Sweetpotato Whitefly in Arizona

P.C. Ellsworth, J.P. Diehl, J.C. Silvertooth, P.W. Brown, T.F. Watson, L.R. Hood, S.H. Husman, G.W. Thacker, L.J. Clark, R.E. Cluff, T.A. Doerge, D.R. Howell, W.B. McCloskey, S.W. Stedman, R.E. Tronstad, and J.C. Wade

Abstract

Whitefly management has become a complex objective in Arizona in the past several years. A tremendous amount of research and extension effort is now focused on this significant pest. The purpose of this paper is to describe the position and guidelines of the University of Arizona's Cotton Team regarding the Sweetpotato Whitefly. The information presented is credited to no single source, but represents a collection of information from numerous research and extension scientists within and outside of the U of A system and careful analyses of the presently available data on whitefly management dynamics. Where possible, only the results of research are reported and suggestions based only on experience or speculation are duly noted.

Identity & Biology

Whiteflies belong to a family of Homopteran insects called Aleyrodidae. They are not true flies, but more closely related to aphids and scale insects. Although there are numerous species in the West; only two species are routinely found in the cotton field. The bandedwinged whitefly, *Trialeurodes abutilonea* (Hald.), is often found in cotton or melons in the early spring and summer. On occasion, its numbers may build to cause concern in cotton, but generally speaking, this insect rarely requires management action. It is more important from the standpoint of not confusing it with the second species, the sweetpotato whitefly (*Bemisia tabaci* [Genn.]). The adult bandedwinged whitefly, as its name implies, has gray-colored bands on its wings, while the sweetpotato whitefly (SPWF) has no bands. In addition, the bodies of bandedwinged adults are ashen gray in color, while the SPWF has a creamy yellow colored body. Certain identification of the immature stages requires pupae or pupal cases. The pupae of the bandedwinged whitefly have numerous hairs or projections, sometimes called pupal fringe. The SPWF has no such fringe, and the pupae are usually completely naked with the occasional exception of a few slender hairs. The distinction of these two species is critical to their proper management and usually comes into play only in the early season when both might be present. We have found that the SPWF generally outnumbers the bandedwinged whitefly later on in the season in Arizona and becomes the dominant whitefly species in cotton.

Some confusion centers around the naming of this animal. The SPWF has been referred to by several common names including cassava, cotton, Florida, poinsettia, pumpkin, silverleaf, and tobacco whitefly. All of these names refer to *Bemisia tabaci*, but the official common name is still the sweetpotato whitefly.

The SPWF has been present in our cotton system for many years, but has only recently gained significant pest status in many parts of Arizona. This is probably due in part to the introduction to our area of a new strain or biotype of the SPWF. The older, resident strain is referred to as "A" strain, and the newer, introduced strain is called the "B" strain. Currently these strains are considered to belong to the same species. Although some recent studies suggest that these two strains may actually be separate species, more data are needed before this issue is resolved. The two strains cannot be distinguished in the field; however, the true identity of these SPWFs has become less important since the widespread distribution of the B strain has become evident. Where it is important is in the understanding that current management of the SPWF has become much more complex than and somewhat unrelated to control of the old A strain. Virtually everywhere that SPWFs reached damaging levels in cotton this past year is considered to be within the known range of the B strain.

SPWF begins its life cycle as a football-shaped egg. These eggs are laid usually on the undersurfaces of leaves and are creamy yellow or white in color changing to brown or tan with age. Huge densities of whitefly eggs on leaves often resemble sandpaper. The egg itself is capable of drawing water from the leaf surface. The egg hatches into a crawler stage which is mobile (usually within the confines of a single leaf) with visible legs. The crawler finds a suitable site for feeding, settles down, and becomes a relatively immobile, scale-like, flattened oval at the next molt. In fact, these insects are so flat that they almost look two-dimensional on the leaf undersurface. It is these nymphal stages that actively feed on the plant sap of the cotton leaf and cause damage. Direct damage caused by adult whiteflies is probably not of major concern except in seedling crops. The SPWF grows through four of these nymphal forms until they reach an immobile, non-feeding pupal stage. The adult whitefly emerges from a T-shaped slit on the back of the pupal case leaving a wispy, white skin behind. Parasitized SPWF can be identified by a circular hole present in the back of these pupal forms (rather than the slit). Though SPWF emergence can occur at any time, most adults emerge in the early morning hours (ca. 6am-9am).

The time required for SPWFs to complete a generation (egg - adult) is intimately tied to the temperature. Warmer temperatures effectively shorten the length of generations up to a point at which there is no additional hastening of development. That point is probably close to 90°F and may very well be the normal temperature of the shaded undersurfaces of leaves in a cotton canopy even during days reaching over 100°F for air temperature. In general, SPWF generation time is around 16-21 days under our summer conditions. Though a model of development using cotton heat unit (HU, 86°/55°F thresholds) developmental patterns has not been developed for this whitefly, mid to late-summer SPWF generational development takes approximately 500-550 HU. These numbers are important in designing control programs for SPWF, especially in determining the number of generations possible from onset of infestation through defoliation. Grower's should realize, however, that generations of SPWF are not usually well synchronized like those of pink bollworm, cotton bollworm, or beet armyworm, which often have well-defined flushes of egg-lay. SPWF generations are usually quite mixed with egg-lay extended over long periods of time with very little separation of generations noticed later in the summer. Winter development is naturally quite a bit slower in time, taking in excess of 70 days to complete a generation. Laboratory studies indicate that the B strain may develop as much as 40% faster than the A strain at medium range temperatures. Lab tests in South Carolina showed that temperatures of 14°F are lethal to most individuals of all stages of the SPWF while 50% of eggs can survive 80 hours at 28.4°F.

Seasonal Cycle

Successful management of this pest must take into consideration the complexities of its seasonal cycle. The insect itself does not pass through a resting or dormant period as may be seen in the Pink Bollworm winter diapause. Thus, SPWF survival from season to season depends greatly on the availability of suitable host plants for feeding and shelter from environmental extremes. Unfortunately, this B strain of the SPWF has an extensive list of plants on which it can feed and survive. The number of hosts for SPWF is in the hundreds. Not all hosts are equally suitable for reproduction, but all contribute to the overall seasonal survival. Many are cultivated hosts, while still more are either weedy species associated with agriculture or ornamentals grown in home landscapes. The cultivated hosts can be viewed as lush islands on which whiteflies can thrive, while these other hosts might serve as bridges between these islands allowing easy passage from one island to the next. The exact role and contribution each of these hosts make to SPWF seasonal dynamics is not explicitly known. However, research results indicate successful seasonal survival as a function of host relationships.

SPWFs are at their lowest levels during the winter. In some cases, they may even be undetectable to most observers. During this period, mainly adult whiteflies are surviving on fall/winter vegetables (broccoli, cauliflower, lettuce), winter weeds (alkali and little mallow and other *Malva spp*., cheeseweed, etc.), perhaps in some perennial hosts (alfalfa, citrus, and possibly volunteer or undestroyed cotton regrowth) and in urban landscape ornamentals (*Lantana spp*., *Hibiscus*, brittlebush, mints, roses, etc.). Late winter and early spring hosts include spring melons, vegetables and various winter weeds in decline. Once cotton is planted and germinates, it is a potential host for whiteflies. When spring vegetables are harvested, this leaves spring/summer melons and cotton as major hosts. With the decline of summer melons, a huge influx of whiteflies in cotton can often be seen. Then, before cotton is defoliated and harvested, fall plantings of vegetables provide for continuation of the SPWF seasonal cycle. Obviously, what makes Arizona so ideal for the cultivation of numerous crops is also ideal for the annual survival of SPWFs.

Economic Impact and Damage

Whiteflies can injure the cotton crop or decrease its profitability in several ways. First, the nymphs and adults produce large amounts of honeydew as a byproduct of their feeding. This honeydew drips onto foliage and open bolls causing sticky lint and supporting the growth of numerous microorganisms including sooty mold fungi. Both stickiness and sooty mold lower the quality of cotton lint. Honeydew and sooty mold may also interfere with defoliation procedures by decreasing the efficiency of uptake of harvest aid chemicals by the leaves. The combination of the honeydew and intense sunlight can also effectively shutdown and/or scald otherwise active leaves. This scalding often leads to leaves which "freeze" on the plant and fail to drop. Pima cottons seemed to be most susceptible to this type of injury. Sooty mold coated leaves are also less able to capture sunlight and produce the photosynthate responsible for yield.

Another indirect impact of SPWF feeding is the potential for greater amounts of disease transmission. Cotton leaf crumple in the past has been associated with SPWF feeding activity; however, the incidence of cotton leaf crumple has not risen proportionately to the recent rise in prominence of the B strain of the SPWF. Nevertheless whiteflies in general are excellent vectors of various plant pathogenic viruses.

The direct impact of SPWF feeding on cotton plants is only partially known; however, experiences this year demonstrate that SPWFs can have a significant direct impact on yield. Major losses in yield ranging up to 1.5 bales of lint and plant death were observed in severe cases of uncontrolled whitefly populations.

There are numerous other problems that may be exacerbated by the presence of whiteflies. First, the increased stress on the plant may increase the plant's water requirement making a shortening of the irrigation intervals necessary. Plants stressed in this way may also progress more quickly into cut-out, and full season varieties may fail to respond to efforts in initiating a second fruiting cycle. Second, the constant use of broad-spectrum insecticides for control of this pest can lead to further devastation by secondary pests including aphids and mites. Finally, the repeated use of the same or similar classes of insecticides can lead to rapid resistance in whiteflies and other exposed pests. The economic impact of the loss of these key agrichemicals is considerable.

Why in 1992?: Risk Factors

This is the question that is on the lips of everyone in the state touched by the devastation caused by the SPWF. It is a question worth asking; however, it is one that we will likely never answer definitively. Nevertheless, lessons can be learned from experiences in 1992 and earlier. The complex nature of system-wide problems often leads to explanation based on correlation. In other words, we can outline all of the factors that were present in 1992 and presume that any or all of them contributed to the SPWF devastations, but we cannot make statements as to what exactly caused the problem. For example, it was recently reported that the rates of suicide were much higher in cities which had significantly more Country & Western radio stations. The "natural" conclusion was, of course, that the more of this type of music you listened to the more likely you were to commit suicide. This example reminds us that conclusions based in anecdotal information or loose correlation are extremely dangerous and should be viewed very skeptically. The difference in the information presented here is that as a group of scientists, we have examined these correlations in light of plausible underlying biological causes.

Introduction of a New Biotype

As mentioned earlier, the existence of a new biotype, the B strain, of the SPWF seems to have a lot to do with its rise in prominence in this state. It is difficult to say when exactly this introduction or change took place, but the B strain has been found in Imperial (CA) and Yuma Counties for at least three years. As with the introduction of a new species to an area, it takes a certain amount of time before the pest reaches the full extent of its range. At present, we do not know the potential extent of this insect's range, but large infield populations have been found in Yuma, LaPaz, Mohave, Maricopa, Pinal, and Pima Counties. The B strain was also identified in Graham County in 1991, but may not be established in the region—damaging populations were not noted there in 1992. Higher elevations may be less suitable for build up to high populations due to cooler summer climates (allowing fewer generations) or cooler winter climates (preventing winter survival) or due to other environmental factors. The increased incidence of SPWFs in central Arizona may have represented the initial arrival of the B strain to these areas. It is unclear why exactly this biotype is more successful as a pest of cotton. Suffice it to say that this strain is better adapted to our environment in its broadest sense (e.g., crop complex, weather, insecticides, natural enemies, etc.). When a similar "invasion" occurred in India, they believed that low rainfall, high temperatures, moderate humidity, and high amounts of sunshine, qualities for which Arizona is known, favored this insect.

Weather

So often weather impacts the distribution of our insects either directly, through regulating the speed of development or affecting survival success, or indirectly by promoting the growth of needed host plants. SPWF may be no exception to this rule. Analyses of past weather trends relative to the outbreak in 1992 and in 1981 have revealed some intriguing patterns. The 1991-92 winter was one of the warmest on record with places like Coolidge experiencing conditions similar to near normal Yuma winters. This could impact the SPWF in several ways: 1) fewer "cold" nights may add to overwintering success, 2) active reproduction may have been possible later into the fall and early winter and earlier in the spring in 1992, and 3) better survival and availability of hosts which might normally have been frosted or otherwise held back under normal winter conditions. [While, at first, the presence of a cold wave in late December in Brawley, CA, in 1990 preceding the 1991 SPWF outbreaks in CA appears to contradict these trends, this cold wave was short-lived and followed by above normal temperatures in January and February and above normal March rains.] This past winter was also one of the wettest, which was evidenced by the spectacular displays of spring vegetation on our desert mountains. This lush winter and spring vegetation may have provided that needed bridge to a cultivated crop. Also, the prolonged "dry down" of desert vegetation this past year extended the bridge well into our various cultivated crops. The 1980-81 winter showed similar patterns of warm and wet winter conditions and was followed by severe outbreaks of SPWF in the summer of 1981. In addition, the 1980 and 1991 summer monsoons were very weak. Though this might impact some pests negatively, it is thought that SPWF does better under these relatively dry conditions. This may have allowed higher than normal populations to develop and contribute to a relatively larger overwintering population (similar to the outbreaks seen in India in the 1980's). Thus, the climate may have been practically ideal for SPWF success in 1981 and 1992.

Other Risk Factors

The above factors affected everyone nearly statewide, but most growers look at their own fields and wonder, "Why me?" or "Why this field and not that one?" These are the most difficult questions to answer; however, there are a number of factors which can be identified as increasing the risk of infestation of an individual field or more broadly even an area or community. **Crop sequence** as mentioned earlier can contribute to the relative risk of an individual field or farm. For example, growers who actively produce a wide variety of crops in addition to cotton should consider the impact of these other potential hosts as bridges or nurseries for whiteflies. Spring vegetables followed by or adjacent to cotton could lead to a transfer of SPWF populations from one crop to the other, especially when the former is in decline. So fields, farms, or areas where the crop diversity is higher may indeed be at more risk for earlier or possibly more intense infestations in cotton. The converse, however, is not true. In the apparent absence of this crop diversity, cotton does not necessarily escape severe infestations. **Topography** may enter into the determination of risk to an individual field or farm in the midst of favorable spring hosts such as melons. Whiteflies can fly but have only a limited capacity to control their flight in the face of the stronger forces of wind. (Experiments in Arizona have shown that whiteflies stop flying at wind speeds greater than 6 miles per hour). Thus, knowing something about the local wind flow (especially the presence of river washes) may explain how some fields are at more or less of a risk of infestation. Wind flow on a farm is related to the topography and air drainage. Spring melons downwind of cotton may increase the risk of infestation of cotton somewhat, but not nearly as much as if these melons were planted upwind of cotton. **Crop condition** must also be considered when assessing risk of individual fields or farms. Though melons are a favored host for whiteflies, movement off of this host may only be minimal until that crop begins to decline (or it becomes completely overpopulated by SPWFs). Until this point, the cotton crop may not be at any greater risk, though the practice of withholding water from melons in cycles to accommodate or anticipate future markets could also lead to mass movement off of the melons during periods of water stress.

The above discussion leads to the question, "How far does my cotton have to be to minimize the impact of SPWFs coming from some other source?" Unfortunately, there is no clear cut answer to this question either. **Isolation** is certainly another factor for determining risk, and the farther the crop is from a SPWF source the lower the expected risk. Given that a single farm may grow vegetables and cotton, it is unlikely that you can achieve adequate isolation; however, **crop position** relative to the source crop and considering the local topography and air drainage should help to minimize the impact of SPWFs on the cotton. Currently, it is thought that distances of about 0.5-1 mile in isolation from a major source of SPWFs should help in reducing risk or delaying the onset of infestation in cotton.

There are other risk factors which are based on agronomic, crop protection, and other crop production decisions. Planting and subsequent crop management to reduce the dependence on later season production of yield should help to reduce the period in which SPWFs are present at damaging levels and the crop is attempting to set and fill bolls. **Early maturity** is one way to minimize the impact of late season SPWF populations. All of the agronomic practices which go into successfully achieving early maturity should help to avoid or reduce the risk of impact by SPWFs. Overzealous attention paid to early planting alone, however, is not necessarily going to contribute to reduced risk, especially if this practice results in a compromised stand or leads to excessive use of insecticides for other pests too early in the season (e.g., Pink Bollworm, Beet armyworm, thrips, *Lygus*, etc.). Other agronomic risk factors which have been suggested by experience in other parts of the world are excessively high nitrate levels, drought-stress, and poor canopy development (and probably any of the stresses contributing to this). On-farm or community-wide **uniformity** should also help to reduce the likelihood of SPWF re-invasion of other later maturing varieties within an area.

The seed that the grower puts into the ground affects almost everything, and it should be no surprise that **varieties** influence the risk of SPWF infestation. One such way may be the degree of hairiness on the leaves. For example, India attributed some of their SPWF devastation to the fact that they had traditionally planted the vast majority of acreage to hairy leaf varieties and now suggests the planting of glabrous varieties. Limited testing in Texas and Arizona have found that there may be an increased risk in general to planting hairy leaf varieties rather than smooth leaf varieties. There is not an absolute relationship, however, and some hairier leaf varieties performed equally well with glabrous ones in 1992. Also, some glabrous varieties performed better than others. In other words, this hairiness may be one of the more minor factors affecting ultimate SPWF risk.

The issues of **when** to apply remedial control measures and with **what material** have some obvious immediate impact on the success of a SPWF infestation. Certainly every grower can appreciate that some materials are inappropriate for the control of certain insect pests. And while still others may work well in controlling the SPWF population at hand, they may not be appropriate choices for the other pests present. Rather than list here all of the materials which may have been inappropriate for a given SPWF situation, a more thorough discussion of chemical control options is provided in the SPWF "Management" section later.

Timing of application is very closely related to **detection and monitoring** of SPWF infestations. A monitoring procedure is dependent on an efficient and accurate sampling technique. Unfortunately there is very little research on **sampling** techniques appropriate for grower use. This fact may have contributed to the relative risk of fields in 1992 because of poorly timed applications. Researchers have the benefit of more intense investment in sampling (e.g., number of different life stages per in^2, whole plant counts, numerous replicates per small field, etc.) and specialized equipment such as microscopes and D-vac machines. These tools are used to carefully evaluate research plots, but may only have limited application at the grower level. Some of the potential sampling techniques are: 1) yellow sticky cards or cylinders, 2) black pan or pie pan counts, 3) leaf counts of immature SPWF, 4) leaf turns for adult counts, 5) various vacuum count methods, and 6) sweep counts. Each technique is inherently flawed for a complete assessment of the situation; however, one or more of these techniques might provide enough information for determining the timing of chemical controls (see Whitefly Management section).

Sweetpotato Whitefly Management

Sweetpotato whitefly management by its very nature requires an integrated crop management approach. Though chemical control may be the tactic of choice once infestations have reached damaging levels, there are many other tactics and practices that may be employed well before the onset of infestation to maximize the likelihood of producing a successful crop. The above discussion also points out the importance of considering crop and non-crop dynamics outside of the cotton field of interest. Thus, cooperation among growers, within communities, or over large areas is encouraged and should result in maximum benefits to all concerned.

Pre-Season Considerations

Winter Sanitation & Overwintering Survey: Early plow-up of the previous season's crops should help deny the SPWF overwintering sites. General sanitation and destruction of volunteer weeds in fields, field edges and non-crop areas is encouraged. Careful survey of potential overwintering sites such as along rivers, washes, in perennial hosts (e.g., alfalfa, citrus, lantana, etc.), adjacent urban areas or farmsteads should help identify future sources of SPWF populations.

Seed Selection: As discussed earlier, although no resistant varieties exist, there is at least a weak association of whitefly susceptibility with hairy leaf varieties. More importantly, however, is selection of varieties that are well-adapted to local conditions. Effort should also be made in selecting varieties to accomodate sequential planting in order to accomplish uniformity in termination (see planting window).

Planting Window: Early planting to set an early crop and avoid whiteflies is one of our best cotton management strategies for 1993, benefits of which could be lost if planting is done prematurely, resulting in crop injury and/or replanting. From the experiences gained through the 1992 growing season, many cotton growers in the desert Southwest are making preparations for planting the 1993 crop in as early a manner as possible. This is largely due to an effort to initiate the crop early in an attempt to avoid the buildup of crop damaging whitefly populations. While there certainly is some merit to carrying out an early planting of the 1993 crop, allowing for an initiation of the fruiting cycle in a timely manner, and providing for a sustained, high fruit retention level; growers should also consider early plantings within reasonable set of constraints.

Fundamentally, the cottonseed has certain minimal requirements for adequate germination and stand establishment that we need to remain conscious of. Soil temperatures of 65°F are considered ideal for cottonseed germination, and planting is generally not recommended without a stable soil temperature of 60°F at seeding depth plus a favorable five-day weather forecast. Many growers will argue that optimum conditions are not realistically achieved in many cases, particularly when early plantings are being managed for. However, the fact remains that if cottonseeds are exposed to substantial chilling during the germination or establishment process, long-term, negative effects can be imparted to the crop. Such problems can come in the form of seedling diseases, stand loss, and/or stunted crop growth. Planting high quality seed and the use of seed treatments can help, but these factors cannot overcome the basic requirements in terms of soil moisture and temperature needed for establishing a crop. Premature planting can result in the delay in early season crop development or in replanting operations. In either case, the resultant crop can then often be more difficult to manage due to poor fruiting and vegetative tendencies.

Overall, it is better to plan for an early/optimum planting. In Arizona, we have developed optimum planting windows which can be described in terms of the heat units accumulated for a given area since January 1 of that season. These planting windows open at or near 300 HU accumulated after January 1, with an optimum window occurring from about 450–700 HU for all locations across the state. We recommend planting of all variety types within this window for the realization of early and optimum growth and development conditions. Weekly planting advisories are distributed from county Extension offices describing HU accumulations based upon local weather station data. Observing soil temperature limits, as stated previously, is always recommended.

Uniformity of Planting: Uniformity of planting is desirable as opposed to stretching plantings from March to June, which will only serve to extend the period of crop termination within an area. Later maturing varieties should be planted first followed immediately by the shorter season varieties so that uniformity in termination can be accomplished. This will help reduce the impact of passing whiteflies from one field to the next because of maturity and termination differences. Yield potentials and avoidance of SPWF infestations is reduced for later plantings. Plantings within the specified window should also assist in the suicidal emergence of Pink Bollworm and reduce the risk of inclement weather and early season insect damage.

Crop Selection, Placement & Isolation: A farmer who grows or leases ground for vegetable production should consider the choice of crop mix. Melons are a favored host for SPWF and growing these and other hosts in close proximity to cotton increases the risk of earlier infestations within cotton. Hosts for SPWF can be loosely ranked in the following order of preference and performance: 1) cantaloupes, 2) watermelon, 3) peanuts, squash, cucumber, groundcherry, 4) broccoli, 5) cauliflower, 6) cotton, 7) tepary beans, 8) alfalfa, 9) lettuce, tomato, and 10) corn and johnsongrass. (This is not an all inclusive list.) Placement of cotton relative to these other hosts should be carefully considered within a farm, community, or larger area.

Efforts should be made to plant cotton upslope or upwind of spring/summer hosts, especially melons. Isolation can be accomplished in time through the establishment of a host-free period or in space by planting cotton as far as possible (preferably) upwind of any SPWF source population (ca. 0.5-1 mile).

Irrigation and Fertility: Management of irrigation and fertility for optimal crop growth is always desirable. With SPWF, this objective is even more critical. Research and experiences here and in other parts of the world suggest that crop stress and/ or excessively high amounts of nitrate can contribute to the susceptibility of a cotton crop. Timing of the first irrigation may become more important in order to establish the fruiting cycle as early as possible with a minimum of stress. Split applications of nitrogen as a "best management practice" should be based on the needs of the plant as determined by crop monitoring and tissue testing procedures.

Management of Other Pests: Cotton is not grown in a vacuum exposed only to SPWF. Consideration and proper management of all other pests in the system should pay dividends in establishing early fruiting, minimizing the impact of SPWF, and maintaining the usefulness of our chemical control arsenal. Early and deep plow-down of the previous cotton crop should help reduce the incidence of pink bollworms early season. If water price and/or availability allows, a winter irrigation may help in the reduction of pink bollworm moths in the spring. Plans should be made now to allow for the strip- or block-cutting of alfalfa to reduce the early and mid-season impact of *Lygus* on cotton and to provide for preservation of natural enemies for our entire pest complex.

Early Season Considerations

Crop Monitoring: Thorough crop monitoring goes hand-in-hand with sound insect management and profitable crop production. Growers should monitor stand emergence and plant populations and identify any early season agronomic problems. Early season plant mapping or monitoring of first square development should be a part of every growers management arsenal. Indications of early difficulty in crop management can be identified by delayed initiation of squaring. The sooner that these types of problems are identified the better chance a grower has to identify the underlying cause and institute corrective action.

Insect & Weather Monitoring: Growers and PCAs should pay careful attention to the insect and weather (HU) situation on a field-to-field basis. The Cotton Team advisories which are developed on a weekly basis through the growing season outline insect and crop development as they relate to the local heat unit accumulations. By recording the number of heat units accumulated at planting and first pinhead square, informed decisions can be made about the degree of pink bollworm suicidal emergence and the need for pinhead square treatments. Growers should monitor their own temperatures relative to the closest AZMET station and make adjustments as necessary. Furthermore, if not already known, the grower should begin to monitor the general windflow patterns and air drainage, especially where suspected SPWF sources are concerned. Pink Bollworm traps should be placed along fields at least two weeks prior to squaring—even earlier (before planting) if the grower would like to monitor the entire spring emergence curve. Weeds and nearby alfalfa should be swept to monitor both *Lygus* and fleahopper densities.

Pinhead Square Programs: A pinhead square program is indicated when $\geq$10 moths per night are captured in Pink Bollworm traps within a two week period prior to first susceptible square which should occur at about 900 HU after planting and less than 95% of the moths have emerged. A variety of materials may be used on about a 6 or 7 day interval; however, the final treatment should contain a material also effective against beet armyworm. The treatments should continue until at least 95% moth emergence has occurred or for three applications, whichever comes first. The use of more than three pinhead square treatments could cause serious problems with resistance, secondary pests, and pest resurgence. The grower should avoid the use of pyrethroids altogether at this stage in the season and any other material that might be directed against SPWFs later in the season (see chemical control options below). Material selection should also consider the other pests present at damaging levels (e.g., *Lygus*, Cotton fleahopper, Beet Armyworm). If at all possible, a banded ground application should be used to reduce cost, maximize effectiveness, and reduce problems with drift and resistance.

In-Season Considerations

Irrigation, Weed Control & Crop Monitoring: Irrigation intervals and plant status should be carefully monitored so as to minimize stress. Once cotton becomes stressed by larger SPWF infestations, it may be necessary to shorten the irrigation interval. Thorough in-season weed control is advisable both within and adjacent to the cotton crop. Many weeds may serve as focal points of early invasion and establishment of SPWFs (e.g., groundcherry). Detailed crop monitoring to include plant mapping, nodes above the white bloom (NAWB), height to node ratios, and petiole analyses should be instituted on a regular basis in order to minimize plant stress, maximize a single cycle fruit set, and identify cut-out.

Non-Cotton Considerations: Growers should be aware of and check other potential local sources of SPWF season long. If SPWFs are present and reproducing in alfalfa, consider summer fallowing or shortening of the cutting interval in order to prevent the completion of a full generation. However, keep in mind that alfalfa may serve as a nursery for predators and parasitoids of SPWF as well as a refuge for the SPWF itself. It is not known which of these roles for alfalfa is the more important one at any given time. If melons are present, monitor the crop condition (i.e., disease incidence and/or SPWF overpopulation), harvest operations, and irrigation termination. These events often induce flushes of adult activity off of the melons. Also, encourage rapid plowdown (within 24 hrs) of melons and other vegetable hosts after the final harvest. In melon fields where the decision to cease harvest operations has been made quickly, a broadcast insecticidal treatment prior to plowdown might also provide some benefit to whitefly management in nearby cotton acreages. Re-visit the area to be sure that re-growth has not occurred which can support huge numbers of SPWF. In citrus, maintain good general orchard sanitation, especially of any broadleaf weeds where SPWFs may be protected. Growers should actively involve local homeowners who have significant amounts of SPWF hosts and encourage them to routinely survey their plants. When reproducing populations are found, homeowners should routinely spray their plants thoroughly every 2-4 days with a liquid dishwashing detergent solution (1 teaspoon to 2 tablespoons liquid soap per gallon of water).

Sweetpotato Whitefly Monitoring: Considering all of the information presented in this document, the grower should focus most attention on fields which carry a number of risk factors (e.g., adjacent to or downwind of SPWF source hosts or river washes, late planted or stressed cotton, hairy varieties, etc.). Monitoring programs should consider both movement of SPWF between fields and in-field population levels. Furthermore, attention should be paid to early signs of SPWF build-up on the field edges or on indicator plants such as Wright groundcherry when determining the need for treatment, and field edges should be sampled separately from the rest of the field.

In a diverse cropping system, growers may want to establish yellow **sticky traps** at the interface of cotton and vegetable acreages. These traps capture only adults and may reflect insects currently moving into an area rather than what is in a given field. When used collectively over a large area (i.e., community or county) sticky trap information may be useful in advising growers of large movements of adult whiteflies. Within a single farm, they may be placed at the interface between early season hosts (e.g., melons and other vegetables) and cotton to determine the general movement out of these hosts. Although these numbers are probably not reliable enough for the development of a trigger to spray a grower's field, they may indicate the need for intensified in-field sampling. During periods of intense migration, growers should check traps every 24 h to prevent overloading of the sticky surface.

In-field whitefly populations may be monitored using oiled pan counts, leaf turns, vacuum methods, and **sweep net counts**. All of these methods are very sampler dependent (the person taking the sample may be more important than the actual number of whiteflies present). Of these methods, the sweep net count is the most familiar to growers and PCAs. Because most PCAs have developed a deliberate and repeatable sweeping rhythm, this technique may provide the most unbiased sample of SPWF currently available to the grower. The grower or PCA should take 10 sweeps in four different locations per field. If counts are averaging 40 adults per sweep, then chemical control should be initiated. Sweep samples must be handled carefully in order to retrieve the adults which are usually clumped at the bottom of the net. These samples can be held in plastic Ziploc™ bags on ice prior to counting. If leaf turns are used to count adults, the sample should be taken in the morning hours when adult whiteflies are less likely to fly up if disturbed. The terminal portion of the plant should be targeted from a distance, a leaf selected (usually the third-fifth leaf from the top of the plant) and carefully turned over, and the number of adults present quickly counted. Leaf turn samples should be taken at at least five locations per field, five plants per location. Leaf counts of immature SPWF may be the most accurate indication of infestation levels but are difficult to conduct, especially without the aid of a low powered microscope.

No detailed studies of the economic impact of SPWF population levels on cotton yield, quality and ultimate profitability have been done. However, the experience of numerous researchers indicates that levels of about **10-12 SPWF adults per leaf** indicate the need for chemical control. How this number relates to each individual sampler's ability to find and count these adults and to the technique used is not known. Knowing when to stop treatment is even less understood; however, the objective should be to establish suppression for a period long enough to finish the crop and defoliate.

Chemical Control: Anyone who attempted to control SPWF in 1991 or 1992 has an opinion on this subject. Everyone should be cautioned that the extent to which you can rely on past successes is unknown. This pest is known for its ability to tolerate and ultimately build resistance to insecticides. The chemical control guidelines presented here are the result of replicated field research on the compounds, combinations, and rates reported. Though each test was compared to an untreated check, all compounds shown here were not necessarily compared head-to-head to every other compound in the list. Efficacy decisions were based on the presence of eggs and nymphs and sometimes the presence of adult SPWFs. In addition, impact on yields was considered if the data were available. Stickiness or other lint quality measures were not available for most tests. All tests were treated by ground at rates of 20-25 gallons of water per acre. The direct relationship of this data to aerial application is unknown, but we suspect that the relative efficacy of these compounds will be similar, though somewhat reduced in their overall effectiveness. Experiences in other parts of the world suggest that aerial and ULV application techniques are not nearly as effective as higher volume ground methods. Maximum benefits can be realized by using ground equipment and nozzle architecture which will ensure full coverage of the upper and lower surfaces of the cotton leaves. Addition of 1-2% oil or soap mixtures in high volume sprays may enhance pesticide treatments; however, higher concentrations may result in phytotoxicity and/or a pH which is incompatible with some pesticides.

Growers will immediately notice that the rates and combinations reported here might in some cases represent significant individual application costs. The temptation, of course, is to substitute cheaper materials and/or reduce rates. We cannot comment on the viability of either of these practices, except to caution the grower that there are no data to support such decisions. Furthermore, the use of lower, possibly sublethal rates of some insecticides have been known to actually stimulate insect development directly (hormoligosis) or indirectly through selective destruction of natural enemies and/or alteration of plant nutrient status. Finally, the grower is asked to consult his/her PCA in great detail about the complement of pests and beneficials present prior to application. Though all of the reported combinations have been found effective against SPWF, several may be completely inappropriate for other significant pests present in individual situations.

The following list of compounds is recommended in combinations when and only when indicated by the presence of an active infestation. The label is the ultimate source of specific use restrictions. Less is known about the intervals required, but 5-7 days should be considered as a general guide. Rotation to different combinations utilizing different classes of chemistry is encouraged at least every 14 days—this effectively exposes only one generation to a given chemical application. All compounds on the left side of the table are synthetic pyrethroids. Orthene, Monitor, and Penncap-M are organophosphates. Endosulfan is a chlorinated bicyclic sulfite, and Ovasyn is a formamidine.

In general, researchers beltwide have found that combinations of a synthetic pyrethroid with some other type of chemistry have shown the greatest efficacy against all stages of SPWF. It should be noted, however, that every possible synthetic pyrethroid has not been tested with every organophosphate, carbamate, or other chemistry. The lists discussed here will expand and change as more information becomes available for other compounds.

An alternative to the pyrethroid combinations that has shown some effectiveness is endosulfan (1.0) with Ovasyn (0.25); however, a population in California has shown a 48-fold increase in resistance to Thiodan applied alone. Nevertheless, this is one combination that may be used as a start to a chemical program that would not require early use of pyrethroids. Other chemicals have shown varying degrees of resistance in the B-strain of the SPWF and include Capture, Curacron, chlorpyrifos (Lorsban, Lockon), and cypermethrin (Ammo, Cymbush). Combinations of an organic phosphate with a pyrethroid have helped to mitigate the effects of whitefly resistance. The organic phosphate helps to disarm the insects ability to resist pyrethroids; however, one combination has resulted in resistance in Pakistan (e.g., Curacron with cypermethrin).

Research tested insecticide combinations effective against SPWF

Baythroid (0.035)†, Capture (0.06), Danitol*(0.20), Fury*(0.0375), Karate (0.025-0.04), or Scout X-Tra (0.024)	+	Orthene (0.50)
Baythroid (0.035)	+	Monitor (1.0)
Capture (0.06)	+	endosulfan (1.0) (Phaser-Thiodan)
Capture (0.06-0.1)	+	Ovasyn*(0.25)
Danitol*(0.20)	+	Penncap-M (1.0)

† lbs. active ingredient per acre.

* Subject to registration in Arizona.

This list is all of the registered compounds that were tested in trials against one or more of the above combinations, but failed to give equivalent control and/or yield response: Asana (0.05), Baythroid (0.035), Capture (0.06) [Capture at 0.10 did provide good control], Fury (0.0375), Karate (0.025-0.40), Lannate (0.68), Monitor (1.0), Orthene (0.50), Ovasyn (0.25), Penncap-M (1.0), Scout X-Tra (0.024), endosulfan (0.75), Vydate (0.75), and Vydate (0.75) plus Asana (0.05).

Alternative Control Tactics: Alternatives always exist and seem to proliferate proportionately to the severity of the problem. Many are untested or under-researched, but the grower should be aware of some of the possibilities. **Trap cropping** is an old and time-tested method for dealing with many insect pests; however, the technique has been explored for SPWF only by using Wright groundcherry as a treated trap crop. Studies have shown that where the trap is healthy and vigorous that a delay in onset of infestation can be attained; however, the gains in time are quite modest and much more work is needed. **Biological control** is another important component to any management scheme. Unfortunately, we do not yet have enough information on potential predators and parasites to suggest their systematic release. We do know, however, that damsel bugs (*Nabis spp.*), minute pirate bugs (*Orius spp.*), big-eyed bugs (*Geocoris spp.*), green lacewings (*Chrysopa spp.*) and *Collops* beetles are all positively identified as predators of SPWF. Furthermore, we do know that there are a number of parasites already present in the system, especially where pesticides are rarely used. Natural parasitism rates as high as 80% have been observed in some unmanaged or unsprayed landscapes. In addition to parasitism, adult parasites may also kill SPWF nymphs directly by stabbing and feeding on the wound. In short, we can encourage their activities through the judicious use of pesticides and preservation of habitat (e.g., alfalfa) wherever possible. Their ultimate impact on the current system is not presently known. A number of fungi pathogenic to whiteflies have also been identified (e.g., *Aschersonia, Beauveria, Paecilomyces* and *Verticillium*); however, most are very experimental and have a high humidity requirement for infection. **Perimeter spraying** is another economically appealing alternative to whole field broadcast applications. We do not know enough about the movement of SPWF especially in relation to continuous, high densities and wind to safely encourage this practice over large areas. Under certain conditions, field edges may have higher SPWF densities than field interiors. The causes of this phenomenon may be numerous and not completely known, but may include: 1) poor insecticidal coverage of field edges, 2) presence of adjacent infestations, and 3) natural airflow and SPWF movement. Other conditions resulted in SPWF infestations without an apparent "edge effect." It was not unusual in mixed cropping systems last year for whole fields to become rapidly infested in less than 5 days due to huge influxes of adult whiteflies.

Late Season Considerations

Crop Termination, Defoliation & Harvest: The ultimate goal is to reach crop termination and defoliation with a timely and fully mature fruit set before SPWF populations have an opportunity to impact yield or lint quality. Several strategies increase the likelihood of this happening, not the least of which is adopting a realistic crop termination and yield potential goal. Pushing cotton into a top crop lengthens the time of exposure to SPWF and other late season pests while only increasing yields by an additional 50 to 150 lbs. lint per acre. Defoliation should be accomplished in as timely and uniform manner as is possible area-wide. This should shorten the period in which huge SPWF populations move and re-invade later maturing cotton acreages and other hosts. Prompt harvest and rapid plowdown pays dividends in succeeding crops and subsequent years by eliminating SPWF supporting host material. Even with optimal fall conditions this past year, many fields had cotton regrowth near the bases of harvested plants which was supporting large numbers of SPWF.

Insect Management: Insect problems often intensify during the latter part of the season. Every effort should be made to finish the crop as quickly as possible so as to minimize the number of generations of insects including Pink Bollworm and SPWF to which the crop is exposed. Once a SPWF control program is initiated, the grower and PCA should not cease monitoring the field for other late season pests (e.g., Cotton Aphid, Beet Armyworm, Pink Bollworm, Cotton Leafperforator, mites, etc.). These pests will have to be considered in the selection of appropriate insecticides. Crop management which prevents the production of small green bolls by mid-September can have dramatic impact on the diapausing generation of Pink Bollworm, thus lessening its impact the following year.

Alternate Host Management: Fall vegetable planting should be delayed as much as is possible to remove this host bridge needed by the SPWF. Earlier plantings will require such intense chemical management that future utility of these agrichemicals could be in jeopardy. Watering back fallowed alfalfa and establishing new alfalfa stands should be delayed until SPWF populations have definitely declined and temperatures have cooled.

SELECTED BIBLIOGRAPHY

Brown, P. & B. Russell 1992. Weather conditions during the 1991 growing season. In Cotton, A U. of Az. Report. pp. 1-6.

Brown, P., J. Silvertooth, L. Moore & T. Watson 1992. Revised planting window for full season cotton varieties. In Cotton, A U. of Az. Report. pp. 241-251.

Brown, P., T. Watson & J. Silvertooth 1993. Weather conditions associated with outbreaks of severe whitefly infestations in Arizona. In Proc. 1993 Beltwide Conf., New Orleans.

Butler, G.D. & T.J. Henneberry 1992. Sweetpotato whitefly: flight activity, effects of wind velocity, and precopulatory pairing activity patterns. In Cotton, A U. of Az. Report. pp. 140-145.

Byrne, D.N. & T.S. Bellows 1991. Whitefly Biology. Ann. Rev. of Entomol. 36: 431-457.

Byrne, D.N., A.C. Cohen & E.A. Draeger 1990. Water uptake from plant tissue by the egg pedicel of the greenhouse whitefly, *Trialeurodes vaporium* (Westwood) (Homoptera: Aleyrodidae). Canad. Journ. of Zool. 68: 1193-1195.

Ellsworth, P.C., J.P. Chernicky, D.N. Byrne, R. Gibson & D. Meade 1992. A native weed as a trap crop for whiteflies in cotton. In Cotton, a U. of Az. Report. pp. 171-176.

Langston, D. & R. Gibson. More about bugs and their relatives No. 2. Whiteflies.

Perring, T.M., A.D. Cooper, R.J. Rodriguez, C.A. Farrar, & T.S. Bellows Jr. 1993. Identification of a whitefly species by genomic and behavioral studies. Science 259 (1):74-77.

Silvertooth, J.C. (editor) 1990, 1991, 1992. Cotton, a University of Arizona Report. [This annual report of research on Cotton in Arizona is a valuable source for further information on many aspects of cotton management in the Southwest].

Silvertooth, J.C., P.W. Brown & J.E. Malcuit 1992. Cotton crop growth and development patterns. In Cotton, a U. of Az. Report. pp. 9-13.

Silvertooth, J.C., L.J. Clark, J.E. Malcuit, E.W. Carpenter, T.A. Doerge & J.E. Watson. 1992. Nitrogen management experiments for upland and Pima cotton. Cotton, a U. of Az. Report. pp. 183-198.

Silvertooth, J.C., T.F. Watson, J.E. Malcuit & P.W. Brown 1992. Evaluation of date of planting and irrigation termination on the yield of upland and Pima cotton. In Cotton, a U. of Az. Report. pp. 252-273.

Silvertooth, J.C., T.F. Watson, D.N. Byrne & P.W. Brown 1992. Sweetpotato whitefly and Arizona cotton. Ariz. Farmer-Stockman: 20-24.

Sivasupramaniam, S., S.E. Kelly, D. Cross, J. Brown & T.F. Watson. 1992. Use of treated vial technique to determine efficacy of several insecticides against the sweetpotato whitefly, *Bemisia tabaci* (Gennad.). In Cotton, a U. of Az. Report. pp. 155-164.

Sundaramurthy, V.T. 1992. Upsurgence of whitefly *Bemisia tabaci* Gen. in the cotton ecosystem in India. Outlook on Agric. 21 (2): 109-115.

Watson, T.F. 1992. Insecticidal control of the sweetpotato whitefly in cotton. In Cotton, a U. of Az. Report. pp. 146-154.

Watson, T.F. & J.C. Silvertooth 1992. Seasonal dynamics of sweetpotato whitefly. In Cotton, a U. of Az. Report. pp. 117-139.

Watson, T.F., J.C. Silvertooth, A. Tellez & L. Lastra 1992. Seasonal dynamics of sweetpotato whitefly in Arizona. Southwest. Entomol. 17 (2): 149-167.