Current and Potential Uses of Acoustic Systems for Detection of Soil Insect Infestations

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ABSTRACT

Acoustic sensors and signal amplifiers have been adapted to accommodate the special needs of subterranean insect pest detection and monitoring. The movement and feeding sounds of underground insects are short, low-intensity signals, 2-200 ms in duration with peak energy between 0.5-1.5 kHz. Acoustically shielded sensors have been developed with waveguides that can be easily inserted near the sites of infestation to improve the likelihood of detection. Easily operable, portable filters and amplifiers have been adapted from nonbiological applications, and user-friendly signal analysis software has been written to process and identify insect-generated sounds. In a recent field study, a new, handheld system was tested for its capability to detect late-instar black vine weevil grubs, *Otiorhynchus sulcatus*, in nursery plant containers in a moderately noisy background. These devices show considerable promise as research instruments and as tools for targeting subterranean insect infestations that would otherwise remain hidden from pest managers.

INTRODUCTION

Acoustic technology sensitive enough to detect hidden infestations of insects in soil, wood, and plant structures has been available since the early 20th century (Brain 1924). However, a high level of skill was needed to operate and maintain the equipment. Considerable training was required to reliably distinguish incidental moving and feeding sounds from background noise. Consequently, practical applications of acoustic detection technology were rare until the 1980’s (see references in Brandhorst et al. 2001, Mankin et al. 2000). The development of modern computer technology enabled digital signal processing techniques that facilitate discrimination of insect sounds from background noise and provided impetus for research on new acoustic tools to detect and monitor infestations of subterranean insect pests. Recently, acoustic technology has been adapted for detection of insects in forage fields (Brandhorst et al. 2001, Crocker et al. 2000), citrus groves (Mankin et al. 2001), and container crops (Mankin and Fisher 2002). In this report, we describe a field test of an acoustic detection system customized for subterranean insect detection applications, the AED-2000 (www.aeconsulting.com/aed-2000.html), and consider the future of such devices.

Acoustic sensors currently used for subterranean insect detection include microphones developed at the National Center for Physical Acoustics (Hickling et al. 1994, 2000), accelerometers (Mankin et al. 2001), piezoelectric disks adapted from studies to detect insects in stored grain (Shuman et al. 1993, Hagstrum et al. 1996), and piezoelectric crystals adapted from ultrasonic signal detection devices (Mankin and Fisher 2002). The microphones and piezoelectric disks are inserted directly into the soil (Mankin et al. 2000). The accelerometers and piezoelectric crystals are attached to waveguides. The microphone, accelerometer, and piezoelectric crystal sensors each have custom-built amplifiers with outputs for headphones and recorders. Studies with the piezoelectric disks (MuRata Erie model PKM28-2AO, Smyrna, GA) have used a Brüel and Kjær (B&K, Nærum, Denmark) model 2610 amplifier (Mankin et al. 2000).

Sounds generated by insects moving and feeding underground are typically 2-200 ms in duration and have significant energy between 0.5-1.5 kHz (Mankin et al. 2000). Frequencies at the higher end of this range are of most significance for distinguishing the sounds from low-frequency background noise. The ideal sensor/amplifier system for these applications would be highly sensitive below 1.5 kHz to capture the energy of weak signals, and would enable filtering of signals below ~0.7 kHz to facilitate signal/noise discrimination. The sensor would be shielded from airborne background noise and, because sound travels only short distances in soil (Mankin et al. 2000), the waveguide would be easily insertable near where the insects are expected to be present. Such considerations figured prominently in the design of the SP-1 sensor tested in this study.

METHODS

Insects and Plants. To investigate the operational characteristics of the customized sensor, acoustic tests were conducted in 15 nursery containers (#1 or #5) planted with Alberta spruce, *Picea glauca* (Moench) Voss 'Albertina'; Norway spruce, *Picea abies* (L.) Karst. 'Mariana Nana'; English yew, *Taxus baccata* L. 'Fastigiata'; bog rosemary, *Andromeda glaucophylla* Link; Virginia creeper, *Parthenocissus quinquefolia* (L.) Planch., or grape, *Vitis* spp., all of which are commonly attacked by the black vine weevil *Otiorhynchus sulcatus*

(Fabricius) in the Northwest US (Mankin et al. 2002). The study was conducted in experimental greenhouses at the USDA-ARS Horticultural Research Laboratory, Corvallis, OR, and at the Monrovia, Inc. nursery near Dayton, OR. The plants were grown in areas exposed to naturally occurring *O. sulcatus* infestations. Temperatures in the greenhouses were 18-25^{o}C. The roots of each plant were examined and any insects found were identified and weighed after the acoustic measurements.

One of the goals of this experiment was to determine if some of the stringent precautions to reduce background noise in previous experiments could be relaxed. Machinery and air conditioning equipment were turned off during these experiments, but the greenhouses had no acoustic insulation and we did not place the pots in sound- or vibration-shielded containers.

Acoustic Detection System. Acoustic signals were monitored using a SP-1 sensor that contained a 20-cm-long, 0.6-cm-diameter stainless steel waveguide attached to a custom-designed, PZT-5 (lead zirconate titanate) piezoelectric crystal sensor system with a 40-dB integrated preamplifier. The sensor housing was shielded to reduce airborne background noise. The spectral range of the sensor-preamplifier system was approximately 1-50 kHz. The waveguide was inserted into the nursery container and, after an initial 5-15 min resting period to allow for settling of disturbed soil, the acoustic signals were monitored for 3-min periods using an AED-2000 acoustic detection system (www.aeconsulting.com/aed-2000.html). The AED-2000 includes a 0-60-dB amplifier, a buffered output for oscilloscopes or recorders, headphones for audio monitoring and quality control, a serial port for computer logging and signal display, and an LCD display of signal intensity and sound pulse counts. The total gain was set at 80 dB and the threshold for registration of a sound pulse was set at 0.6 V after amplification. Threshold crossings separated by <1 ms were considered as belonging to a single sound pulse. During the experiments, external noises (doors slamming, electrical equipment cycling on or off, etc.) occurred that occasionally produced invalid counts even with the use of a 1 kHz filter. We restarted the monitoring periods whenever such events were observed.

RESULTS AND DISCUSSION

We anticipated that the SP-1 sensor measurements would only be moderately successful at predicting grub infestations because they were conducted under relaxed precautions against background noise during a period of low feeding activity. In the Willamette valley, *O. sulcatus* feed most vigorously during the fall and become sluggish as they begin pupating in March and April (e.g., Moorhouse et al. 1992). Consequently, the rate of sound production was expected to be lower than rates found in previous studies with subterranean insects (e.g., Mankin et al. 2001, Brandhorst et al. 2001). A reduced activity rate can be expected to increase the number of false negatives, where an infestation is found in a container in which no sound has been detected. Relaxed precautions against background noise can be expected to increase the number of false positives, where no insects are found in a container where significant noise is detected.

These expectations were confirmed in representative 3-min recordings listed in Table 1, where the containers are categorized into two groups of *medium* and *low* likelihood of infestation on the basis of sound activity ratings that had provided reliable predictions in previous studies. In Mankin et al. (2001), the likelihood of infestation was rated *high* if the insect sound rate exceeded 60 per 3-min record, *low* if it fell below a background noise level of 6 sounds per record, and *medium* in between. When the field-test samples were verified by visual inspection, insects were confirmed in all samples rated *high*, 71% of samples rated medium, and 36% of samples rated *low*. Applying these two thresholds to the current study, none of the containers were rated at a *high* likelihood of infestation, 63% of eight *medium*-rated containers were infested, and 57% of 7 *low*-rated containers were infested. Late winter is not the ideal time to reliably detect *O. sulcatus* larvae in container crops. To reliably detect larvae under these conditions would require a longer recording period and increased precautions to reduce background noises like those that apparently produced the false positive ratings in containers, *c9*, *m3*, and *c6*. With increased shielding precautions, the mean background rate of 7.7 sounds per 3-minute recording period would have decreased closer to the 1-2 sounds per 3-minute period typically detected in uninfested containers of soil kept in an anechoic chamber (Mankin unpublished).

Keeping such concerns about behavioral activity levels and background noise in mind, the customized acoustic detection system nevertheless shows considerable promise as a versatile tool for entomological research and insect pest management decisions. In research applications, for example, little is known about the biology and life history of many subterranean insect pest species. Long-term studies are now in progress in laboratories at Texas A&M University (Crocker et al. 2000) and Montana State University (Mankin et al. 2002) to use sound activity to monitor behavioral patterns of hidden insect larvae. There is also considerable potential for use of these devices as a pest management decision tool because subterranean pest infestations often are clustered rather than uniformly distributed (e.g., Brandhorst et al. 2001). In these cases, the use of pesticides can be reduced by targeting only those areas where infestations have been identified. Previously, there has often been no practical way to target the infestations. Finally, we anticipate that the development of robust, easily operable acoustic detection devices will enable improved testing of the efficacy of new integrated pest management treatments for subterranean insect pests, e.g., the use of kaolin dust foliar treatments to reduce *D. abbreviatus* larval populations (Lapointe 2000). The new system will be easier to operate in field environments where successful tests have already been conducted with less robust equipment. And continued improvements in sensor sensitivity, background noise shielding, and signal processing software will improve the reliability of acoustic detection systems for predicting hidden infestations of subterranean insects.

Table 1. Numbers of sounds detected in representative 3-min recordings from containers of different plant species, their associated computer-rated likelihood of infestation, and the numbers of *O. sulcatus* grubs subsequently recovered from the containers (listings are sorted in order of high to low numbers of sounds detected)

Container[1]	Plant species	No. sounds	Rated likelihood[2]	No. grubs
c3	*T. baccata*	41	*medium*	8
c5	*P. mariana nana*	31	*medium*	185
c9	*Vitis* spp.	22	*medium*	0
m1	*P. quinquefolia*	17	*medium*	25
c4	*T. baccata*	17	*medium*	36
m3	*A. glaucophylla*	12	*medium*	0
c2	*T. baccata*	10	*medium*	39
c6	*P. mariana nana*	8	*medium*	0
m4	*A. glaucophylla*	6	*low*	3
c10	*Vitis* spp.	6	*low*	0
c8	*P. glauca*	5	*low*	0
m5	*A. glaucophylla*	4	*low*	5
c1	*T. baccata*	4	*low*	11
m2	*P. quinquefolia*	2	*low*	12
c7	*P. glauca*	1	*low*	0

[1] Containers designated with *c* were monitored at the Corvallis laboratory and those designated with *m* were monitored at the Monrovia nursery.

[2] Basis of computer-rated likelihood of infestation: *medium*, ≥6 per 3-minute record, *low*, <6 per record (see text).

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