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ABSTRACT

The silverleaf whitefly (*Bemisia tabaci* B type) is a world-wide pest on many crops, with a particular appetite for cotton.

Although the SLW has reached pest status in the Horticultural industries of the Northern Territory and Queensland, the cotton industry in Australia is not affected by the silverleaf whitefly. However, the presence of this pest in Australia's cotton growing areas and the current worldwide problems associated with SLW management, has presented the industry with a potential disaster.

Is it a matter of time as for other countries? Is Australia's climate suitable? Is cotton a good host? are competition and predation our saving grace? These and more detailed questions need to be addressed. Australian cotton growers and researchers may then play a role in either; keeping the present situation as it is (if the SLW has simply not been able to establish). Or, by not providing the pest with a chance of a foothold if the opportunity still awaits.

Outbreaks of SLW in other countries have been studied, and theories have been presented as to the development of its major pest status. Major theories include the effect of climate, reduction in beneficials, poor insecticide management, and changes in farming practices including the increase in suitable hosts.

Most of these factors we can examine to enable us to identify the risks that would elevate the SLW to a major pest in Australian cotton.

CHAPTER 1

WHITEFLY BIOLOGY AND ECOLOGY

Whiteflies are a group of plant sap-feeding insects (Hennig, 1980 CHECK REFS) that belong to the sub-family Aleyrodinae, family Aleyrodidae, super-family Aleyrodoidea in the suborder either Homoptera or Sternorrhyncha (Avila, 1986 CHECK REFS). Over one thousand different whitefly species have been identified to date, with most existing in tropical and subtropical regions of the world (Bedford 2000)[BEMISIA 13 NEWSLETTER ON WEB].

BACKGROUND ON BEMISIA TABACI

Bemisia tabaci has numerous biotypes (Figure *) established or distributed throughout the world, with some being devastating economic pests. First described in Greece in 1889 as *Aleurodes tabaci* Gennadius as a pest of tobacco, *B tabaci* is now considered the most common and important whitefly vector of plant viruses worldwide and is the only known whitefly vector of problematic geminiviruses (Brunt, 1986; Duffus, 1987; Harrison, 1985, Brown, 1994 CHECK REFS). Although its true origin is still undecided, it is believed to have originated in the Indian subcontinent based on the abundance of natural enemies in this locale (Cock, 1986; Mound and Halsey, 1978 CHECK REFS). The insect may have spread from there to Africa, Europe and the Americas by human transport of plant material (Cock, 1986 CHECK REFS), such as during the introductions of soybean, okra and eggplant into the New World and cassava from South America to Africa (Brown, 1994).

Regardless of the SLW's origin, it has now developed major pest status in many countries, in both greenhouse and outdoor crops (Gerling and Jones, (ed's) 2000) and one prominent example is its outbreak and the subsequent devastation it causes in USA (see SILVERLEAF WHITEFLY Honours Thesis, David Lea etc).

Since the 1950's there has been suspicion that *B. tabaci* is a heterogeneous assemblage of genetically different populations based on differences in biological characteristics, host preference, and virus-transmission efficiency (Wool, 1988). The

SLW has been proposed to be a separate species (*Bemisia argentifolii* (Perring & Bellows)) from the SPW by Bellows *et al.* (1994) (Shapiro 1995) based on the biology and genetics of the organism. The new species status has been conjectured based on the criteria that there is reproductive isolation between the two biotypes, and there is genetic variation as characterised by biochemical assays of allozymes (Perring *et al.* 1993 CHECK REFS). There is also support for basic biological differences between the two biotypes when considering the significantly larger host range of the SLW than the SPW, and the differences in virus transmission specificities. Subtle morphological differences have also been identified between the biotypes (Toscano *et al.*, 1998). However, because of the genetic and phenotypic plasticity of *Bemisia* species, many researchers are not in full agreement with the elevation of the SLW or biotype B to a new species (Wang *et al.*, 1996). Brown (1994) states that because the dissimilar characteristics (host range and phytotoxic disorders) of the SLW were only recently observed, either a genetic change occurred simultaneously in local populations worldwide or an exotic whitefly with these characteristics has been dispersed throughout the world. One suggestion for the emergence of different biotypes of *B. tabaci* is the change in agricultural practices that have a subsequent effect on the dynamics of whitefly pest-vector populations (Brown and Bird, 1992 or Bedford *et al.*, 1994 CHECK REFS). De Barro *et al.* (2000) [BEMISIA NEWSLETTER 13 ON WEB] suggests to acknowledge the *B. tabaci* complex belongs to one species, with distinct geographically based populations with variation across traits, until further evidence is accumulated.

The following table displays the biotypes of *B. tabaci* of concern for this thesis;

Figure 1:-

BIOTYPE	COMMON NAMES	DESCRIPTION
B. tabaci Biotype A	Sweetpotato whitefly Tobacco whitefly Poinsettia whitefly	This biotype was replaced by B Biotype in many countries (Including America, Africa and in Europe)
B. tabaci Biotype B (*B. argentifolii*)*	Silverleaf whitefly	
B. tabaci EAN	Eastern Australian native Indigenous Biotype whitefly(IBW)	
B. tabaci WAN	Western Australian native	

*B. argentifolii is grouped with *B. tabaci* B Biotype for the reasons mentioned previously

WHITEFLY BIOLOGY

The whitefly is a plant feeder with piercing and sucking mouthparts (Byrne and Bellows 1991), and its general biology is comparable to that of aphids and mealybugs (Campbell, 1993). The six stages in the whitefly lifecycle are the egg, first instar or crawler stage, 2nd instar, 3rd instar, 4th instar or pupal stage (used to make taxanomic decisions) and the adult (Appendix A.1 – my own diagram!!). The juvenile stages and adult feeding, mating and oviposition occur on the undersurface of the host plant leaves (Coudriet *et al.*, 1985). The adult and the first instar are the only mobile stages, the other intermediate stages are sessile except for brief periods during ecdysis. Movement at this time is usually limited to reinserting the stylets into the phloem of the host plant. After eclosion the crawlers generally need move only short distances from the egg to find a suitable site in which to insert their stylets, settle and begin feeding (Summers, 1997 CHECK QUOTE).

FECUNDITY

Bemisia tabaci generally lays its eggs on the undersurface of young leaves (David and Jesudasan, 1986 CHECK REF) either singly or in clusters. An extension at the base of the egg, called the pedicel, is inserted into the plant tissue by the ovipositor (Paulson and Beardsley, 1985), securing the egg to the leaf and serving as a conduit for moisture for the developing whitefly (Deshpande, 1936 or Poinar, 1965 CHECK REF). Eggs are minute (0.5mm), oval in shape with a pointed apex, and creamy in colour. The minimum threshold for incubation is regarded as 10°C. High crawler emergence (on ??) under artificial conditions was recorded between 20 and 30°C, and 90.61 – 103.40 accumulated day-degrees was required for egg hatch (Verma *et al.*, 190)

One of the major factors influencing densities of SLW within a plant is leaf age, where adults are frequently observed aggregating and laying most eggs on young plant leaves (Byrne & Draeger 1989, Gerling & Lindenbaum 1991, Naik & Lingappa 1992 (CHECK REF), however, newly emerged females may lay a few eggs on the leaf on which they hatch before moving to the upper leaves (Gameel, 1977 CHECK REF).

The fact that whiteflies develop from egg to adult on a single plant (in most cases on a single leaf), stresses the importance of oviposition preference (Blua *et al.*, 1995). This is even more intensified for SLW where hosts are frequently annual with high senescence.

Bentz *et al* (1995) in a review on *B. tabaci* oviposition found studies that support preference for young leaves (on eggplant, lubia and tomato and cassava). Leaf age preference on cotton has been found to vary, with studies showing preference for young leaves, old leaves, and in some cases mixed results.

The reproductive system in *B. tabaci* is arrhenotokous (Havron *et al.*, 1987, Byrne *et al.*, 1996), where males are produced uniparentally from unfertilised haploid eggs and females are produced biparentally from fertilised diploid eggs (Havron *et al.*, 1987 CHECK REF, Byrne *et al.*, 1996).

The silverleaf whitefly, like many other whitefly species may produce unequal numbers of male and female offspring (Toscano *et al.*, 1998). Field surveys of silverleaf whitefly populations suggest a mostly female-biased sex ratio throughout their annual cycle (Toscano *et al.*, 1998).

Oviposition of *B. tabaci* may vary considerably with age, and is influenced by host plant and environmental conditions. Wang and Tsai (1996) found average oviposition of SLW to decrease sharply as temperature increased. The peak of oviposition per female per day (on what!) at 4-7d after emergence to be 12.77, 14.29, 7.61 and 3.33 at 25, 27, 30, and 35°C respectively. Reproductive periods were found to last as long as adult longevity at all temperatures.

JUVENILE STAGES (Crawler, 2nd instar, 3rd instar, 4th instar or pupa)

The 2nd stage of development, the crawler, is the only juvenile stage that is mobile, the other stage being the adult. The crawler emerges from the egg and generally moves only a small distance to find a suitable leaf vein for feeding (Lopez and Avila 1986, or Byrne and Bellows 1991 CHECK REF). The crawler usually settles within a few hours (Dowell *et al.*, 1978 CHECK REF), however Summers *et al.*, (1996) found that under cool conditions (12-18 o C), crawlers remained active for 5 days. The crawlers ability to disperse intraplant and interplant may be an important factor in successful overwintering (Summers *et al.*, 1996). Once the crawler is established it will remain there through the following sessile instars (2^{nd}, 3^{rd} and 4^{th} instars), and finally the adult will emerge from the pupa via a slit made in the dorsal surface of the pupal case. Mortality within the juvenile stages is similarly dependent on many factors like those discussed for egg mortalily. However, there is evidence of higher mortality of the early juvenile stages, particularly crawler establishment.

ADULT EMERGENCE

Verma *et al.*, (1990) found percentage adult emergence under artificial conditions to be greatest between 20 and 30°C, with a maximum at 23°C, with 303.28 – 336.80 accumulated day-degrees required for proper emergence.

RATE OF IMMATURE DEVELOPMENT

Verma *et al.*, (1990) found that the rate of development of SLW from egg to adult is primarily influenced by the accumulated of heat, or day-degrees. The authors examined *B. tabaci* in the field on (??) and found the duration of generations varied from 16 to 33 days with the accumulation of day-degrees varying from 307.20 to 356.65. The number of generations per season, in differing climatic regions, can be estimated on the basis of the accumulated day degrees for that season (Verma *et al.*, 1990).

The optimum temperature for development from egg to adult of the SLW is approximately 28-30°C (Butler *et al.* 1983, Zalom *et al.* 1985, Natwick and Zalom 1987, Wagner 1995 CHECK REFS, Skinner, 1996). Wang and Tsai (1996) found development time at 15°C and 30°C to be 105d and 13.6d respectively. The development threshold for overall juvenile stages was estimated at 12.5°C.

ADULT LONGEVITY

The average longevity of adult females on (??) was found to decrease exponentially as temperature increased, with significantly greater longevity at 20 °C (44.36d), and longevity falling to 12.73 and 10.43d at 30 and 35°C respectively(Wang and Tsai, 1996).

The following table gives examples of *B. tabaci* life history traits over the last 20 years;

Fecundity	Location	Host	Temp						
	F								
	G								
	L								
Immature survival	F								
	G								
	L								
Development time	F								
	G								
	L								
Adult longevity	F								
	G								
	L								

F = Field, G = Glasshouse, L = Laboratory

ADULT FLIGHT

The movement of adult SLW in the field is particularly difficult to monitor due to their small size and fragile nature, however it is one of the most important factors in the ability of this pest to establish in new areas. Dispersal is an aspect of SLW biology that is integral to understanding its pest potential. Whitefly populations are able to move from one field to another, or one crop to the next, either in large flights or incremental movements over a period of days to locate a suitable host (Toscano *et al.*, 1998). The ability to migrate is a key component in an insect's life history allowing the choice of both time and place of breeding (Blackmer and Byrne 1993 CHECK REF).

Bemisia tabaci are not considered strong fliers (Blackmer and Byrne 1993 CHECK REF), and dispersal is generally linear and in the direction of the wind (Isaacs and Byrne, 1998). However adults can sustain flight in nature in a manner similar to aphids (Blackmer and Byrne 1993 CHECK REF).

Studies have shown that *B. tabaci* can migrate up to 7km from a source (Cohen & Ben-Joseph 1986), allowing movement from terminated crops to other crops in regional areas, as is the case movement from cotton, melon and lettuce in to another sequentially planted crop (Blua *et al.*, 1994).

Although there is limited studies on SLW movement in the field, several studies on movement in controlled conditions have provided useful information. There is evidence for two distinct dispersal morphs of *B. tabaci*, supported by differences found in the wing configuration in field populations (Byrne and Houck, 1990 CHECK REF). A trivial flying morph and a migratory morph have been proposed (Byrne and Houck 1990; Blackmer and Byrne 1993 CHECK REFS, Brewster *et al*, 1997, Environ Ento. 26 (3)). A small proportion of individuals enter the behavioural phase of predominantly flying vertical toward skylight ignoring host plant cues (Blackmer and Byrne 1993 CHECK REF), while the majority produce enough lift to either maintain altitude close to the ground, or ascent into the higher airflows until the behavioural phase of the insect reverts to foraging flight resulting in orientation to host plant cues (Isaacs and Byrne, 1998).

Blackmer and Byrne (1993) using flight chambers found that trivial flight occurred throughout the day, while long duration phototactic flights were primarily undertaken in the early morning. The benefits of restricted flight times may include a reduction in dessication, predation or harmful effects of radiation (Johnson, 1969, Blackmer and Byrne, 1993). Long duration flights by females were found to be restricted to early morning while males were observed to fly throughout the day (Blackmer and Byrne, 1993). There is little flight activity of *B. tabaci* at night (Gerling and Horowitz 1984, Bellows *et al.* 1988 CHECK REFS).

The ability to predict when and where the movement of SLW populations from known sources will occur would be invaluable to preventing new infestations. Small insects such as the SLW (~ 35μg) may benefit from initiating flight in the early morning by allowing more control over the direction of flight when wind speeds are lower at dawn (Johnson, 1969 CHECK REF, Blackmer and Byrne, 1993). Convection currents in the mornings are capable of carrying *B. tabaci* aloft (up to 1600m) (Glick and Noble, 1961 CHECK REF, Blackmer and Byrne, 1993) which would also assist in dispersal. Although meteorological conditions are a significant factor in the movement of small insects to new habitats, much of their aerial dispersal is active where the timing and duration are controlled by the insect (Isaacs and Byrne, 1998).

Blackmer and Byrne (1993) found that temperature, solar radiance and relative humidity had a significant impact on take off under glasshouse conditions. Larger percentages of egg-laden individuals were found to respond to skylight than those remaining on poinsettia, highlighting the ability of SLW to move with full reproductive capacity.

DISTRIBUTION AND HOST RANGE

Bemisia tabaci is an established pest of agricultural and horticultural crops worldwide (Byrne *et al.*, 1996), and it thrives in warm climates despite its small size and hyperosmotic diet (Wolfe *et al.*, 1998). Unlike most other whiteflies which are primarily monophagous or oligophagous and typically infest woody perenials, members of the genus *Bemisia* are polyphagous and infest herbaceous annual plant species (Byrne and Bellows, 1991; Mound and Halsey, 1978; Russell, 1975 CHECK REFS). This preferential feeding ability has assisted in its extensive geographic range to include tropical and subtropical agricultural systems, with establishment in temperate climates as well (Brown 1994 CHECK REF). In many regions that would have initially been considered unsuitable, ornamentals and vegetable crops grown in and adjacent to greenhouses and glasshouses as well as ornamentals in nearby urban centres are supporting large populations of the SLW (Brown 1994).

Over 500 host plant species have been recorded for the SLW, including agricultural, horticultural, ornamental crops and weeds. The SLW is able to breed and move freely on a vast amount of commercial crops throughout the annual growing season (Yee & Toscano 1996, Yee *et al.*, 1997), however there may be some spillover effect of having massive population densities on certain hosts which forces colonisation of marginal hosts (Toscano *et al.*, 1998), increasing the host range. Toscano *et al.* (1998) states that the physiological basis for whitefly host plant selection is poorly understood, although several plant factors may be cues for acceptability, including leaf sucrose concentration (Berlinger *et al.*, 1983, Rajam *et al.* 1992, Skinner and Cohen 1994), nitrogen supply (Joyce 1958, Bentz *et al.* 1995), pH (Berlinger *et al.* 1983), and water status (Mor *et al.* 1982, Castane and Save, 1993, Skinner 1996).

The environment plays a considerable role in population development of SLW, where low rainfall, high temperature, moderate humidity and high sunshine levels are more suitable (David *et al.*, 1987; Joyce, 1959) than high rainfall and cold weather ((Hussain and Trehan, 1933 CHECK REF, Sundaramurthy, 1992).

CONTINUOUS CROPPING

The SLW's high capacity for colonising various crops, weeds, ornamentals and citrus is a major reason why continuous cropping throughout the year is favourable for the SLW (Toscano *et al.*, 1998). These agricultural practices may be beneficial for the whiteflys survival and host adaptation (Brown 1994). Annual cropping of diverse crops in close proximity to one another in overlapping crop development stages acts as a resource base for the SLW to exploit (Toscano *et al.*, 1998). As the SLW lacks an adaptive resting stage in its lifecycle, it is important for a continuous supply of hosts, which a continuous cropping system readily provides. Coupled with the effective dispersal ability of the SLW that enables movement from declining crops to new plantings, there is a good chance SLW will be present where these cropping systems are used (Toscano *et al.*, 1998).

In many cotton growing areas in the United States there is large populations of SLW on sunflowers, potatoes, cucurbits, ornamentals and weeds when the cotton is very young (Berlinger *et al.*, 1983). These populations provide a source for the subsequent infestations seen in cotton. A prominent example is the high populations and persistence of the SLW in the Imperial Valley of California where there is continuous cropping of acceptable hosts. The cycle is movement from cole crops, where the whiteflies overwinter, to cucurbits in the spring, then to cotton, later to cucurbits and vegetables planted in late summer and early fall. The whitelies then return to cole crops and possibly lucerne for overwintering (Brazzle *et al.*, 1997).

CROP INJURY AND ASSOCIATED PROBLEMS FROM INFESTATION

The SLW produces a suite of problems on host plants, both directly and indirectly. Nymphal and adult stages suck plant sap, reducing productivity by the consumption of transportable water, carbohydrates and other nutrients (Blackmer and Byrne, 1993). As a product of phloem feeding, the honeydew that they secrete and the subsequent growth of sooty mould fungi, especially on cotton (Nuessly *et al.*, 1989), causes quality reduction (Blua *et al.*, 1994). Feeding may also instigate physiological disorders, including silverleaf of cucurbits and irregular ripening (see piccies) of tomatoes, however a particularly devastating problem is virus transmission from the SLW and its associated diseases, such as pathogenic phytotoxic disorders (Brown, 1994).

Of the three whitefly species currently known to transmit plant viruses (the tobacco whitefly, *Bemisia tabaci*, the banded whitefly, *Trialeurodes abutilonea*, and the glasshouse whitefly, *T. vaporariorum*) (Bedford, 2000), *B. tabaci* is the most important virus vector (Butler *et al.* 1986a) capable of acquiring and transmitting over 60 different viruses of several groups including the Clostero-, Luteo-, Poty-, Carla-, Nepo- and Geminiviruses (Bedford, 2000). The increase in world trade of ornamental plants, exotic produce and warming temperate regions is a window of opportunity for these viruses and vectors to spread into new locations, such as those recently experienced in Europe (Bedford 2000). The associated diseases from whitefly-transmitted viruses, in particular the geminiviruses, are a considerable constraint to the sustainable production of food and fibre crops in tropical and subtropical locales worldwide. The establishment of SLW in temperate zones is threatening crops grown in these regions as well (Brown, 1994).

Unfortunately, elimination of the SLW entirely is not a practicable solution to controlling plant viruses due to the high virulence of the SLW and the low population numbers required for successful transmission (Brown, 1994).

OUTBREAKS AND ASSOCIATED RISK FACTORS

Outbreaks of SLW have been reported from several cotton growing countries (Butter *et al.*, 1990). Information on prior outbreaks of SLW in different regions has uncovered a general consensus that there is a few limiting factors, including climate, cropping system (including host availability and suitability), and pest management strategies(with particular emphasis on insecticides). Of course we need the pest to be present in these regions first, which unfortunately is not a concern for most of the worlds cropping regions.

Sundaramurthy (1992) summarises the outbreak situation in India in a nutshell;

"The upsurge of *B. tabaci* is due to excessive intervention of man in the system, together with ecological succession accelerated by changes in the environment. The existence of diverse hosts with differing but ideal morpho-physiological habitats, and application of insecticides with resultant elimination of natural enemies of *B. tabaci*, displacement of species, insecticide resistance, increased reproductive capability of *B. tabaci*, and altered nutritive status of host plants are considered causes for the upsurge of this species in the cotton production area of India."

The importance of climate as a major factor in outbreaks cannot be underestimated, however in cotton production at the present that cannot be altered to any significant amount (localised microclimatic effects through canopy differences and irrigation effects are acknowledged). Once we know that the cropping areas are suitable habitats, we need to investigate further.

In many instances where large-scale outbreaks and continued problems have been encountered it has been blamed on poor pest management strategies, with an emphasis on insecticidal use and its associated spin-offs. Sundaramurthy (1992) states that these insecticide-induced outbreaks are mainly a result of elimination of natural enemies, displacement of competitive species, development of insecticide resistance in the insect population, reproductive stimulation, and altered physiology and nutritive status of the host plants.

Although *B. tabaci* had been resident for many years in various agricultural regions throughout the southern United States there had been few outbreaks recorded prior to the 1980's (Toscano *et al.*, 1998). The problems that arise as a result of insecticidal abuse are highlighted by Veierov *et al.*, (1993) who state that massive insecticidal sprays were used into the early 1990's to try and control *B. tabaci*, however their efficiency was low and were probably causing outbreaks.

Once the SLW is established, although populations may fluctuate throughout the seasons, it is generally the indiscriminate use of insecticides that is responsible for resurgence of the pest (Sundaramurthy, 1992).

The unquestionable evidence of the importance of beneficial insects, both predators and parasitoids, in management of the SLW is also a key player in preventing outbreaks. Bogran *et al.*, (1998) working on parasitism of the SLW on (??) states that parasitism at low host densities (<1 nymph per leaf), which is probably the case in many new infestations, may be a contributing factor in preventing outbreaks. However SLW outbreaks may be unlikely to occur solely as a result of the absence of parasitoids (Gerling and Kravchenko 1996 CHECK REF cited in Devine *et al.*, 1998).

Local environmental factors may contribute to the development of SLW outbreaks, Toscano *et al.*, (1998) notes that the absence of rainfall may benefit whiteflies as decreases in populations have been reported following intense rainfalls or extended periods of rain.

Cropping practices and cultural control have a significant impact on the pest-predator ecosystem within a cropping system. Time of planting, crop nutrition, planting regime, and water usage are a few of the factors that may or may not assist in SLW establishment. The nutrition of the crop has a positive effect on the population of *B. tabaci* (Sundaramurthy, 1992). In a polycrop cotton system, late sown crops generally harbour greater *B. tabaci* populations than early sown crops. Crop density, for instance with reference to insecticidal coverage may be an issue where thick foliage may reduce pest targeting and can lead to outbreaks (Sundaramurthy, 1992).

There would be an abundance of cropping techniques that are risks for SLW population development, however, we can examine and eliminate the factors that aren't risks

ASSESSING DAMAGE AND MONITORING

Identifying that the SLW is infesting a crop, or cropping area is once again difficult due to its small size, and the location of the juvenile stages under the leaves. Early detection is integral for an effective management strategy. This may be particularly the case where the implications of management for other pests, such as heavy chemical usage for heliothis, may disrupt beneficials that may be preventing the SLW from establishing.

A common and reasonably effective method for detecting SLW in a crop (particularly cotton) is the pupal sampling method. This involves random sampling within the field of the middle canopy leaves (generally the fifth leaf down) to detect pupae. Being able to identify the population density within a field is an essential part of experimentation (for example on chemical control, effects of irrigation and fertilisation and the susceptibility of different cultivars) as well as population studies (Ohnesorge & Rapp, 1986).

Limitations are that the SLW must already be established to have pupal stages present and a large sample of leaves need to be collected in order to detect an early infestation. The age of the plants should also be considered when sampling as older plants do not produce new nodes on the mainstem as frequently, so the target stage may be missed. The ability to estimate the population density of whiteflies can assist the grower to make decisions in management (Ohnesorge & Rapp, 1986).

SLW MANAGEMENT

Pest management strategies for the SLW are complicated due to its multivoltine life cycle, high reproductive potential, broad host range, and intercrop movement (Blackmer and Byrne, 1993).

The successful forecasting, monitoring and management of this pest relies on an understanding of its dispersal capabilities and underlying behavioural and physiological mechanisms (Blackmer and Byrne, 1993).

Due to the complexity and widespread nature of the SLW problem a multidisciplinary integrated pest management (IPM) approach is required (Brown, 1994). Kogan (1996) notes that complications for an areawide management strategy for the SLW include its highly dispersive nature, broad host range and that it is not amenable to economic control such as mating disruption or sterile male release (as cited in Legaspi *et al.*, 1997). Rather, management strategies must include the consequences of farming practices and cropping patterns in heterogeneous fields, especially when they are under different management (Legaspi *et al.*, 1997).

There has been valuable information on area-wide management of *B. tabaci* gathered by researchers working where the SLW is a major pest. Although the main focus is on chemical control, developments in products that reduce whitefly resistance and conserve natural enemies are positive steps. Conservation of natural enemies, biological control programs, host plant resistance and crop management strategies that include environmental and cultural control are also being investigated (Brazzle *et al.*, 1997).

Rao *et al.*, (1989) states that the only alternative may be to grow resistant or tolerant cotton due to the failure to control *B. tabaci*. Resistant plant varieties provide a basis for integration of other IPM tactics such as biological control and cultural control (Bogran *et al.*, 1998).

BIOLOGICAL CONTROL

Predators of SLW overseas include lacewings, damsel bugs, big-eyed bugs, dusty wings, pirate bugs and ladybirds. Many of these predators are active in Australian cotton and effective species could be incorporated into management strategies of the SLW if it develops pest status in cotton. Many species of spiders are also abundant in cotton crops, and may possibly have a predatory effect on the SLW. In the USA spiders of the family *Theridiidae* build small webs on the lower surface of the leaves where they catch adults of the sweet potato whitefly and were frequently observed in heavily infested cucumber, squash, sweet potato and tomato fields in the Western and Central regions of the country (Castineiras, 1995).

The estimation of predation is difficult to assess for nymphal stages in some cases due to the consumption of whole individuals, facilitating a need for better methods of predator documentation (Bogran *et al.* 1998).

The two most effective parasitoid genera of the SLW in Australia are *Encarsia* sp. and *Eretmocerus* sp. There are atleast 200 described species of Encarsia (Woolley & Heraty 1999 CHECK REF, as cited in Heraty, 2000 – Bemisia 13 Newsletter), and parasitism by both genera can be extremely high in SLW infestations (Franzmann and Lea, 1999?). *Eretmocerus mundus* is the most widespread parasitoid of the sweetpotato whitefly in the Old World (Greathead & Bennett 1981; Gerling, 1986; Lopez-Avila, 1986 CHECK REF, Jones *et al.*, 1995). Parasitism of the SLW is usually the early juvenile stages (the 2^{nd} to 3^{rd} instar) with parasitised individuals very easily distinguished due to changes in colour and shape of the SLW pupal case prior to the parasitoid emerging from it.

Pathogens of the SLW are active in the field, one species considered as a potential biological control agent is *Paecilomyces fumosoroseus* (Wize) (Osborne *et al.*, 1990 CHECK REF, Castineiras, 1995). Although the pathogen can show a high infection rate it requires humid conditions limiting the use to greenhouses (Castineiras, 1995).

The many advantages of natural enemies include the use of them early in the season when pest pressure is low thus delaying the use of insecticides (Devine *et al.*, 1998). In particular, parasitoids are very effective in low SLW population densities. This would contribute in the prevention of outbreaks (Bogran *et al.*, 1998) and may be the principal reason why the SLW is not capable of causing economic damage in some situations (Stam & Elmosa, 1990). It is still not clear whether natural enemies are adept enough to disperse and follow whiteflies from crop to crop, and the use of broad-spectrum insecticides hampers their establishment and survival in relevant crops. To allow native and exotic to operate effectively in an area there needs to be a reduction in insecticide use, and registration of selective compounds (pg. 33, Toscano *et al.*, 1998).

CULTURAL CONTROL

Unfortunately cultural control techniques were not given enough consideration in early SLW management issues. It was not until the failures of conventional chemical controls were witnessed that alternative methods were considered as management options (Skinner and Cohen, 1994). Strategies to investigate for better SLW management include changes to crop sequence and rotation, planting and harvest time and general farm hygiene practices. Aims include delaying SLW infestation using early maturing crop varieties and crop sanitation practices. Development of resistant and tolerant crop varieties should be considered, and in relevant cropping systems it is important to ensure safe movement of germplasm and to plant healthy seedlings (Brown, 1994).

Skinner and Cohen (1994) state that manipulation of host plant water and fertilisation regimes could provide one alternative to chemical controls. In irrigated cotton, water stress increases SLW populations (Mor and Marani, 1984, Sundaramurthy, 1992, Flint *et al.*, 1992 CHECK REF) by increasing oviposition (Flint *et al.*, 1992 CHECK REF) and by enhancing survival of 1st instar nymphs (Mor, 1987 CHECK REF, Skinner and Cohen 1994 CHECK REF). There may be an effect of high nitrogen and phosphorus fertilisation on SLW outbreaks (Sundaramurthy, 1992 CHECK REF, Skinner and Cohen 1994). Purohit *et al.*, (1991) concluded that cotton alternately sprayed with cypermethrin and monocrotophos while having excessive fertiliser (NPK) applied lead to higher whitefly populations.

Planting regime may also have a significant impact on development of the SLW. Densely planted cotton may provide a protective habitat for pests from unsuitable conditions (Asim, A *et al.*, ??.).

Brazzle *et al.*, (1997) state that early planted cotton experienced lower whitefly densities relative to those planted later. Where there is a reasonable planting window it would be a viable option to plant when the crop is less susceptible to pest pressure.

INSECTICIDAL USE

The SLW is generally difficult to control with insecticides due to its preference for the undersurface of leaves, high reproduction rate and broad host range throughout the year (Cahill *et al.*, 1995). Crops that are susceptible to colonisation, such as cotton and melon, are likely to experience heavy exposure to insecticides. The threat of insecticide resistance development is high, particularly in continuous cropping systems where there may be continuous exposure to certain chemical groups (Castle *et al.*, 1996).

Insecticide resistance management strategies, such as those employed in the Imperial Valley, may include the alternation between different insecticide classes between crops, areas of spray-free cropping and ornamental and weed habitats (enabling conservation of susceptible whiteflies) (Castle *et al.*, 1996).

SILVERLEAF WHITEFLY IN AUSTRALIA

The ability of the SLW to colonise ornamentals has led to its introduction into Australia and New Zealand (Cheek & Macdonald, 1994, pg. 214, De Barro *et al.*, 1998). The silverleaf whitefly is the most economically important of the few whitefly species that are pests in Australia (see SILVERLEAF WHITEFLY Honours Thesis David Lea). The current distribution of the SLW is throughout the continent. However, large scale outbreaks and their associated problems appear to be primarily influenced by climate (Figure !@!#!- CLIMEX), with several known hosts (including cotton) not being utilised where the environment they are grown in has low average temperatures or fairly extreme climatic differences. Cropping areas that are currently encountering problems associated with SLW are mainly in coastal areas in NT / QLD / Northern NSW. The main concerns for the Australian cotton industry is the possible extension of the cotton agroecosystem to new, more suitable climates, and control methods for primary pests that may eventually lead to a whitefly problem. Although we are currently not experiencing SLW problems, cotton is the most economically important crop that is attacked by whitefly species (Greenberg and Jones, 1999).

The few localised colonies of SLW found in areas where the general climate would be considered unsuitable (Franzmann and Lea 1996?- SLW survey) may persist from small microclimatic effects of the surroundings. The colonies are generally found in sheltered and confined areas, such as public and private gardens and parks, where there may be relief from climatic extremes.

There are several effective parasitoids of the SLW, both endemic and introduced. From collections of SLW from the field (Franzmann and Lea 1996?) a few species of the common parasitoid genera *Encarsia* sp and *Eretmocerus* sp showed very high parasitism rates which may have a significant limiting factor on SLW establishment and development.

The intriguing question of competition with our local native *B. tabaci*, the Eastern Australian parthenogenic form known as IBW (Indigenous Biotype Whitefly), has recently been adressed by DeBarro (1999?). Cross breeding experiments showed regular mating although offspring were infertile F1 progeny. In areas where the SLW has been found it is frequently found in the same areas, aswell as on the same hosts as IBW, possibly leading to negative interaction between the two biotypes.

SLW management in countries where it has reached pest status is continually put to the test. This has demanded that the management of this pest must begin by first addressing the factors that lead to its establishment and outbreak.

AUSTRALIAN COTTON AND THE SLW

Cotton production is an extremely dynamic cropping system with a wealth of interacting biota. Mans frequent intervention into this complex system to meet his needs is causing changes to the diversity of this biota. In some cases the imbalance may lead to certain species of minor importance to assume key pest status (Sundaramurthy, 1992).

DIAGRAM OF COTTON AREAS / SLW POTENTIAL ESTABLISHMENT OVERLAPPED

General overview of cotton in Australia

Current distribution of SLW

Potential areas for SLW to colonise

Reasons for SLW current distribution (ie. reason for no outbreaks in cotton yet- relate to infestations up north)

It hasn't been because we have excluded it from our cotton deliberately. We have found it in cotton growing areas but it has not been found in numbers in cotton yet.

- climate, relate to cotton grown up north (bad) BUT SLW in Aust is present in Oakey, Dalby, Biloela, etc. so these areas are able to support populations. BF says the actual amount of hot continuous days in, say summer, allow the bugs to generate population numbers over this time and then outbreak(also what De Barro sorta says with his gen/yr)
- farming system, on downs, Narrabri; current findings (cotton conf. me and robin G!)

- acceptable hosts

(DeBarro presented these factors which play a role in SLW establishment, in this order of importance in R&D talk at Narrabri (need lit. on this – ring him. + get data on no. generations / yr at Narrabri, Bilo, Bowen, Ayre etc/….. in my red book)

- Factors that may contribute; biology of beast (high repro rate etc., resistance, overwintering), continuous cropping, selection pressure.

** We need to investigate the cropping system in these areas to provide insight into whether the SLW hasn't had the opportunity to colonise, or whether it has had that chance and hasn't been able to establish.

CHAPTER II

SUITABILITY OF COTTON CULTIVARS

The development of SLW outbreaks will be initially influenced by factors such as the source of SLW infesting the crop, conditions affecting their survival early in the season, the distribution of the SLW population, and resistance mechanisms in the host plants.

There is an abundance of fecundity trials of the SLW on varying cotton strains throughout the world. The large variability in the literature on the suitability of cotton that expresses different morphological and physiological attributes for whitefly oviposition has provided uncertainty in assessing the factors that may limit oviposition. With this in mind it is important to assess the suitability of our most common cotton varieties grown in Australia, in the growing conditions of Australia's cotton areas. There will always be a change in cultivar use over the seasons, however it is the effects of particular plant traits, such as leaf shape, hairiness, and chemical composition within the plants that are the major determining factor in whitefly oviposition.

Microclimatic effects of cage fecundity trials are of considerable importance, not only for the effects on the whiteflies, but also the effects on the host plants. These effects have no doubt contributed to the variation in host suitability observed not only in varieties with similar attributes, but the same cotton varieties.

Fecundity of the SLW on 13 cotton varieties

Aims

To investigate the ovipositional behaviour of the SLW on Australian cotton, several commonly used cotton varieties on the Darling Downs and a few select cultivars expressing extreme variability in morphological traits were assessed in no-choice trials, both in a glasshouse and the field.

General methods

Silverleaf whiteflies were reared on eggplant (*Solanum melongena* 'Black Beauty') and were cultured for over 2 years in whitefly proof cages in a glasshouse at the Department of Primary Industries (DPI) in Toowoomba. The insects were originally collected off eggplant at Redland Bay, Brisbane (Lea, 1998. The purity of each species was ascertained as described by De Barro 1995?. The colony was maintained since 1992, with introgression of individuals collected from the field every few years. For the purposes of analysis, throughout the duration of the trial the cotton varieties were given a code name for identification. These were as follows:

Cotton Varieties	Corresponding code name	Description and comments
89230-244-1028	89	*Okra, glabrous breeding line*
N73 Okra	730	Okra, delta smooth hairiness
N73 Normal	73N	Normal, delta smooth hairiness
Sicot 189	S189	Normal, major commercial variety
N73 Glabrous	73G	Normal, glabrous
Sicot 50I	S50I	Normal, ingard equivalent of CS50
Pima S-7	S-7	Pima, commercial variety *G barbadense*
Sicala V-2	V-2	Normal, major commercial variety
Emerald	EM	
Zimbabwe line TK	TK	Normal, African line very hairy
Siokra V-16	SV16	Okra, major commercial variety
Sicala 40	S40	*Normal, major commercial variety*
CS 50	CS50	Normal, minor commercial variety
N73 Okra Glabrous	730G	Okra, glabrous

Figure 2: Cotton varieties used in the field trial and their corresponding code names given.

TRIAL 1 Winter 1999 (July/ August 1999)- Glasshouse trial;

No-choice study of SLW fecundity on 13 cotton varieties in the glasshouse

Methods

This study was conducted in a glasshouse located at the Department of Primary Industries (DPI), Toowoomba, Qld, from July to August 1999. The glasshouse was kept at moderate temperature between __°C and __°C with relative humidity varying from __% to __% with a natural photoperiod.

Plant growth conditions

The host plants tested were grown in soil, sand and peat moss (5: 1: 2) in 19 cm high by 19.5 cm diameter pots in the glasshouse. Fertiliser (Osmocote plus) was added to the mix once at a rate of 20-30 g / pot. Thirteen cotton varieties (see list pg.) were planted at a rate of 5 seeds per pot, followed by another 5 seeds 2 weeks later. Once emerged, the seedlings thinned out to 6 and were watered every 2-4 days or as needed. Five weeks after germination, several plants appeared wilted with some leaf malformation. Advised that there may be a deficiency in the plants I applied 14.5 g Phosul / 10 L at a rate of 1\3 to ½ L to each pot. Zinc sulphate (0.5% soln.) 5g / L was sprayed liberally over the plant foliage. In hindsight these symptoms may have been attributed to a broadmite infestation that was detected the following week.

Protocols

To initiate the trial, several eggplant leaves loaded with whiteflies from the breeding cages were placed in emergence containers in a constant temperature room in the evening. The following day, I caged 1 pair of freshly emerged male/ female whiteflies in clip cages on a plant in each pot. The cage was placed over a minor vein in similar locations on each leaf. Whiteflies were sexed by observation of the hind section of the abdomen under a compound microscope at x130 magnification. Specimen tubes (x cm in diameter) were used for collecting and transferring the adults for experimental purposes. The following day the whiteflies were removed (the males were discarded), and the females were recaged on fresh fully emerged leaves. The females were recaged every 2-3 days until they died.

Four weeks after germination, plants were infested with B. argentifolii by placing 10 females in a clip cage (Prabhaker et al., 1985) on theabaxial surface of the youngest fully expanded leaf of each plant, where they were allowed to oviposit for 1hr. The females and all but 10 eggs were removed. Six days after oviposition, eggs were checked daily for eclosion, and the date was recorded. A small permanent ink markm, in red, black or blue, was made on the leaf near each newly settled first instar to identify their date of eclosion. Preliminary studies indicated that the ink mark did not cause discernible damage to either the cotton leaf tissue or B. argentifolii nymphs. Numbers, written in ink near five nymphs on each leaf (one per plant), allowed us to track individual development through adult emergence. Individuals were monitored daily with a 14X hand lens. Nymphs that were not numbered were removed. Stage specific survivorship was noted throughout the trial. After nymphs developed to late fourth instars, clip cages were replaced on each plant. The experimental design consisted of 3 treatments X 12 replicates (plants) X 5 subsamples (nymphs). (Blua et al., 1994.)

Statistical Analysis

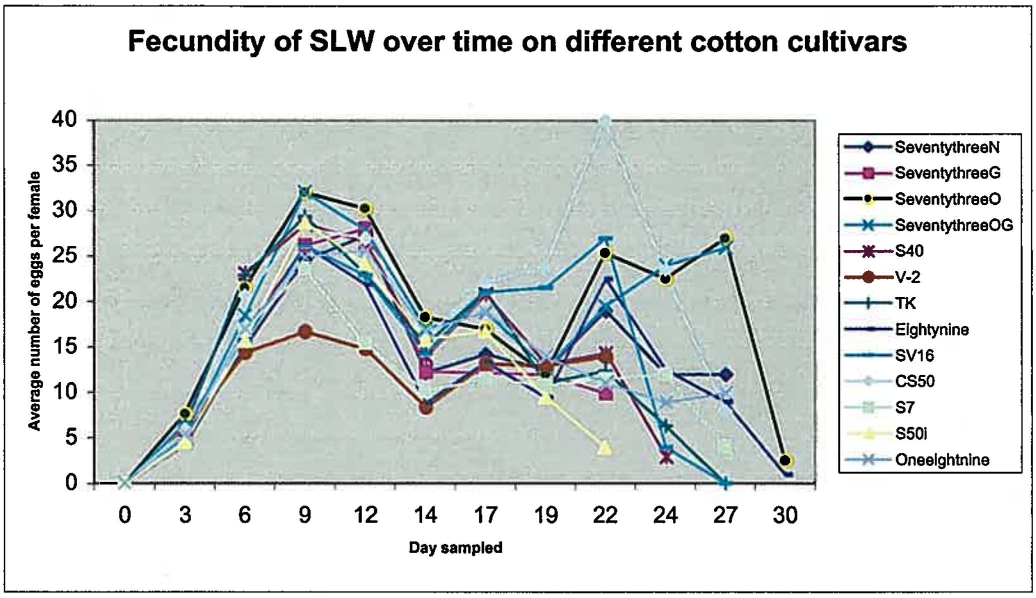
Genstat (V.5) was used where ANNOVAS were performed for analysis.

Results

Total adult SLW fecundity was recorded for all cotton cultivars, with data excluded only under certain conditions (see Appendix *). A severe broadmite infestation only detected on initiation of the trial may have had a significant effect on the oviposition of whitefly females. The broadmites were observed to attach to the females legs while under the cages, in some instances up to a dozen were recorded on a single female, in some cases with a mite attached to the proboscis. Mite laden females were observed to have problems standing and orientating on the abaxial surface of the leaf. Due to the difficulties in assessing mite effect on fecundity, and since mite numbers were relatively equal across all cotton varieties, the factor was ignored in analyses.

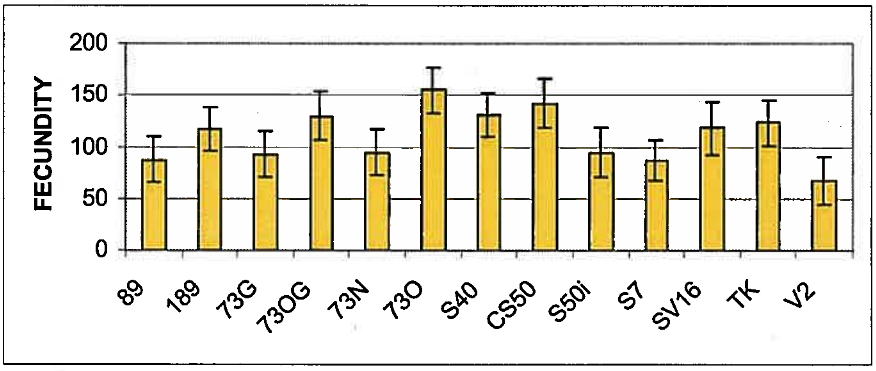
The following figure shows average fecundity of female SLW over time. Where the graph lines stop indicates the death of the last female on that particular cotton variety.

This fecundity is based on the exclusion of individual females where they died or went missing within the first 4? days;



Statistical analysis of this data gave significant variation for some cotton varieties. The implications of host preference, particularly after day 14 may have been influenced by a reduction in female survival, with low numbers recorded for some varieties. Analyses were performed on varietal preference up to day 14 to account for this (Appendix *). Cotton varieties Sicala V-2 and Pima S-7 both had the lowest fecundities over 2 days of 8.81 and 9.38 eggs per day respectively. Discuss varieties according to traits

Graph X illustrates the fecundity of SLW females until death according to cotton variety. There was no significant difference in total fecundity across all varieties.



Discussion

A considerable variation in total fecundity was observed across some varieties of cotton tested. Adult mortality was also recorded early for some varieties. The cotton varieties under test show many different morphological and physiological traits including leaf shape, size, hairiness, thickness, and gossypol content. These factors have been recorded as influencing SLW fecundity. The significant variation in SLW fecundity over time for some cotton varieties in this trial highlights the importance of cultivar preference for planting in areas where there is a risk of SLW infestation. The use of cotton cultivars expressing resistant traits may limit damage by the whitefly (Wilson F. D et al, 1993 (J Ec Ent)) and should be considered for use in the event of an outbreak. However, this trial was a no-choice situation for the ovipositing females, Skinner (1996) states that SLW females will oviposit on less favourable leaves if preferred sites are not available. Although oviposition has only a moderate role in the assessment of the resistance of a particular plant, many factors (including sunlight, leaf shape, colour (Mound 1962, Ohnesorge et al. 1980, El-Helaly et al. 1981 CHECK REF), and physiological factors within the host plant may affect oviposition (Simmons, 1994). These attributes are important in the ability of the SLW to establish in a crop, having a bearing on whether there will be an outbreak.

Pg. 228, Flint and Parks, 1990.

"Sippell et al. (1983) found that the okra and super-okra leaf types conferred resistance to the sweetpotato whitefly. They suggested that the drier microclimate associated with the more open canopy was less favourable for this whitefly."

Pg. 228, Flint and Parks, 1990

"The cotton cultivars planted early and sprayed more often in the planting date test had more whitefly nymphs late in the season."

TRIAL 2 Summer 1999/2000

No-choice study of SLW fecundity on 13 cotton varieties in the field

Methods

The field trial was located at Kingsthorpe Field Station, Kingsthorpe, Toowoomba. The experimental layout for the trial consisted of fourteen cotton varieties replicated 10 times in a completely randomised block design (Figure 1).

Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10
89	EM	S40	SC50	730	EM	V-2	*730G*	EM	S40
730	89	73G	730G	S50i	V-2	89	S40	73N	89
73N	S50I	73N	S-7	EM	73N	S189	S-7	730	73G
S189	73G	730G	SV16	S-7	S40	73G	CS50	V-2	EM
73G	S-7	89	TK	89	SV16	S40	73G	S-7	S50I
S50I	SV16	S-7	89	S189	730G	EM	SV16	S40	730
S-7	TK	SV16	S40	73G	730	73N	730	TK	73N
V-2	S189	S50I	730	73N	CS50	730	S50I	730G	CS50
EM	730	730	73G	V-2	89	730G	V-2	73G	S189
TK	V-2	CS50	S189	S40	S-7	S50I	EM	CS50	730G
SV16	730G	EM	73N	TK	S50I	TK	89	S50I	SV16
S40	73N	V-2	S50I	SV16	TK	CS50	73N	89	V-2
CS50	S40	TK	EM	730G	S189	S-7	TK	S189	S-7
730G	CS50	S189	V-2	CS50	73G	SV16	S189	SV16	TK

Figure 1: Trial Layout, fourteen cotton varieties replicated 10 times in a completely randomised block layout.

On the 12th March, eggplant leaves containing SLW pupae were collected from the breeding cages in the glasshouse, where colonies have been established. These leaves were placed in ventilated plastic containers and left in the constant temperature (25 ±1°C) room overnight for the pupae to emerge. On Monday 13th March, freshly emerged adults were removed from the ventilated plastic containers and sexed to obtain 140 female SLW and 280 male SLW. One female and two males were then stored in each of the 140 glass vials used, which were then placed in an eski with an ice block to keep them cool before transferring them to cages in the field.

The whitefly cages used are ventilated plastic containers with a cardboard base which has an 8 mm hole punched in the centre to allow the whitefly access to the leaf material for feeding and breeding. The cages were attached to the youngest fully expanded cotton leaf for each variety in each replicate. Due to the weight of the cages and the threat of breaking the leaves, the cages were attached to tomato sticks (80 cm to 1 m in length) to support the weight of the cage. Clips and rubber bands were used to attach the cage to the tomato sticks. The whiteflies in the glass vials were transferred to the cages by placing the vials over a 10 mm hole in the side of the cages. A black cardboard slip was then inserted over the glass vials to ensure that the whiteflies entered the cage. Once all three whitefly had entered the cages, the glass vials were removed and the cages were sealed.

On the 16th March, both the leaves and their corresponding attached cages were removed and taken back to the lab. Using a sleave, the whitefly were released from the cage and the female was transferred to a glass vial before being transferred back to the cage on a fresh fully expanded leaf on the same cotton variety and replicate. An egg count was conducted on each of the leaves that the whitefly had been attached to.

On 19th March, the leaves were removed from the cotton plants (with the cages still attached) and a second egg count was completed. Again, in order to count the eggs laid by each female, the females were released from their cages and temporarily transferred to a glass vial until they were placed back in their cages attached to a fresh fully expanded leaf out in the field.

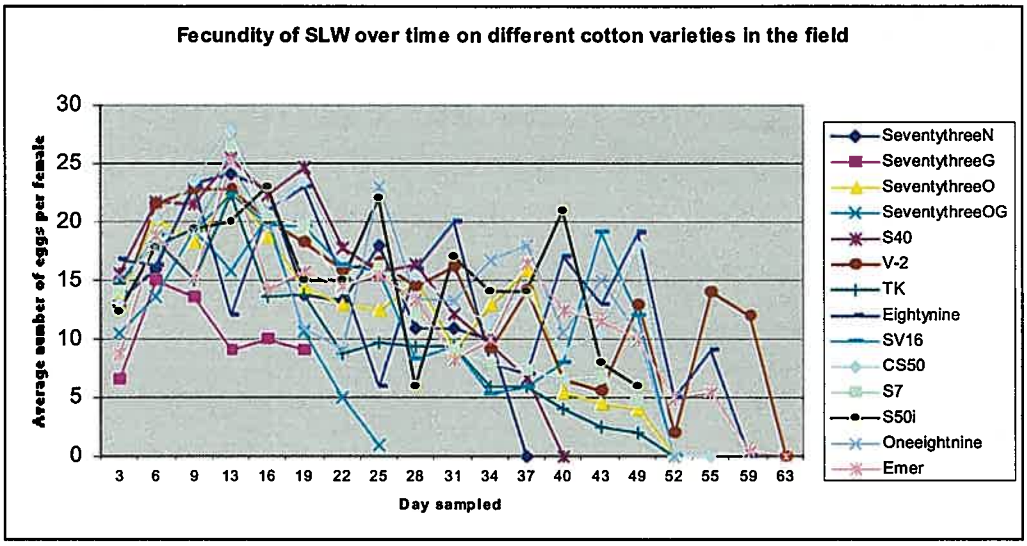
This procedure was carried out again on the 22nd March, 26th March, 29th March, 1st April and 4th April.

Statistical Analysis

Genstat (V.5) was used where ANNOVAS were performed for analysis.

Results

The following figure shows average fecundity of female SLW over time, where lines stop indicates the death of the last female on that particular cotton variety. This fecundity is based on the exclusion of data where females are dead or missing.



Statistical analysis of this data gave significant variation for some cotton varieties. The implications of host preference as for the glasshouse trial may have been influenced by a reduction in female survival, with low numbers recorded for some varieties. Analyses were performed on varietal preference up to day 14 to enable comparisons with the glasshouse trial (Appendix *). Significant differences were found between varieties. Cotton varieties N73 Glabrous and N73OG both had the lowest fecundities over 2 days of 10.23 and 15.17 eggs per day respectively. Adult survival was also lowest for these two varieties. The erratic nature of the fecundity over time lines in the graph was probably in part attributed to the effects of weather experienced in the field. On several occasions when recaging females on fresh leaves, the insides of the clip cages were wet with perspiration, in some cases females were stuck. A few rainstorms occurred over the trial period which may have been responsible for variations in adult survival and egg lay, depending on how much water each cage was exposed to. Spiders were also found in a few of the cages, resulting in the death of the female.

Table ** Fecundity of SLW over time for select cotton varieties (show both average over 14 days and average over entire life (do I need to make sure its every two days sampled?!) for glasshouse and field trials;

GLASSHOUSE FECUN OVER TIME TO DAY 14			
VARIETY	REPS	AVERAGE	
V-2	60	9.94	a
S-7	60	11.72	ab
89	60	12.85	bc
73N	60	13.85	bcd
SV16	60	14.62	cde
189	60	14.84	cde
73 G	60	14.88	cde
S50I	60	15.17	cde
S40	60	16.32	def
TK	60	16.45	def
73 OG	60	16.47	def
CS50	60	16.86	ef
73OKRA	60	18.58	f
	LSD =	**2.717**	

FIELD FECUN OVER TIME TO DAY 16			
VARIETY	REPS	AVERAGE	
73G	50	10.23	a
73OG	50	15.17	b
EMER	50	16.38	bc
TK	50	16.87	bcd
89	50	17.5	bcd
SV16	50	18.58	cde
S50I	50	19.1	cde
73O	50	19.14	cde
189	50	19.23	cde
73N	50	19.6	de
V-2	50	19.86	de
S7	50	20.02	de
CS50	50	21	e
S40	50	21.43	e
LSD =	**3.198**		

GLASSHOUSE FECUN OVER TIME TO DEATH			
VARIETY	REPS	AVERAGE	
V-2	120	8.81	a
S-7	120	9.38	ab
73 G	120	11.44	bc
S50i	120	11.58	c
89	120	11.69	c
73N	120	12.21	c
TK	120	12.57	c
189	120	12.75	c
S40	120	12.99	c
SV16	120	13.17	c
73 OG	120	16.51	d
CS50	120	18.33	d
73OKRA	120	18.45	d
	LSD =	**2.192**	

FIELD FECUN OVER TIME TO DEATH			
VARIETY	REPS	AVERAGE	
73G	190	2.46	a
73OG	190	5.8	b
TK	190	7.64	c
S7	190	11.85	d
SV16	190	11.86	d
73N	190	12.09	d
EMER	190	12.46	d
189	190	12.71	de
S40	190	12.81	de
V-2	190	13.22	de
73O	190	13.33	de
89	190	14.09	ef
CS50	190	14.22	ef
S50I	190	15.45	f
	LSD =	**1.533**	

NB: Means with same subscript are not significantly different at the 5% level

There is very little similarity for each cotton variety when comparisons between the glasshouse fecundity and field fecundity are made. For field and glasshouse trials, both to day 14 (or 16) and over the entire life of females, there is significantly more egglay over time for females on CS50 than on many other varieties. Variety N73 Glabrous was consistently lower than most varieties for both trials with the significantly lowest egg lay over time for the field trial (10.23 eggs for females to day 16 and 2.46 eggs for females till death).

Discussion

The contrast in the suitability of similar hosts for SLW fecundity that is available in the literature provides scepticism when evaluating the fecundity on different cotton varieties. Although significant differences were observed between varieties, the variability in the data puts doubt in identifying any particularly good or poor host for oviposition. There are consistencies for some varieties when comparing the glasshouse to field fecundities. Meagher et al., (1997) states that although there is limited significance of glasshouse trials, data for whitefly oviposition is comparable to that in field tests.

TRIAL 3 Winter 1999

Preimaginal survival of the SLW on 13 cotton varieties

Aims

To investigate the development of the SLW on Australian cotton, several commonly used cotton varieties on the Darling Downs and a few select cultivars expressing extreme variability in morphological traits were assessed in no-choice trials in a glasshouse.

Methods

This study was conducted in a glasshouse located at the Department of Primary Industries (DPI), Toowoomba, Qld, from September to October 1999. The glasshouse was kept at moderate temperature between __°C and __°C with relative humidity varying from __% to __% with normal sunlight.

Plant growth conditions

The host cotton plants used were those used from the previous glasshouse fecundity trial. Plants were thinned to one plant per pot.

Protocols

A freshly emerged leaf on each plant was covered with a gauze sleeve to prevent whiteflies and other insects inhabiting it. Five days later 3 adult female whiteflies were caged (using similar cages as in the fecundity trial) on the young leaves for 24 hrs. Eggs laid were reduced to clusters of 30 (or less if that number was not reached) on each leaf, and recovered with the gauze sleeves to prevent interference from other insects (Appendix X). Examination of the cohorts of eggs was undertaken daily until the first crawler emergence, then assessment of the number of alive stages (and dead where possible) was made on the following dates;

Eggs: September 25th
Crawlers: October 14th
2nd – 3rd Instars: October 17th
Pupae: October 25th
Adult emergence: October 31st – November 21st

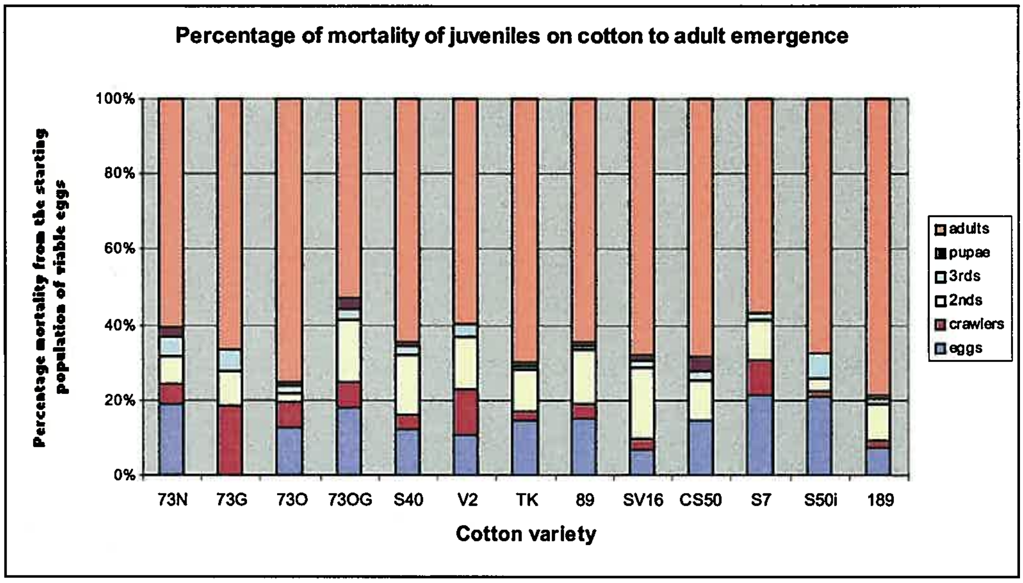
Statistical Analysis

Genstat (V.5) was used where ANNOVAS were performed for analysis.

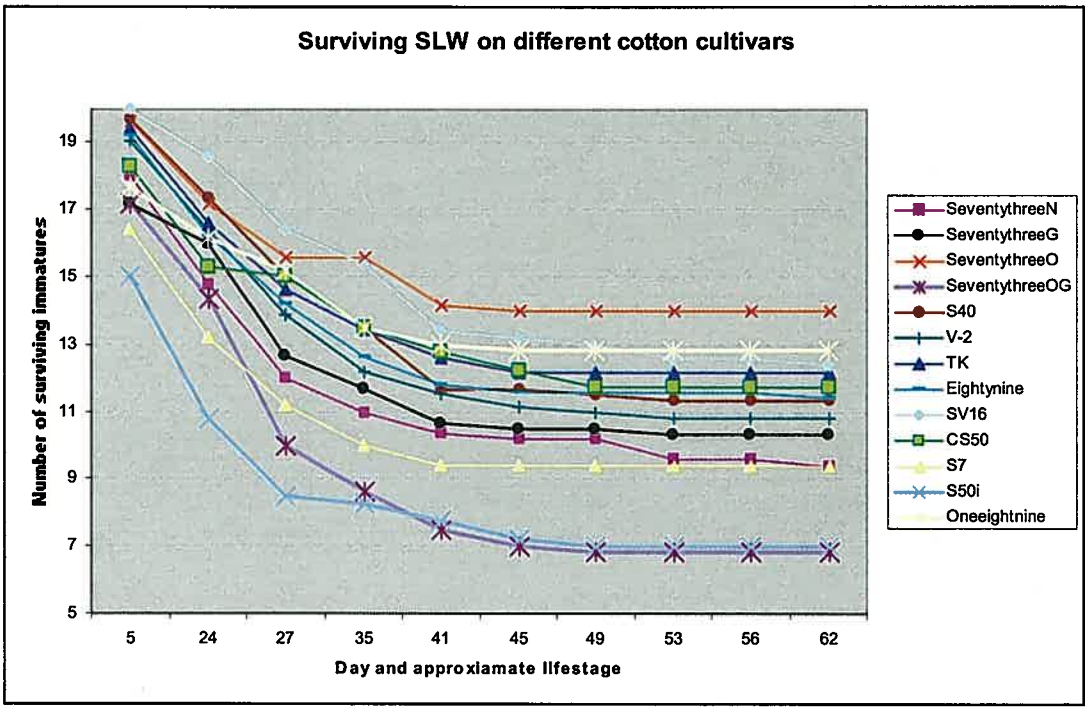
Results

The survival of successive stages of whiteflies to adult emergence was graphed (Figures _ to _) as a percentage of the initial starting population. There was no significant difference in immature survival for any cotton variety.

The following figure illustrates the mortality of each lifestage as a percentage of the starting population for all cotton varieties.



The following figure shows the number of surviving immatures over time on each cotton variety. The specific stages according to time were approximated from the numbers of each stage recorded at the sampling dates;



For the purposes of inference, the survival curves appear to be fairly normally plotted.

The numbers of individuals surviving over time was analysed using an ANOVA (Appendix **). There were significant differences in the number of individuals surviving over time for cotton variety(Table Table#$#;

Variety	Reps	Mean	
S50I	60	9.03	a
73OG	60	9.2	a
S7	60	11	b
73N	60	11.66	bc
73G	60	12.02	bcd
V-2	60	12.75	cde
89	60	12.86	def
CS50	60	13.31	ef
S40	60	13.43	ef
189	60	13.97	fg
TK	60	14.04	fg
SV16	60	15.04	gh
73O	60	15.5	h
	LSD =	**1.184**	
NB: Means with the same subscript are not significantly different at the 5% level			

Although there was no significant difference between immature survival over time between any host plants, the significant differences in number of individuals surviving over time gave some interesting results. N73 okra glabrous has traits that are known to be poor for SLW, as reflected by the low average survival recorded here. However, N73 Okra, apparently with an unsuitable leaf structure for immature development had the highest survival of individuals over time.

Discussion

Bindra (1985) notes that bushiness, hairiness and larger leaf area are factors that make a cotton variety more prone to infestation. The difficulties in drawing conclusions from these trials may not necessarily be a result of influences from unwanted sources, rather the effects of other factors (such as environmental conditions

The possibility also exists that the differences observed between survival rates on different cultivars was more influenced by the sleeves used to cover the leaves with the immatures. There may have been a microclimatic effect, upgrading open leaf structured plants, such as those with okra leaves to be as suitable as normal leaf varieties. The excess of a microclimatic effect may have been unsuitable on normal leaves that were covered. The physiology of the host plants must also be considered as having an impact on immature development. Studies have shown that the distance from leaf surface to vascular bundles may be a determining factor in the success of immature establishment and feeding.

CHAPTER III

HOSTS IN THE COTTON AGROECOSYSTEM

Successful management of the SLW in cotton will only come from examining the entire cotton agroecosystem, and associated cropping areas. There are similarities in the approach needed as with the significant problem of *Helicoverpa armigera* in cotton. Areawide management strategies for *Helicoverpa* are currently being implemented in part for similar reasons as for the SLW overseas, insecticide resistance. At present we are fortunate enough to not have a SLW problem in our cotton, however its presence dictates that we assess the likelyhood of it developing into one.

TRIAL 4 Summer 1999/2000

SLW population establishment and development in 7 summer crops (+ cage releases)

Aims

The large variety of crops grown in and around cotton areas, such as lucerne as a refuge for beneficials, chickpea as a trap-crop for Helicoverpa, and other crops grown during and between cotton seasons may be potential sites for SLW development. To increase our chances of understanding the events that may lead to an outbreak, we need to assess their suitability. A commercially important cotton variety and six common crops were assessed for their ability to sustain SLW populations throughout the growing period in the field.

Methods

Field trial was located at Kingsthorpe Field Station, Kingsthorpe, Toowoomba. The seven crops evaluated were cotton (Sicala 40), lucerne (Trifecta), sunflower (Hysun 47), mungbean (Emerald), pigeon pea (Quest), soybean (Centaur) and cowpea (Red Caluna). All crops were seed planted in plots in a randomised complete block design with four replicates. Each plot measured 10 m wide x 11 m long. Lucerne was hand planted on 20 September 1999, and watered in on 22 September, 1999. The other crops were planted on 22 October, 1999. Forage sorghum (Chopper) was planted on 8 October, 1999 at 3 rows / metre such that every plot was surrounded by a 1 m sorghum barrier. All crops were planted or thinned out to commercial densities prior to starting the trials. The lucerne plots were cut back to around 10 cm in height on 30 November, 1999, just prior to flowering using a self-driven push mower.

On 9 December, 1999, a survey of plant terminals was performed in each plot to establish whether any Bemisia species were present in the trial area. Fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5th leaf, randomly within each plot.

Once the trial area had been examined for the presence of whiteflies, cages were placed in each plot for silverleaf whiteflies to be released into. Cylindrical sleeve cages (120 cm high x 60 cm diameter) were covered with a fine mesh terralian gauze and placed over one plant in the corner of each plot.

At 7pm, eggplant leaves laden with silverleaf whitefly pupae were collected from a glasshouse colony and were cut into strips containing approximately 500 pupae for the field release, and strips containing approximately 100 pupae to be released into the cages placed in the plots. The leaf sections were then placed in eskies and stored in the constant temperature room overnight.

On 10 December, 1999, each plot was infested with 2500 silverleaf whitefly pupae. At 5 am each leaf containing 500 pupae was tied onto a tomato stick with twist ties and five sticks were placed at a height of 30 cm above the ground in each plot. One stick was placed in the centre of each plot and the remaining four were placed 2 – 3 m out from the centre in north, south, east and westerly directions. The base of each tomato stick at ground level was smeared with tanglefoot to discourage ants and other crawling insects.

At 10 am, tomato sticks with leaves containing 100 silverleaf whitefly pupae (attached in the same manner as above) were placed in each cage in each plot. Each release point was checked on 13 December, 1999, the leaf was retied if fallen off, or notes were taken if the leaf was missing. On 15 December, 1999, a survey of plant terminals was performed in each plot to establish whether adults had established in each plot. Fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5th leaf, randomly within each plot. On 16 December, 1999, the release points (tomato sticks with leaves) were removed from the trial area, noting any missing or damaged leaves.

On 21 December, 1999, plant terminals down to the 5th leaf were examined in the cages in each plot and numbers of adult silverleaf whiteflies were counted. The release points were removed from the cages noting any missing or damaged leaves.

On 22 December, 1999, fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5th leaf, randomly within each plot. Adult silverleaf whitefly numbers were counted and recorded.

On 31 December, 1999, fifty leaves (trifolate in the case of lucerne, cowpea, soybean, mungbean and pigeon pea) at the fifth terminal down were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted. Two leaves were also collected from the 4th and 5th terminal of each caged plant and were examined under the stereo microscope for immature stages of silverleaf whitefly.

On 12 January, 2000, half of each lucerne plot was cut-back in strips with a lucerne slasher.

On 21 January, 2000, collected one leaf (10 in the case of lucerne) from the 2nd, 5th and 2nd terminal up from the bottom terminal from the caged plants. All leaves were examined for third and fourth instars and pupae (emerged and unemerged).

On 22 January, 2000, fifty leaves at the fifth terminal were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted.

On 24 January, 2000, the soybean plants in the cages were cut-back half as there was too much plant material in the cages.

On 1 February, 2000, fifty leaves at the fifth terminal were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted.

On 2 February, 2000, cut-back blocks two and four of the cotton plants in the cages as the plants were pushing into the top of the cages.

On 8 February, 2000, all lucerne plots were cut back half in strips with a Briggs and Stratton sidecutting mower. Collected one leaf (10 in the case of lucerne) from the 2nd terminal from the top from the caged plants. All leaves were examined for third and fourth instars and pupae (emerged and unemerged).

A temperature and humidity data recorded was placed in one plot in the field trial area.

Field plan

PIGEON PEA	SUNFLOWER	LUCERNE	SOYBEAN
SOYBEAN	COTTON	MUNGBEAN	PIGEON PEA
SUNFLOWER	PIGEON PEA	COWPEA	COTTON
LUCERNE	SOYBEAN	SUNFLOWER	LUCERNE
COTTON	COWPEA	PIGEON PEA	MUNGBEAN
MUNGBEAN	LUCERNE	SOYBEAN	SUNFLOWER
COWPEA	MUNGBEAN	COTTON	COWPEA

TRIAL LENGTH (91m)

TRIAL WIDTH (48m)

Notes

* Individual plots are 12 m wide x 13 m long, with a 1 m sorghum barrier around the perimeter. The actual plot size of each crop is 10 m wide x 10.3 m length rows. Graham put 200kg / 700 crop king fertiliser on paddock in Aug 99.

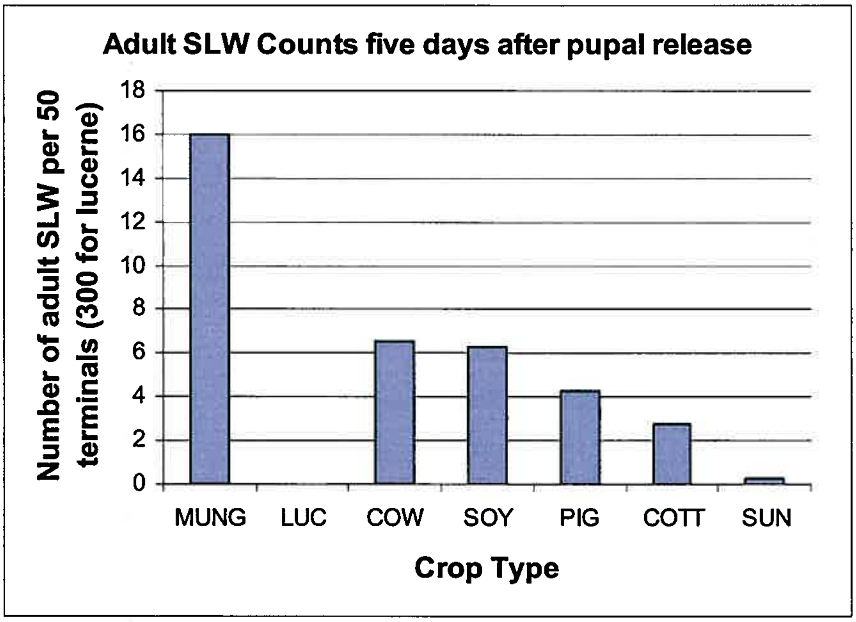
Statistical analysis

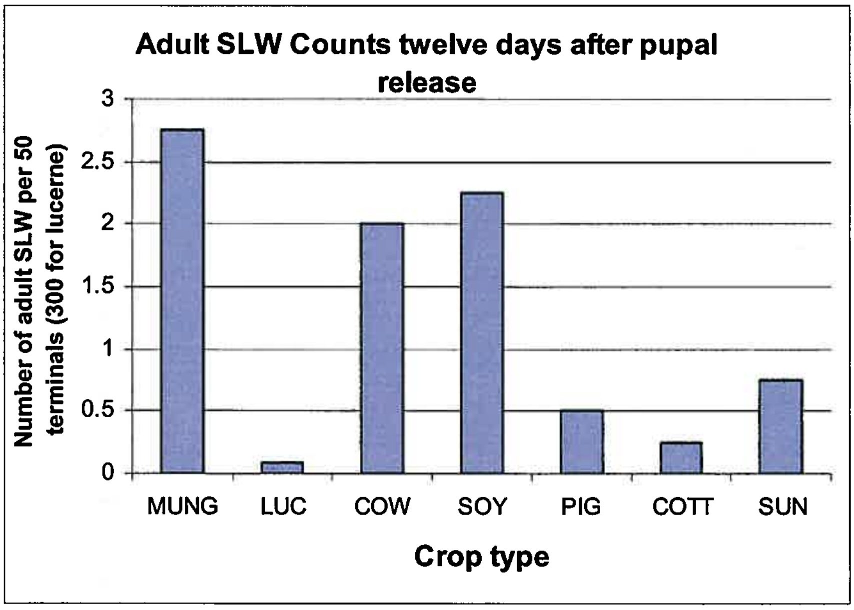
ANNOVAS were used analysis of data.

Results

Assessment of success of release method of SLW at Kingsthorpe

Adult numbers counted on 50 plant terminals in each crop (except 300 for lucerne) showed relatively low numbers in some plots. The counts made using the leaf turn method showed the adults in the usual position under the surface of the uppermost leaves.





There was a significant decrease in the numbers of adults detected 12 days after release, however adults were detected in all crops.

Statistical analysis showed significant differences in the population of adults observed in each plot on 15th December, ** days after pupal release;

Table *&*:-

Crop	Reps	Mean	
SUN	200	0.005	a
COT	200	0.055	ab
PIG	200	0.085	b
SOY	200	0.125	b
COW	200	0.13	b
MUNG	200	0.32	c
LSD =	**0.07662**		

NB: Means with the same subscript are not significantly different at the 5% level

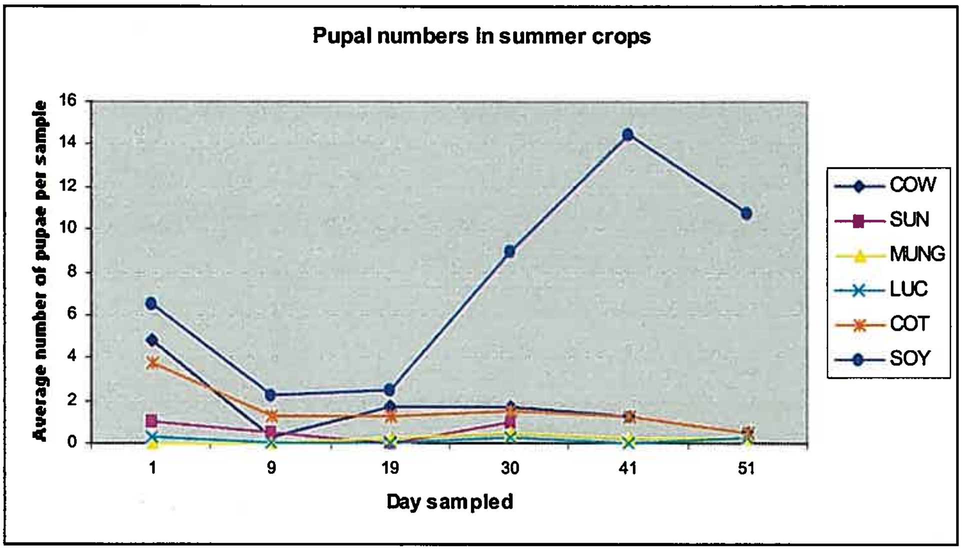
Statistical analysis showed significant differences in the population of adults observed in each plot on 22nd December, ** days after pupal release;

Crop	Reps	Mean	
COT	200	0.005	a
PIG	200	0.01	ab
SUN	200	0.015	abc
COW	200	0.04	bcd
SOY	200	0.045	cd
MUNG	200	0.055	d
LSD =	**0.0343**		

NB: Means with the same subscript are not significantly different at the 5% level

Data for lucerne was left out of analysis because an increased number of leaves were picked due to the smaller size of the leaflets compared to the other crops. Mung bean had the most adults per 50 leaves collected and was significantly higher than all other crops on day 15, and significantly higher than adults on sunflower, pigeon pea and cotton on day 22.

The following figures show the average numbers of pupae collected from the crops every 2 weeks:-



This graph was made on a slight variation in the number of leaves collected from each plot (50 for all crops except 300 for lucerne) to assimilate same leaf surface area per crop. Although there was reasonable establishment of SLW in cotton and cowpea, there was a massive increase of the population in soybean after 3 weeks. The soybean crops were bushier and hairier than all other crops, with plants so thick that walking through the rows was difficult (see picture).

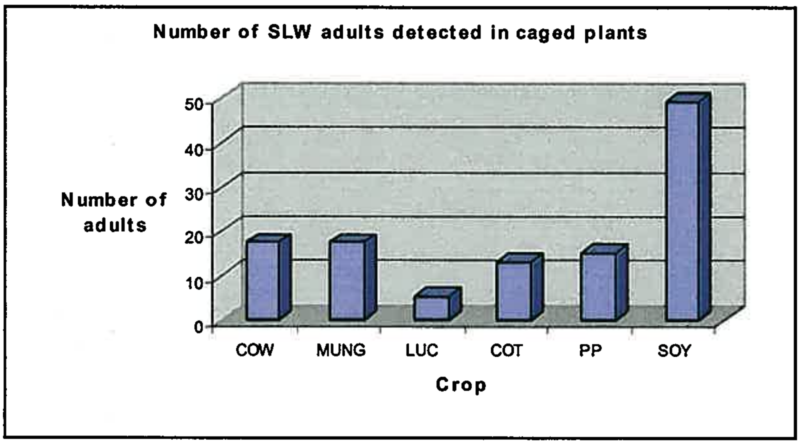
Statistical analysis on the number of pupae collected for each crop is presented below;

CROP	REPS	MEAN	
LUC	24	0.125	a
MUNG	24	0.208	ab
SUN	24	0.979	ab
COT	24	1.583	ab
COW	24	1.708	b
SOY	24	7.583	c
	LSD=	**1.573**	
Means with the same subscript are not significantly different at the 5% level			

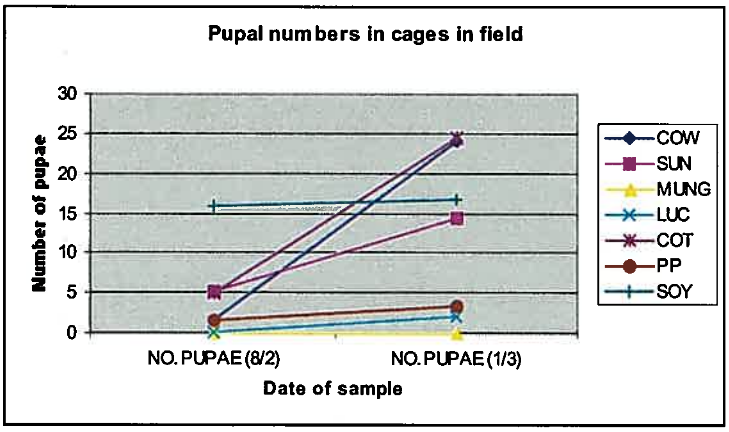
Soybean was an exceptional host for the SLW, at 7.583 pupae per 50 leaves it was significantly higher than all other crops.

Significant differences were also recorded for number of pupae collected at each date (see appendix).

Plants that were caged in each plot that were assessed for the presence of adults held reasonably large populations 11 days after the initial pupal release of 100 pupae per cage;

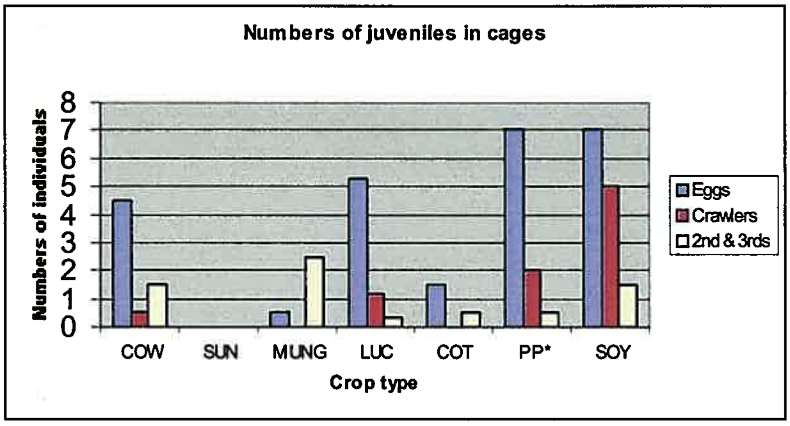


The following figure shows the number of pupae recovered from the caged plants in each plot:-



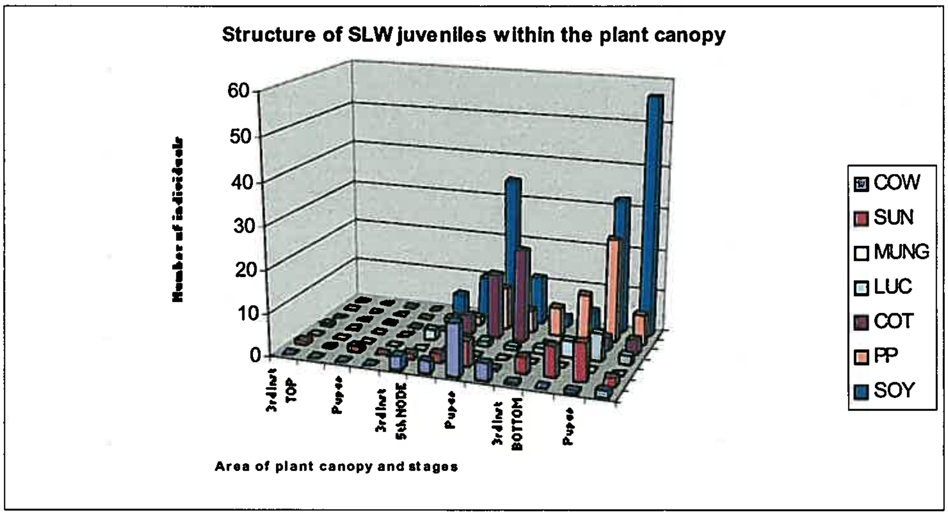
This data was based on an initial starting population of 100 pupae in each cage on 10-12-99, all crops sustained populations of whitefly except mungbean. The mungbean plants under cages were smaller with less foliage than the field mungbeans, and by the second sample date the plants were nearly dead. In most cases the population size appeared to at least double.

It was noted that the stages of development of SLW in the cages appeared to be lower down on pigeon pea, with adults found in the normal feeding position on the 2nd – 4th true leaves. To assess this possible difference in host preference, all life stages were recorded on the 5th leaf of all crops except the 2nd last leaf on pigeon pea. The data is presented in the following figure;



PP* - 2nd last leaf sampled instead of 5th leaf like all other crops.

Further assessment of the variation in the structure of whitefly development on the different crops via the collection of leaves from the top, 5th and bottom node within the plant canopy on all plants gave the following figure;



Although there was relatively more pupae collected from pigeon pea and soybean off the bottom plant leaves, collecting from the 5th node gave the most pupal counts for all crops.

Discussion

Sampling is an essential element in many field research programs and is a major component of pest management programs that are based on the prescriptive control of pest populations (Naranjo et al., 1997).

The effectiveness of the soybean as a host may not just have been the result of the crop or varietal preference. The extensive foliage forming a complete blanket in the blocks may have had a positive effect on the population development. While walking through the plots sampling for pupae I frequently noticed an increase in temperature when reaching into the centre of the plants that was not noticed in the other crops.

"Selection pressures acting on males and females are different in that host plant location and oviposition are of primary importance to the female, whereas mate location is of utmost importance to the male. Because male whiteflies are shorter lived than females (Byrne & Bellows, 1991) they have less time to locate a potential mate and as a result may be more likely to fly for longer periods throughout the day."

"Whiteflies rarely flew before Day 1 regardless of their rearing conditions. Thereafter, however, individuals that had been reared on a low-quality host exhibited greater response levels earlier in life and had a narrower window of activity than did individuals that had been reared on high-quality hosts."

pg. 718, Devine et al., 1998.

"Female whiteflies oviposit on young foliage and this leads to a vertical distribution of immatures, with older instars being more predominant on progressively older foliage (Gerling et al., 1980). As a result, older instar nymphs tend to be most common on particular leaves. These leaves have been called 'maximal' leaves, and searching for and sampling these is an accepted method of monitoring B. tabaci nymphs and their larval parasitoids (Gerling et al., 1980; von Arx et al., 1984; Naranjo and Flint, 1994; Gerling and Kravchenko, 1996)."

Pg. 384, Simmons, 1994.

"Gameel (1974) suggested that, in the field, B. tabaci moves to upper leaves as a result of negative geotropism and nutrient selection for feeding and breeding. No attempt was made to compare proportions of B. tabaci among crops. Thompson (1988) noted that such a comparison can be misleading because of differences in plant densities."

Pg. 386.

"Pubescence may partly explain the ovipositional preference for lower leaf surface in the field, but other factors are apparently more important in vegetable crops."

"Different vegetable hosts support varying whitefly infestation. Infestation is affected by the amount of foliage, i.e., leaf area and number of leaves, among other factors."

Pg. 388.

"On the early growth stages of the 10 vegetables tested, most oviposition occurs on the lower leaf surface, although a notable number occurs on the upper. Hence, consideration should be given to immatures on the lower surface in sampling and management of this pest. Although several factors may be involved in whitefly oviposition, B. tabaci is strongly attracted to lower leaf surfaces because of a negative geotropic response."

Pg. 8, Schuster, 1998.

Authors found that the distribution of the lifestages of SLW varies within tomato plants, with the eggs most abundant on leaflets at nodes 4-6, nymphs at nodes 6-8 and pupae at nodes 8-10. As the plants aged, the nodal position of most infested leaflets increased, so that lifestages were structured lower on the plants.

"The distribution of immature lifestages on leaflets at different nodes generally was independent of stem origination as long as there were sufficient nodes present on lateral stems. Thus, samples can be drawn from any stem having at least the minimum number of nodes. When laterals are too short (i.e., when plants are younger), sampling should focus on the main stem which is easier to identify when plants are young and not tightly compressed through staking and tying."

TRIAL 5 Winter 2000

SLW population establishment and development in 3 Winter crops

Aims

To determine the suitability of common commercial winter crops; canola, chickpea and faba beans for SLW establishment and subsequent development in the field.

Methods

Field trial was located at Kingsthorpe Field Station, Kingsthorpe, Toowoomba. The four crops evaluated were Canola( ), chickpea(Jimbour), faba beans (Fiord) and lucerne (Trifecta). The chickpea and faba beans were inoculated as for standard farming practice. All crops except for lucerne were seed planted in plots in a randomised complete block design with four replicates. The lucerne from the previous summer field trial was cut back and maintained for this trial. Each plot measured 10 m wide x 11 m long. The other crops were planted on 8 June 2000. The forage sorghum (Chopper) that was planted on 8 October, 1999 that surrounded each plot was slashed and allowed to regrow for this trial. All crops were planted or thinned out to commercial densities prior to starting the trials. The lucerne that was left growing from the previous summer trial was slashed regularly and sampled fortnightly for whiteflies.

On ?? (did I do this??)a survey of plant terminals was performed in each plot to establish whether any Bemisia species were present in the trial area. Fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5^{th} leaf, randomly within each plot.

Once the trial area had been examined for the presence of whiteflies, cages were placed in each plot for silverleaf whiteflies to be released into. Cylindrical sleeve cages (120 cm high x 60 cm diameter) were covered with a fine mesh terralian gauze and placed over one plant in the corner of each plot.

On the evening of 3 September 2000, eggplant leaves laden with silverleaf whitefly pupae were collected from a glasshouse colony and leaf strips were separated into groups providing 800 – 1000 pupae. Each group was then placed inside a small (15 *15cm) starched string sleeve, with sleeves placed in an esky prior to release. Eggplant leaf strips containing approximately 200 pupae were also placed inside string sleeves to be released into the cages placed in the plots. The leaf sections were then placed in eskies and stored in the constant temperature room overnight.

On 4 September 2000, four string sleeves were placed in each plot of the trial area in a box configuration (3m * 3.5m in from each corner), providing an infestation of 3200 – 4000 pupae per plot. At 5 am each string sleeve containing the pupae laden leaves was tied onto a tomato stick with twist ties and placed at a height of 30 cm above the ground in each plot. The base of each tomato stick at ground level was smeared with tanglefoot to discourage ants and other crawling insects.

At 8 am, tomato sticks with leaves containing 200 silverleaf whitefly pupae (attached in the same manner as above) were placed in each cage in each plot. Each release point was checked over the following few days. On 7 September 2000, a survey of plant terminals was performed in each plot to establish whether adults had established in each plot. One hundred terminals in each plot were carefully examined down to the 5th leaf, 25 terminals randomly within 2m of each release point within each plot. On 19 September 2000, the release points (tomato sticks with leaves) were removed from the trial area, noting any missing or damaged leaves, aswell as the number of unemerged pupae.

On 3 October, 3 November, and 28 November 2000, 100 leaves (trifolate in the case of lucerne and faba bean, and branchlets for the chickpea) at the fifth terminal down were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted. Ten leaves were also collected from the 4th and 5th terminal of each caged plant (except 20 for lucerne) and were examined under the stereo microscope for immature stages of silverleaf whitefly.

The release points were removed from the cages noting any missing or damaged leaves.

Between the 6th and 10th November 2000, 100 5th leaves were checked in each plot without removing leaves, for the presence of immatures.

The canola plots periodically had the flowering stages cut off the flowering sections of the plants to prevent seeding.

On ????, half of each lucerne plot was cut-back in strips with a lucerne slasher.

On ………. a temperature and humidity data recorded was placed in one plot in the field trial area.

The following figure shows the planting layout of the trial site;

CANOLA	**CANOLA (2)**	LUCERNE	**CANOLA (2)**
CHICKPEA	COTTON	FALLOW	FALLOW
FABA BEAN	**CANOLA**	**CHICKPEA**	COTTON
LUCERNE	**FABA BEAN**	**CANOLA**	LUCERNE
COTTON	**CHICKPEA**	**FABA BEAN**	**CANOLA**
FALLOW	LUCERNE	**CANOLA (2)**	**CHICKPEA**
CANOLA (2)	FALLOW	COTTON	**FABA BEAN**

(91m)
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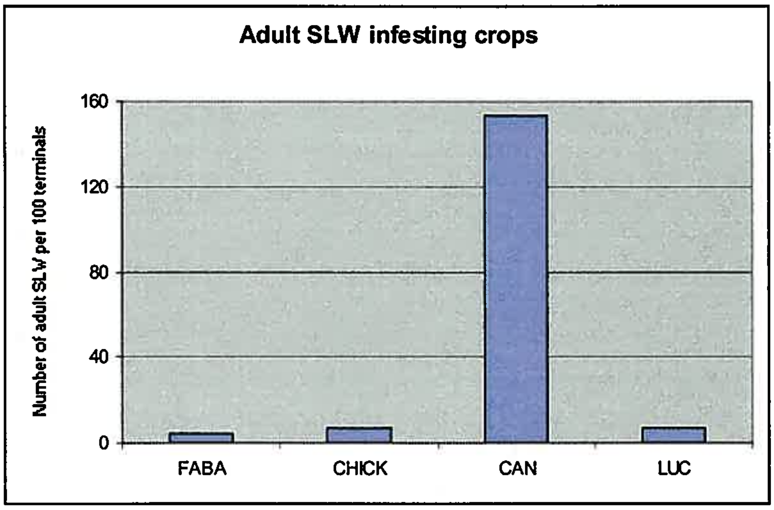
CANOLA (2) refers to the planting of canola on 7-7-00 as the first planting did not come up well.

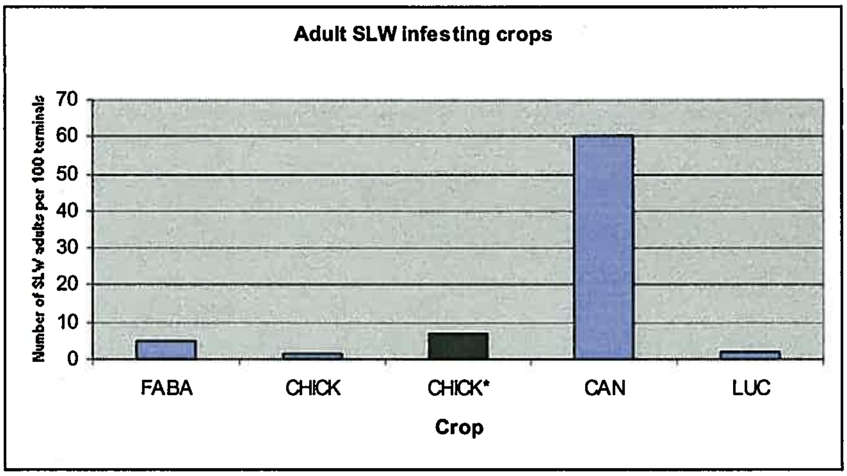
Results

Upon inspection of the release points in each plot, there was no damage to any of them. The variation in adult emergence was recorded, with initial population numbers being lower than anticipated. There was no significant difference in the number of pupae that didn't emerge from the release points.

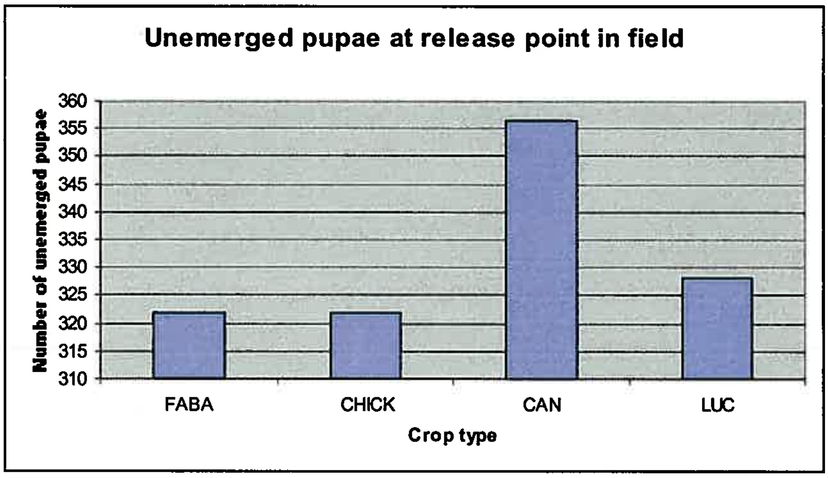
The following graph shows the average number of adults SLW found in each crop __ days after infestation of SLW pupae;



The following graph shows the average number of adults SLW found in each crop __ days after infestation of SLW pupae;

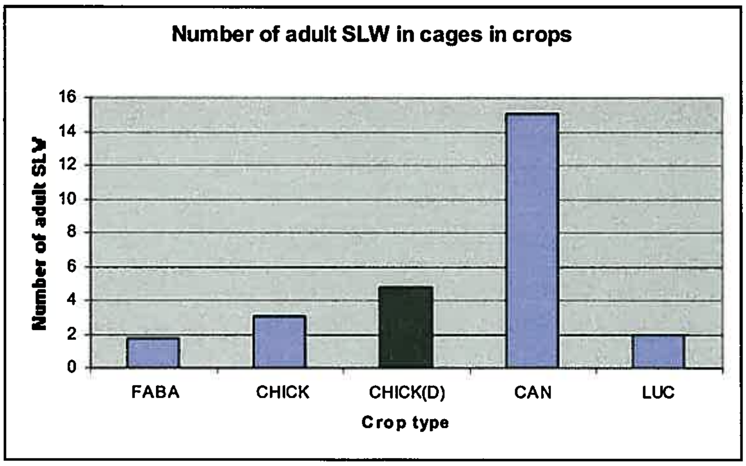


The number of emerged pupae versus the number of unemerged pupae from the release points is provided below. Statistical analysis showed no significant difference in the number of emerged per plot. So the average infestation rate was lower than initially planned;

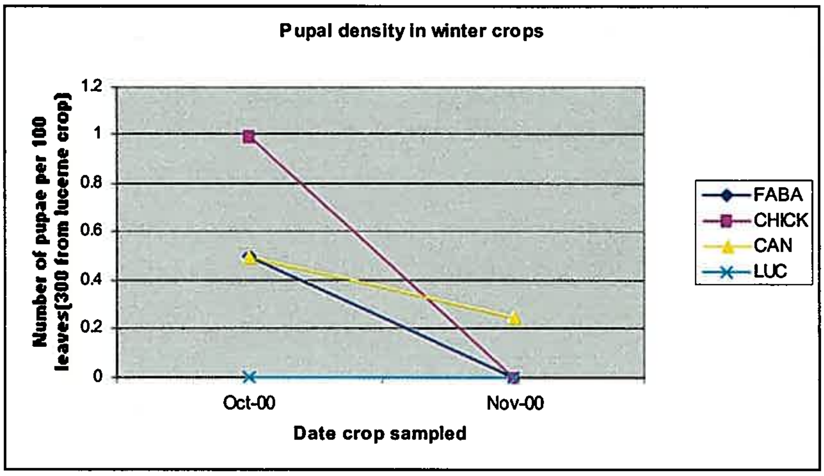


An interesting observation was made on the chickpea crops in this second inspection of the terminals for adult SLW. In many instances adult SLW were found dead on the foliage, presumably from the stickiness of the acidic glands on the plants. The figure above also shows the number of dead adult SLW found on the chickpea plants in relation to the other plants (* red).

The caged plants with SLW established in them, when sampled on 11th September 2000, showed a similar trend to the field data in terms of the establishment of the adults, including the high number of adults stuck on the chickpea terminals (CHICK(D));

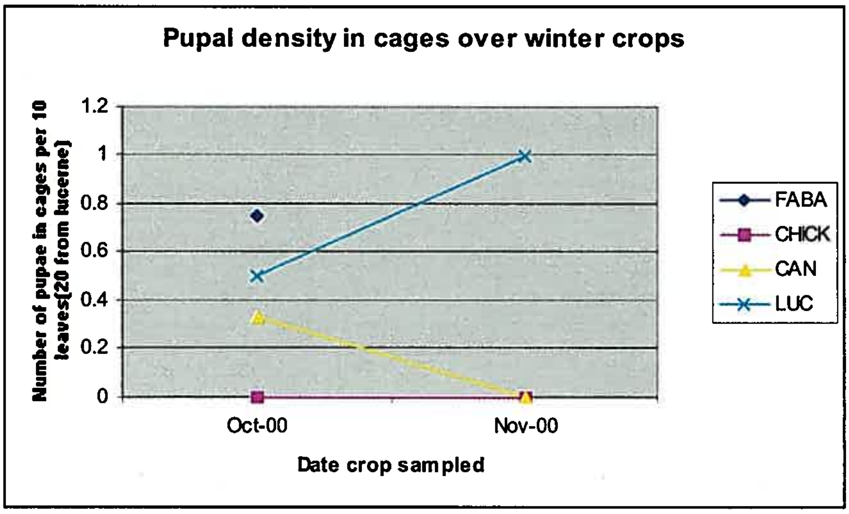


The following figures show the average numbers of pupae collected from the crops twice over the growing season;



The data was considered too sparse for analysis.

The following figure shows the number of pupae recovered from the caged plants in each plot;



The data was too sparse for analysis.

Discussion

pg. 228, Ohnesorge et al., 1980.

"In Autumn and Winter, the development of the whiteflies usually is delayed to such an extent that the pupae can only be found on the very oldest, already decaying leaves. They will be, therefore, missed very easily in ordinary sampling procedures."

- winter grown crops (canola, chickpea and faba beans) – will these enable a continuous breeding cycle?
- Winter monocots should not be a problem

pg. 447, Legaspi et at., 1997.(reason why maybe no good in Kthorpe + Downs??)

"Hard winter freezes are rare (Texas), providing insect pests with a benign temperature environment throughout the year. Insects such as B. argentifolii are best able to exploit these climatic circumstances, because the whitefly has no dormant overwintering stage."

pg. 135, Ohnesorge et al., 1981.

"Weather conditions during the winter might effect the mortality directly or indirectly."

"Moderately low temperatures can affect the immature stages of B. tabaci indirectly by upsetting the synchronism of pest development and leaf ageing. The development of the eggs and larvae slows down considerably or ceases completely while leaf ageing and destruction by microorganisms are continuing. It could be shown that on some plants no whiteflies had completed their development when the host leaf died. This dyschronism of pest development and leaf ageing must be considered, therefore, to be a major mortality factor, perhaps even a key factor in the population dynamics during the winter months."

"The extent of the mortality due to this dyschronism is governed in part by the temperature but in part by the host plant species, too. On plants with persistent leaves, for instance on cauliflower, the immature stages of B. tabaci may survive rather low temperatures as far as the host leaves remain intact. On the other hand on plants with rather short-lived leaves (e.g. squash) mortality may be complete."

pg. 130, Ohnesorge, 1981.

"Immature whiteflies remain on the leaves on which they hatch. Changes in density cannot be brought about by the dispersal of individuals. If we consider, therefore, all immature whiteflies on leaves of a given age group as a separate population, changes in the size of this population could have been brought about a. by additional subsequent oviposition. Since the female whiteflies prefer the young leaves, this influence will become smaller and smaller with time.

b. by mortality. Any decline of population size must be due to mortality, but every estimate of mortality which is based on the reduction in density has the tendency to be too small because of a. However, under the conditions of declining oviposition this source of error might not be too important. Dead individuals can be found on the leaves and give also an indication of the occurring mortality, but since they dry and are easily removed by wind and since their colour soon changes, they are easily missed in counting. So the examination of tagged leaves gives at least a rough idea of the extent of mortality."

TRIAL 5 Summer 2000-2001

SLW population establishment and development in 6 summer crops (+ cage releases)

Aims

Where the SLW has been extremely successful it has benefitted from the ability to survive year round, reinfesting crops from season to season. I investigated whether crops left in the ground out of season, such as lucerne and cotton stubble, might provide the continuous hosts required for reinvasion in following seasons.

Methods

Field trial was located at Kingsthorpe Field Station, Kingsthorpe, Toowoomba. The seven crops evaluated were cotton (Sicala 40), regrowth cotton (Sicala 40), lucerne (Trifecta), mungbean (Emerald), pigeon pea, soybean (Centaur) and cowpea (Red Caluna). All crops were seed planted on ( ) in plots in a randomised complete block design with four replicates, except for the lucerne and regrowth cotton that planted last season. Each plot measured 10 m wide x 11 m long. The forage sorghum (Chopper) that was planted last season was slashed in August to be used as a barrier again. All crops were planted or thinned out to commercial densities prior to starting the trials. The lucerne plots were cut back to around 10 cm in height on ( ), just prior to flowering using a self-driven push mower.

On ( ), a survey of plant terminals was performed in each plot to establish whether any Bemisia species were present in the trial area. Fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5th leaf, randomly within each plot.

Once the trial area had been examined for the presence of whiteflies, cages were placed in each plot for silverleaf whiteflies to be released into. Cylindrical sleeve cages (120 cm high x 60 cm diameter) were covered with a fine mesh terralian gauze and placed over one plant in the corner of each plot.

At _am, a small hand held aspirator was used to gently suction adult SLW from a glasshouse colony. Small vials were used to collect approximately _adults for the field release, and vials containing approximately _adults were to be released into the cages placed in the plots. The adults were then placed in eskies to keep cool prior to release.

On ( ), each plot was infested with_ adults. At _ am each vial was tied onto a tomato stick with twist ties and five sticks were placed at a height of 30 cm above the ground in each plot. One stick was placed in the centre of each plot and the remaining four were placed 2 – 3 m out from the centre in north, south, east and westerly directions. The base of each tomato stick at ground level was smeared with tanglefoot to discourage ants and other crawling insects.

At _ am, tomato sticks with vials containing _adults(attached in the same manner as above) were placed in each cage in each plot. Each release point was checked several minutes after the adults were released to ensure there was no dessication. On ( ) a survey of plant terminals was performed in each plot to establish whether adults had established in each plot. Fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5th leaf, randomly within each plot.

On ( ), plant terminals down to the 5th leaf were examined in the cages in each plot and numbers of adult silverleaf whiteflies were counted. On ( ), fifty terminals in each plot (300 in the case of lucerne) were carefully examined down to the 5th leaf, randomly within each plot. Adult silverleaf whitefly numbers were counted and recorded.

On ( ), fifty leaves (trifolate in the case of lucerne, cowpea, soybean, mungbean and pigeon pea) at the fifth terminal down were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted. _leaves were also collected from the 4th and 5th terminal of each caged plant and were examined under the stereo microscope for immature stages of silverleaf whitefly.

On ( ), fifty leaves at the fifth terminal were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted.

On ( ), fifty leaves at the fifth terminal were collected (300 in the case of lucerne) randomly from within each plot, and were examined under the stereo microscope in the laboratory for silverleaf whitefly pupae and exuviae. Parasitoids and emerged parasitoids from exuviae were noted.

A temperature and humidity data recorded was placed in one plot in the field trial area.

Field plan

COTTON	MUNGBEAN	LUCERNE	COWPEA
COWPEA	REGROTH COTTON	SOYBEAN	COTTON
PIGEON PEA	SOYBEAN	MUNGBEAN	REGROWTH COTTON
LUCERNE	PIGEON PEA	COWPEA	LUCERNE
REGROWTHCOTTON	COTTON	PIGEON PEA	SOYBEAN
SOYBEAN	LUCERNE	COTTON	MUNGBEAN
MUNGBEAN	COWPEA	REGROWTH COTTON	PIGEON PEA

(91m) LENGTH TRIAL

TRIAL WIDTH (48m)

Notes

* Individual plots are 12 m wide x 13 m long, with a 1 m sorghum barrier around

the perimeter. The actual plot size of each crop is 10 m wide x 10.3 m length rows.

Statistical analysis

ANNOVAS were used analysis of data.

Results

Assessment of success of release method of SLW at Kingsthorpe

Adult numbers counted on 50 plant terminals in each crop (except 300 for lucerne) showed relatively low numbers in some plots. The counts made using the leaf turn method showed the adults in the usual position under the surface of the uppermost leaves.

There was a significant decrease in the numbers of adults detected 12 days after release, however adults were detected in all crops.

Statistical analysis showed significant differences in the population of adults observed in each plot on 15th December, ** days after pupal release;

Table *&*;

Crop	Reps	Mean	
SUN	200	0.005	a
COT	200	0.055	ab
PIG	200	0.085	b
SOY	200	0.125	b
COW	200	0.13	b
MUNG	200	0.32	c
LSD =	**0.07662**		

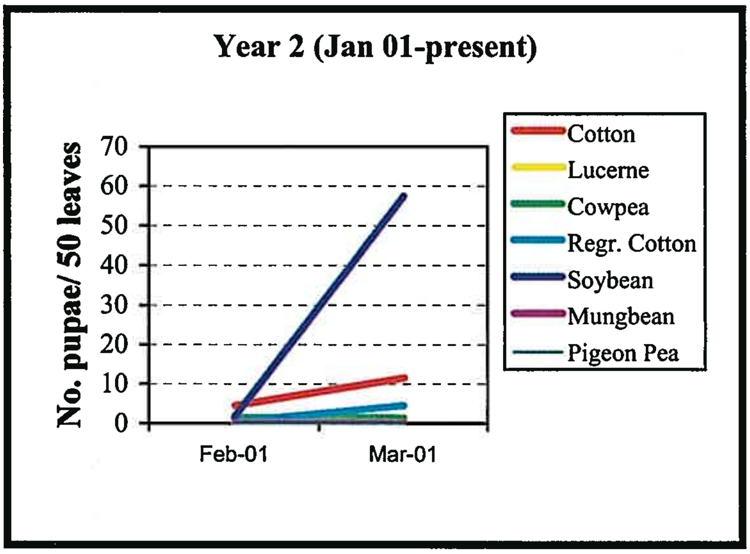
NB: Means with the same subscript are not significantly different at the 5% level

Statistical analysis showed significant differences in the population of adults observed in each plot on 22nd December, ** days after pupal release;

Crop	Reps	Mean	
COT	200	0.005	a
PIG	200	0.01	ab
SUN	200	0.015	abc
COW	200	0.04	bcd
SOY	200	0.045	cd
MUNG	200	0.055	d
LSD =	**0.0343**		
NB: Means with the same subscript are not significantly different at the 5% level			

Data for lucerne was left out of analysis because an increased number of leaves were picked due to the smaller size of the leaflets compared to the other crops. Mung bean had the most adults per 50 leaves collected and was significantly higher than all other crops on day 15, and significantly higher than adults on sunflower, pigeon pea and cotton on day 22.

The following figures show the average numbers of pupae collected from the crops every 2 weeks;



This graph was made on a slight variation in the number of leaves collected from each plot (50 for all crops except 300 for lucerne) to assimilate same leaf surface area per crop. Although there was reasonable establishment of SLW in cotton and cowpea, there was a massive increase of the population in soybean after 3 weeks. The soybean crops were bushier and hairier than all other crops, with plants so thick that walking through the rows was difficult (see picture).

Statistical analysis on the number of pupae collected for each crop is presented below;

CROP	REPS	MEAN	
LUC	24	0.125	a
MUNG	24	0.208	ab
SUN	24	0.979	ab
COT	24	1.583	ab
COW	24	1.708	b
SOY	24	7.583	c
	LSD=	**1.573**	

Means with the same subscript are not significantly different at the 5% level

Soybean was an exceptional host for the SLW, at 7.583 pupae per 50 leaves it was significantly higher than all other crops.

Significant differences were also recorded for number of pupae collected at each date (see appendix).

Plants that were caged in each plot that were assessed for the presence of adults held reasonably large populations 11 days after the initial pupal release of _ adults per cage;

The following figure shows the number of pupae recovered from the caged plants in each plot;

This data was based on an initial starting population of 100 pupae in each cage on 10-12-99, all crops sustained populations of whitefly except mungbean. The mungbean plants under cages were smaller with less foliage than the field mungbeans, and by the second sample date the plants were nearly dead. In most cases the population size appeared to at least double.

CHAPTER IV

EFFECTIVENESS OF COTTON INSECTICIDE CHEMISTRY

Only recently in Australia have we had to consider insecticidal management of SLW in cotton. The chemistry suitable for use overseas is still currently being put to the test, with the unfortunate problems of insecticidal resistance development with this pest. Although there may be some similarities to overseas situations in our management strategies for SLW in cotton if and when it does become an economic situation, we need to look at the present suite of chemicals that are currently in use in cotton. Target and non target chemicals may impact the development of this pest in cotton.

Chemical usage in the horticultural industry of Australia is a good starting point to identify the target chemicals that may be integrated into the cotton industry. The significant whitefly problem that we have in our Horticultural industry has had some success in IPM management using a few groups of chemicals. The integration of the use of some of these into cotton is probably just a matter of time. The impact of non-target insecticides used in the cotton industry that should be considered as whitefly friendly is probably similar to other pest outbreak situations as a result of heavy chemical usage, in particular those targeting the major pest Helicoverpa sp., and the unfortunate reduction in beneficials. It may be important to also consider the genetic manipulation of cotton as it is the feeding site of the pest.

TRIAL 7 Summer 2000/2001

Efficacy of six insecticides on SLW in the field

Aims

To examine the development of cohorts of SLW juveniles in cotton blocks applied with different chemistry. To examine the effect of common commercial spray treatments on SLW population development on cotton.

Methods

Sicala 40 cotton, normal leaf common commercial variety, planted to give 7 treatment plots (5m long by 3m wide[7 rows of cotton]), replicated 4 times in a randomised block design. The plots are separated between treatments by a sorghum (Jumbo) + Grahams other sorghum that was accidentally planted!! barrier 3 rows wide (to prevent drift) see below.

FIELD PLOT

REP 1	REP 2	REP 3	REP 4
Control	Decis	Imidacloprid	Nuvaluron
Oil	Steward	Oil	Control
Steward	Imidacloprid	Decis	Tracer
Tracer	Nuvaluron	Control	Steward
Decis	Oil	Tracer	Oil
Nuvaluron	Control	Steward	Imidacloprid
Imidacloprid	Tracer	Nuvaluron	Decis

Note:

The cotton on the left of the page is damaged by Roundup, left it till early Feb before start trial.

* Six chemical treatments:

"Decis"

"Tracer"

Imidacloprid ("Confidor")

Oil ("DC Tron")

"Nuvaluron"

"Steward" (Indoxacarb)

and an unsprayed treatment.

Steel frame cages (cylindrical) approximately 1m high with a diameter of 60cm covered with fine gauze; one for each plot. One open cage and one velcro strap cage in each plot.

Cotton was planted at Kingsthorpe on 14th November, 2000, and watered in, with the sorghum barrier planted on 1st December, 2000. Row spacing of the cotton was 75cm, and plants were thinned to 8 per metre.

To establish SLW in the field, cotton, planted one week later on 21st November, and grown in the glasshouse will be infested with SLW when it reaches the 4th true leaf. The cotton has been planted in small pots(one plant per plot) and fertilised and watered accordingly. The seedlings are growing under gauze cages so upon introduction of SLW adults, SLW numbers will build up on these banker plants.

Once the plants have been infested for ** weeks (approximately ** SLW generations), 8 plants in total will be placed in each plot (2 plants in each of the four treatment rows, 1.25m in from each end of the row). The banker plants will have all lifestages of the SLW on them, as in the case of a small field infestation. Several hundred SLW pupae from each banker plant will also be placed under a sealed cage, and an open cage, aswell as one cotton plant in each plot to exclude all parasitoids predators, and sprayed just prior to caging. Remove banker plants 3 weeks after infestation.

Spray regime

Day before spraying, collection of 20 leaves per plot for whitefly pupae.

All cotton in field sprayed early morning plus cotton to be caged.

Banker plants then established in field after 2 days and left for 2 weeks, including cages set up and banker plants leaves laden with pupae put under them.

Samples taken 2 weeks after spray (100 leaves collected randomly from each plot at the 5th node of cotton plants (banker plants will be marked and not sampled), and 2 leaves from each cage in each plot.

Respray day after take samples (ie. spray every 2 weeks), then repeat collection of leaves after 2 weeks.

Continue sequence till cotton bolls open (just prior to harvest).

The rates for the chemicals applied were based on commercial usage;

DC Tron (5ml / L H2O), Nuvaluron (0.75L / Ha), Steward (850ml? / Ha), Tracer 0.15-0.2L / Ha, Confidor (0.25L / Ha), Decis (0.5-0.7L / Ha). A back pack pump spray at 3 Bar (45 PSI) was used to apply the chemicals at a walk speed of XX m/s. Six nozzles (flat spray?) were equally spaced along the boom, 2 dropper nozzles (45cm) to cover under the leaf surfaces and one boom nozzle to apply chemical directly onto the plant surface (giving 3 nozzles per row).

On 4th February 2001, due to inclement weather the trial was delayed and all cotton squares were hand picked from the cotton block to delay maturity for the trial.

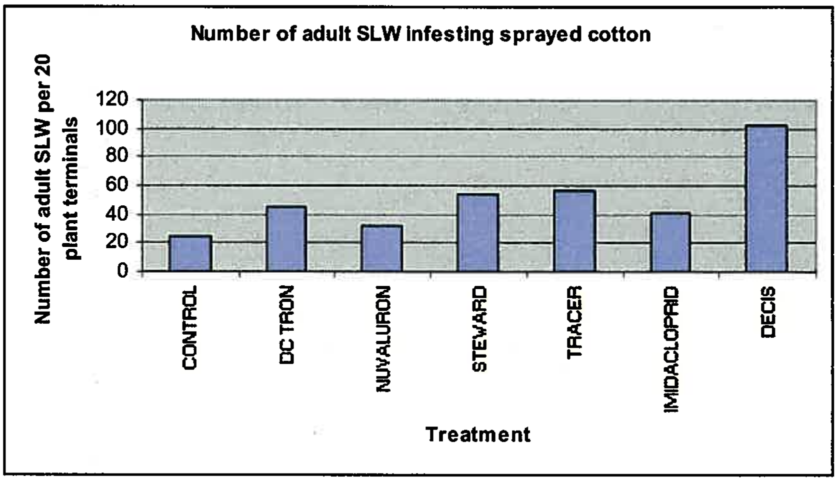
Results

Field plot treated cotton-

Meteorological data pre and post sprays showed no significant problems associated with drift or inclement weather (Table XX in Appendix). Slight drift of roundup sprayed in the XXth week of cotton growth prior to release of SLW onto the fourth rep of the cotton block gave negligible visual effects on cotton growth, normal growth resumed prior to starting the trial.

Ten leaves at the 5th node were randomly sampled from plants within each plot on 5th February, and were examined for whiteflies. The sampling of the cotton block prior to banker plant release showed no presence of any *Bemisia* sp., so the assumption was made that an entire SLW population would be established. The release of the banker plants containing SLW immatures was successful in all plots, with seedlings in the pots (with the bottom removed) placed between plants and watered in.

Populations of SLW did established in all cotton plots via the use of banker plants. The following figure shows the numbers of adults detected in each plot __ days after banker plant release. Sampling of the plots for establishment of SLW adults on 16th February 2001, _days after banker plant release, gave the following graph;



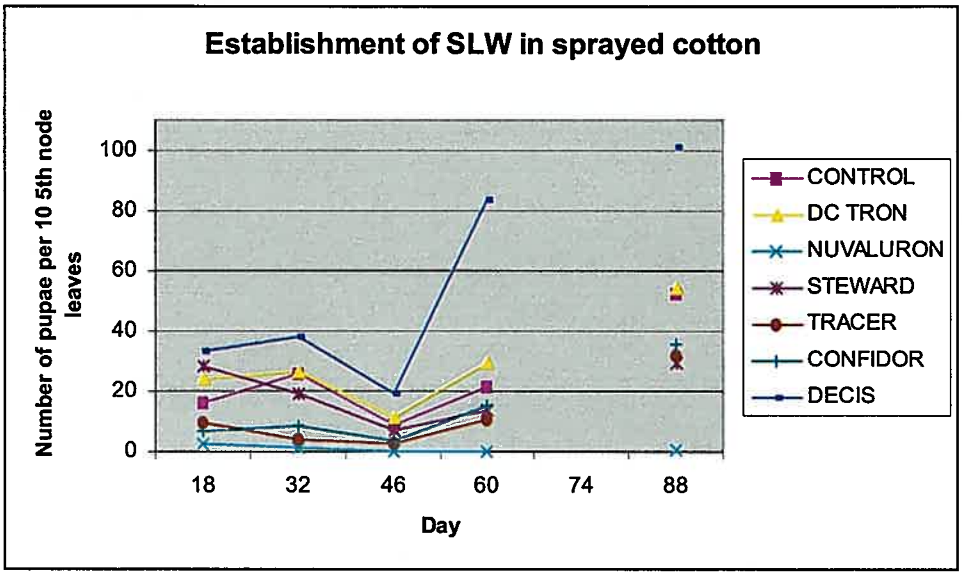
There were significant differences in the number of adults per terminal between treatments (see appendix V) as represented in the table below;

TREATMENT	REPS	MEAN
CONTROL	80	1.187 a
NUVALURON	80	1.612 ab
CONFIDOR	80	2.012 bc
DC TRON	80	2.213 bcd
STEWARD	80	2.7 cd
TRACER	80	2.837 d
DECIS	80	5.113 e
	LSD =	**0.773**

NB: Means with the same subscript are not significantly different at the 5% level

The number of adults was significantly higher of Decis treated cotton than all other treatments. Interestingly there was no difference between the control treatment and nuvaluron treated cotton. Nuvaluron is an effective SLW insecticide, having similar adult numbers present to the control, which had the lowest number of adults could be partly attributed to predation in the control treatment.

Collections of 40 leaves from the fifth node from each cotton plot on 6th March (2 weeks after adult counts) and every 2 weeks until the cotton finished gave the following graph based on numbers of pupae per 10 leaves;



Note: no sample was taken on day 74 as no sprays were applied.

The trend for all pupal numbers for all treatments staggers similarly across sampling dates probably due to the development time required to find pupal stages. The population trend appears to be an increase for all treatments, except Nuvaluron, with time. However it is clear that there is a significantly greater increase in pupal numbers in Decis treated cotton compared to all other treatments.

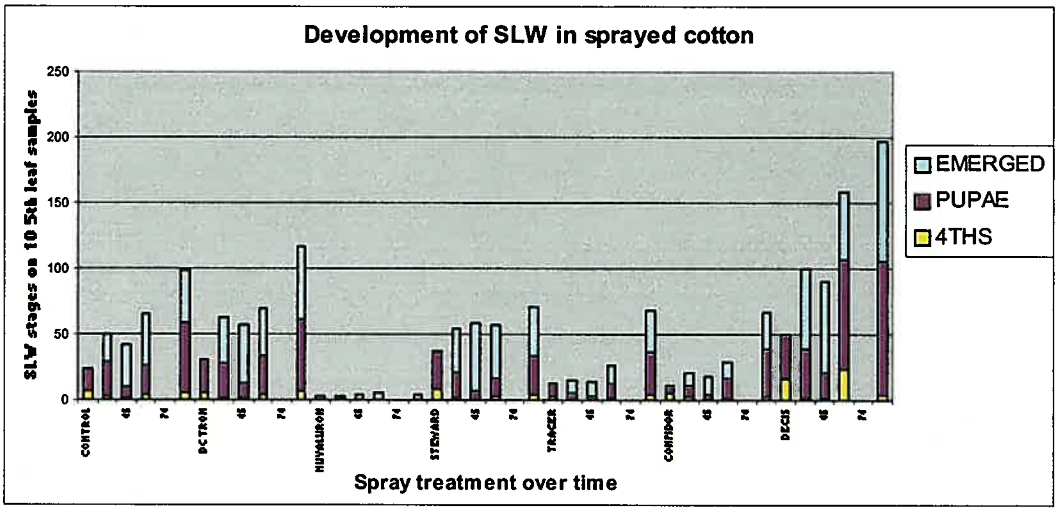
Statistical analysis revealed significant differences for some treatments, results of the analysis are given below;

TREATMENT	REPS	MEAN
NUVALURON	24	1.44 a
TRACER	24	24.23 ab
CONFIDOR	24	27.76 ab
STEWARD	24	39.55 bc
CONTROL	24	50.23 bc
DC TRON	24	58.44 c
DECIS	24	110.03 d
	LSD =	30.28

NB: Means with the same subscript are not significantly different at the 5% level

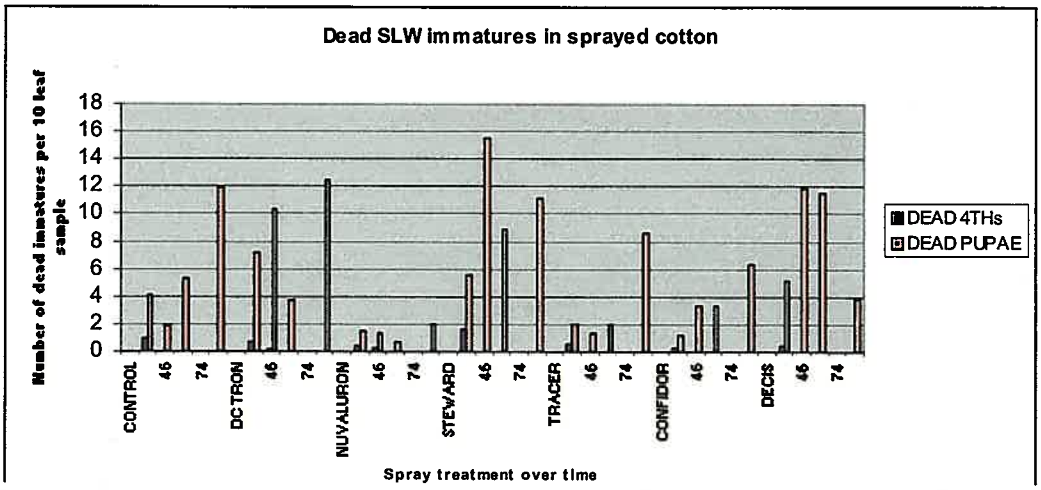
The Decis treated cotton, like for the adult counts, had the significantly highest population of whiteflies for all treatments. As expected the Nuvaluron treated cotton had the lowest population of whiteflies, and was not significantly different from Tracer and Confidor treated cotton. Confidor is an active against SLW, however the results for Tracer may indicate that beneficial numbers may have been reasonably high as it is not a whitefly insecticide.

The following figure shows the number of 4th instars, pupae and emerged pupal cases recorded on the sample leaves collected from the 5th node of the treatment plants. The number of each stage on 10 leaves is indicated (insert lines on graph between treatments).



The figure above indicates that the pupal stage was targeted by the sampling technique, giving a fair representation of the population in each treatment. High numbers of emerged pupae collected at the end of the trial may have been a result of slowed growth in the cotton, and selecting the leaves from the 5th node may have been targeting older stages on those leaves.

Dead 4th instars and pupae were also recorded from the leaf collections, providing

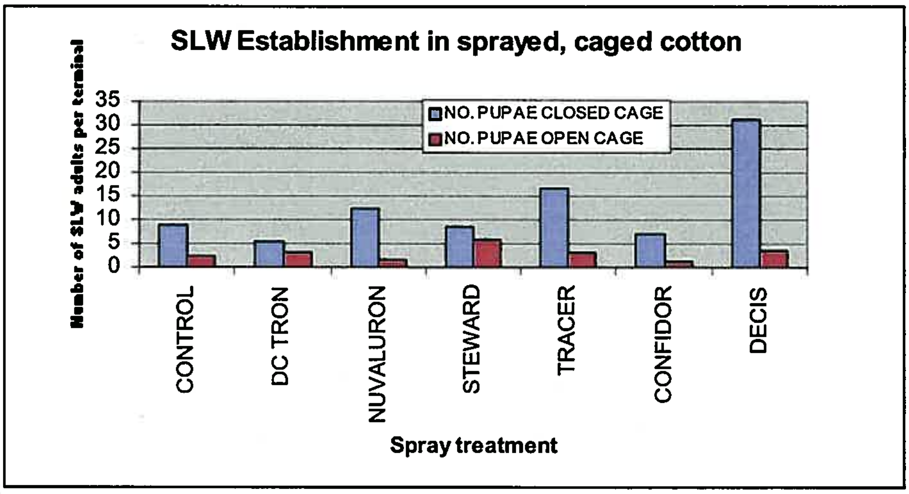


some interesting results in relation to the treatments;
Significant differences were also found in the statistical analysis of dead pupal numbers according to time for treatment;
Table__;

There was some parasitism recorded in some plots. The following table indicates where parasites were observed in the plots or where parasitised pupae were found.

NOTE: The collection of all pupae from the leaf samples into emergence vials allowed parasitoids to emerge and be counted. In the case of emerged pupae, the distinctive circular emergence hole chewed through the dorsal surface of the pupal case was used to assess parasitism.
There may have been a source of beneficial insects from the sorghum barriers between the cotton blocks.

Caged and treated cotton-



The numbers of adult SLW above were counted by the leaf turn method, adults were observed in all cages, if not seen on the terminal adults were seen on the cage material. This indicated that the release method was successful.

Unfortunately, in several instances the caged cotton in each block suffered serious aphid and / or mite infestations so the following figure showing pupal numbers shows the number of reps used (in brackets), and statistical analysis was based on these numbers.

The same general trend of treatment effect was evident in the caged cotton as the field cotton, with significant population build up in the Decis treatment. An interesting observation of the apparent effectiveness of beneficials was provided by these caged treatments, where even the chemical treatment of the caged cotton in most cases had serious different pest outbreaks (loopers, mites, aphids).

The cage-effect should also be considered for these results. Upon spraying the caged plants I did notice mostly shorter and more sparse foliage on these plants, including in the open caged treatments.

Statistical analysis revealed some significant differences in population development in the caged treatments;

CLOSED CAGE TREATMENT	**REPS**	**MEAN**	
NUVALURON	24	1.631	a
CONFIDOR	24	2.7	ab
TRACER	24	2.9	ab
DC TRON	24	7.544	ab
STEWARD	24	9.665	ab
CONTROL	24	10.541	bc
DECIS	24	18.8	c
	++ LSD = 8.744		

NB: Means with same subscript are not significantly different at the 5% level

OPEN CAGE TREATMENT	**REPS**	**MEAN**	
NUVALURON	24	0.457	a
CONFIDOR	24	0.65	a
DC TRON	24	0.994	a
CONTROL	24	2.216	ab
TRACER	24	2.25	ab
DECIS	24	2.95	b
STEWARD	24	3.7	b
	LSD = 1.869		

NB: Means with same subscript are not significantly different at the 5% level

Suction sample data of cotton blocks-

The mid-season pre- and post-spray suction sample trial was abandoned due to the possible impact of removing whiteflies and / or beneficials from the trial sites. After noticing only moderate populations of whiteflies in some blocks it was decided to only suction sample towards the end of the trial period to limit any effect on the system.

The pre-spray suction samples showed a suite of beneficials present in many of the blocks, both predators and parasitoids of whiteflies and other pests. Populations of beneficials recorded in the cotton that are known to attack whitefly are shown in Table __.

Table __;

It was exciting to find whitefly parasitoids in the cotton, and even more impressive to find they were active (SLW cohort study in sprayed cotton - section __).

Discussion

Effects of microclimate in cotton insecticide trial may be +ve for SLW – see cotton insect beneficial guide(B Pyke).

pg. 448, Sieburth et al., 1998.

"Oil is important in the control of whiteflies. It does not prevent neonates from eclosion, but does prevent attachment of first stage nymphs to leaves, and kills those that do attach."

pg. 449.

"Oil is most effective when applied on eggs for control of first stage nymphs. When first stage nymphs are treated, they are prevented from developing normally by oil treatments with or without the addition of oil surfactants. Some of the nymphs do not die and are not able to molt and grow normally. They appear very rounded, as if they need to, but are not able to molt. Oil treatments also prevent the emergence of adults from treated pupae. Again, of the ones that do not emerge, not all are killed outright. Control with paraffinic oil is not affected by the addition of oil surfactants except to impact whether or not the treated nymphs continue to live in an abnormal state or are killed by the oil."

Pg. 405, Ann. Appl. Biol. (1997) 130: 397-407. Effect of imidacloprid on the silverleaf whitefly, Bemisia argentifolii Bellows and Perring (Homopera: Aleyrodidae), and whitefly parasitism, Bethke, J.A. and Redak, R.A.

"Given the very good efficacy and duration of control for whiteflies provided by imidacloprid, the potential for overuse and the build-up of insecticidal resistance is great. The low concentration of imidacloprid is compatible with the use of commercially available E. formosa as well as with the use of other pest management strategies such as the use of resistant cultivars, and cultural and physical controls."

pg. 113, Sundaramurthy, 1992.(Use for effects of sprays on cotton-increase in mites aphids etc causing decrease in SLW!@#!)

"Insecticides eliminate several competing species from target sites and neighbouring areas in the agroecosystem by their non-selective action and drift effect. The indiscriminate removal of species invariably results in an altered biological balance which could lead to the upsurge of a weak species."

"Continuous use of insecticides including synthetic pyrethroids has led to the displacement of one species by another. In the cotton system low populations of B. tabaci and high populations of Aphis gossypii existed when insecticides were used. Neem oil, by preventing the build-up of B. tabaci, allowed A. gossypii to occupy the niches. The existence of an inverse relationship between homopteran species in the occupation of a habitat under the influence of xenobiotic stress indicates that the displacement of one species predisposes the habitat to the upsurgence of another."

TRIAL 8 Summer 2001

Study of cohorts of SLW in sprayed cotton

Aims

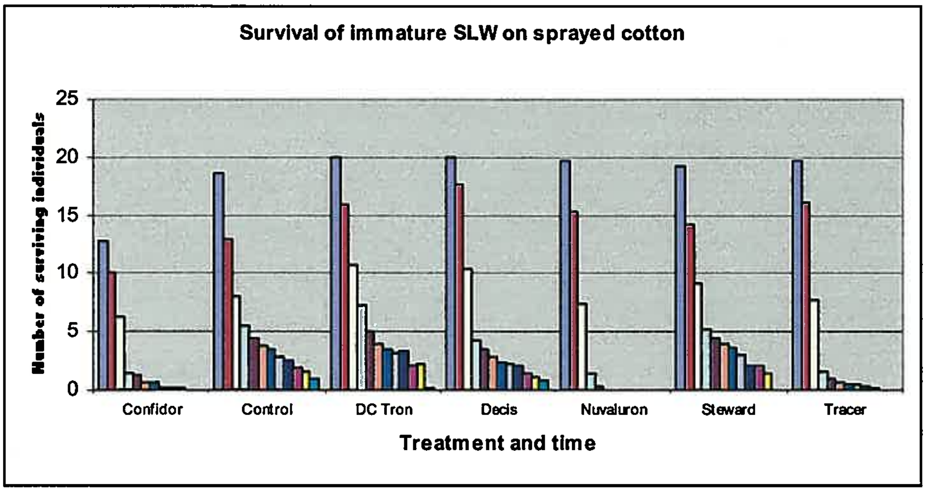
To examine the development of cohorts of SLW juveniles in cotton blocks applied with common commercial insecticides.

Methods

Four cohorts of eggs were thinned to clusters of 20 (or less) on freshly emerged fully expanded leaves in each cotton block. The eggs and developing juveniles were monitored every few days, with the cohorts of individuals being sprayed at the same rate and frequency as the cotton blocks.

Results

The following graph shows the number of alive individuals on cotton over time for each treatment;



Low survival was recorded for Nuvaluron, Tracer and Confidor treated cotton, in a similar way to the slower population development recorded in the pupal counts in the sprayed blocks.

The following table shows the significant differences found between treatments for the average survival of immatures across all sampling dates;

TREATMENT	REPS	MEAN
CONFIDOR	192	2.795 a
NUVALURON	192	3.676 b
TRACER	192	3.977 b
CONTROL	192	5.542 c
STEWARD	192	5.643 c
DECIS	192	5.691 c
DC TRON	192	6.451 d
	++ LSD =	**0.6279**

NB: Means with the same subscript are not significantly different at the 5% level

Discussion

Pg. 218, Gerling et al., 1980, "Dynamics of B. tabaci attacking cotton….."

"B. tabaci appears to be well-adapted to develop in cotton, where it is able to build up very high populations during the summer. The whiteflies established themselves until mid-July on the upper parts of the plant, and the maximal population of 'pupae' occurred on the sixth or seventh leaf. This was due to the tendency of the females to oviposit on the young foliage at the top of the plant. After mid-July, the foliage of the cotton plant ceased growing at the terminals of the main branches, but the side branches continued to grow and small groups of young leaves sprouted out in various places along the branches."

pg. 31, Toscano et al., 1998.

"The level of infestation of crops attained by colonising pests such as the silverleaf whitefly depends on: (1) biological factors: those traits of an organism which, under environmental influence, characterise its intrinsic potential to utilise a given resource; (2) agricultural factors: the crops grown, relative acreages, spatial and temporal proximity to one another, etc.; and (3) management factors: the efficacy of chemical, biological and cultural controls."

pg. 263, Pasian et al., 2000.

"Systemic insecticides applied as granules or potting mix drenches can be very effective long-term controls for certain insect groups (particularly piercing-sucking pests). An example is the application of imidacloprid granular or wetable powder for whitefly control on poinsettias. Although effective, granular and drench applications can be very labor intensive with attendant risks of operator exposure. In addition, correct timing can be critical. Applications too early, before proper development of root systems, may result in insufficient amounts of pesticide being taken up by plants. Applications too late and control may be delayed or insufficient, resulting in plant injury."

pg. 717, Devine et al., 1998.

"The high resistance of B. tabaci is the result of both increased detoxification of chemicals and an alteration of insecticide target sites (e.g. Prabhaker et al., 1988; Denholm et al., 1996)."

"Although products such as the chitin synthesis inhibitor, buprofezin and the juvenile hormone analogue, pyriproxyfen, have been shown to exert good control over B. tabaci on cotton in Israel (Horowitz and Ishaaya, 1994), data from glasshouses and greenhouses suggest that these compounds can be compromised by the development of insecticide resistance (Cahill and Denholm, 1993; Horowitz and Ishaaya, 1994; Devine et al., in press). Resistance to imidacloprid, also used against B. tabaci and acting on the nicotinic acetylcholine receptors, is also developing in Southern Europe (Cahill et al.,1996)."

CHAPTER V

PARASITIOD PROFILE OF A COTTON FIELD

Through previous trials, assess what parasitoids have been collected and make statement on the likelyhood of self management through biological control.

Field release immatures only on banker plants in large cotton fields – are there parasitoids out there?? + get 3-4 different scenarios – IPM fields, heavy pyrethroids etc.

+ as a side – release some near / far from Tv infestations – do parasitoids work well on SLW from Tv colonies??

Marker trial (read paper) – how far do SLW move once emerge – will relate to my small field plots.

Plant cotton plots at Kingsthorpe (or use gatton?), look at population development in relation to different management options. Eg. IPM vs heavy sprays (Ha and whitefly control).

TRIAL 9 Summer 2000/2001 – Assessing parasitism through field release of immature SLW

Aim

To determine the parasitoid profile present in a typical cotton field. Releasing immature SLW (immobile) at locations within the cotton crop may determine whether parasitoids are active in cotton. By releasing SLW in different managed cotton crops

(IPM, heavy insecticide sprays, Bt cotton and chemistry), the effectiveness of parasitoids may be assessed.

PROJECT SUMMARY:-

RISK FACTORS FOR SLW OUTBREAKS IN COTTON

PhD Project – David Lea

Background

The silverleaf whitefly (SLW) B-biotype of *Bemisia tabaci* is a serious pest of cotton in many overseas countries. It was first detected in Australia in 1994 and has recently been found infesting commercial cotton in Queensland. At the end of the 99/00 season it was found infesting weeds close to cotton fields in all cotton growing areas in Queensland. The pest's spread in cotton areas has been slow in comparison with other countries. The reason(s) for this slow spread are unclear. This Ph.D study is examining the effect of the availability of alternative hosts and the effect of biotic and abiotic factors on the population development and spread of the SLW using a combination of field observations, manipulative experiments and glasshouse studies.

The concept of using crops to manipulate the balance between pests and natural enemies is being investigated in cotton. The use of lucerne strips to increase natural enemies and chick pea and pigeon pea as trap crops for heliothis are being evaluated. Lucerne is an important link in the host sequence of SLW in the Western USA. The effect of these new alternative technologies on the SLW in Australia needs to be investigated.

Australian cotton growers are currently facing a SLW problem in the northern cotton growing districts and these studies may help to explain why this is so and point to options to implement or avoid in order to reduce further problems. This essentially means defining the likely risk of SLW outbreaks in particular locations and conditions.

The objectives of this project include;

1. **To investigate the use of management options (spraying, irrigating) on the population dynamics of the SLW.**
2. **Determine the effect of morphological and phenological attributes of cotton on SLW populations.**
3. **Investigate the influence of IPM practices on the probability of SLW outbreaks.**

These objectives are to be investigated through the following trial proposals;

YEAR 1.

1. **Determine the suitability of various crop hosts in cotton agroecosystems.**
2. **Establish and monitor small plot experiments involving important crop hosts in the cotton agroecosystem to determine the importance of these to SLW population build-up which may lead to outbreaks.**

YEAR 2.

1. **Continue studies involving important crop hosts in the cotton agroecosystem to determine the importance of these to SLW population build-up which may lead to outbreaks.**
2. **Examine the effect of insecticides on cotton/SLW interaction.**
3. **Determine the effect of cotton morphology and phenology on SLW.**
    1. **Study SLW population establishment and dispersal.**

YEAR 3.

1. **Examine the effect of insecticides used in cotton production on SLW populations and biocontrol.**
2. **Investigate the effect of the health of the cotton host on SLW population development.**
3. **Monitor SLW populations in IPM situations to determine the effect of IPM practices.**

Trial sites;

All field trials will be located at Kingsthorpe Field Station, Kingsthorpe, Toowoomba. All SLW infestations are produced from colonies reared on eggplant (*Solanum melongena* 'Black Beauty') and were cultured for over 2 years in whitefly proof cages in a glasshouse at the Department of Primary Industires (DPI) in Toowoomba. The insects were originally collected off eggplant at Redland Bay, Brisbane. The colony was maintained since 1992, with introgression of individuals collected from the field every few years.

Experiments;

1. EVALUATION OF COTTON CULTIVARS

The development of SLW outbreaks will be initially influenced by factors such as the source of SLW infesting the crop, conditions affecting their survival early in the season, the distribution of the SLW population, and resistance mechanisms in the host plants.

There is an abundance of fecundity trials of the SLW on varying cotton strains throughout the world. The large variability in the literature on the suitability of cotton that expresses different morphological and physiological attributes for whitefly oviposition has provided uncertainty in assessing the factors that may limit oviposition. With this in mind it is important to assess the suitability of our most common cotton varieties grown in Australia, in the growing conditions of Australia's cotton areas. There will always be a change in cultivar use over the seasons, however it is the effects of particular plant traits, such as leaf shape, hairiness, and chemical composition within the plants that are the major determining factor in whitefly oviposition.

Microclimatic effects of cage fecundity trials are of considerable importance, not only for the effects on the whiteflies, but also the effects on the host plants. These effects have no doubt contributed to the variation in host suitability observed not only in varieties with similar attributes, but the same cotton varieties.

No-choice study of SLW fecundity on 13 cotton varieties in the field.

To investigate the ovipositional behaviour of the SLW on Australian cotton, several commonly used cotton varieties on the Darling Downs and a few select cultivars expressing extreme variability in morphological traits were assessed in no-choice trials, both in a glasshouse and the field.

2. THE ROLE OF ALTERNATIVE HOSTS ON THE DEVELOPMENT OF POPULATIONS OF SLW

Successful management of the SLW in cotton will only come from examining the entire cotton agroecosystem, and associated cropping areas. There are similarities in the approach needed as with the significant problem of *Helicoverpa armigera* in cotton. Areawide management strategies for *Helicoverpa* are currently being implemented in part for similar reasons as for the SLW overseas, insecticide resistance. At present we are fortunate enough to only have a SLW problem in Northern grown cotton, however its presence dictates that we assess the likelyhood of its outbreaks in the other major cotton growing areas.

The large variety of crops grown in and around cotton areas, such as lucerne as a refuge for beneficials, chickpea as a trap-crop for Helicoverpa, and other crops grown during and between cotton seasons may be potential sites for SLW development. To increase our chances of understanding the events that may lead to an outbreak, we need to assess their suitability.

SLW population establishment and development in 7 summer crops (+ cage releases).

A commercially important cotton variety and six common crops were assessed for their ability to sustain SLW populations throughout the growing period in the field.

SLW population establishment and development in 3 Winter crops.

To determine the suitability of common commercial winter crops, canola, chickpea and faba beans were examined for SLW establishment and subsequent development in the field.

SLW population establishment and development in 6 summer crops (+ cage releases).

Where the SLW has been extremely successful it has benefited from the ability to survive year round, reinfesting crops from season to season. I investigated whether crops left in the ground out of season, such as lucerne and cotton stubble, might provide the continuous hosts required for reinvasion in following seasons.

3. EFFECTIVENESS OF COTTON INSECTICIDE CHEMISTRY

Only recently in Australia have we had to consider insecticidal management of SLW in cotton. The chemistry suitable for use overseas is still currently being put to the test, with the unfortunate problems of insecticidal resistance development with this pest. Although there may be some similarities to overseas situations in our management strategies for SLW in cotton if and when it does become an economic situation, we need to look at the present suite of chemicals that are currently in use in cotton. Target and non target chemicals may impact the development of this pest in cotton.

Chemical usage in the horticultural industry of Australia is a good starting point to identify the target chemicals that may be integrated into the cotton industry. The significant whitefly problem that we have in our Horticultural industry has had some success in IPM management using a few groups of chemicals. The integration of the use of some of these into cotton is probably just a matter of time. The impact of non-target insecticides used in the cotton industry that should be considered as whitefly friendly is probably similar to other pest outbreak situations as a result of heavy chemical usage, in particular those targeting the major pest Helicoverpa sp., and the unfortunate reduction in beneficials. It may be important to also consider the genetic manipulation of cotton as it is the feeding site of the pest.

Efficacy of six insecticides on SLW in the field.

A field trial was established in SLW infested cotton to examine the effect of common commercial spray treatments on SLW population development.

Study of cohorts of SLW in sprayed cotton.

Cohorts of SLW juveniles were examined over their entire development in cotton blocks applied with common commercial insecticides.

4. EFFECT OF IPM PRACTICES ON SLW ESTABLISHMENT AND DEVELOPMENT

The morphology and physiology of the cotton plant as a host of SLW may have effects on population establishment and development. The level of available nutrients and water in the host plant may influence the biology and subsequent infestation levels of pest species.

Effect of nitrogen fertiliser on SLW population development in cotton.

Different levels of nitrogen were applied to cotton blocks and were subsequently infested with SLW to observe any differences in population development over the season.

Investigate the effect of the health of the cotton host on SLW population development.

Glasshouse trials will be established with cotton grown under various water / fertiliser stresses to investigate the effects on population development.