EFFECTS OF MULCHES ON THE ABUNDANCE OF APHIDS AND THE GREENHOUSE WHITEFLY, *TRIALEURODES VAPORARIORUM* (WESTWOOD) ON POTATOES

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ABSTRACT

Field experiments indicated that reflective mulches reduced the numbers of migrant alate aphids as well as adults of the greenhouse whitefly, Trialeurodes vaporariorum. All tested mulches viz. aluminium foil, yellow plastic, transparent 'Xiro' sheet and green plastic, were found to be effective in reducing the colonisation rate of these insect vectors. Myzus persicae (Sulzer) is the most important insect vector of potato leaf roll virus (PLRV) and its migrant alatae were greatly reduced by these mulches.

The mulches however were found to be effective only against the migrating alate aphids but not against all forms of all species of aphids found on the plant. Later in the study period (1 June, 1984), green plastic and 'Xiro' sheet were found to enhance the build up of aphid populations particularly M. persicae which occurred on the plant.

Aluminium foil, green plastic and 'Xiro' sheet were found to have no favourable or deleterious effect on the height of the plant, numbers of leaves and total leaf area per plant. But yellow plastic enhanced the growth of potato plant by increasing the number of leaves and the total leaf area per plant.

The glasshouse experiment demonstrated that the order of the relative attractiveness of the reflective mulches to adult T. vaporariorum were as follows: yellow $>$ green plastic $>$ 'Xiro' sheet $\geq$ aluminium foil $=$ soil. The alighting response of whiteflies to green plastic, 'Xiro' sheet, aluminium foil and soil was considered negligible compared to yellow plastic.

Other materials have also been suggested to be used as mulches. These are straw, sawdust, almond shell and husk, living weeds and other crop plants. Finally, the advantages of mulches other than reducing the colonisation rate of insect vectors and their potential as a means of manipulating the crop environment in the IPM programmes of potatoes were discussed.

STATEMENT

This thesis contains no material which has been accepted for the award of any degree or diploma in any University and, to the best of my knowledge and belief, this thesis contains no material previously published or written by any other person, except where due reference is made in the text of this thesis.

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MOHAMED RANI YUSOH

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

Many reviews have recently been written of the control of insect vectors of plant virus diseases (Broadbent, 1969; Smith and Webb, 1969; Loebenstein and Raccah, 1980; Nomura, 1980; Harpaz, 1982; Cohen, 1982; Simons, 1982 and Maelzer, 1984). Maelzer (*ibid*) points out that the control of insect vectors of plant virus diseases has a different slant from the control of insect pests generally because:

i) the spread of virus disease in a crop is usually difficult to control once the virus is there because it can be spread by a very small number of vectors.

ii) insecticides may increase rather than decrease the spread or incidence of virus diseases (e.g. Broadbent *et al*., 1963).

iii) parasites, predators and pathogens seem not to be as effective or as promising for the control of vectors, presumably because economic threshold densities for vector species are much lower than those that would be expected for pest species inflicting direct damage to the crop (e.g. Jepson and Green, 1982).

In general, insecticides seem not to have been effective against vectors of non-persistent viruses which infect the crop from sources outside it. Even just after application, insecticides do not kill the vectors quickly enough to prevent crop plants being infected, and later, when they have weathered to sublethal doses, they may cause the vectors to be more restless and visit more plants. The end results is often an increase rather than a decrease in the spread of virus within a crop (Broadbent *et al.*, *ibid*).

For the control of insect vectors of plant virus diseases, a considerable amount of attention has therefore been given to a) minimising the amount of inoculum at the start of a crop season, and b) minimising the number of colonising vectors (see Maelzer, 1984). One of the strategies which has been widely used to minimise the number of colonising vectors at the start of a crop season is the modification of the visual properties of a crop with mulches.

The use of mulches between plants to reduce colonization rate by vectors seems to have started with Avidov's (1956) report that sawdust mulching among cucumbers greatly reduced the numbers of whiteflies (*Bemisia tabaci*), followed by Kring's (1964) discovery that aluminium foil repelled aphids and the observation by Smith *et al.* (1964) that reflective aluminium sheets reduced the number of aphids and the spread of cucumber mosaic virus. Since then, many successful experiments have been done mostly using aluminium foil and reflective black, white or yellow polyethylene plastic film to reduce virus incidence caused by many aphids and some whitefly species (Wyman *et al.*, 1979; William, 1981; Harpez, 1982; Cohen, 1982). Specific colours seem to be used by some insects, such as species of aphids, whiteflies and other Homoptera, to locate host plants. For example, various tints and hues of yellow attract at least 3 aphid species (Kring, 1972; Smith and Webb, 1969). Reflected light from mulches may therefore alter the stimuli received by such flying insects and so affect their plant-finding and/or settling behaviour. Many homopterans seem to be attracted after flight, to light of the larger wavelengths, e.g. yellow that are reflected from young plants and bare soil. But the light reflected from aluminium and other foils or mulches is similar to that reflected from the sky, with a large proportion of it comprising the shorter wavelengths such as blue (Kring, 1964; Smith et al., 1964; Heinze, 1967). When aluminium foil is placed between rows of plants, aphids tend, therefore, to continue to fly rather than alight (Wilson and Taylor, 1981).

Other mulches, e.g. yellow plastic or straw, have a different action. They seem to differentially attract some species of whitefly which therefore alight in the mulch rather than on the crop plants (Bosch and Telford, 1964; Cohen and Melamed-Madjar, 1978; Nitzany et al., 1964).

Yet again, the alatae of many insect species seem to be attracted to small or sparsely spaced plants which stand out against a bare soil background (A'Brook, 1968). Various authors (Smith, 1976; A'Brook, 1968 and 1973) have suggested that this attraction of flying insects to a contrasting plant/soil surface can often be reduced by maintaining an artificial green background of foam rubber or by maintaining a uniform plant coverage, e.g. by increasing crop density or maintaining a cover of weeds or some other plant species within a crop.

The use of mulches

Many experiments have now indicated that, to be effective, a mulch must usually cover more than 50-60% of the soil surface. For aphids, aluminium foil is usually effective, and is more so than any of the plastics, of which the most effective is usually white; e.g. Wyman et al. (1979) reduced the incidence of watermelon mosaic virus in summer squashes by 94% and 77% with aluminium foil and white plastic respectively. But aluminium foil is not always effective, e.g. against the green peach aphid, Myzus persicae, on potatoes in the U.S.A. (Shands and Simpson, 1972).

Similar experiments with whiteflies, and viruses they transmit, have given quite different results from those on aphids, suggesting that the alighting behaviours of the two groups of insects are different. When aphids first fly, they are attracted to light of short wavelengths and are attracted towards the sky. After flying for some hours, they are repelled by the short wavelengths and are attracted, instead, to yellow and green and start searching for suitable host plants; hence they are repelled by UV reflecting surface which appear to them as 'sky'.

Whiteflies, on the other hand, tend to be attracted to aluminium foil (Vaishampayan et al., 1975a) and to the blue/UV part of the spectrum (Mound, 1962). They are also strongly attracted to yellow plastic or straw mulches; and in hot, dry climates such mulches seem to attract and hold whiteflies until they are killed by the reflective heat from the surfaces, thus greatly reducing the numbers of whiteflies and the incidence of transmitted diseases in crops (Cohen, 1982).

Opaque mulches also reduce competition from weeds, reduce fertilizer leaching, conserve water and trap heat in the soil so that crops can be planted earlier in the season. They usually therefore provide better conditions for plant growth and so increase crop yields irrespective of their effect on vectors and virus diseases.

Mulches may also be useful in crops which need to be irrigated because of their compatibility with trickle irrigation. Thus the incidence of watermelon mosaic virus in irrigated melon crops in Western Australia could not be reduced by either insecticides or oil sprays, but mulches plus trickle irrigation greatly reduced the proportion of infected plants and increased the yield of watermelons by 77 to 270% in different trials (McLean et al., 1982).

The high initial cost of aluminium foil and problems in its use have restricted its commercial use to high-value crops, but plastic mulches - either black or white embossed on black - are being widely used in the U.S.A. for establishing vegetable crops (Zitter and Simons, 1980).

This project involved the use of mulches to reduce the colonisation rate of insect vectors of virus diseases in potato crops in South Australia.

Insect vectors of potato virus diseases

In Australia, the important insect vectors of virus diseases on potato crops are aphids, mainly the green peach aphid, *Myzus persicae* (Sulzer) and the potato aphid, *Macrosiphum euphorbiae* (Thomas) (Hussein, 1982). Another species of aphid, *Aulacorthum solani* Kaltenbach, which is known as a major pest of potatoes overseas, has also been reported to colonise potatoes in Australia (Helson, 1958). The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), another important vector of virus disease of many crops in many parts of the world including Australia, has also been reported to infest potato crops (Goodyer, 1977).

M. persicae is reported as a major vector of well over 100 diseases of plants including crops such as beans, sugar beets, sugar cane, brassicas, tobacco and potatoes (Kennedy *et al.*, 1962; Powell and Mondor, 1973). This aphid is also known to be a vector of several virus diseases of potatoes, the most important being potato leaf roll virus (PLRV). There is now general agreement that *M. persicae* is the species which is generally responsible for the dissemination of PLRV in potatoes (Davies, 1934; Kennedy *et al.*, 1962; Close, 1965). One or two individuals only of *M. persicae* are sufficient to transmit PLRV from an infected to a healthy plant (Smith, 1929).

T. vaporariorum is highly parasitic on over 200 host plants worldwide (Russell, 1963). It has been reported to transmit pseudo-yellows virus to sugar beet and some weed plants, in which case a single whitefly is able to transmit the disease (Muniyappa, 1980).

Attempts to prevent the spread of potato viruses by controlling the aphid vectors have so far been unsuccessful or only partially successful. Chemical control, while effective on a shortterm basis, has the obvious disadvantages of producing insecticide-resistant biotypes when applied frequently or in large doses. There is evidence of frequent insecticide-induced aphid resurgences caused by the destruction of natural enemies as well as the aphids (Peterson, 1963; Radcliffe, 1972 and 1973).

Similarly, populations of T. vaporariorum have been controlled with only some success by the use of cyanide fumigation (Lloyd, 1922), insecticides (Smith et al., 1969) and the whitefly parasite, Encarsia formosa (Gahan) (Webb and Smith, 1980). However, resistance to certain insecticides has been reported by Wardlow et al. (1972), and the difficulties involved in handling and maintaining Encarsia colonies limit the amount of reduction that can be achieved in whitefly infestation (Affeldt et al., 1983).

Because of the difficulties of controlling these insect vectors of potato virus diseases, there is a need to evaluate and employ other methods of protecting crops in Australia as in other parts of the world. One of the most promising of the alternative non-chemical methods which has been largely ignored in Australia is the use of mulches to reduce the rate of colonization of crops by vectors. This method if successful, could become an important component of integrated pest management (IPM) of potatoes.

In this project the effects of mulches on the rate of colonization of a potato crop by aphids (mainly M. persicae) and the greenhouse whitefly (T. vaporariorum) were investigated and evaluated.

Two field experiments (one in a big plot and the other, in a small plot) were simultaneously conducted, and later followed by a glasshouse experiment.

The main objectives of the field experiments were to determine:

i) which mulches (of different materials and colours) could effectively reduce the colonization rate by vectors, and

ii) whether there was any effect of mulches on the growth of the potato plant.

The objective of the glasshouse experiment was to measure the alighting response of the adults of T. vaporariorum on the various mulches which were used in the field experiments. The results of this experiment were necessary to elucidate the outcome of the field experiments.

It is hoped that the results reported in this thesis will provide information for a better understanding of the importance of mulching as a means of manipulating the crop environment to reduce insect infestations on potatoes.

CHAPTER 2

GENERAL MATERIALS AND METHODS

2.1 Growing of potato plants

2.1.1 Growing of potato plants for the field experiments

Seed potatoes cv. Pontiac purchased from a local supplier in Adelaide were used in this study. The seeds were first planted in seed boxes located in a temperature-controlled glasshouse. Before planting, the apical eyes (2-3 eyes) of the seed were scooped out using a melon scoop (2.8 cm in diameter) and dipped in a 2 ppm gibberellic acid solution for 10 minutes to break the dormancy of the seeds. The treated apical eyes were then planted 2-2.5 cm deep in "jiffy-pots" (6 cm x 6 cm x 6 cm) containing a recycled University of California soil mixture. The planting rate was 1 per "jiffy-pot". The plants were allowed to grow under natural light at 20-25°C until they were 2 weeks old, at which time they were ready for transplanting. They were watered once a day or when necessary.

2.1.2 Growing of potato plants for the glasshouse experiment

Some of the gibberellic acid treated seeds as discussed in 2.1.1 were planted 2-3 cm deep in 15 cm (in diameter) black plastic pots containing a soil mixture, as described in 2.1.1. The planting rate was 1 per pot. The plants were allowed to grow under natural light at 20-25°C in the same glasshouse as described in 2.1.1. The plants were watered once a day or when necessary.

2.2 General preparation and maintenance for field experiments I and II

The field experiments I and II were conducted simultaneously in the experimental orchard of the Waite Agricultural Research Institute (W.A.R.I), Glen Osmond, South Australia, from April to June, 1984. The experimental orchard consisted of several small blocks of fruit trees such as apple, peach, apricot, citrus and grape vines. There were also small blocks of almond trees and roses. The rest of the area was either bare ground or ground covered with weeds and other wild plants. Several buildings including an insectary, glasshouses, laboratories and houses, and several big experimental cages were not far from the plots.

After the land had been prepared for planting, a pre-emergence herbicide (Dacthal) was applied at the rate of 10-14 kg/ha. No insecticide, fungicide or post-emergence herbicide was applied throughout the study period. Two to three days later, the 2-week old potato seedlings grown in the glasshouse were transplanted into the field at the depth of approximately 10 cm and at the planting density of 30 cm apart within rows and 75 cm between rows (for the field experiment I) and of 60 cm apart within rows and 75 cm between rows (for the field experiment II).

The size of the plot for the field experiment I (termed the big plot) was 43.6 m x 10.6 m; it was divided into 4 blocks and each block was further divided into 4 experimental plots with each plot in each block being allocated to a treatment (detail is given in Chapter 3). For field experiment II, the size of the plot was 12 m x 4.3 m (termed the small plot); it was divided into 2 blocks and each block was further divided into 2 plots, with each plot being allocated to a treatment (detail is given in Chapter 4).

The treatments were immediately applied after transplanting for both big and small plots. Watering was done only when necessary by furrow irrigation. Approximately one week after transplanting, a basal dressing of a mixture of superphosphate, sulphate of ammonia and sulphate of potash at the ratio of 3:2:1 was applied as fertilizer. All plots were kept free of weeds during the period of study. Weeding was routinely done manually.

2.3 Trapping and sampling methods in the field

2.3.1 Trapping of alate aphids in the field

Trapping is one of the methods of estimating relative numbers of insects. In spite of the great difficulty in interpreting relative numbers, such estimates are extensively used in animal ecology and economic entomology. Estimates based on trapping methods, in particular, are useful because they collect specimens continously and provide a large return of information for a relatively small amount of effort. Basically, traps may be divided into those that attact insects in some way and those that catch insects randomly. A strict division is impossible as some traps, e.g. some water and sticky traps, are intermediate in position (Southwood, 1966).

Water traps have been used extensively to trap alate aphids (Broadbent, 1948; Eastop, 1966; Lamb, 1958; Fisken, 1959b; Evans and Medler, 1966; Landis, 1972; Sandvol and Cunningham, 1975; Bacon et al., 1976; Byrne and Bishop, 1979). Usually they are simple plastic or metal bowls or trays filled with water to which a small quantity of detergent or a preservative have been added (Southwood, 1966). The efficiency of water traps in catching flying aphids depends on several factors such as trap background (Landis, 1972 and Hussein, 1982), height of traps above ground (Heathcote, 1958;Landis, 1972) and size of bowl (Costa and Lewis, 1968 and Southwood, 1978).

The main purpose of setting up water traps in this study was to examine the effects of different reflective mulches on the colonisation rate of migrating alate aphids (M. persicae and all aphid species termed the total aphids) coming into the potato field. One yellow bowl (30 cm diameter and 12 cm deep) was placed in the furrow in the middle of each plot. Each bowl was filled to within 4 cm from the top with water and provision for drainage of excess water was provided by two screen-covered holes (15 mm diameter) made on opposing sides and 2.5 cm below the rim. A few drops of detergent was added to the water.

The trapped alate aphids were collected, using a fine camel brush, from each trap every two days over a period of 8 days for each period of trapping. The collected alate aphids were kept in screw-capped glass vials containing ethyl alcohol 70% and were taken to the laboratory for counting as soon as possible thereafter. A pictorial field key given by MacGillvray (1979) was used to identify alate M. persicae.

Trapping was started on May 8, 1984 i.e. two weeks after transplanting and terminated on June 17, 1984. This trapping period was chosen to coincide with the major period of migration of alate M. persicae into potato crops which had been reported to occur in April-May (Hussein, 1982).

2.3.2 Sampling aphids and whiteflies

Sampling insect populations may be either extensive or intensive. Extensive sampling usually is used to survey large areas, while intensive sampling stresses the continued sampling of a population through time within a smaller area or plot (Morris, 1960; Strickland, 1961). Several workers have concluded that no one sampling method will be suitable for all insects because of the different habitats and life stages that should be sampled. In this study, I was only concerned with intensive sampling.

Several methods have been described for estimating aphid abundance on potato plants. In most of them the aphids are counted while they are on the leaves (Hussein, 1982). Davies (1934) described one of the first methods of estimating aphid populations in the field; he counted the aphids on lower leaves chosen at random, and expressed the population as aphids per 100 leaves. Other workers counted the aphids on all of the leaves of 20 to 30 plants chosen at random and expressed the population as aphids per plant (Heinze and Profft, 1940; Adams, 1946). In Australia, Bald et al. (1946) counted the aphids on equal numbers of top, middle and bottom leaves; they estimated the areas of the leaves of the sample and the total leaf area of the plant from which leaves were chosen; with these data they expressed the population as aphids per 48 leaves, per plant and per unit leaf area. There has not been nearly as much work done on sampling whiteflies. In some of the more recent work in relation to mulches, populations of whiteflies were estimated by counting the number of larvae on whole young plants (up to 15 cm tall) or on the third and fourth leaves from the top of older plants, and then the populations were expressed as numbers of larvae per 5 plants (Cohen and Melamed-Madjar, 1974 and 1978).

In the field experiments I and II, the populations of aphids and whiteflies were estimated by counting the numbers of aphids and whiteflies on whole young and older plants.

Sampling was initiated 2 weeks after transplanting and was done for 2 consecutive days every week over the period of 3 weeks. On each day, thirty and twenty plants were randomly chosen for the big and small plots, respectively. On each plant, all plant parts such as shoots, stems, upper and lower surfaces of leaves were thoroughly inspected for the whitefly adults and the alatae, apterae and nymphs of total aphids. For the big plot, the populations of whitefly and total aphids were expressed as the number per 30 plants while in the case of small plot, it was expressed as the number per 20 plants. This sampling procedure was adopted because the numbers of whitefly and aphids were quite low during the study period.

Insect counts were made *in situ* throughout the month of May (in late autumn), but later in the study period i.e. in the first week of June (in early winter), destructive sampling was employed, in which case three and two plants were destructively sampled from plot for big and small plots, respectively. In this sampling procedure, the plants in the entire plot were mapped out before sampling was done. This was to make sure that there were plants present on each sampling point. In addition, this crop map could also be used as a guide to exclude plants that were too small, unhealthy or dying. A random number of healthy plants was then selected. Each of the selected plants was carefully enclosed with a thin transparent bag (66 cm x 41 cm in size) and the plant was cut off at the ground level. Each plant was then taken to the laboratory and was immediately stored at 5^{o}C and counts alatae, apterae and nymphs of *M. persicae* and *M. euphorbiae* were made. The same pictorial field key as described in section 2.3.1 was used to identify all forms of these two aphid species.

Besides the counts of insects, the height, the number of leaves and the total leaf area of each plant were also taken. Methods of measuring plant height, number of leaves and leaf area were discussed in section 2.4.

2.4 Estimating the height, number of leaves and total leaf area of each potato plant

The purpose of measuring various plant features was to determine whether the mulches would affect the growth of the plants.

Potato plants grown in the big and small plots produced either one, two or three stems. The plant features were recorded from all stems on each plant.

Plant height was estimated by taking the average length of each stem per plant, with the length of each stem being measured from the ground level (cut end) to the tip of the longest leaf. The number of leaves per plant was counted on all stems of each plant. Total leaf area was also estimated by taking three leaves - one upper, one middle and one lower - from each plant. The length and width were first estimated using the graph paper, so by multiplying the length and the width, the estimated area of each leaf was obtained. The average area of these three leaves was then multiplied by the number of leaves per plant to estimate the total leaf area of each plant. This method of measuring leaf area was employed because it is simple, easy and quick. However, it gives only a rough estimate.

2.4.1 More accurate estimation of the leaf area

A simple experiment was done to determine the relationship between the leaf area as estimated roughly by the graph paper method and the leaf area as more accurately estimated by a Paton electronic planimeter.

Materials and methods

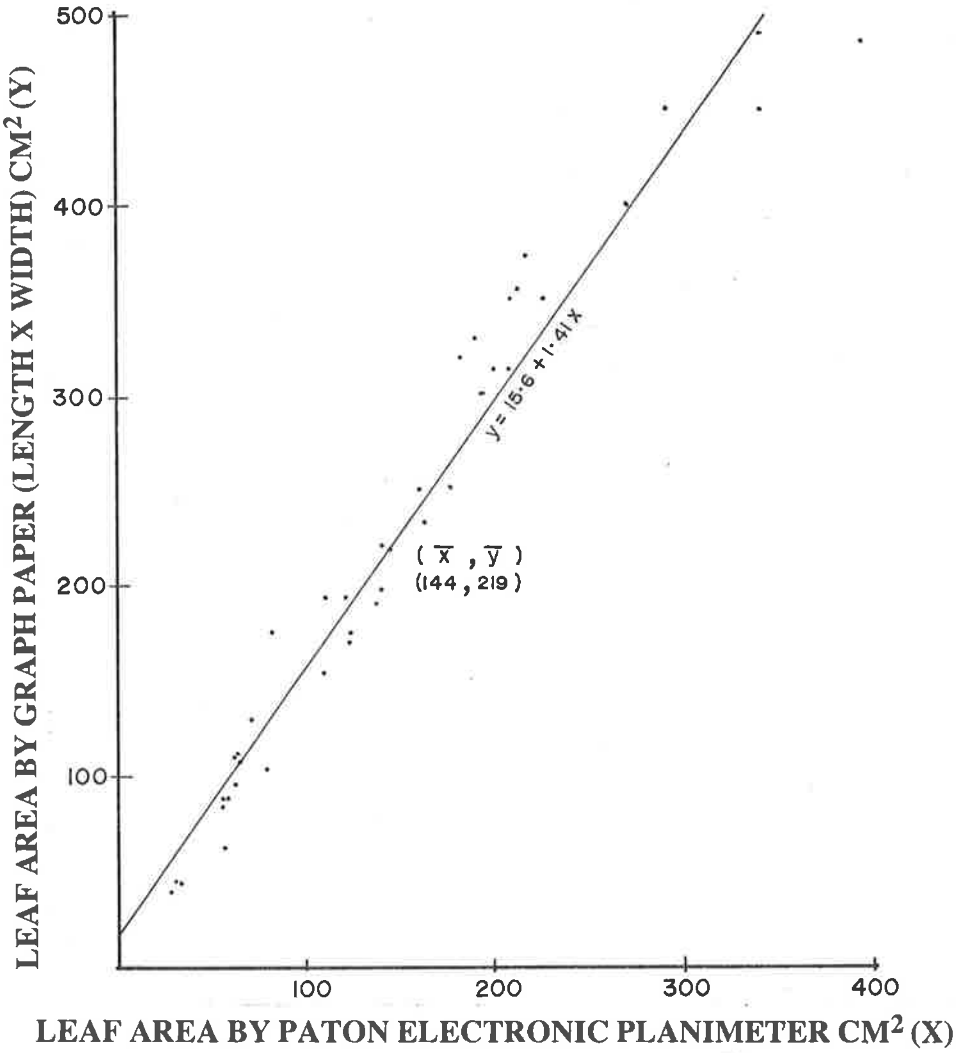
A largish number of randomly collected leaves were categorised into eight size groups, and then five leaves were randomly chosen from each group for the determination of the leaf area. The area of these 40 leaves was first measured by the graph paper method as described earlier, and then was determined by the Paton electronic planimeter. For the latter method, each leaflet was detached from the leaf and was fed through the planimeter. The time involved in each method was recorded using a stop watch.

Results and discussion

The results of this experiment are presented in Appendix Table 1 and are plotted in Figure 1. Since there was an obvious linear relationship between the two sets of values, the estimates obtained from the graphical method were regressed on those obtained from the planimeter. The calculated equation for the regression line was $Y=15.6 + 1.41X$, where Y is the leaf area by graph paper (i.e. the product of leaf length times width) and X is the area by Paton electronic planimeter. The correlation coefficient of 0.9911, with 38 d.f. and $P < 0.001$, indicated the regression was highly significant. And the value of r^2 (=0.9823) suggested that 98.2% of the variability could be attributed to the regression.

A paired t-test was then used to compare the mean involved in both methods; that for the graph paper method was significantly shorter ($P \leqslant 0.001$) than that for the Paton

Figure 1: Regression line for leaf area by graph paper as a function of leaf area by Paton electronic planimeter


500
400
300
200
100
100
200
300
400
y = 15·6 + 1·41 x
(x̄ , ȳ)
(144 , 219)
LEAF AREA BY GRAPH PAPER (LENGTH X WIDTH) CM2 (Y)
LEAF AREA BY PATON ELECTRONIC PLANIMETER CM2 (X)

electronic planimeter. Because the time involved in the graph paper method was significantly less than that for the planimeter method, the graph paper method was used in all future determinations of leaf area. The regression equation mentioned above was then used to convert each of these preliminary estimates to a more accurate one.

2.5 Analysis of data

Data from the main experiment in this study were first subjected to a Bartlett's test of homogeneity of variance. A newly written programme of the Apple II minicomputer was used to execute the test. Data with non-homogeneous variances were transformed to either $\sqrt{X}$, $\sqrt{X+1}$ or $\log_{10}(X+1)$. Original or transformed data with homogeneous variances were then analysed by the analysis of variance except for the data on determination of leaf area which were analysed by a paired t-test as described in section 2.4.1. A fixed model was used for all analyses of variance. The analysis of variance was then followed by the new Duncan's multiple range test for the multiple comparison of means. The analyses of data are presented and discussed in the respective experimental chapters.

CHAPTER 3

FIELD EXPERIMENT 1 -

REPELLENT MULCHES FOR THE CONTROL OF APHIDS AND WHITEFLIES

3.1 Introduction

The state of the art regarding the use of reflective surfaces in the control of vector-borne viruses has been well-reviewed by Smith and Webb (1969) and Harpaz (1982). In the late sixties, the use of aluminium (whether as a reflective foliar spray or as mulch) and white plastic mulches appeared to be the most promising as repellents of migrating winged aphids. Subsequent studies pertaining to such an approach have, however, extended over a much wider range of virus diseases and vector species (Wyman *et al.*, 1979). For examples, aluminium mulches have been found effective for suppression of different aphid-borne viruses in gladiolus (Smith *et al.*, 1964; Johnson *et al.*, 1967), squash (Wolfenbarger and Moore, 1968; Wyman, *et al.*, 1979), watermelon (Adlerz and Everett, 1968) and lettuce (Nawrocka *et al.*, 1975). Insects other than aphids have included the flower thrips, *Frankliniella tritici* (Fitch) (Ota and Smith, 1968), gladiolus thrips, *Taeniothrips simplex* (Morison) (Smith *et al.*, 1972) and leafminers, *Liriomyza* sp. on squash and tomato (Wolfenbarger and Moore, 1968).

In contrast, there have also been reports in which aluminium mulches have little or no repellency; rather attractancy was noted. For example, Smith and Webb (1969) found infestations of the cotton aphid (*Aphis gossypii* Glover) more common on cucumbers and squash when soil mulches of aluminium were present. Similarly more mines of

Liriomyza munda Frick were observed on leaves of squash and tomatoes plants (Webb and Smith, 1973). On squash fruits injuries by the pickleworm, *Diaphania nitidalis* (Stoll), were noted to be greater in plots protected by aluminium foil mulch (Wolfenbarger and Moore, 1968). While similarly protected potatoes have increased aphid populations (Shands and Simpson, 1972). In the case of whiteflies, even though aluminium mulch attracts them (Vaishampayan *et al.*, 1975a; Cohen and Melamed-Madjar, 1978) it however was effective in reducing the spread of the associated virus diseases in tomatoes (Cohen and Melamed-Madjar, *ibid*). To date, most of such studies have largely involved aluminium mulching. That involving other materials, based either on the principles of different colour shades or mechanical barrier, have been rather limited. For instance, the use of green rings of foam rubber placed around potted Brussels sprout plants was noted to be capable of reducing the colonisation rate of the cabbage aphid, *Brevicoryne brassicae* L. (Smith, 1976), whereas in an investigation on potato cultivation under 'Xiro' sheet (a slotted and transparent, but reflecting polyethylene sheet) 93% fewer immigrant aphids were recorded when compared with exposed plants (Wilson and Taylor, 1981).

Evidently, depending on the crops and the pest species involved, mulches or protective barriers may have contrasting effects — repel or attract — and as such can be advantageously employed in pest management. However, how such reflective mulches can affect the colonisation rates of virus-borne vectors (aphids and whiteflies) of potatoes has been little investigated, particularly green plastic material which has yet to be examined. This study therefore aims to evaluate their potentials and to assess their relative values in relation to the more common aluminium foil.

3.2 Materials and methods

In the experimental study a randomised complete block design (RCBD) in four replicates of plot size 3.75 mm x 3.3 m was employed (Figure 2). Three mulching treatments were evaluated viz. aluminium foil, green polyethylene (plastic) sheet, and 'Xiro' sheet (Plate 1). A nonmulching treatment served as the control. To each plot, there were 60 potato plants.

In the aluminium foil treatment 0.22 m x 5.3 m strips were placed in between the potato seedlings across the hills. The green plastic strips of size 0.26 m x 5.3 m were also similarly placed. With 'Xiro' sheet which had been marketed as a weather-protection sheet to enhance earlier harvesting and increased yields (Wilson and Taylor, 1981), the sheets (1.45 m x 5.5 m) were perforated by 9 mm slits in rows of 3 mm apart so that, when stretched, the slits would open to give a fine plastic mesh (Plate 2). The sheets were loosely laid down along the length of the hill, and as loosely across the width as the potato hill would allow. Throughout the study the mulching materials were held down over the soil by small rocks and bricks; these being laid mainly on the edges or on the overlaps. In general, the area covered by the aluminium foil, green plastic and 'Xiro' sheet were 73, 87 and 100 percent, respectively.

During the first and second week of sampling, visual counts of the insects infesting the plants were made for three treatments

Figure 2: Arrangement of blocks and treatments of the field experiment I (big plot)

Treatments: A = Control (no mulch)

B = Aluminium foil

C = Green plastic

D = 'Xiro' sheet

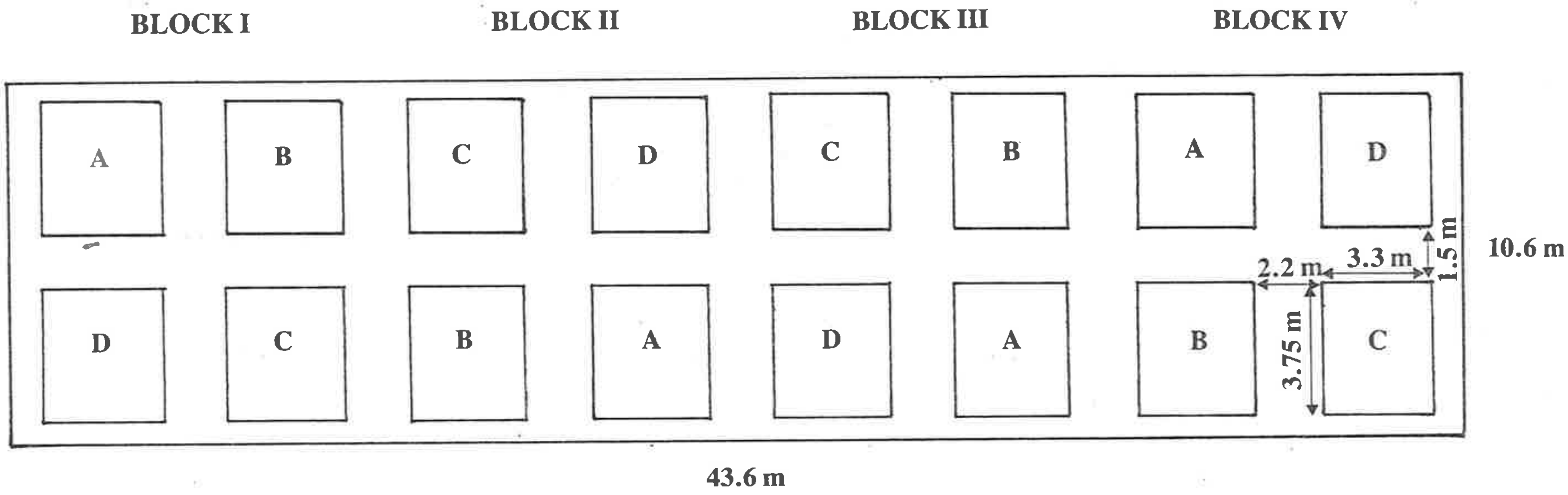

BLOCK I
BLOCK II
BLOCK III
BLOCK IV
A
B
C
D
C
B
A
D
D
C
B
A
D
A
B
C
2.2 m
3.3 m
1.5 m
3.75 m
10.6 m
43.6 m

Plate 1: The plots mulched with aluminium foil, green plastic and 'Xiro' sheet in the field experiment I (big plot)

Plate 2: The slits of 'Xiro' sheet open as plants grow to give a fine plastic mesh

only, viz. aluminium foil, green plastic and the control. However, in both the third and fourth week assessments were done for all the four treatments. That for the 'Xiro' sheet were made while the sheets were temporarily removed prior to sampling.

In the statistical analyses, the trapping data on M. persicae were transformed to $\sqrt{x+1}$ while those of total aphids transformed to $\sqrt{x}$. For the trapping data on alate aphids and the visual counts of insects,a three-way ANOVA was employed. A two-way ANOVA was however done for the counts of insects on plants in both the third and fourth week samples. In addition, a two-way ANOVA with subsampling was also performed for the data of plant features.

3.3 Results

Table 1 presents the mean numbers of alate M. persicae (both arithmetic and transformed $\sqrt{x+1}$ and the mean total aphids per yellow water trap in each treatment over five periods of time, while Table 2 presents the respective ANOVAs.

As evident from Table 1, the mean numbers per time of M. persicae alatae and of total aphids per yellow water trap were significantly lower ($P \leqslant 0.01$) in the aluminium foil mulched plots than all the other treatments. Although there was no significant difference ($P \leqslant 0.05$) between the mean numbers of M. persicae and of total aphids per yellow water trap in the green plastic and 'Xiro' sheet mulched plots, both these however were significantly lower ($P \leqslant 0.01$) than those in the control plots (Table 1).

Table 1: Mean numbers of alatae of *Myzus persicae* (with means of $\sqrt{X+1}$ transformed data in parenthesis) and of total aphids caught per yellow water trap in each of 4 treatments over 5 periods of time a/

Time period	*M. persicae*				Mean per treatment	Total aphids				Mean per treatment
	Control	Aluminium foil	Green plastic	'Xiro' sheet		Control	Aluminium foil	Green plastic	'Xiro' sheet	
8-16.5.84	9.5(3.07)	1.5(1.55)	3.5(2.09)	2.3(1.75)	4.2(2.12b)	NA	NA	NA	NA	NA
16-24.5.84	3.8(2.18)	0.3(1.10)	2.3(1.78)	2.0(1.65)	2.1(1.68c)	NA	NA	NA	NA	NA
24.5-1.6.84	10.8(3.42)	2.3(1.73)	4.0(2.13)	4.0(2.14)	5.3(2.36ab)	38.3	6.0	19.8	12.5	19.1a
1-9.6.84	10.3(3.33)	2.0(1.72)	7.8(2.87)	6.5(2.68)	6.6(2.65a)	18.5	3.5	15.8	11.3	12.3b
9-17.6.84	6.0(2.55)	2.8(1.90)	5.8(2.57)	4.5(2.31)	4.8(2.33ab)	7.8	4.3	9.8	9.8	7.9c
Mean per time	8.1(2.91a)	1.8(1.60c)	4.7(2.29b)	3.9(2.10b)		21.5a	4.6c	15.1b	11.2b	

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$ as determined by the new Duncan's multiple range test

NA = Not available

Table 2: Analyses of variance of the numbers of *Myzus persicae* alatae and of total aphid alatae caught in each of 4 yellow water traps in each of 4 treatments over 5 periods of time.
B = Blocks; T = Treatments; t = Times

M. persicae (data transformed to $\sqrt{x+1}$)					Total aphids (untransformed data)				
Source	df	ss	ms	F	Source	df	ss	ms	F
a) First ANOVA									
B	3	0.25	0.08	0.31 NS	B	3	39.00	13.00	0.65 NS
T	3	17.60	5.87	22.58 ***	T	3	1809.17	603.06	30.20 ***
t	4	8.32	2.08	8.00 ***	t	2	1029.17	514.59	25.77 ***
BxT	9	3.96	0.44	1.69 NS	BxT	9	131.50	14.61	0.73 NS
Bxt	12	6.90	0.58	2.23 *	Bxt	6	295.00	49.17	2.46 NS
Txt	12	3.45	0.29	1.12 NS	Txt	6	1116.33	186.06	9.32 ***
BxTxt (Error)	36	9.18	0.26		BxTxt (Error)	18	359.50	19.97	
Total	79	49.66			Total	47	4779.67		
b) Second ANOVA									
B	3	0.25	0.08	0.28 NS	B	3	39.00	13.00	0.55 NS
T	3	17.60	5.87	20.24 ***	T	3	1809.17	603.06	25.32 ***
t	4	8.32	2.08	7.17 ***	t	2	1029.17	514.59	21.60 ***
Bxt	12	6.90	0.58	2.00 *	Txt	6	1116.33	186.06	7.81 ***
Error	57	16.60	0.29		Error	33	786.00	23.82	
Total	79	49.66			Total	47			

NS indicates not significant at $P \leqslant 0.05$
* " significant at $P \leqslant 0.05$
** " " " $P \leqslant 0.01$
*** " " " $P \leqslant 0.001$

The mean numbers per treatment of M. persicae and of total aphids caught per yellow water trap were noted to vary considerably among the different assessment time periods. In general, a higher number of alate M. persicae per trap was recorded in the last three periods of trapping, viz. 24.5-1.6.84, 1-9.6.84 and 9-17.6.84. Among these, the number of M. persicae trapped in the fourth period of trapping (1-9.6.84) was the highest but this did not differ significantly ($P \geqslant 0.05$) from the third (24.5-1.6.84) and the fifth (9-17.6.84) period of trapping. There was also no significant difference ($P \geqslant 0.05$) among the numbers of M. persicae trapped in the first (8-16.5.84), third and fifth period of trapping. In the second period of trapping (16-24.5.84), the number of M. persicae caught per trap was significantly lower ($P \leqslant 0.05$) than those caught in the other periods of trapping. There was a highly significant interaction ($P \leqslant 0.001$) between the treatments and trapping periods for the number of alatae of total aphids caught per trap (Table 2). In terms of chronological time the mean number per treatment of total aphids was significantly higher ($P \leqslant 0.01$) in the last week of May (24.5-1.6.84) and declining gradually by the first (1-9.6.84) and second (9-17.6.84) week of June (Table 1).

In Tables 3 and 5 the data on insect counts in situ for both adults T. vaporariorum and alatae + apterae + nymphs of total aphids are presented, while their respective ANOVAs are given in Tables 4 and 6.

From Table 3, it is evident that the mean numbers per time of T. vaporariorum in aluminium foil and green plastic mulched plots

Table 3: Mean numbers of adults of *Trialeurodes vaporariorum* and of total aphid alatae + apterae + nymphs (with means of $\sqrt{x}$ transformed data in parenthesis) on 30 plants in each of 3 treatments over 3 periods of time (weeks) a/

Week	*T. vaporariorum*			Mean per treatment	Total aphids			Mean per treatment
	Control	Aluminium foil	Green plastic		Control	Aluminium foil	Green plastic	
1	27.3	6.3	11.5	15.0b	26.3(4.88)	12.8(3.21)	23.0(4.49)	20.8(4.19b)
2	33.5	6.8	15.8	18.7b	22.5(4.71)	20.5(4.25)	36.5(5.97)	26.5(4.98b)
3	34.5	17.0	28.3	26.6a	42.0(6.38)	37.3(5.77)	104.0(9.80)	61.1(7.32a)
Mean per time	31.8a	10.0c	18.5b		30.3(5.32ab)	23.5(4.41b)	54.5(6.75a)	

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$ as determined by the new Duncan's multiple range test

Table 4: Analyses of variance for the numbers of *Trialeurodes vaporariorum* adults and of total aphids on 30 plants in each of 3 treatments over 3 periods of time.
B = Blocks; T = Treatments; t = Times

T. vaporariorum (untransformed data)					Total aphids (data transformed to $\sqrt{x}$)				
Source	df	ss	ms	F	Source	df	ss	ms	F
a) First ANOVA									
B	3	134.31	44.77	0.85 NS	B	3	19.99	6.66	2.40 NS
T	2	2883.50	1441.75	27.25 ***	T	2	33.39	16.70	6.03 *
t	2	841.17	420.59	7.95 **	t	2	63.45	31.73	11.45 **
BxT	6	413.61	68.94	1.30 NS	BxT	6	18.83	3.14	1.13 NS
Bxt	6	345.94	57.66	1.09 NS	Bxt	6	26.35	4.39	1.58 NS
Txt	4	183.33	45.83	0.87 NS	Txt	4	16.72	4.18	1.51 NS
BxTxt (Error)	12	634.89	52.91		BxTxt (Error)	12	33.25	2.77	
Total	35	5436.75			Total	35	211.97		
b) Second ANOVA									
B	3	134.31	44.77	0.79 NS	B	3	19.99	6.66	1.96 NS
T	2	2883.50	1441.75	25.59 ***	T	2	33.39	16.70	4.91 *
t	2	841.17	420.58	7.46 **	t	2	63.45	31.73	9.33 ***
Error	28	1577.78	56.35		Error	28	95.14	3.40	
Total	35	5436.75			Total	35	211.97		

NS indicates not significant at $P \leqslant 0.05$
* " significant at $P \leqslant 0.05$
** " " " $P \leqslant 0.01$
*** " " " $P \leqslant 0.001$

Table 5: Mean numbers of *Trialeurodes vaporariorum* adults and total aphid alatae + apterae + nymphs (with means of $\sqrt{x}$ transformed data in parenthesis) on 30 plants in each of 4 treatments in week 3 [a/]

Treatment	*T. vaporariorum*	Total aphids
Control	34.5a	42.0(6.38b)
Aluminium foil	17.0bc	37.3(5.77b)
Green plastic	28.3ab	104.0(9.80ab)
'Xiro' sheet	2.8c	270.0(15.49a)

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$ as determined by the new Duncan's multiple range test

Table 6: Analysis of variance for the numbers of *Trialeurodes vaporariorum* adults and of total aphids on 30 plants in each of 4 treatments in week 3

Source	df	ss	ms	F
		T. vaporariorum		
Blocks	3	292.25	97.42	1.21 NS
Treatments	3	2333.25	777.75	9.67 **
Error	9	724.25	80.47	
Total	15	3349.75		
		Total aphids (data transformed to $\sqrt{x}$)		
Blocks	3	14.81	4.94	0.28 NS
Treatments	3	238.09	79.36	4.51 *
Error	9	158.32	17.59	
Total	15	411.23		

NS indicates not significant at $P \leqslant 0.05$
* " significant at $P \leqslant 0.05$
** " " " $P \leqslant 0.01$

were significantly lower ($P \leqslant 0.01$) than that of the control plot. Between the aluminium foil and green plastic treatments, the former, however, had significantly lower ($P \leqslant 0.05$) number of T. vaporariorum. When counts of different sampling times were compared, that from the third sampling was noted to be significantly higher ($P \leqslant 0.05$) than those of the first and second week.

For total aphids, the mean number per time was also significantly lower ($P \leqslant 0.01$) in the aluminium foil treatment plot than that in the green plastic mulched plot (Table 3). Even though the total aphids in the former treatment was lower than that in the control, the difference was however not significant ($P \geqslant 0.05$); this was also observed for those between the control plot and the green plastic treatment. In general, the mean number per treatment of total aphids appears to follow the same trend as that of T. vaporariorum, i.e. a significantly higher ($P \leqslant 0.01$) numbers occuring in the third-week sample than those in the first and second week.

In the analyses of data concerning insect populations on 30 plants in each of the four treatments from the third-week sampling, the mean numbers of adults T. vaporariorum and alatae + apterae + nymphs of total aphids were considered. For the latter, analysis was also made on the $\sqrt{x}$ transformed data (Table 5). The relevant ANOVAs are given in Table 6.

From the data analyses (Tables 5 and 6) it is clear that the mean number of adults T. vaporariorum was significantly lower ($P \leqslant 0.01$) in plots mulched with 'Xiro' sheet than those mulched with green plastic or the unmulched control. But it was not significantly different ($P \geqslant 0.05$) from that of the aluminium foil treatment despite a lower number.

Between the aluminium foil plots and the unmulched control there was however a significantly lower ($P \leqslant 0.05$) mean number of T. vaporariorum in the former, but no significant difference ($P \geqslant 0.05$) was obtained between plots mulched with aluminium foil and the green plastic (Tables 5 and 6). The latter however was not significantly different from the control plots. On the other hand, the mean number of total aphids in plots mulched with 'Xiro' sheet was significantly higher ($P \leqslant 0.05$) than those with aluminium foil and unmulched control. No significant difference ($P \geqslant 0.05$) however occurred between the mean number of total aphids in the 'Xiro' sheet and green plastic treatments, as well as, among the plots mulched with green plastic, aluminium foil and the unmulched control.

Table 7 gives the mean numbers of alatae + apterae + nymphs of M. persicae and M. euphorbiae on three destructively-sampled plants in each of the four treatments taken during the fourth sampling week. The ANOVA based on untransformed data of M. persicae and of M. euphorbiae are given in Table 8.

From this sampling, it was found that the mean number of alatae + apterae + nymphs of M. persicae in the plots mulched with 'Xiro' sheet was significantly higher ($P \leqslant 0.05$) than those in plots mulched with green plastic and aluminium foil as well as the unmulched control. For the last three treatments, there was no significant difference ($P \geqslant 0.05$) among the mean numbers of M. persicae. There was also no significant difference ($P \geqslant 0.05$) in the mean numbers of alatae +

Table 7: Mean numbers of alatae + apterae + nymphs of *Myzus persicae* and *Macrosiphum euphorbiae* on 3 destructively sampled plants in each of 4 treatments in week 4[a]

Treatment	*M. persicae*	*M. euphorbiae*
Control	32.3b	20.3a
Aluminium foil	51.3b	24.3a
Green plastic	60.8b	28.8a
'Xiro' sheet	129.8a	26.3a

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$ as determined by the new Duncan's multiple range test

Table 8: Analyses of variance of numbers of *Myzus persicae* and *Macrosiphum euphorbiae* on 3 destructively sampled plants in each of 4 treatments in week 4

Source	df	ss	ms	F
		M. persicae		
Blocks	3	3702.00	1234.00	0.81 NS
Treatments	3	21693.00	7231.00	4.74 *
Error	9	13737.00	1526.33	
Total	15	39132.00		
		M. euphorbiae		
Blocks	3	1368.75	456.25	0.74 NS
Treatments	3	154.75	51.58	0.08 NS
Error	9	5570.25	618.92	
Total	15	7093.75		

NS indicates not significant at $P \leqslant 0.05$

* " significant at $P \leqslant 0.05$

apterae + nymphs of _M. euphorbiae_ in the control and plots mulched with 'Xiro' sheet, green plastic and aluminium foil.

In Table 9 the means of plant height, numbers of leaves and total leaf area per plant in the four treatments are presented. From the ANOVA for these data (Table 10), there appears to be no significant differences ($P \geqslant 0.05$) for these plant features among the four different treatments, suggesting that these treatments did not have any significant effect over the plant features considered in the study.

3.4 Discussion

Reflective mulch treatments can greatly reduced the influx of aphids and whiteflies (William, 1981 and Maelzer, 1984). This is also found in the present investigation. Based on comparative trap catches (Table 1) aluminium foil was found to be most effective in reducing migrant _M. persicae_ and many other aphids when compared with reflective plastics (green plastic and 'Xiro' sheet). Its effectiveness in repelling migrants aphids supports earlier findings by Kring (1964); Wyman _et al_. (1979); Johnson _et al_. (1967); Smith _et al_. (1964); Wolfenbarger and Moore (1968), and Adlerz and Everett (1968). However, measurements of repellency of aluminium for aphids have been in most instances limited to alate forms. This was clearly shown by Shands and Simpson (1972) who conducted a study to determine the effect of aluminium foil mulches upon populations of apterous aphids on potatoes, and wherein they found that aluminium foil mulching did not reduce the number of _M. persicae_. Such a case was

Table 9: Means of plant height (cm), numbers of leaves and total leaf area (cm^2) per plant in 4 treatments

Treatment	Plant height	No. leaves	Total leaf area
Control	32.5	13.2	1254
Aluminium foil	36.3	17.9	2203
Green plastic	34.8	19.1	2085
'Xiro' sheet	39.5	16.3	1952

Table 10: Analyses of variance of plant height (cm), numbers of leaves, and total leaf area (cm^2) per plant sampled in week 4

Source	df	ss	ms	F
		Plant height		
Blocks	3	236.13	78.71	2.60 NS
Treatments	3	303.76	101.25	3.34 NS
Experimental error	9	272.69	30.30	0.64 NS
Sampling error	32	1508.14	47.13	
Total	47	2320.72		
		No. leaves		
Blocks	3	68.06	22.69	0.88 NS
Treatments	3	237.73	79.24	3.09 NS
Experimental error	9	231.02	25.67	0.65 NS
Sampling error	32	1268.65	39.65	
Total	47	1805.48		
		Total leaf area		
Blocks	3	3547000	1182330	0.76 NS
Treatments	3	6517000	2172330	1.40 NS
Experimental error	9	13940000	1548880	1.62 NS
Sampling error	32	30630000	957200	
Total	47	54634000		

NS indicates not significant at $P \leqslant 0.05$

also obtained in the present study involving population counts of insects in situ (Table 3), thus showing that aluminium foil is effective only in repelling migrants alate aphids but not those already present on the plants. One other possible explanation is that the different methods of insect sampling used might have produced the different outcome.

In the present study, the alate M. persicae under investigation was entirely that of the autumn dispersal forms. But Shands and Simpson (1972) tested the aluminium mulches against spring migrant M. persicae. As such, it thus appears that the responses to reflected light from aluminium foil by autumn migrant aphids are not different from that of the spring dispersal forms.

With regards to T. vaporariorum, although aluminium foil led to reduce number of the adult whiteflies on the plants the mechanism(s) involved are perhaps different from that for migrant alate M. persicae and other aphids. This is because adult T. vaporariorum tend to be attracted to aluminium foil (Vaishampayan et al., 1975). However, this attraction is not a straight forward mechanism, but rather the visual behaviour as reported by Coombe (1982) is a much more complex process where the insect will eventually walk away or take off away from the illumination of the noon sun. Such a response of T. vaporariorum to illumination of noon sunlight thus explains why there was a low number of T. vaporariorum in plots mulched with aluminium foil.

With 'Xiro' sheet the suppressing effects on insect infestations are believed to be due to its acting as a mechanical barrier as well as through a repelling effect resulting from the reflection of high wavelength light (Wilson and Taylor, 1981). The suppressing effects obtained in the present investigation further confirmed the finding of Wilson and Taylor (1981) who showed that 'Xiro' sheet can greatly reduce alighting by migrant potato aphids and subsequent colonisation of the crop by the aphids. However, it is unable to provide any effective control of the overall aphid population as was observed by Wilson & Taylor (*ibid*).

For green plastic mulch the effectiveness in suppressing migrant alate *M. persicae* and total aphids parallels that of large field cage studies by Smith (1976) who found less numbers of alate *Brevicoryne brassicae* L. settling on cabbage plants surrounded by rings of grass (living or cut) or by artificial green rings of foam rubber (Tables 3 and 5). However, in general, the green plastic as demonstrated by this experiment increased the number of alatae + apterae + nymphs of total aphids found on the plant.

As with aphids, adult *T. vaporariorum* colonised potato plants in control plots more than those mulched with green plastic. A similar response to green background was also noted in *Aleyrodes brassicae* (another species of whitefly) as reported by Smith (1976). By having the green plastic mulch in between plants, the contrast between plants and bare soil was greatly reduced, thereby interfering with the alighting response of these insects.

From the results of destructive sampling (Table 7) it is evident that the reflective mulches did not suppress the numbers of alatae + apterae + nymphs of *M. persicae* and *M. euphorbiae*. Rather, the mulch treatments increased the number of aphids, particularly *M. persicae*. The apparent ineffectiveness of mulches in reducing the numbers of alatae + apterae + nymphs of *M. persicae* and of *M. euphorbiae* in this sampling (week 4, 1 June, 1984) may possibly be associated with the higher numbers of migrant aphids occuring during that period (Table 1). Another contributing factor is the relative decrease in the amount of exposed mulch as the plant becomes bigger. This was also noted by Shands and Simpson (1972). For the case of the 'Xiro' sheet, in addition to the higher numbers of migrant aphids during that period, another contributing feature would be the stretched sheet (caused by growing plants) admitting some migrant aphids through the opened slots (Wilson and Taylor, 1981).

That 'Xiro' sheet will encourage the development of the population of *M. persicae* on potato plants was clearly evident from the present investigation (Table 7). Largely, this is due to several favourable conditions such as the protection from adverse weather (rainfall, wind) as well as the parasites and predators. The much higher temperature inside the cover which may cause an increase in developmental and reproductive rates of *M. persicae* is another contributing factor.

On general plant growth, the mulching treatments in this study are found to have no favourable or deleterious effect. The height of the plant, number of leaves per plant and total leaf area per plant were not significantly different ($P \geqslant 0.05$) from that for the unmulched plants. Shands and Simpson (1972), experimenting with aluminium foil mulching for potatoes have also obtained the same finding. On the other hand, the results of mulching with 'Xiro' sheet in this experiment were contradictory to that of Rothamsted Experimental Station, Harpenden by Wilson and Taylor (1981). In the latter instance, it was found that covering with 'Xiro' sheet may be detrimental to normal growth of the main-crop potatoes such as Pentland Crown which is a tall, erect variety, that can quickly pushed the cover to full stretch. Probably, the different potato cultivars used may respond differently to 'Xiro' sheet, hence the differing results obtained. It would thus appear desirable that additional studies be carried out to further clarify this.

CHAPTER 4

FIELD EXPERIMENT II -

THE USE OF YELLOW PLASTIC MULCH FOR THE CONTROL OF APHIDS AND WHITEFLIES

4.1 Introduction

Reflective surfaces, for example, yellow plastic has been reported to attract aphids and whiteflies (Cohen and Marco, 1973; Cohen and Melamed-Madjar, 1978; Cohen, 1982; and Maelzer, 1984). It has also been used as "colour bait" for trapping alate aphids, based on the long establish principle that alate aphids are attracted to yellow colour (Van Emden, 1972), in order to reduce the spread of aphid-transmitted viruses in peppers. In this case, the spread of aphid transmitted viruses in peppers was reduced by traps made of sticky yellow sheets, 120 cm wide, erected vertically outside the field, where 70 cm of their bottom edges above the ground formed, a screen around 50% of the crop perimeter at 6 m away from the crop (Cohen and Marco, 1973). According to Harpaz (1982), due to the effectiveness of the traps, they are now a standard practice for the control of potato virus Y (PVY) and cucumber mosaic virus (CMV) in peppers in Israel. On the other hand, Cohen *et al*. (1975), reported that similar traps around a crop of tomatoes had no effect on the numbers of whitefly or the incidence of tomato yellow leaf curl virus (TYLCV). As a result, Maelzer (1984) pointed out that a control measure that is highly effective for one vector-virus-crop system may not be effective for another.

The purpose of this experiment was then, to study the effects of yellow plastic sheets applied as mulch on the populations of aphids and the greenhouse whitefly, T. vaporariorum, as well as to determine whether the mulch will affect the plant features.

4.2 Materials and methods

The arrangement of plots, 4.3 m x 3 m each is shown in Figure 3. Each block contains only one mulching treatment with the yellow polyethylene (plastic) sheet and a control i.e., no mulching (Plate 3). A randomised complete block design (RCBD) in 2 replicates was employed. The plots, each containing 30 potato plants were not spaced out from each other.

Yellow plastic strips, each 4.5 m x 0.5 m in size, were placed in between potato seedlings across the plots. The yellow plastic strips which covered 83% of the plots were held on the soil by small rocks and bricks.

A three-way ANOVA based on untransformed data (transformation of data found to be unnecessary) was used to analyse trapping data of alate aphids and the insect counts on the plants. For destructive sampling conducted in the fourth week, a two-way ANOVA was used. In the case of plant features, a two-way ANOVA with subsampling was used.

4.3 Results

The mean numbers of alate M. persicae and total alate

Figure 3: Arrangement of blocks and treatments of the field experiment II (small plot)

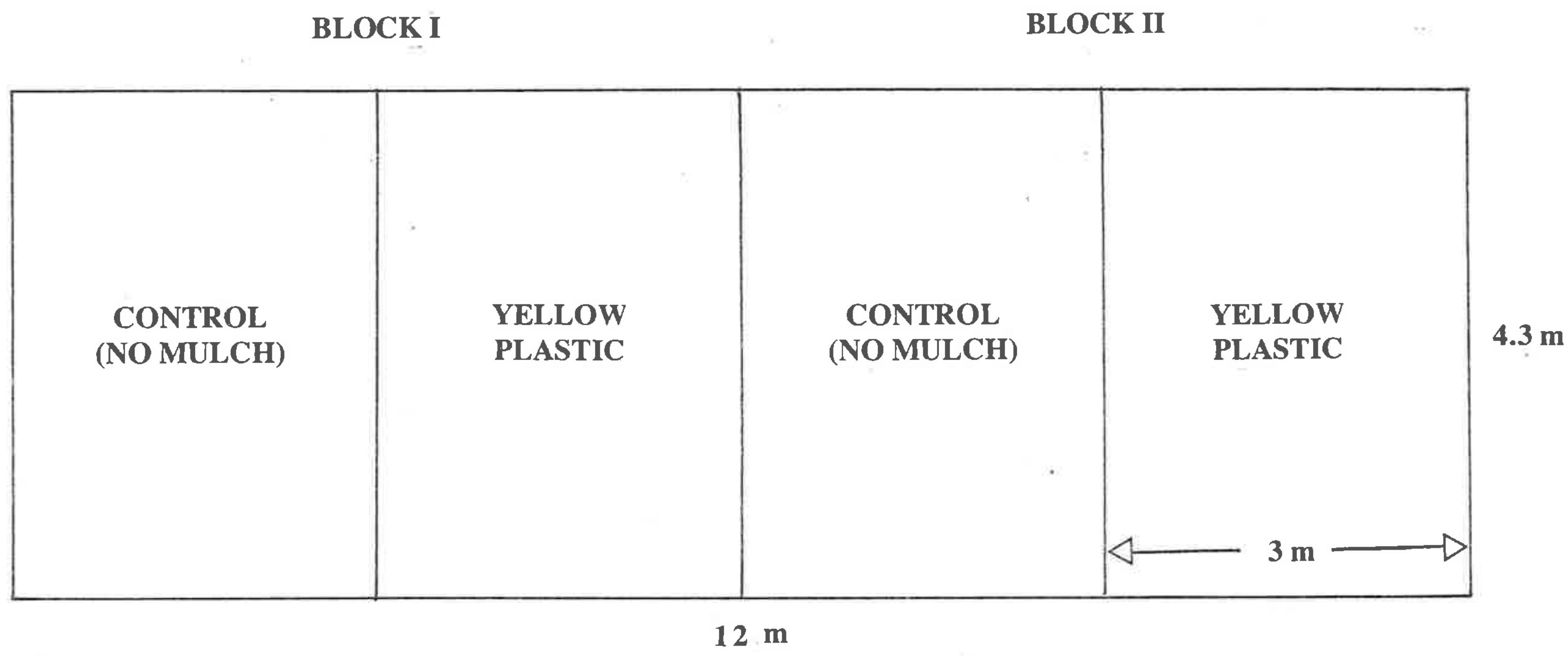

BLOCK I
BLOCK II
CONTROL (NO MULCH)
YELLOW PLASTIC
CONTROL (NO MULCH)
YELLOW PLASTIC
4.3 m
3 m
12 m

Plate 3: Yellow plastic mulched and unmulched plots in the field experiment II (small plot)

aphids caught per yellow water trap in each treatment over five periods of time are shown in Table 11. The ANOVAs are given in Table 12.

The result shows that the mean numbers of alate M. persicae and total alate aphids caught per trap over the whole period of time were significantly lower ($P \leqslant 0.001$) in plot mulched with the yellow plastic sheet than that of the control plot. But, there was no significant difference ($P \geqslant 0.05$) in the numbers of alate aphids caught in both treatment between each time period (Table 11).

Table 13 shows the mean numbers of adult T. vaporariorum and alatae + apterae + nymphs of total aphids on 20 potato plants per treatment per week, and Table 14 gives the details of the ANOVA. The result shows that there was a significantly lower ($P \leqslant 0.001$) mean number of adult T. vaporariorum in the mulched plot but not in the case of aphids. The mean number of T. vaporariorum (but not aphids) over the two treatments is highest ($P \leqslant 0.001$) in sampling week 2 followed by week 3 and lowest in week 1 (Table 13). Also, as shown in Table 14, there was a highly significant interaction ($P \leqslant 0.01$) between the treatments and sampling periods for the number of adult T. vaporariorum.

Table 15 shows the mean numbers of M. persicae and M. euphorbiae on two destructively sampled plants in the mulched and control plots in sampling week 4. Table 16 gives the mean numbers of M. persicae and M. euphorbiae in blocks I and II, and Table 17 gives the ANOVA.

Table 11: Mean numbers of alatae of *Myzus persicae* and of total aphids caught per yellow water trap in each of 2 treatments over 5 periods of time a/

Time period	*M. persicae*		Mean per treatment	Total aphids		Mean per treatment
	Control	Yellow plastic		Control	Yellow plastic	
8-16.5.84	19.5	1.0	10.3a	NA	NA	NA
16-24.5.84	5.5	1.0	3.3a	26.0	7.5	16.8a
24.5-1.6.84	11.5	0.5	6.0a	39.5	2.5	21.0a
1-9.6.84	14.0	1.5	7.8a	31.5	8.0	19.8a
9-17.6.84	11.5	0.5	6.0a	18.0	4.5	11.3a
Mean per time	12.4a	0.9b		28.8a	5.6b	

a/ Means followed by the same letter are not significantly different at $P \leq 0.05$ by the new Duncan's multiple range test

NA = Not available

Table 12: Analyses of variance for the numbers of alatae of Myzus persicae and of total aphids caught in each of 2 yellow water traps over 8 days for 5 periods of time.
B = Blocks; T = Treatments; t = Times

M. persicae					Total aphids				
Source	df	ss	ms	F	Source	df	ss	ms	F
a) First ANOVA									
B	1	26.45	26.45	3.14 NS	B	1	126.56	126.56	3.91 NS
T	1	661.25	661.25	78.44 ***	T	1	2139.06	2139.06	66.02 **
t	4	106.30	26.58	3.15 NS	t	3	226.19	75.40	2.33 NS
BxT	1	42.05	42.05	4.99 NS	BxT	1	217.56	217.56	6.71 NS
Bxt	4	41.30	10.33	1.23 NS	Bxt	3	77.19	25.73	0.79 NS
Txt	4	99.50	24.88	2.95 NS	Txt	3	306.69	102.23	3.16 NS
BxTxt (Error)	4	33.70	8.43		BxTxt (Error)	3	97.19	32.40	
Total	19	1010.55			Total	15	3190.44		
b) Second ANOVA									
B	1	26.45	26.45	1.59 NS	B	1	126.56	126.56	1.81 NS
T	1	661.25	661.25	39.70 ***	T	1	2139.06	2139.06	30.62 ***
t	4	106.30	26.58	1.60 NS	t	3	226.19	75.40	1.08 NS
Error	13	216.55	16.66		Error	10	698.63	69.86	
Total	19	1010.55			Total	15	3190.44		

NS indicates not significant at $P \leqslant 0.05$
** " significant at $P \leqslant 0.01$
*** " " " $P \leqslant 0.001$

Table 13: Mean numbers of adults Trialeurodes vaporariorum and of total aphid alatae + apterae + nymphs on 20 plants in each of 2 treatments over 3 periods of time (week) a/

Week	T. vaporariorum			Total aphids		
	Control	Yellow plastic	Mean per treatment	Control	Yellow plastic	Mean per treatment
1	24.0	14.0	19.0c	14.0	4.0	9.0a
2	90.0	32.0	61.0	20.0	7.5	13.8a
3	43.5	28.5	36.0b	7.5	12.5	10.0a
Mean per time	52.5a	24.8b		13.8a	8.0a	

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$ by the new Duncan's multiple range test

Table 14: Analyses of variance for the numbers of Trialeurodes vaporariorum adults and total aphids on 20 plants in each of 2 treatments over 3 periods of time.
B = Blocks; T = Treatments; t = Times

T. vaporariorum					Total aphids				
Source	df	ss	ms	F	Source	df	ss	ms	F
a) First ANOVA									
B	1	588.00	588.0	45.23 *	B	1	52.08	52.08	10.23 NS
T	1	2296.33	2296.33	176.64 **	T	1	102.08	102.08	20.06 *
t	2	3570.67	1785.34	137.33 **	t	2	50.17	25.08	4.93 NS
BxT	1	147.00	147.00	11.31 NS	BxT	1	114.08	114.08	22.41 *
Bxt	2	62.00	31.00	2.38 NS	Bxt	2	193.17	96.59	18.98 NS
Txt	2	1392.67	696.34	53.56 *	Txt	2	179.17	89.59	17.60 NS
BxTxt (Error)	2	26.00	13.00		BxTxt (Error)	2	10.17	5.09	
Total	11	8082.67			Total	11	700.92		
b) Second ANOVA									
B	1	588.00	588.00	12.51 *	B	1	52.08	52.08	0.82 NS
T	1	2296.33	2296.33	48.86 ***	T	1	102.08	102.08	1.60 NS
t	2	3570.67	1785.33	37.99 ***	t	2	50.17	25.08	0.39 NS
Txt	2	1392.67	696.33	14.82 **	BxT	1	114.08	114.08	1.79 NS
Error	5	235.00	47.00		Error	6	382.50	63.75	
Total	11	8082.67			Total	11	700.92		

NS indicates not significant at $P \leqslant 0.05$
* " significant at $P \leqslant 0.05$
** " " " $P \leqslant 0.01$
*** " " " $P \leqslant 0.001$

Table 15: Mean numbers of alatae + apterae + nymphs of *Myzus persicae* and of *Macrosiphum euphorbiae* on 2 destructively sampled plants in each of 2 treatments in week 4

Treatment	*M. persicae*	*M. euphorbiae*
Control	11.5	8.5
Yellow plastic	12.0	8.0

Table 16: Mean numbers of alatae + apterae + nymphs of *Myzus persicae* and of *Macrosiphum euphorbiae* on 2 destructively sampled plants in each of 2 blocks in week 4 [a/]

Block	*M. persicae*	*M. euphorbiae*
I	17.5a	12.5a
II	6.0a	4.0b

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$

Table 17: Analyses of variance of numbers of Myzus persicae and Macrosiphum euphorbiae on 2 destructively sampled plants in each of 4 treatments in week 4

Source	df	ss	ms	F
		M. persicae		
Block	1	132.25	132.25	1.47 NS
Treatment	1	0.25	0.25	0.0028 NS
Error	1	90.25	90.25	
Total	3	222.75		
		M. euphorbiae		
Block	1	72.25	72.25	289.00 *
Treatment	1	0.25	0.25	1.00 NS
Error	1	0.25	0.25	
Total	3	72.75		

NS indicates not significant at $P \leqslant 0.05$

* " significant at $P \leqslant 0.05$

The result (Table 15) shows that there was no significant difference ($P \geqslant 0.05$) in the mean numbers of M. persicae and M. euphorbiae between the mulched and that of the control plots. However, there was a significant difference ($P \leqslant 0.05$) in the mean numbers of M. euphorbiae (but not M. persicae) between block I and II (Table 16).

The means of plant height, number of leaves and total leaf area per plant in each treatment and block are presented in Tables 18 and 19, respectively. The ANOVAs are given in Table 20.

The result of Table 18 shows that there was no significant difference ($P \geqslant 0.05$) in the means of plant height between the mulched and the control plots. However, the means of number of leaves and total leaf area were significantly higher ($P \leqslant 0.05$) in the mulched compared to the control plots. Table 19 shows that there were more ($P \leqslant 0.05$) leaves per plant in block I than in block II. However, there was no significant difference ($P \geqslant 0.05$) in the mean number of leaves and the mean total leaf area per plant between blocks I and II.

4.4 Discussion

The yellow plastic mulch was found to greatly reduced the numbers of migrant M. persicae and some other aphid species as well as T. vaporariorum. This finding is in agreement with the works of other workers (Cohen and Melamed-Madjar, 1978; and Cohen, 1982). It was also found that the numbers of alatae, apterae and nymphs of

Table 18: Means of plant height (cm), number of leaves and total leaf area (cm^2) per plant sampled in each of 2 treatments in week 4 a/

Treatment	Plant height	No. leaves	Total leaf area
Control	28.9a	11.5b	714b
Yellow plastic	33.1a	16.8a	2204a

a/ Means followed by the same letter are not significantly different at $P \leq 0.05$

Table 19: Means of plant height (cm), number of leaves and total leaf area (cm^2) per plant sampled in each of 2 blocks in week 4 a/

Block	Plant height	No. leaves	Total leaf area
I	29.4a	15.8a	1504a
II	32.6a	12.5b	1415a

a/ Means followed by the same letter are not significantly different at $P \leqslant 0.05$

Table 20: Analyses of variance of plant height (cm), numbers of leaves and total leaf area (cm^2) per plant sampled in week 4

Source	df	ss	ms	F
		Plant height		
Block	1	21.13	21.13	10.57 NS
Treatment	1	36.13	36.13	18.07 NS
Experimental error	1	2.00	2.00	0.06 NS
Sampling error	4	129.24	32.31	
Total	7	188.50		
		No. leaves		
Block	1	21.13	21.13	162.54 *
Treatment	1	55.13	55.13	424.08 *
Experimental error	1	0.13	0.13	0.0029 NS
Sampling error	4	178.50	44.63	
Total	7	254.88		
		Total leaf area		
Block	1	16088.02	16088.02	20.03 NS
Treatment	1	4440930.50	4440930.50	5527.81 **
Experimental error	1	803.38	803.38	0.00031 NS
Sampling error	4	10534157.00	2633539.30	
Total	7	14991979.00		

NS indicates not significant at $P \leqslant 0.05$

* " significant at $P \leqslant 0.05$

** " " " $P \leqslant 0.01$

M. persicae, M. euphorbiae and other aphid species caught were reduced by the mulch, however, the reductions were not significant ($P \geqslant 0.05$). These results seem to indicate that yellow plastic mulch, like any other reflective mulches is only effective against migrating insects.

The reduction in the population of T. vaporariorum in each treatment plot was found to be greatly determined by the sampling time period in Autumn. This seems to suggest that the effectiveness of yellow plastic mulch in reducing T. vaporariorum may vary from time to time depending on the period of the year trappings were conducted. Cohen (1982) noted that in hot and dry climates, such mulches not only attract, but hold whiteflies until they are killed by the reflective heat from the surfaces of the mulches.

The above results also shows that very few alate aphids were caught in yellow water traps. It seems that the attractancy of the reflected light from the yellow plastic mulch was stronger than that from the yellow water trap. This could also be due to the fact that the water inside the yellow trap may affect the nature of the reflected light. Perhaps, the attraction of yellow water trap is reduced, thus insects are more attracted to the mulch than the yellow water trap itself.

The build-up of aphid populations may differ from one place to another within the potato plot, for example the build-up of M. euphorbiae population was somewhat higher in block I than that in block II. This is probably due block I being closer to the sources of M. euphorbiae located outside the experimental potato plots.

The yellow plastic mulch was also found to enhance the plant growth. It seems that such an enhance growth is brought about by the reduction of aphids and T. vaporariorum population which indirectly reduced the incidence of virus diseases transmitted by these insect vectors. Such effect could also be due to some other factors as noted in Chapter 1. This growth enhancement effect of yellow plastic mulch on plants has been reported earlier by Cohen and Melamed-Madjar (1978). However, as observed in this study, although the build-up of M. euphorbiae population was higher in block I but the plants in this particular block still produced more leaves than block II. Therefore, it seems that factors other than the level of M. euphorbiae infestations were responsible for the plant growth enhancement phenomenon.

CHAPTER 5

GLASSHOUSE EXPERIMENT - ALIGHTING RESPONSE OF WHITEFLIES TO THE VARIOUS MULCHING MATERIALS

5.1 Introduction

The strong attraction that the greenhouse whitefly show to yellow and yellow-green was first recorded by Lloyd (1921). Vaishampayan *et al*. (1975a) measured the response of *T. vaporariorum* to reflected and transmitted light of various colours and like Lloyd, found that most whiteflies were trapped on a yellow surface.

Light reactions of other species of whiteflies have been investigated by Butler (1938), Husain and Trehan (1940) and Mound (1962). Coombe (1982) found that at the wavelength of under 400 nm the whiteflies took-off more readily and walked faster than under 500 nm. In flight they oriented towards 400 nm when simultaneously illuminated with equal quanta of 400 and 550 nm lights. He concluded that in nature, flying adults would orient towards the sky (i.e. ca. 400 nm) but would tend to land on green plants which reflect maximally at 550 nm. After landing on a suitable food-plant the position where the insect finally feeds and reproduces is probably also determined by visual stimuli. This is because whiteflies will walk to the shaded side of a leaf regardless of whether it is the bottom or top surface.

There has been little work on the response of *T. vaporariorum* to the reflected light from reflective surfaces particularly green plastic and transparent 'Xiro' sheet. Therefore, the experiment was carried out to measure the alighting response of the adults of T. vaporariorum to the various mulches used in the field experiments and soil (a control). The mulches used were aluminium foil, green and yellow plastics and 'Xiro' sheet.

T. vaporariorum was chosen for this experiment because this insect vector was the most abundant in the field during the period of study.

5.2 Materials and methods

An experiment was conducted in a compartment of a glasshouse as described in section 2.1.1 from 19 until 29 June, 1984. T. vaporariorum were first bred on potato plants as described in section 2.1.2. The experiment was initiated when many adult whiteflies occurred on the plants.

Sticky traps, consisting of petri dishes (15 cm in diameter) covered with the various mulching materials namely, aluminium foil, green and yellow plastics and 'Xiro' sheet was set up.

A set of petri dishes containing soil covered by petri dish covers (as a control), was also set up. The traps were then smeared with a thin layer of 'tangle foot' glue. There were five traps of each material used and they were arranged in a 5 x 5 Latin square design at a distance of ca. 2 cm apart on a glasshouse bench covered with white computer paper. The infested potato plants were placed close together in the surrounding area of these traps. The gradient of light within the compartment of glasshouse was considered negligible.

Trapping was done for two time periods of five days each from 19 to 24 June, 1984 and from 24 to 29 June, 1984. After counting and removing the whiteflies from the first trapping, the second trapping was then initiated on the same day (24 June, 1984). The number of whiteflies trapped was also recorded.

Data of trapping of whiteflies were transformed to $\log_{10}(x+1)$, these data were then analysed using a two-way ANOVA for Latin square design.

5.3 Results

The mean numbers both arithmatic and of $\log_{10}(x+1)$ of adults of *T. vaporariorum* in each treatment in the experiment for each of the five days period are given in Table 21. The ANOVA based on the data transformed to $\log_{10}(x+1)$ is given in Table 22. The results in Table 21 reveal that the whiteflies were more attracted to yellow plastic than other materials ($P \leqslant 0.01$). In the first period of trapping, the mean numbers of whiteflies caught on trap made up of yellow plastic was significantly higher ($P \leqslant 0.01$) than on the other traps. There was a significantly higher ($P \leqslant 0.01$) mean numbers of whiteflies caught on green plastic than those caught on control, aluminium foil and 'Xiro' sheet. The differences among the mean numbers of whiteflies caught on control, aluminium and 'Xiro' sheet were not significant ($P \geqslant 0.05$).

Table 21: Mean numbers of *Trialeurodes vaporariorum* adults (with means of $\log_{10}(x+1)$ transformed data in parenthesis) caught on sticky traps made of different mulching materials over 2 periods of 5 days each

Material of trap	Trapping period	
	1 (19-24.6.84)	2 (24-29.6.84)
Soil (control)	2.0(0.45c)	1.2(0.31d)
Aluminium foil	1.2(0.26c)	0.4(0.12d)
Green plastic	8.2(0.95b)	14.4(1.17b)
'Xiro' sheet	2.2(0.44c)	6.8(0.83c)
Yellow plastic	43.2(1.61a)	113.8(2.05a)

N.B. Means followed by the same letter are not significantly different at $P \leqslant 0.05$ by the new Duncan's multiple range test

Table 22: Analyses of variance of the numbers of adults of *Trialeurodes vaporariorum* $[\log_{10}(x+1)]$ caught on sticky traps of different mulching materials over 2 periods of 5 days each

Source	df	ss	ms	F
		Trapping period no. 1		
Rows	4	0.06	0.02	0.33 NS
Columns	4	0.18	0.05	0.83 NS
Treatments	4	6.00	1.50	25.00 ***
Error	12	0.72	0.06	
Total	24	6.96		
		Trapping period no. 2		
Rows	4	0.20	0.05	1.25 NS
Column	4	0.05	0.01	0.25 NS
Treatments	4	11.82	2.96	74.00 ***
Error	12	0.43	0.04	
Total	24	12.50		

NS indicates not significant at $P \leqslant 0.05$

*** " significant at $P \leqslant 0.001$

In the second period of trapping, the mean numbers of whiteflies caught on yellow plastic was also significantly higher ($P \leqslant 0.01$) than those caught on the other traps. More whiteflies were attracted to green plastic than soil, aluminium foil and 'Xiro' sheet ($P \leqslant 0.05$). The results of second period of trapping are slightly different from that of the first period in that traps made of 'Xiro' sheet caught significantly higher ($P \leqslant 0.01$) numbers of whiteflies than those caught on control and aluminium foil. There was however no significant difference ($P \geqslant 0.05$) between the numbers of whiteflies caught on traps made of soil (control) and aluminium foil.

5.4 Discussion

Adult *T. vaporariorum* appeared to be attracted to the mulching materials used as follows: yellow > green plastic > 'Xiro' sheet ≥ aluminium foil = soil (control). The strong attractiveness of yellow plastic to adult *T. vaporariorum* agreed with reports by Lloyd (1921), Vaishampayan *et al*. (1975a) and Affeldt *et al*. (1983). The spectral reflectance of light which strongly attracted *T. vaporariorum* was in yellow-green region, from 520 to 610 nm (Vaishampayan *et al*., 1975a). Affeldt *et al*. (1983) however indicated that the region was a little wider i.e. from 500 to 600 nm. In this experiment the spectral reflectance was not measured.

The alighting response to green plastic, 'Xiro' sheet, aluminium foil and soil was almost negligible when compared to yellow plastic. The unattractiveness of green plastic to *T. vaporariorum* was reported by Vaishampayan et al. (1975a). The response to aluminium foil, which reflected ultraviolet light (< 400 nm), in this experiment, was however different from the result of the other workers. In this experiment, *T. vaporariorum* tends to avoid illumination from aluminium foil, similar to the finding by Coombe (1982). Vaishampayan et al (1975a) and Coombe (1982) in another finding however reported that *T. vaporariorum* was moderately attracted to ultra-violet light. 'Xiro' sheet was less attractive because of its repelling effects. This comes from the reflection of light of high wavelength, as indicated by Wilson and Taylor (1981). The low ultra-violet emission of the soil surface (Smith, 1976) is perhaps the most important factor which contributed to the unattractiveness of soil to adult *T. vaporariorum*.

The results of this experiment would help to elucidate the effects of mulches on the abundance of adults of *T. vaporariorum* on potato plants in the field.

CHAPTER 6

GENERAL DISCUSSION

Chapters 3 and 4 have revealed that reflective mulches such as aluminium foil, green and yellow plastics and 'Xiro' sheet are effective in reducing the migratory alate aphids and adult white-flies. However, this varies with time of the year when trapping is conducted. The major factor attributed to this variation seems to be the weather conditions, for example rain, wind and the brightness of the sky prevailing at the time of trapping.

The results of the glasshouse experiment as described in Chapter 5 were useful in understanding the mechanism(s) which renders the effectiveness of reflective mulches against the greenhouse whiteflies in field conditions. As illustrated by the results of alighting response in Chapter 5, adult whiteflies were less attracted to soil. In the field experiments, however, there were more whiteflies in control (no mulching) plots. This would indicate that whiteflies are attracted to the contrast between the plants and soil rather than to the soil itself. By putting mulches in between plants to cover the bare soil, the contrast could be reduced, hence interfering with the orientation of insects towards this cue. Thus, illumination and/or reflective light from these mulches might repel the adult whiteflies. On the other hand, yellow plastic mulch was very attractive to whiteflies. In the field, whiteflies would alight on yellow plastic mulch rather than on the plants. These mechanisms explained why there were low numbers of whiteflies on the plants in mulched plots as compared to plots with bare soil background (control).

The high initial cost of aluminium foil, 'Xiro' sheet, green and yellow plastics may restrict their commercial use to high-value crops, but plastic mulches - either black or white embossed on black are being widely used in the U.S.A. for establishing vegetable crops (Zitter and Simons, 1980). In the case of aluminium foil, in addition to high cost, it is difficult to use because it will easily break especially during windy days and when being trampled.

For many years now, yellow plastic has been utilised as sticky traps, the traps worked so well that they are now a standard practice for the control of PVY and CMV in peppers in Israel (Harpaz, 1982). Because of the high cost of these mulching materials therefore, cheap alternatives need to be identified, tested and used. Among the cheap materials which can easily be utilised are straw, sawdust, almond shell and husk, etc. In addition, living plants such as certain weeds and other crops can also be maintained in between rows of main crops as a cover to eliminate the contrast between plant and bare soil.

Several workers such as Cohen (1978), Wyman et al. (1979), and Maelzer (1984) have reported that opaque mulches usually provide better conditions for plant growth. This is because, their beneficial effects such as sunlight enhancement, soil temperature adjustment, retention of soil moisture, weed control and soil conservation increase crop yields irrespective of their effects on vectors and virus diseases. However, the only problem with potato crops is that hilling needs to be done, which is quite impossible for mulched plots. In order to avoid the requirement for hilling, the crops need to be planted deep. If the crop is mulched to provide the better conditions for plant growth, their protection from insect vectors would be an added bonus. This form of mulching could be very useful to farmers who wish to grow their own seed crops in areas that are not advisable to be grown with such crops because of the high activity of viruliferous insect vectors.

In general, mulching is necessary especially during the early immigration stage of aphids and whiteflies into the crop, so as to prevent the introduction and spread of the potato leaf roll virus and other virus infections. This study has revealed the potential of mulching as a means of manipulating the crop environment so as to reduce the infestations of insect vectors in potato crops. This could become an important component of IPM of potatoes. However, more extensive local trials are needed before the benefit of this approach are fully realized in any crop. Its potential however, could be considerable for small plots of high value crops, such as seed crops, and in areas with high populations of insect vectors or virus risk.

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APPENDICES

Appendix Table 1: The area of potato leaves (cm^2) measured by the graph paper and Paton electronic planimeter methods and the time (in second) involved for each method

Size group	Leaf no.	Graph paper method		Paton electronic planimeter method	
		Leaf area	Time	Leaf area	Time
1	1	450	20.0	338.00	52.5
	2	450	17.5	290.75	41.5
	3	485	46.4	392.13	54.4
	4	490	37.4	337.90	48.6
	5	400	26.7	270.20	38.0
2	6	357	20.8	211.82	40.3
	7	352	15.7	227.16	37.0
	8	315	19.2	207.10	28.9
	9	374	19.0	217.09	31.2
	10	330	18.5	195.31	41.7
3	11	195	15.2	110.43	26.8
	12	154	15.1	108.91	29.4
	13	192	15.1	139.33	27.4
	14	176	14.4	123.93	29.2
	15	195	15.5	119.22	34.9
4	16	170	18.4	123.42	29.1
	17	234	17.4	162.62	27.3
	18	221	20.3	139.07	32.0
	19	198	19.2	139.24	24.6
	20	252	23.0	159.70	28.1
5	21	300	21.4	193.05	25.7
	22	252	15.9	175.73	32.4
	23	320	24.0	182.72	30.7
	24	352	21.3	207.69	28.9
	25	315	16.1	198.64	28.0
6	26	96	9.6	62.70	22.3
	27	108	13.9	66.38	29.8
	28	104	11.9	79.27	18.9
	29	84	13.8	56.20	16.5
	30	130	8.5	70.59	18.4
7	31	88	6.7	58.38	22.8
	32	110	8.3	63.39	25.7
	33	88	8.0	55.85	24.3
	34	110	6.5	63.59	19.1
	35	88	8.5	55.82	23.7
8	36	40	5.5	26.77	19.4
	37	63	7.1	36.68	20.9
	38	45	7.2	32.76	28.2
	39	45	13.2	29.28	24.1
	40	45	7.0	31.50	22.7

Appendix Table 2: Numbers of alatae of Myzus persicae and of total aphids caught in each of 4 yellow water traps over 8 days for 5 periods of time a/

Time period (date)	Block no.	M. persicae				Total aphids			
		T1	T2	T3	T4	T1	T2	T3	T4
1 (8-16.5.84)	I	14	2	2	1				
	II	8	0	5	1				
	III	1	2	2	2				
	IV	15	2	5	5		NA		
Total		38	6	14	9				
Mean		9.5	1.5	3.5	2.3				
2 (16-24.5.84)	I	4	0	2	0				
	II	4	1	2	2				
	III	4	0	4	1		NA		
	IV	3	0	1	5				
Total		15	1	9	8				
Mean		3.8	0.3	2.3	2				
3 (24.5-1.6.84)	I	11	2	0	4	39	6	13	12
	II	9	0	4	2	35	1	18	5
	III	13	5	5	9	40	13	23	27
	IV	10	2	7	1	39	4	25	6
Total		43	9	16	16	153	24	79	50
Mean		10.8	2.3	4	4	38.3	6	19.8	12.5
4 (1-9.6.84)	I	9	3	4	5	15	4	15	12
	II	14	2	15	6	25	3	20	8
	III	11	1	4	3	19	2	10	6
	IV	7	2	8	12	15	5	18	19
Total		41	8	31	26	74	14	63	45
Mean		10.3	2	7.8	6.5	18.5	3.5	15.8	11.3
5 (9-17.6.84)	I	9	5	5	3	12	7	8	7
	II	2	1	9	4	2	2	13	13
	III	10	3	5	8	11	4	8	9
	IV	3	2	4	3	6	4	10	11
Total		24	11	23	18	31	17	39	39
Mean		6	2.8	5.8	4.5	7.8	4.3	9.8	9.8
Total over time:		16.1	35	93	77	258	55	181	134
Mean per time :		8.1	1.8	4.7	3.9	21.5	4.6	15.1	11.2

a/ T1 = Control; T2 = Aluminium foil; T3 = Green plastic;
T4 = 'Xiro' sheet
NA = Not available

Appendix Table 3: Numbers of adults of Trialeurodes vaporariorum and alatae + apterae + nymphs of total aphids on 30 plants for 3 periods of time a/

Time period (week)	Block no.	*T. vaporariorum*				Total aphids			
		T1	T2	T3	T4	T1	T2	T3	T4
1	I	28	3	11	-	31	6	13	-
	II	22	12	4	-	50	24	55	-
	III	33	3	6	-	15	1	12	-
	IV	26	7	25	-	9	20	12	-
Total		109	25	46	-	105	51	92	-
Mean		27.3	6.3	11.5	-	26.3	12.8	23	-
2	I	41	4	14	-	24	39	22	-
	II	34	12	17	-	30	28	31	-
	III	29	5	15	-	20	7	42	-
	IV	30	6	17	-	16	8	51	-
Total		134	27	63	-	90	82	146	-
Mean		33.5	6.8	15.8	-	22.5	20.5	36.5	-
3	I	24	12	16	2	45	61	168	60
	II	41	15	39	3	57	59	37	167
	III	50	12	26	5	46	16	146	446
	IV	23	29	32	1	20	13	65	407
Total		138	68	113	11	168	149	416	1080
Mean		34.5	17	28.3	2.8	42	37.3	104	270
Total over time:		381	120	222		363	282	654	
Mean per time :		31.8	10	18.5		30.3	23.5	54.4	

a/ T1 = Control; T2 = Aluminium foil; T3 = Green plastic; T4 = 'Xiro' sheet
\- = indicates no sampling

Appendix Table 4: Numbers of adults of *Trialeurodes vaporariorum* and alatae + apterae + nymphs of *Myzus persicae* and *Macrosiphum euphorbiae* on 3 destructively sampled plants in week 4 (1.6.84)

Block no.	*T. vaporariorum*				*M. persicae*				*M. euphorbiae*			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
I	4	3	7	0	47	44	77	56	22	46	15	16
II	0	0	2	0	23	60	29	94	31	39	7	16
III	2	1	0	0	56	30	54	174	10	2	75	68
IV	0	0	1	0	3	71	83	195	18	10	18	5
Total	6	4	10	0	129	205	243	519	81	97	115	105
Mean	1.5	1	2.5	0	32.3	51.3	60.8	129.8	20.3	24.3	28.8	26.3

a/ T1 = Control; T2 = Aluminium foil; T3 = Green plastic; T4 = 'Xiro' sheet

Appendix Table 5: Plant height (cm), number of leaves and total leaf area (cm^2) per plant sampled in week 4 (1.6.84) a/

Block no.	Plant no.	Plant height				Number of leaves				Total leaf area			
		T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
I	1	29	39.5	42	28	10	23	13	18	604	3133	2001	1829
	2	40	44	36	49	13	12	24	12	1358	2271	1590	1980
	3	33	37	44.5	46	19	20	28	11	2136	2136	4422	1237
II	1	44	35	36	33	12	22	10	18	1457	3490	648	2054
	2	27	33	28.5	50	15	21	19	18	916	2346	2127	3763
	3	36	46	31	40.5	10	13	31	22	969	2543	3661	2645
III	1	31	24	30	40	11	9	8	10	980	463	413	1643
	2	40	30.5	24	43	24	22	8	20	4135	2142	592	3738
	3	27	37	38.3	37.5	9	12	22	20	501	968	2304	1858
IV	1	24.5	40	30.2	48	15	11	30	12	764	1602	2207	1324
	2	29	31	44	27	9	24	14	17	325	1907	2142	550
	3	30	39	33	31.5	11	26	22	17	905	3438	2909	802
Total		390.5	436	417.4	473.5	158	215	229	195	15049	26439	25016	23420
Mean		32.5	36.3	34.8	39.5	13.2	17.9	19.1	16.3	1254	2203	2085	1952

a/ T1 = Control; T2 = Aluminium foil; T3 = Green plastic; T4 = 'Xiro' sheet

Appendix Table 6: Numbers of alatae of *Myzus persicae* and of total aphids caught in each of 2 yellow water traps over 8 days for 5 periods of time

Time period (date)	Block no.	*M. persicae*		Total aphids	
		Control	Yellow plastic	Control	Yellow plastic
1 (8-16.5.84)	I	25	1	NA	
	II	14	1		
Total		39	2		
Mean		19.5	1		
2 (16-24.5.84)	I	9	0	38	6
	II	2	2	14	9
Total		11	2	52	15
Mean		5.5	1	26	7.5
3 (24.5-1.6.84)	I	9	0	39	2
	II	14	1	40	3
Total		23	1	79	5
Mean		11.5	0.5	39.5	2.5
4 (1-9.6.84)	I	17	1	39	9
	II	11	2	24	7
Total		28	3	63	16
Mean		14	1.5	31.5	8
5 (9-17.6.84)	I	15	1	25	2
	II	8	0	11	7
Total		23	1	36	9
Mean		11.5	0.5	18	4.5
Total over time:		124	9	230	45
Mean per time :		12.4	0.9	28.8	5.6

NA = Not available

Appendix Table 7: Numbers of adults of Trialeurodes vaporariorum and alatae + apterae + nymphs of total aphids on 20 plants for 3 periods of time

Time period (week)	Block no.	T. vaporariorum		Total aphids	
		Control	Yellow plastic	Control	Yellow plastic
1	I	31	15	7	3
	II	17	13	21	5
Total		48	28	28	8
Mean		24	14	14	4
2	I	103	34	10	6
	II	77	30	30	9
Total		180	64	40	15
Mean		90	32	20	7.5
3	I	55	36	9	18
	II	32	21	6	7
Total		87	57	15	25
Mean		43.5	28.5	7.5	12.5
Total over time:		315	149	83	48
Mean per time :		52.5	24.8	13.8	8

Appendix Table 8: Numbers of adults of *Trialeurodes vaporariorum* and alatae + apterae + nymphs of *Myzus persicae* and *Macrosiphum euphorbiae* on 2 destructively sampled plants in week 4 (1.6.84)

Block no.	*T. vaporariorum*		*M. persicae*		*M. euphorbiae*	
	Control	Yellow plastic	Control	Yellow plastic	Control	Yellow plastic
I	2	1	22	13	13	12
II	1	1	1	11	4	4
Total	3	2	23	24	17	16
Mean	1.5	1	11.5	12	8.5	8

Appendix Table 9: Plant height (cm), number of leaves and total leaf area (cm^2) per plant sampled in week 4 (1.6.84)

Block no.	Plant no.	Plant height		Number of leaves		Total leaf area	
		Control	Yellow plastic	Control	Yellow plastic	Control	Yellow plastic
I	1	26.5	28	15	11	1047	934
	2	29.0	34	11	26	452	3585
II	1	36.0	31	12	10	1061	340
	2	24.0	39.4	8	20	298	3959
Total		115.5	132.5	46	67	2857	8818
Mean		28.9	33.1	11.5	16.8	714	2204

Appendix Table 10: Numbers of adults of <u>Trialeurodes vaporariorum</u> caught on each of 5 sticky traps made of different mulching materials over 2 periods of 5 days each

Trapping period	Column no.	Soil (Control)	Aluminium foil	Green plastic	'Xiro' sheet	Yellow plastic
1 (19-24.6.84)	1	1	1	10	5	78
	2	2	0	5	2	29
	3	4	1	7	2	26
	4	1	0	8	2	32
	5	2	4	11	0	51
Total		10	6	41	11	216
Mean		2	1.2	8.2	2.2	43.2
2 (24-29.6.84)	1	2	1	16	2	141
	2	1	0	8	8	99
	3	1	0	21	8	95
	4	2	0	12	13	100
	5	0	1	15	3	134
Total		6	2	72	34	569
Mean		1.2	0.4	14.4	6.8	113.8