure 83. Mean ul dye / cm^2 with 96% confidence interval on different leaf ages and positions by different presseures.

The numbers of droplets and the amount of dye produced by each pressure on all leaf ages and tree positions are represented by bar graphs in Figure 85 and 86. These figures indicate that the 50 p.s.i. pressure produced many droplets and also more amount of dye than other pressures but the differences between them were not significantly different as their mean and ± 95% confidence indicate (Tables 49 and 50).

Table 50. Mean, standard deviation and ± 95% confidence interval of the amount of dye in µl / cm^2 produced by different pressure on all leaf ages and tree positions.

Statistics	Pressures		
	50 p.s.i.	100 p.s.i.	150 p.s.i.
Mean	79.67	56.54	69.74
Standard deviation	60.96	56.17	80.87
95% conf. interval	70.37-88.97	47.24-65.84	60.44-79.04
l. per ha.	796.7	565.4	697.4

The amount of dye in microliter / cm^2 on different leaf ages and positions in each table above were transformed into liter / ha. Laboratory bioassey carried out by various workers; for example, the LC50 value (% concentration) for susceptible and resistant population of red spider mite to dicofol was 0.00046 and 0.00679, respectively (Pree and Wagner, 1987). Cranham (1969) monitored resistance in field population of red spider mite to tetradifon and found that 2.4 - 4.7 ppm gave 50% mortality while 6.4 - 8.6 ppm killed 90% population of

Figure 85. Distribution of dye droplets on all leaf ages and tree positions by different pressures.

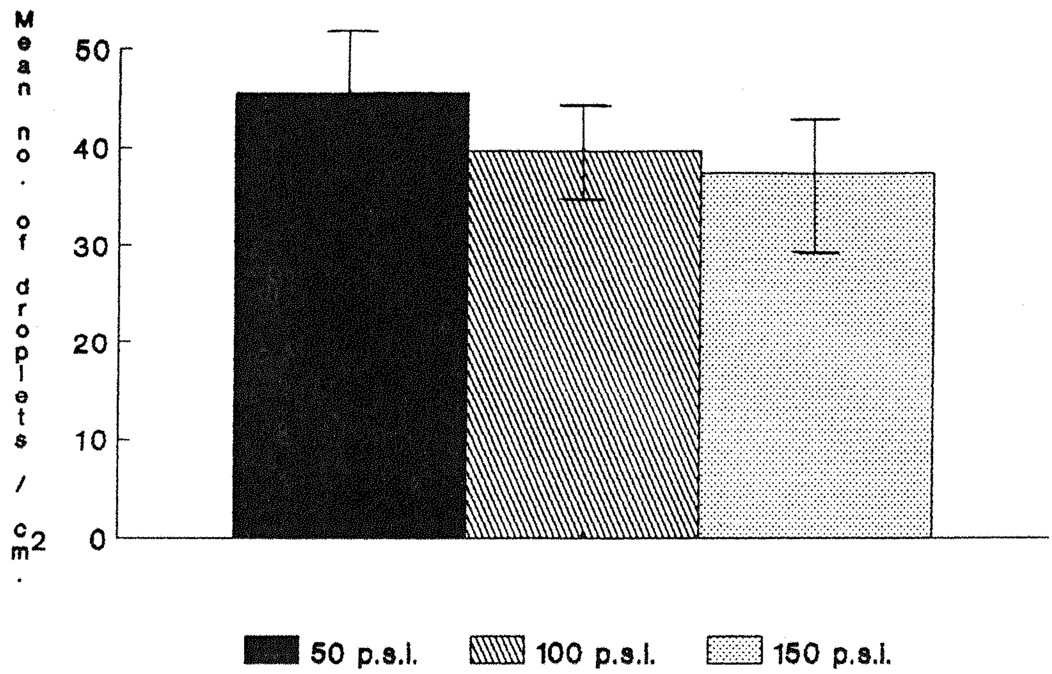
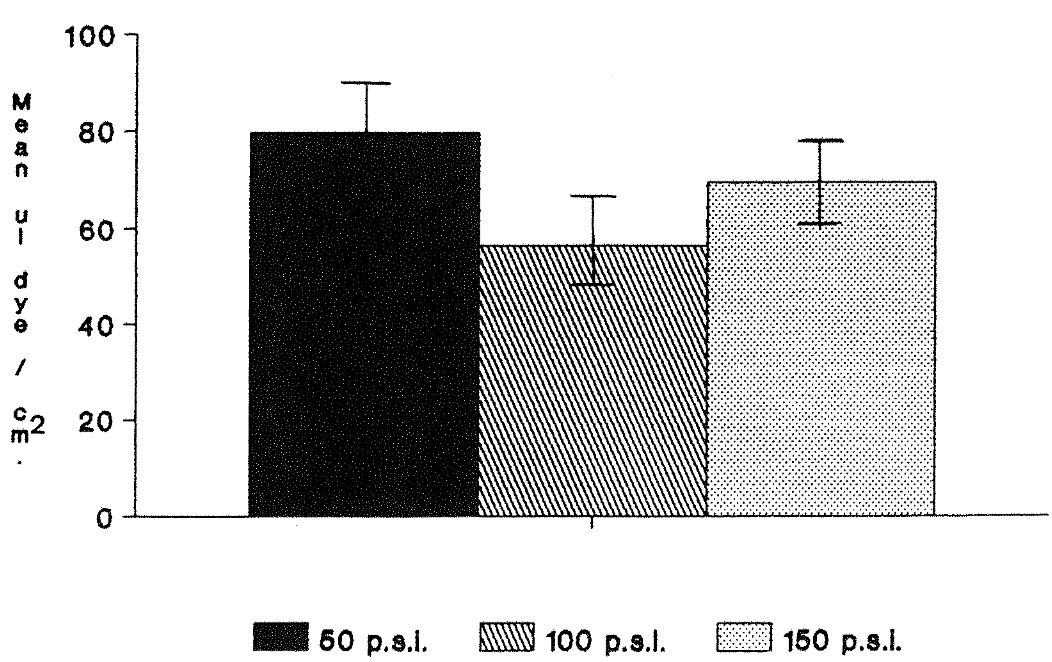


Figure 86. Distribution of dye on all leaf ages and tree positions by different pressures.



P. ulmi. He also observed that 13 - 47 ppm and 202 - 877 ppm killed 50% and 90% of the resistant population of same spider mite. Similarly, 36.1 oz. and 16.5 oz. Plictran (Cyhexatin 50 Wr.) per 100 gallon of water was enough to kill susceptible and resistant strain of *Neoseiulus (Typhlodromus) fallacis* (Garman) (Acarina: Phytoseiidae), respectively (Rock and Yeargan, 1970).

By comparing these laboratory and field bioasseys with our spray distribution it seems that all leaf ages particularly in the outer position received more dye (pesticide). This may be the reason why no predatory mites were found during sampling in 1988 and 1989 seasons (Chapter 1) but when few branches were caged and left untreated for one season (1989) few *T. pyri* were observed on these branches (Chapter 3). Since in the present studies no laboratory bioassey were carried out and it is difficult to relate our spray distribution results with bioassey results reported in the literature because thier aim was different than ours. In future spray distribution and laboratory/field bioasseys should be carried out with similar aims and objectives to related laboratory/field bioasseys with spray distribution.

CONCLUSIONS

The spray studies were started with the aim of finding out the pattern of spray distribution on different leaf ages and tree positions and to relate this with mite distribution.

In the first experiment when the trees were sprayed at the normal pressure used by the grower, higher numbers of droplets and lower amounts of dye were found on young leaves than other leaf ages in both positions. This was possibly because of position of leaves and branches.

In second experiment when the trees were sprayed with different pressures it was observed that numbers of droplets and amount of dye on leaf ages varied. It was not confirmed that one leaf age will definately always receive more amount of dye or droplets than other leaf ages. After conducting this experiment it has now become confirmed that outer position received higher numbers of droplets and higher amount of dye than inner position. Therefore, it can be related with mites distribution when higher numbers of mites were found in the inner position as compared with outer position. Different numbers of mites on leaf ages may be related with other factors, for example leaf hairs or nutrient contents of the leaves as reported by other workers.

When the results of each pressure on leaf ages and positions were combined higher numbers of droplets and amount of dye by 50 p.s.i. than other pressures. It is likly that with higher pressures (100 p.s.i. and 150 p.s.i.) more spray drift occures and less spray lands on leaves and trees. On the other hand as the present studies indicates with less pressure more spray lands on trees and leaves surfaces and less drift occures. Although our aim was not to study the spray drift.

Chapter 5

OVERALL DISCUSSION

Studies of phytophagous mite distribution on leaf ages and positions varied during both year, 1988 and 1989 and were significantly different. The distribution of *P. ulmi* and *A. schlechtendali* varied. The numbers of red spider mites were higher on middle aged leaves followd by older and younger leaves whereas, the numbers of rust mite were higher on younger leaves. The distribution of both species were similar in the inner and outer positions with higher numbers in the inner zone. It was concluded that these differences were because of uneven spray distribution on leaves and positions. During spray distribution significant differences were found between leaf ages and zones but overall dye distribution was similar to red spider mite distribution i.e. highest amount of dye on middle aged leaves and lowest on younger leaves, while the amount of dye on older leaves was intermediate between these leaf ages. Similarity in these two results may be because of the size of leaves. Since middle aged leaves are bigger than younger and older leaves therefore many mites occupied this leaf age. The distribution of mite on leaf ages may also depend on other factors such as leaf nutrients (Dabrowski and Beilak, 1977), (Beilak, 1977), (Post, 1962) and (Van De Vrie and Boersma, 1970). Mite distribution may also depend on leaf appearance; for example, young leaves are more hairy than middle aged and older leaves which may make it difficult for red spider mites to reach the leaf surface and suck sap from it. While the apple rust mite are smaller than red mites and they can pass through leaf hairs present on young leaves and young leaves are also softer than middle aged and older leaves, therefore highest numbers of rust mite were found on young leaves.

From spray distribution study it is clear that all leaf ages in both positions received more amount of dye therefore no predators were observed and spider mites were free from any natural control.

Studies on spider mite movement from untreated (caged/covered) branches to treated (uncaged/uncovered) branches were carried out under glasshouse and field conditions. In glasshouse the numbers of mites were higher on caged and covered branches than uncaged and uncovered branches while in field the results were different. In field experiment the numbers of mites were equal on caged and uncaged branches which may be due to *T. pyri* found only on caged branches. The numbers on covered/uncovered branches were also not significantly different which may be due to movement of mite between these branches also higher numbers of mites were observed on uncovered branches than uncaged ones.

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Appendices

Appendix 1

Table 1. Spray schedule of a commercial orchard during 1988.

Dates, 1988	Pesticides	Rate per acre.
31/03	Delancol	1 Pt.
14/04	Apollo	5 Fl. oz. (141.75 ml)
19/04	Delancol	1 Pt.
28/04	Systhane Thinsec	15 Fl. oz. (425.25 ml) 54 Fl. oz. (1530.9 ml)
11/05	Systhane Regulex	15 Fl. oz. (425.25 ml) 6 Fl. oz. (170.1 ml)
23/05	Systhane Regulex	15 Fl. oz. (425.25 ml) 6 Fl. oz. (170.1 ml)
27/05	Thinsec	1 lit.
31/05	Thinsec	1 lit.
2/06 15/06	Delancol Palitop Systhane Metasystox	1 Pt. 14 oz. (396.9 gm) 15 Fl. oz. (425.25) 4 Fl. oz. (113.4 ml)
28/06	Pallitop	14 oz. (396.9 gm)
11/07	Stempor Thinsec Childion	1 Ib. 54 Fl. oz. (1530.9 ml) 64 Fl. oz. (1814.4 ml)
26/07	Pallitop Calcium	14 oz. (396.9 gm) 7 Ib. (3.179 Kg)
24/10	Stempor	14 oz. (396.9 gm)

Table 2. Spray schedule of an commercial orchard with old trees. during 1989.

Spray dates, 1989.	Pesticides	Rate per acre
21/3	Delancol	1 pt.
7/4	Delancol Urea	1 pt. 7 Ib. (7.84 Kg / ha)
21/4	Thinsec Systhane Urea	14 fl. oz. (980.7 ml / a) 14 fl. oz. (980.7 ml / ha) 7 Id. (7.84 Kg / ha)
3/5	Delawca Urea	16 fl. oz. (1.12 l. / ha) 7 Ib. (7.84 Kg / ha)
18/5	Thinsec Systhane Regulex	1 lit. 10 fl. oz. (700.5 ml / ha) 6 fl. oz. (420.3 ml / ha)
5/6	Systhane Regulex	10 fl. oz. (700.5 ml / ha) 6 fl. oz. (420.3 ml / ha)
19/6	Systhane Regulex Metasystox	10 fl. oz. (700.5 ml / ha) 4 fl. oz. (280.2 ml / ha) 4 fl. oz. (280.2 ml / ha)
4/7	Thinsec Childion	2 lit. 64 fl. oz. (4.48 l. / ha)
26/8	Childion	36 fl. oz. (2.52 l. / ha)

Table 3. Analysis of covariance for the numbers of *P.ulmi* during 1988.

Adult

Source of Variation	Sum of Squares	D.f.	Mean Squares	F ratio	Significant Level
Dates	3.47	10	0.34	10.32	0.00
Position	1.35	1	1.35	40.09	0.00
Interaction Dates X Positions	0.67	10	0.06	2.01	0.02
Error	43.73	1298	0.03		
Dates	3.47	10	0.34	10.63	0.00
Leaf ages	2.29	2	1.14	35.14	0.00
Interaction Dates X leaf ages	1.35	20	0.06	2.06	0.00
Error	42.11	1287	0.03		
Leaf ages	2.29	2	1.14	33.82	0.00
Positions	1.35	1	1.35	39.74	0.00
Interaction Leaf ages X Positions	0.92	2	0.46	13.63	0.00
Error	44.66	1314	0.03		

Table contd. on next page.

Egg

Source of Variation	Sum of Squares	D.f.	Mean Squares	F ratio	Significant Level
Dates	25.39	10	2.53	9.46	0.00
Position	14.56	1	14.56	54.30	0.00
Interaction Dates X Positions	4.20	10	0.42	1.56	0.11
Error	348.22	1298	0.26		
Dates	26.27	10	2.62	11.97	0.00
Leaf ages	72.62	2	36.31	165.53	0.00
Interaction Dates X leaf ages	12.03	20	0.60	2.74	0.00
Error	282.33	1287	0.21		
Leaf ages	71.28	2	35.64	153.86	0.00
Positions	14.10	1	14.10	60.89	0.00
Interaction Leaf ages X Positions	2.16	2	1.08	4.67	0.00
Error	304.37	1314	0.23		

Table 4. Analyses of variance for the numbers of *A. schlechtendali* during 1988.

Source of Variation	Sum of Squares	D.f.	Mean Squares	F ratio	Significant Level
Dates	43.00	10	4.30	13.70	0.00
Position	19.76	1	19.76	63.01	0.00
Interaction Dates X Positions	13.49	10	1.34	4.30	0.00
Error	406.56	1296	0.31		
Dates	43.28	10	4.32	15.82	0.00
Leaf ages	37.29	2	18.64	68.16	0.00
Interaction Dates X leaf ages	50.99	20	2.54	9.32	0.00
Error	351.53	1285	0.27		
Leaf ages	37.12	2	18.56	57.67	0.00
Positions	19.88	1	19.88	61.77	0.00
Interaction Leaf ages X Positions	3.62	2	1.81	5.62	0.00
Error	422.31	1312	0.32		

Table 5. Analyses of variance for the numbers of *P.ulmi* during 1989.

Adult

Source of Variation	Sum of Squares	D.f.	Mean Squares	F ratio	Significant Level
Dates	16.13	11	1.46	17.11	0.00
Position	0.92	1	0.92	10.76	0.00
Interaction Dates X Positions	1.31	11	0.11	1.39	0.17
Error	34.96	408	0.08		
Dates	16.13	11	1.46	22.16	0.00
Leaf ages	5.59	2	2.79	42.27	0.00
Interaction Dates X leaf ages	5.40	22	0.24	3.71	0.00
Error	26.20	396	0.06		
Leaf ages	5.59	2	2.79	25.46	0.00
Positions	0.92	1	0.92	8.39	0.00
Interaction Leaf ages X Positions	0.02	2	0.01	0.09	0.90
Error	46.79	426	0.10		

Table contd. on next page.

Egg

Source of Variation	Sum of Squares	D.f.	Mean Squares	F ratio	Significant Level
Dates	44.34	11	4.03	11.87	0.00
Position	15.31	1	15.31	45.09	0.00
Interaction Dates X Positions	4.08	11	0.37	1.09	0.11
Error	138.52	408	0.33		
Dates	44.72	11	4.36	12.78	0.00
Leaf ages	12.38	2	4.03	11.79	0.00
Interaction Dates X leaf ages	10.21	22	0.46	1.35	0.13
Error	135.31	396	0.34		
Leaf ages	12.38	2	6.19	16.07	0.00
Positions	15.31	1	15.31	39.75	0.00
Interaction Leaf ages X Positions	10.47	2	5.23	13.60	0.00
Error	164.09	426	0.38		

Table 6. Analyses of variance for the numbers of *A. schlechtendali* during 1989.

Source of Variation	Sum of Squares	D.f.	Mean Squares	F ratio	Significant Level
Dates	19.32	11	1.75	16.87	0.00
Position	0.86	1	0.86	8.34	0.00
Interaction Dates X Positions	1.12	11	0.10	0.97	0.00
Error	42.49	408	0.10		
Dates	19.32	11	1.76	22.45	0.00
Leaf ages	0.58	2	0.29	3.71	0.02
Interaction Dates X leaf ages	12.90	22	0.58	7.49	0.00
Error	30.99	396	0.07		
Leaf ages	0.58	2	0.29	1.98	0.00
Positions	0.86	1	0.86	5.94	0.00
Interaction Leaf ages X Positions	0.05	2	0.02	0.19	0.82
Error	62.30	426	0.14		

Table 7. Analyses of variance for winter egg of *P. ulmi* in the inner and outer positions during 1988.

Sources of variation	Sum of squares	D.f.	Mean squares	F ratio	Significant level
Dates	4.47	3	1.49	4.15	0.00
Positions	19.48	1	19.48	54.30	0.00
Dates x positions	0.84	3	0.28	0.78	0.50

Table 8. Analyses of variance for winter egg of *P. ulmi* on twig ages and positions during 1988.

Sources of variation	Sum of squares	D.f.	Mean squares	F ratio	Significant level
Dates	19.03	3	6.34	13.19	.0000
Positions	22.57	1	22.57	46.94	.0000
Twig ages	14.59	1	14.59	30.35	.0000
Dates x positions	2.50	3	0.83	1.73	.1589
Dates x twig ages	3.14	3	1.04	2.18	.0898
Positions x twig ages	0.39	1	0.39	0.82	.3733
Error	177.93	370	0.48		

Table 9. Analyses of variance for winter egg of *P. ulmi* on twig ages and positions during 1989.

Sources of variation	Sum of squares	D.f.	Mean squares	F ratio	Significant level
Dates	0.02	1	0.02	0.18	0.66
Positions	0.78	1	0.78	4.99	0.02
Twig ages	1.55	1	1.55	9.91	0.00
Dates x positions	0.30	1	0.30	1.92	0.16
Dates x twig ages	0.00	1	0.00	0.00	0.93
Positions x twig ages	0.029	1	0.02	0.16	0.69
Error	26.40	168	0.15		

Appendix 2

Table 10. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on caged and uncaged branches in the glasshouse.

10a. adults on Cox orange.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	5501.5	8	687.68	2.85	0.007
Between branches	7786.0	1	7786.0	32.28	0.0
Interaction dates X branches	5935.9	8	741.98	3.07	0.004
Error	21706.8	90	241.18		

Eggs on Cox orange.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	5514.57	8	689.32	1.04	0.40
Between branches	21505.33	1	21505.3	32.60	0.0
Interactio dates X branches	4035.50	8	504.43	0.76	0.63
Error	59364.33	90	659.60		

***A. schlechtendali*. on Cox orange**

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	48348.63	8	6043.57	3.68	0.0
Between branches	11865.03	1	11865.0	7.23	0.0
Interaction dates X branches	23202.96	8	2900.3	1.77	0.09
Error	147513.3	90	1639.0		

Table contd. on next page.

10b. adults on Exquisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	5082.29	8	635.2	3.24	0.002
Between branches	2790.75	1	2790.7	14.25	0.0
Interaction dates X branches	3178.33	8	397.2	2.02	0.05
Error	17625.1	90	195.8		

Eggs on Exquisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	17723.40	8	2215.42	4.82	0.0
Between branches	7416.89	1	7416.89	16.15	0.0
Interactio dates X branches	4069.18	8	508.64	1.10	0.36
Error	41313.50	90	459.03		

A. schlechtendali. on Exquisitte

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	51184.35	8	6398.04	3.22	0.0
Between branches	8748.00	1	8748.0	4.41	0.03
Interaction dates X branches	6605.50	8	825.6	0.41	0.90
Error	178527.3	90	1983.6		

Table 11. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on uncaged branches Cox orange before and after spray in the glasshouse.

Adult, *P. ulmi*

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	30.083 54.833	1 10.	30.083 5.48	5.48	.041
16/6 23/6 Error	52.083 174.833	1 10	52.083 17.48	2.97	.115
29/6 12/7 Error	6.750 14.166	1 10	6.750 1.416	4.77	.054

Eggs, *P. ulmi.*

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	36.750 866.166	1 10	36.750 86.61	0.42	.536
16/6 23/6 Error	120.333 639.666	1 10	120.333 63.96	1.88	.200
29/6 12/7 Error	5.333 385.666	1 10	5.333 38.566	0.13	.721

Apple rust mite, *A. schlechtendali.*

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	12.000 11726.667	1 10	12.000 1172.666	0.01	.922
16/6 23/6 Error	2324.083 16176.833	1 10	2324.083 1617.683	1.43	.258
29/6 12/7 Error	14.083 22.83	1 10	14.083 2.28	6.16	.032

Table 12. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on uncaged branches of Exquisitte before and after spray in the glasshouse.

Adult, *P. ulmi*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	468.75 1281.50	1 10	468.750 128.15	3.65	.084
16/6 23/6 Error	14.08 52.83	1 10	14.083 5.28	2.67	.133
29/6 12/7 Error	1.33 1.33	1 10	1.333 0.333	4.00	.073

Eggs, *P.ulmi*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	65.333 847.333	1 10	65.333 84.73	0.77	.409
16/6 23/6 Error	408.333 3879.333	1 10	408.333 378.933	1.05	.329
29/6 12/7 Error	1.333 20.666	1 10	1.333 2.066	0.64	.448

Apple rust mite, *A. schlechtendali*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	0.333 7429.333	1 10	0.333 742.93	0.0	.983
16/6 23/6 Error	2241.333 20748.333	1 10	2241.33 2074.83	1.08	.323

Table 13. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on covered and uncovered branches in the glasshouse.

Adults, *P. ulmi*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	377.66	8	47.20	2.12	0.04
Between branches	40.33	1	40.3	1.81	0.18
Interaction dates X branches	361.66	8	45.20	2.03	0.05
Error	2001.0	90	22.23		

Eggs, *P. ulmi*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	959.74	8	119.96	3.13	0.0
Between branches	62.25	1	62.25	1.62	0.20
Interactio dates X branches	744.40	8	93.05	2.43	0.01
Error	3443.0	90	38.25		

***A. schlechtendali*.**

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	4053.52	8	506.69	2.76	0.0
Between branches	285.18	1	285.18	1.55	0.21
Interaction dates X branches	2037.55	8	254.69	1.39	0.21
Error	16483.89	90	183.15		

Table 14. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on uncovered branches before and after spray in the glasshouse.

Adult, *P. ulmi*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	5.33 26.66	1 10	5.33 2.66	2.00	.187
16/6 23/6 Error	3.00 148.66	1 10	3.00 14.86	0.20	.667
29/6 12/7 Error	96.33 1.33	1 10	96.33 0.333	8.18	.016

Eggs, *P. ulmi*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	6.75 23.50	1 10	6.75 2.35	2.87	.121
16/6 23/6 Error	30.08 86.83	1 10	30.08 8.68	3.46	.092
29/6 12/7 Error	330.75 555.50	1 10.	330.75 55.55	5.95	.034

Apple rust mite, *A. schlechtendali*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
23/5 2/6 Error	40.33 369.33	1 10	40.33 36.93	1.09	.320
16/6 23/6 Error	161.33 3013.33	1 10	161.33 301.33	0.53	.488
29/6 12/7 Error	385.33 540.66	1 10	385.33 54.06	7.12	.023

Table 15. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on caged and covered branches in the glasshouse.

15a. adults, Cox orange.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	8090.0	8	1011.2	3.96	0.0
Between branches	6378.70	1	6378.7	25.0	0.0
Interaction dates X branches	3793.29	8	474.1	1.85	0.07
Error	22957.6	90	255.0		

Eggs, Cox orange.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	7663.74	8	957.9	1.49	0.16
Between branches	26320.33	1	26320.3	41.11	0.0
Interactio dates X branches	2692.66	8	336.5	0.52	0.83
Error	57614.00	90	640.1		

***A. schlechtendali*, Cox orange**

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	50353.83	8	6294.22	4.43	0.0
Between branches	18382.28	1	18382.2	12.96	0.0
Interaction dates X branches	17217.68	8	2152.2	1.51	0.16
Error	127648.5	90	1418.3		

Table contd. on next page.

15b. adults, Exquisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	5693.24	8	711.6	3.67	0.0
Between branches	2852.08	1	2852.0	14.70	0.0
Interaction dates X branches	2374.16	8	293.3	1.51	0.16
Error	17450.5	90	193.8		

Eggs, Exquisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	13524.16	8	1690.5	3.97	0.0
Between branches	11285.33	1	11285.3	26.50	0.0
Interactio dates X branches	5863.50	8	732.9	1.72	0.10
Error	38316.66	90	425.7		

A. schlechtendali, Exqisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	50353.83	8	6294.22	4.43	0.0
Between branches	16875.00	1	16875.0	9.68	0.0
Interaction dates X branches	34550.35	8	4318.7	2.47	0.01
Error	15255.16	90	1906.8		

Table 16. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on uncaged and uncovered branches in the glasshouse.

Adult, on Cox orange.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	203.35	8	25.41	3.05	.004
Between branches	4.48	1	4.48	0.53	.472
Interaction dates X branches	83.35	8	10.41	1.23	.278
Error	748.66	90	8.31		

Eggs, on Cox orange.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	457.62	8	57.18	0.99	.446
Between branches	507.00	1	507.00	8.802	.003
Interactio dates X branches	518.33	8	64.79	1.12	.354
Error	5184.00	90	57.60		

Apple rust mite, *A. schlechtendali*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	7087.18	8	885.89	2.19	.034
Between branches	1833.56	1	1833.56	4.55	.035
Interaction dates X branches	3069.85	8	383.73	0.95	.478
Error	36262.83	90	402.92		

Table 17. Analyses of variance for the numbers of *P. ulmi* and *A. schlechtendali* on uncaged and uncovered branches in the glasshouse.

Adult, *P. ulmi* Exquisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	462.07	8	57.75	2.39	.021
Between branches	46.67	1	46.67	1.93	.168
Interaction dates X branches	490.74	8	61.34	2.53	.015
Error	2174.16	90	24.15		

Eggs, *P. ulmi* Exquisitte.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	2218.74	8	227.34	3.87	.000
Between branches	784.08	1	784.08	10.95	.001
Interaction dates X branches	1890.33	8	236.29	3.30	.002
Error	6439.83	90	71.55		

Apple rust mite, *A. schlechtendali*.

Sources of variation	Sum of squares	D.F	Mean square	F - ratio	Sig. level
Dates	9750.29	8	1218.78	2.85	.007
Between branches	2760.33	1	2760.33	6.46	.012
Interaction dates X branches	4411.00	8	551.37	1.29	.257
Error	38401.66	90	426.68		

Appendix 3

Table 18. Analyses of variance for the numbers *P. ulmi* on caged and uncaged branches in a commercial orchard.

Adult

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	0.090	10	0.009	1.04	0.40
Branches	0.000	1	0.001	0.01	0.91
Error	1.530	176	0.008		
Total	1.665	179			

eggs

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	0.605	10	0.060	0.94	0.49
Branches	0.041	1	0.041	0.65	0.42
Error	11.336	176	0.064		
Total	12.673	179			

Table 19. Analyses of variance for the numbers *T. pyri* on caged and uncaged branches in a commercial orchard.

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	0.118	10	0.011	2.60	0.00
Branches	0.023	1	0.023	5.08	0.02
Error	0.800	176	0.004		
Total	1.060	179			

Table 20. Analyses of variance for the numbers *A. schlechtendali* on caged and uncaged branches in a commercial orchard.

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	14.291	10	1.42	6.58	0.00
Branches	48.584	1	48.58	223.86	0.00
Error	38.195	176	0.21		
Total	115.902	179			

Table 21. Analyses of variance for the numbers *P. ulmi* on covered and uncovered branches in a commercial orchard.

Adult

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	3.267	10	0.326	10.46	0.00
Branches	0.067	1	0.067	2.15	0.14
Error	5.498	176	0.031		
Total	10.978	179			

Eggs

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	23.328	10	2.332	17.52	0.00
Branches	0.028	1	0.028	0.21	0.64
Error	23.423	176	0.133		
Total	48.016	179			

Table 22. Analyses of variance for the numbers *A. schlechtendali* on covered and uncovered branches in a commercial orchard.

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	18.64	10	1.86	17.57	0.000
Branches	0.21	1	0.21	1.98	0.160
Error	18.67	176	0.10		
Total	45.42	179			

Table 23. Analyses of variance for the numbers *P. ulmi* on caged and covered branches in a commercial orchard.

Adult

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	0.46	10	0.04	2.27	0.016
Branches	0.13	1	0.13	6.72	0.010
Error	3.60	176	0.02		
Total	4.71	179			

Egg

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	6.96	10	0.69	9.32	0.000
Branches	1.28	1	1.28	17.16	0.000
Error	13.14	176	0.07		
Total	28.58	179			

Table 24. Analyses of variance for the numbers *A. chlechtendali* on caged and covered branches in a commercial orchard.

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	26.07	10	2.60	10.96	0.000
Branches	28.50	1	28.50	119.86	0.000
Error	41.84	176	0.23		
Total	111.52	179			

Table 25. Analyses of variance for the numbers *P. ulmi* on uncaged and uncovered branches in a commercial orchard.

Adult

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	2.29	10	0.22	11.77	0.000
Branches	0.41	1	0.41	21.09	0.000
Error	3.42	176	0.01		
Total	8.40	179			

Egg

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	6.66	10	0.66	5.43	0.000
Branches	1.20	1	1.20	9.79	0.002
Error	21.61	176	0.12		
Total	34.51	179			

Table 26. Analyses of variance for the numbers *A. schlechtendali* on uncaged and uncovered branches in a commercial orchard.

Source of variation	Sum of square	D.f	Mean square	F ratio	sig. level
Dates	10.52	10	1.05	12.33	0.000
Branches	1.37	1	1.37	16.10	0.000
Error	15.02	176	0.08		
Total	30.88	179			

Appendix 4

Table 27. Analysis of variance for the numbers of droplets / cm^2 on leaf ages and tree positions.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	9753.07	2	4876.53	2.02	0.135
Positions	17900.13	1	17900.13	7.42	0.007
Error	419548.57	174	2411.19		
Total	449892.33	179			

Table 28. Analysis of variance for the amount of µl dye / cm^2 on leaf ages and tree positions.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	792.11	2	396.05	3.64	0.028
Positions	989.59	1	898.59	9.10	0.002
Error	18911.04	174	108.68		
Total	20814.89	179			

Table 29. Analysis of variance for the numbers of droplets / cm^2 on leaf ages and tree positions by 50 p.s.i.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	1498.90	2	749.45	0.54	0.583
Positions	11344.67	1	11344.67	8.17	0.004
Error	241522.50	174	1388.06		
Total	254578.55	179			

Table 30. Analysis of variance for the amount of µl dye / cm^2 on leaf ages and tree positions by 50 p.s.i.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	16865.24	2	8432.62	2.38	0.094
Positions	15558.34	1	15558.34	4.40	0.037
Error	614488.17	174	3531.54		
Total	665587.01	179			

Table 31. Analysis of variance for the numbers of droplets / cm^2 on leaf ages and tree positions by 100 p.s.i.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	166.43	2	83.21	0.08	0.920
Positions	17523.20	1	17523.20	17.37	0.000
Error	175539.47	174	1008.84		
Total	194111.80	179			

Table 32. Analysis of variance for the amount of µl dye / cm^2 on leaf ages and tree positions by 100 p.s.i.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	46.69	2	23.34	0.008	0.991
Positions	72677.58	1	72677.58	25.86	0.000
Error	488919.68	174	2809.88		
Total	564909.23	179			

Table 33. Analysis of variance for the numbers of droplets / cm² on leaf ages and tree positions by 150 p.s.i.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	7495.01	2	3747.50	4.90	0.008
Positions	4898.45	1	4898.45	6.45	0.011
Error	131987.57	174	758.54		
Total	145397.66	179			

Table 34. Analysis of variance for the amount of µl dye / cm² on leaf ages and tree positions by 150 p.s.i.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	37411.57	2	18705.78	3.23	0.041
Positions	97600.47	1	97600.47	16.85	0.000
Error	1007620.4	174	5790.92		
Total	1170906.2	179			

Table 35. Analysis of variance for the numbers of droplets / cm^2 on leaf ages and tree positions by different pressures.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	3038.54	2	1519.27	1.45	0.235
Positions	31786.01	1	31786.01	30.38	0.000
Pressures	6316.47	2	3158.23	3.01	0.049
Error	550229.92	526	1046.06		
Total	600386.58	539			

Table 36. Analysis of variance for the amount of µl dye / cm^2 on leaf ages and tree positions by different pressures.

Source of variance	Sum of squares	D.F	Mean squares	F ratio	Sig. level
Leaf ages	34353.89	2	17176.94	4.25	0.014
Positions	166138.88	1	166138.88	41.19	0.000
Pressures	48491.69	2	24245.85	6.01	0.002
Error	21211372.1	526	4033.02		
Total	2449560.6	539			