Acoustic Detection of Otiorhynchus sulcatus (Fabricius) (Coleoptera: Curculionidae) Larval Infestations in Nursery Containers

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Abstract

Several different acoustic sensor systems have been used successfully to detect root weevil infestations in nursery containers in laboratory and field environments, including a portable accelerometer system and an acoustic emission detector adapted from applications in utility pipe leak detection. Considerable experience has been obtained about different types of sounds produced by subterranean insects and methods to distinguish insect-produced sounds from incidental background noise. This experience is being applied in development of modified instruments with improved utility for insect detection applications. Training materials have been developed to instruct people about the use of an acoustic detection system in field survey applications.

Introduction

Subterranean insects are difficult to detect and study, but they cause billions of dollars in damage yearly to container-grown crops, agricultural crops, trees, turf, and golf courses (Tashiro 1987, Crocker et al. 1996, Cowles et al. 1997, Riley et al. 1997, Nigg et al. 2001). The traditional method for detecting subterranean insects in the field is a labor-intensive, visual search for damaged vegetation, followed by destructive digging, removal of the root mass, or water flushing of samples (e.g., Cobb and Mack 1989, Villani and Wright 1990). Growers and managers need new tools to assess infestation and reduce management costs. Researchers need new tools to develop basic knowledge about life cycles, behavior, and population distributions, and to determine the efficacy of pest insect management strategies.

Acoustic technology offers potential as a means of identifying and targeting insect populations that can be found now only by laborious, destructive techniques. Several acoustic systems have been developed for monitoring and detecting hidden infestations. Examples include the insect activity monitoring systems of Hagstrum et al. (1991, 1996), the acoustic-location fixing insect detector (Shuman et al. 1993, 1997), the multiple acoustic sensor system (Hickling et al. 1994), the acoustic emissions detector (Fujii et al. 1990, Scheffrahn et al. 1993), and the biomonitor of Shade et al. (1990). Recently, Mankin et al. (2000, 2001) and Brandhorst-Hubbard et al. (2001) conducted laboratory and field studies with a soil microphone and an accelerometer system that have potential for subterranean insect detection applications. Digital signal analysis methods were developed to distinguish subterranean larval sounds from incidental environmental noises and sounds made by earthworms and other nonpest organisms. The success of these studies has fostered further interest in the development of practical acoustic instruments for field application. A notable example is the AED-2000 instrument from Acoustic Emission Consulting, Inc. (AEC, Fair Oaks, CA see URL: www.aeconsulting.com). A field-portable version of the AED-2000 has been adapted for acoustic detection and quantification of insect activity.

This report describes recent experiments conducted with currently available acoustic sensors and instruments to detect *Otiorhynchus sulcatus* (Fabricius) (Coleoptera: Curculionidae), and offers some perspective on the future use of acoustic technology as an insect detection tool in the container-crop industry.

Materials and Methods

Insects and Plants

Laboratory studies at AEC, Inc. were performed on wheat kernels infested with *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) from a colony maintained at the Agricultural Research Service (ARS) Center for Medical, Agricultural, and Veterinary Entomology (CMAVE), Gainesville, Florida. A field study in 2001 included *Hydrangea arborescens* L. 'Annabelle', *Picea abies* 'Mariana Nana', *Picea abies* 'Pumila', and *Andromeda glaucophylla* Link. Temperatures were maintained at 20–24^{o}C in the laboratory tests but were only 10–15^{o}C in the nursery tests.

One method to acoustically monitor a plant for *O. sulcatus* infestation was to insert a 30-cm nail (waveguide) into the root system and magnetically attach an accelerometer (see Acoustic Instruments below) to the head. Sounds detected by the accelerometer were monitored with headphones by an experienced listener and simultaneously recorded. The recorded signals were subsequently analyzed in the laboratory with custom-written signal processing software (Mankin et al. 2000, 2001).

The second measurement method included an AED-2000 detector (see Acoustic Instruments) with one of two different input sensors. One sensor was a custom-designed piezoelectric crystal with a 40-kHz resonance frequency and an integrated preamplifier. Like the accelerometer, the crystal unit was attached to the end of a metal waveguide inserted into the root system. The second input was a piezoelectric film sensor, less bulky but somewhat less sensitive than the piezoelectric crystal system. The film was attached to the trunk of the plant using wall-mount mastic, or taped to a waveguide inserted into the soil. Sounds detected by the AED-2000 were monitored with headphones and recorded on a digital audio tape recorder (DAT) or observed on an oscilloscope.

At the nursery, the acoustic tests were conducted inside a greenhouse to reduce background noise. The roots of each plant were examined and any insects found were identified and weighed after the acoustic measurements.

Acoustic Instruments

The initial studies were conducted with an acoustic system that included an accelerometer (Brüel and Kjær [B&K] Nærum, Denmark, sensitivity 10 pC/ms^{-2}, weight 54 g), a charge amplifier (B&K model 2635), and a DAT. A >180-s period was recorded on the DAT and monitored with headphones at each container. Subsequent studies also used an AED-2000 system with two different sensors. One sensor included a custom-designed piezoelectric crystal with a 40-kHz resonance frequency and an integrated preamplifier (1 kHz–2 mHz bandpass). The second included a Measurement Specialties, Inc., Model SDT1-028k piezoelectric film (www.msiusa.com, Norristown, PA) and a Model 2460 preamplifier (40 dB, 1-30 kHz bandpass). The AED-2000 detector included a user-adjustable amplifier (0–60 dB), a buffered signal output for oscilloscopes or recorders, headphones for audio monitoring and quality control, an RS232 serial port for data logging to a Windows-based computer, and an LCD display for visual monitoring of signal intensity and sound pulse counts. Adaptations that have been incorporated into the AED-2000 for *O. sulcatus* detection include a demodulator that converts the audio output, enabling a listener to monitor signals at higher frequencies than normal hearing levels. The demodulator feature is particularly useful near highways and other sources of high-intensity, low-frequency background noise because the bandpass can be set to filter out signals below 1 kHz or 25 kHz.

Signal Analysis

The signals recorded on the DAT were digitized and analyzed with a digital signal processing system (Mankin 1994, Mankin et al. 2000, 2001) that provided computer assessment of activity and distinguished larval sounds from background noise. Moving and feeding larvae generated short (0.5–5 ms) pulses that were distinguished from non-insect noises by computer subroutines that analyzed differences in temporal pattern or frequency. High-frequency signals were analyzed using a Tektronix model 3012 portable oscilloscope.

Results and Discussion

Tests with the accelerometer and AED-2000 systems in a variety of laboratory and field environments have confirmed that *O. sulcatus* larvae can be detected in nursery containers by acoustic techniques. In the 2001 field tests with both the accelerometer and AED-2000 systems, for example, sounds were detected in two *Picea abies* 'Mariana Nana', two *Andromeda glaucophylla* and one *Hydrangea arborescens* from which 805, 412, 44, 9, and 5 *O. sulcatus* were recovered, respectively. Neither system detected sounds in the container of one *H. arborescens* and one *P. abies* 'Pumila', and no larvae were recovered from those containers. Examples of sounds produced by *O. sulcatus* larvae in containers with different plants can be found at URL: cmave.usda.ufl.edu/~rmankin/blackvineweevilsounds.html. The frequency spectra of *O. sulcatus* sounds have high frequency components that can be used by an experienced listener or a computer to distinguish them from background noise (see Fig. 6 in Mankin et al. 2000). Typical background sounds also have been recorded and analyzed for comparison with insect-produced sounds and can be used as training tools to instruct new users (see URL: cmave.usda.ufl.edu/~rmankin/soundlibrary.html).

Although the initial acoustic tests have been successful, experience suggests modifications that would further improve the efficacy of currently available detection systems for practical entomological applications. The accelerometer systems used in this study, although portable, were designed primarily for laboratory use, and considerable training and care were required to collect and interpret the acoustic signals. Precautions were taken to protect the instruments that would not be practical for long-term field applications. High winds and high background noise, e.g., from a major highway, sometimes impeded analysis of accelerometer-collected sounds. Because these sounds are primarily of low frequency, they can be filtered out of the signals from the AED-2000 instrument if the insect-produced sounds have sufficient high-frequency components. Figures 1 and 2, for example, show the spectra of two different sound pulses produced by a *S. oryzae* larva, recorded using the piezoelectric crystal with a 1-kHz filter, and a 25-kHz filter. In Figure 1, there are significant peaks near 15 and 25 kHz. In Figure 2, the 15-kHz peak is reduced due to filtering, but there remains a significant peak near 25 kHz. Low-frequency interference cannot be filtered from the accelerometer signal as easily as from the piezoelectric crystal signal because the accelerometer is not designed to detect high-frequency signals. Consequently, the handheld AED-2000 proved in many respects to be a more practical system for field use. However, the housing for the piezoelectric film sensor was not sufficiently durable for long-term field use, and under conditions of low background noise, the accelerometer was more sensitive to low-intensity insect sounds than either the piezoelectric crystal or the film. An ideal system would have high sensitivity from ~0.5 kHz to ultrasonic frequencies, with a user-adjustable filter to reduce background noise.

Several potential improvements are being addressed in a new version of the AED-2000 sensor unit. The new unit will include a more sensitive piezoelectric crystal housed in a repackaged structure to isolate it from external sounds except at the connection to the waveguide inserted into the soil. The goal is to obtain ~20 dB of noise immunity between the waveguide and the handle assembly. Alternatively, background noise could be reduced by use of a large, acoustically shielded box that held the plants during testing.

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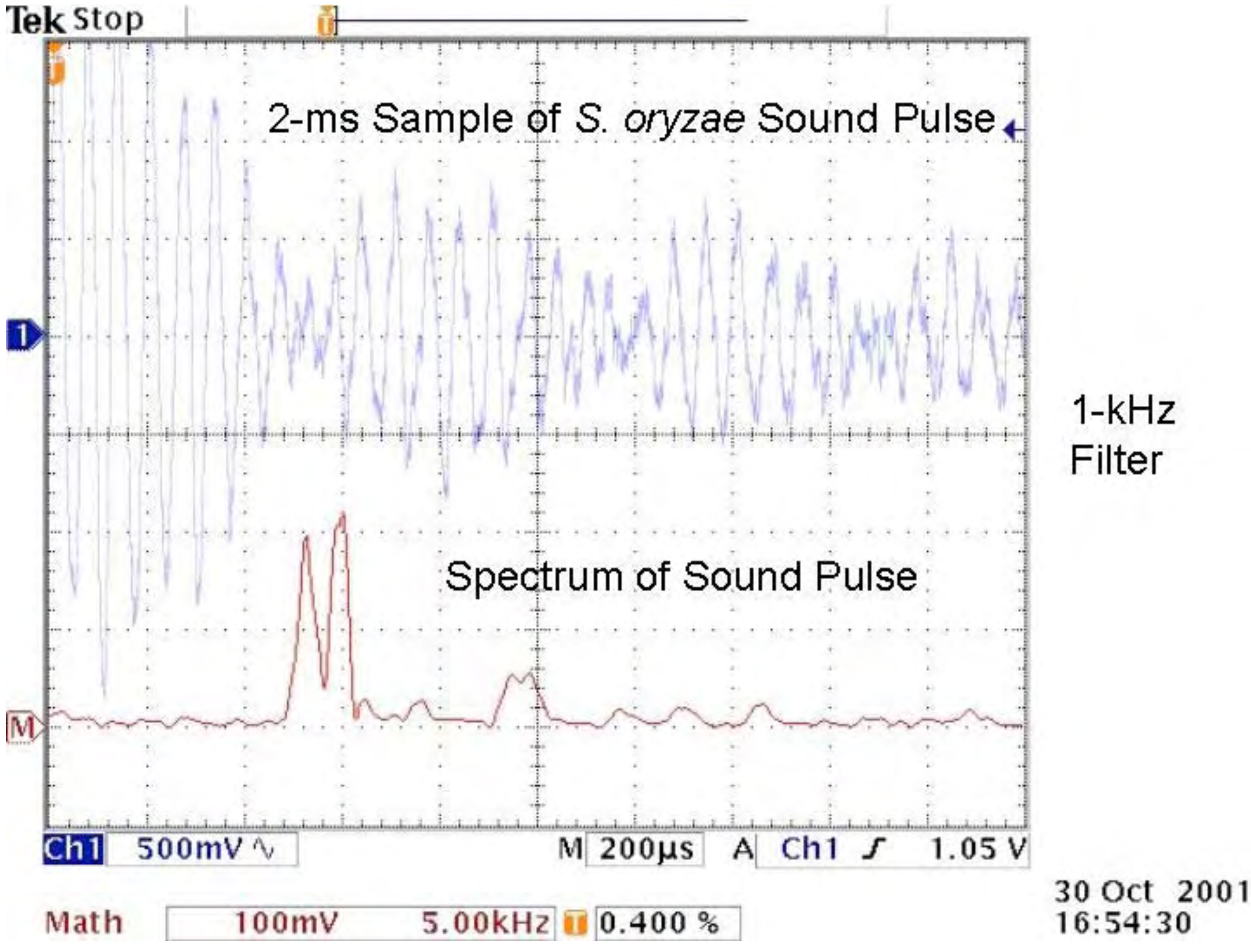

Figure 1. (Top) Sound pulse recorded from *Sitophilus oryzae* using a 1-kHz high-pass filter (0.2 ms per division on horizontal axis); (Bottom) frequency spectrum of sound pulse (5 kHz per division on horizontal axis).

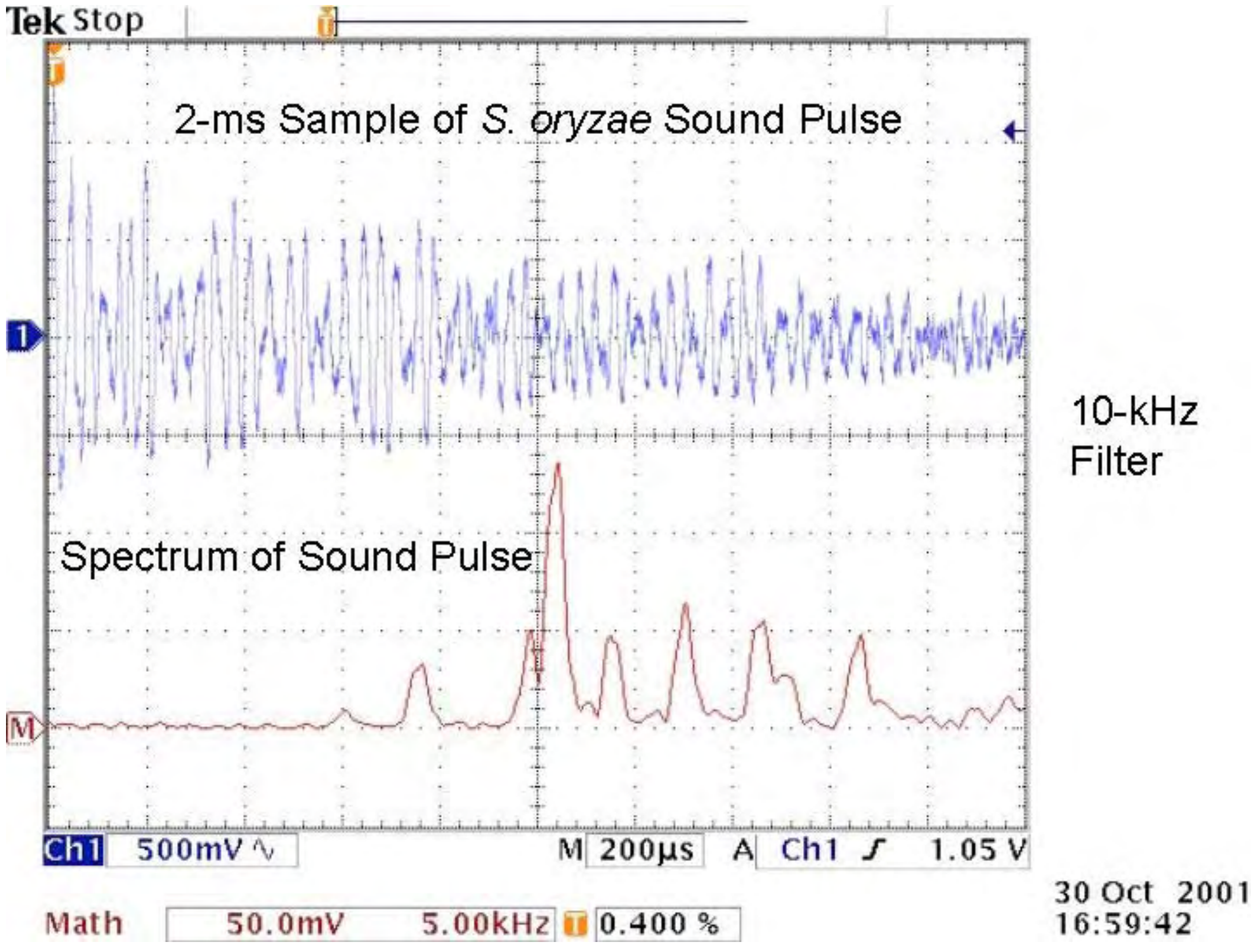

Figure 2. (Top) Sound pulse recorded from *Sitophilus oryzae* using a 25-kHz high-pass filter (0.2 ms per division on horizontal axis); (Bottom) frequency spectrum of sound pulse (5 kHz per division on horizontal axis).