Integrating Airborne Imagery and GIS Technology to Map and Compare Citrus Blackfly Infestations Occurring in Different Years

Reginald S. Fletcher¹,
James H. Everitt²,
Michael R. Davis³, and
David E. Escobar⁴

ADDITIONAL INDEX WORDS. color-infrared, sooty mold, remote sensing, geographic information system

SUMMARY. Major citrus blackfly (*Al-eurocanthus woglumi*) outbreaks occur periodically in the Lower Rio Grande Valley (LRGV) of Texas, causing a reduction in citrus (*Citrus* sp.) tree yields. This research reports on the integration of airborne color-infrared (ACIR) imagery and geographic information system (GIS) technology for mapping citrus blackfly outbreaks appearing in this area in separate years. For this study, the 1993 and 2002 citrus blackfly infestations were mapped and compared. Outbreaks did not appear at the same sites for 1993 and 2002. In 1993, infestations occurred in the southern part of Hidalgo and Cameron counties compared with outbreaks primarily appearing in the western portion of Hidalgo County in 2002. For both years, Hidalgo County was affected more than the other citrus producing counties in the LRGV. This study

demonstrated airborne remote sensing imagery integrated with GIS technology could be used to develop maps for comparing citrus blackfly infestations appearing in separate years.

The citrus blackfly, a pest native to southern Asia (Clausen, 1978), can cause extensive damage to citrus trees. They injure leaves during feeding, and their nymphs excrete honeydew that promotes growth of sooty mold fungus (*Capnodium citri*) on the leaves. Sooty mold reduces photosynthesis and respiration of affected trees. The combined effects of blackfly feeding and sooty mold growth on the leaves reduce yields.

In the Lower Rio Grande Valley of Texas, the first reported citrus blackfly outbreak occurred in 1955 (Smith and Maltby, 1964) followed by another major outbreak in 1971 (French et al., 1997). Biological mechanisms have been used to control and suppress infestations (Hart, 1978; Summy et al., 1983). By the end of the 1970s (French et al., 1997), blackfly ceased to be a major problem in the LRGV. However, an unknown factor has periodically affected the biological control of this insect, leading to major outbreaks. Current field maps showing the locations of citrus blackfly outbreaks occurring in different years could lead to a better understanding of blackfly infestations in this area; however, no such maps are available.

Airborne color-infrared imagery has been used by researchers to detect citrus blackfly infestations of citrus groves (Everitt et al., 1994; Hart et al., 1973). Detection of infested areas is attributed to the blackfly sooty mold complex. On ACIR imagery, healthy citrus tree canopies have a red magenta appearance; blackfly-infested trees appear in shades of dull gray to black because of sooty mold deposits on the leaves. Affected areas within groves appear as a "black bulls eye" surrounded by red healthy trees (Hart et al., 1973).

Geographic information systems are computers that can store, retrieve, and manipulate geographic data. These systems have evolved side by side with remote sensing technology, leading to the combination of these technologies to aid in management decisions. Everitt et al. (1994) integrated ACIR imagery, global positioning system (GPS),

and GIS technologies to map blackfly infestations in the LRGV.

The previous studies are limited to detecting and or mapping citrus blackfly outbreaks occurring at specific times. The objective of this study was to integrate remote sensing and GIS technologies to map the 1993 and 2002 citrus blackfly infestations of citrus groves in the LRGV. This objective specifically focused on comparing the locations of the outbreaks.

Materials and methods

Because of its subtropical climate, the LRGV (Fig. 1A) is the only area suitable for large-scale commercial citrus production in Texas. It consists of four counties: Starr, Hidalgo, Willacy, and Cameron; however, citrus is only grown in Cameron, Hidalgo, and Willacy counties (Fig. 1B). Producers grow grapefruit (*Citrus paradisi*) and oranges (*Citrus* sp.), but grapefruit is the major citrus crop. Growers use flood or drip irrigation to supply water to their groves.

In 1993 and 2002, major citrus blackfly infestations occurred in the LRGV. The 1993 outbreak was mapped by Everitt et al. (1994), and a detailed description of data collection is provided in their publication. For this study, we used their coordinates of infested orchards to represent the 1993 blackfly outbreak on our map. For the 2002 citrus blackfly survey, ACIR photography was obtained with a large format photographic camera [22.8 × 22.8-cm (9 inches) photos] mounted in a hole in the belly of a fixed winged aircraft. This camera has a 30.5-cm (12 inches) focal length lens. Kodak Aerochrome II Infrared Film 2443 (Eastman Kodak Co., Rochester, N.Y.) was used in the camera. Photos of orchards in Willacy and Hidalgo counties west of Weslaco were obtained at an altitude of 6096 m (20,000 ft) aboveground on 15 Jan. 2002 (Fig. 1B). Photography of Cameron and Hidalgo counties groves east of Weslaco were acquired at an altitude of 1524 m (5000 ft) aboveground on 16 Jan. 2002 (Fig. 1B).

After the film was processed by a commercial company, we scanned the CIR transparencies, saved them to a desktop computer, and qualitatively assessed the scanned images using Adobe Photoshop software (version 6.0; Adobe Systems Inc., Mountain View, Calif.). Hardcopies were made

United States Department of Agriculture, Agricultural Research Service, Kika de la Garza Subtropical Agricultural Research Center, Integrated Farming and Natural Resources Research Unit, 2413 E. Hwy. 83, Weslaco, TX 78596.

We thank USDA-ARS at Weslaco, Texas, and USDA-APHIS at Harlingen, Texas, personnel and the Rio Grande Valley citrus growers for their assistance in this study. Trade names are included for the benefit of the reader and do not imply endorsement of or a preference for the product listed by the U.S. Department of Agriculture.

¹Soil Scientist; to whom reprint requests should be addressed. Phone: 956-969-4834; fax: 956-969-4893; e-mail: rfletcher@weslaco.ars.usda.gov

²Range scientist.

³Aircraft pilot.

⁴Remote sensing specialist.

Fig. 1. (A) Map of Texas showing the location of the Lower Rio Grande Valley (enclosed in the rectangular box). (B) Close up of the Lower Rio Grande Valley depicting the counties in which citrus is grown and the locations of citrus orchards within each county. Orchards in the western portion of Hidalgo County are clustered (white arrow), whereas orchards in the southern part of Hidalgo and Cameron counties are dispersed (black arrows); 1 km = 0.62 mile.

of images showing sooty mold deposits on citrus tree canopies. United States Department of Agriculture–Agricultural Research Service (USDA–ARS) personnel at Weslaco visited these locations to confirm the presence of blackfly (i.e., presence of eggs, instars, pupa, and/or adult flies within the grove).

Using PC ArcInfo software (version 3.5.1; Environmental System Research Institute, Redland, Calif.) in 1996, USDA–ARS at Weslaco and USDA–Animal and Plant Health Inspection Service at Harlingen personnel developed a digital map of citrus grove boundaries located in the LRGV. This file and the coordinates of the 1993 sites infested with blackfly were imported to MapInfo Professional software (version 5.0.1, MapInfo Corp.,

Troy, N.Y.) for further assessment. In MapInfo, the citrus grove boundaries were displayed, and locations infested by citrus blackfly in 1993 and 2002 were located on the map and marked with black and white circles, respectively. MapInfo Streetworks (version 3.0) and U.S. High Resolution County Boundaries (version 1997) were used to add city names and locations, water bodies, and county boundaries and names to the map. These features were used to assist in the interpretation of the map. Geographic layers used in the development of the citrus blackfly infestation map are expressed in the latitude longitude coordinate system.

Results and discussion

Blackfly nymphs excrete a honeydew substance that promotes growth of

sooty mold on citrus tree foliage. The light reflectance characteristics of sooty mold and healthy green vegetation attributed to the differences observed between infested and noninfested foliage seen in Fig. 2A (Hart and Myers, 1968; Hart et al., 1973). Sooty mold absorbs visible light (blue, green, and red light), resulting in the darker color of the infested tree foliage. Healthy green leaves absorb blue and red light and moderately reflect green light, causing leaves to have a green color (Fig. 2A) (Campbell, 1987; Jensen, 2000; Knipling, 1970).

Color-infrared (CIR) film is sensitive to green, red, and near-infrared light instead of blue, green, and red light. On CIR images, objects reflecting green light appear blue; objects reflecting red light appear green; and

Fig. 2. (A) Ground-level photograph of noninfested (left) and blackfly-infested (right) foliage. Honeydew substance excreted by developing blackflies promotes growth of sooty mold on leaves of infested trees (right). (B) Color-infrared image of blackfly-infested orchards northwest of Edinburg, Texas. Yellow and cyan arrows point to infested (sooty mold deposits caused trees to have a black tone) and noninfested trees, respectively.

objects reflecting near-infrared light appear red. Healthy leaves moderately reflect green light and highly reflect near-infrared light (Jensen, 2000; Knipling, 1970), leading to the red magenta color of noninfested trees on the CIR image shown in Fig. 2B. Absorption of near-infrared, red, and green light by sooty mold resulted in the black color of the infested trees'

foliage seen on the CIR image.

Figure 3 shows a map of the LRGV counties that produce citrus, including locations of blackfly-infested sites for 1993 and 2002. In 1993, infestations occurred in the southern part of Hidalgo and Cameron counties compared with outbreaks primarily appearing in the western portion of Hidalgo County in 2002. The 1993 outbreak affected

fewer sites than the 2002 outbreak, and the former was scattered throughout the area. Sites infested in 1993 were not infested in 2002. For both years, the infestations predominately occurred in Hidalgo County.

Environmental conditions, management practices, and locations of the infestations probably attributed to the similarities and or differences observed between the two outbreaks on the map. When this map was created, we did not have environmental data. Therefore, research needs to be conducted to determine the role of the environment on the infestations.

Biological mechanisms have been an effective means of controlling and suppressing citrus blackfly outbreaks in the LRGV (Hart, 1978; Summy et al., 1983). Between 1993 and 2002, chemicals used to control other citrus pests and or pests in neighboring fields could have reduced the population of the natural enemies of the citrus blackfly. This reduction could have resulted in an increase in the blackfly population, leading to the severe outbreak seen in 2002.

Figure 1 shows the locations of citrus groves in the LRGV. When an outbreak occurs, it begins in a small area of a grove primarily affecting three to four trees (Hart et al., 1973). As the citrus blackfly population intensifies, it disperses causing an enlargement in the sooty mold area observed within the grove and the development of outbreaks at other locations. The groves in the western section of Hidalgo County are clustered (Fig. 1B, white arrow); therefore, the flies could have easily migrated to another location, leading to more sites being infested in 2002. Orchards in the southern portion of Hidalgo and Cameron counties are scattered (black arrows) probably prohibiting the spread of the infestation in 1993, which resulted in fewer sites being infested. In addition, Hidalgo County contains 85% [12,148.3 ha (30,018 acres)] of the 14,292.0 ha (35,315 acres) of citrus grown in the LRGV. The greater number of infested sites observed in this county for both years could have been related to the percentage of citrus grown.

Conclusions

Airborne remote sensing imagery and GIS technology can be used to compare citrus blackfly outbreaks occurring in separate years. Using these

Fig. 3. Map showing the locations of citrus blackfly-infested sites in the Lower Rio Grande Valley of Texas for 1993 and 2002. Circle sizes were increased for publication purposes; 1 km = 0.62 mile.

technologies, we developed a map showing the locations of citrus blackfly-infested sites in the LRGV of Texas for 1993 and 2002. Outbreaks primarily occurred in Hidalgo County; however, the locations of the infestations within this county were distinctly different for both years. The map developed in this study can serve as a database to compare future citrus blackfly outbreaks. In addition, these maps should be beneficial to citrus producers, state and federal agencies, consultants, and other scientists because they can use these maps to assist them in implementing pest management strategies such as parasitoid releases and chemical applications, in determining the success of current management strategies, and in predicting where future outbreaks may occur.

Literature cited

- Campbell, J.B. 1987. Introduction to remote sensing. Guilford Press, New York.
- Clausen, C.P. 1978. Biological control of citrus insects, p. 276–320. In: W. Reuther, E.C. Calavan, and G.E. Carman (eds.). The citrus industry. Vol. 4. Crop protection. Agr. Sci. Publ., Univ. of California, Berkeley.
- Everitt, J.H., D.E. Escobar, K.R. Summy, and M.R. Davis. 1994. Using airborne video, global positioning system, and geographical information system technologies for detecting and mapping citrus blackfly infestations. *Southwestern Entomol.* 19(2):129–138.
- French, J.V., D.S. Moreno, K.R. Summy, A.N. Sparks, Jr., and P.F. Lummus. 1997. Citrus blackfly. 20 Nov. 2003. <<http://primera.tamu.edu/kcchome/pubs/cblkfly.htm>>.
- Hart, W.G. and V.I. Myers. 1968. Infrared aerial color photography for detection of populations brown soft scale in citrus groves. *J. Econ. Entomol.* 61(3):617–624.
- Hart, W.G., S.J. Ingle, M.R. Davis, and C. Mangum. 1973. Aerial photography with infrared color film as a method of surveying for citrus blackfly. *J. Econ. Entomol.* 66(1):190–194.
- Hart, W.G. 1978. Some biological control successes in the southern United States. *Proc. Intl. Soc. Citricult.* 3:154–156.
- Jensen, J.R. 2000. Remote sensing of the environment: An earth resource perspective. Prentice Hall, Upper Saddle River, N.J.
- Knipling, E.B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sensing Environ.* 1:155–159.
- Smith, H.D. and H.L. Maltby. 1964. Biological control of the citrus blackfly in Mexico. U.S. Dept. Agr. Tech. Bul. 1311.
- Summy, K.R., F.E. Gilstrap, W.G. Hart, J.M. Caballero, and I. Saenz. 1983. Biological control of citrus blackfly (Homoptera: Aleyrodidae) in Texas. *Environ. Entomol.* 12:782–786.