Evaluation of Pheromone Traps for Monitoring Sweetpotato Weevils

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ABSTRACT Ten types of pheromone traps for monitoring sweetpotato weevils, *Cylas formicarius* (F.) (Coleoptera: Brentidae), were evaluated in sweetpotato fields at the U.S. Vegetable Laboratory, Charleston, South Carolina, during 2001 and 2002. A funnel trap, a modification of a water-pan trap, and the Pherocon sticky trap were the most effective for capturing male sweetpotato weevil adults. A universal trap, Multipher trap, boll weevil trap, a trap constructed from a five-gallon pail, and a trap made from a milk jug also captured significant numbers of weevils. A Japanese beetle trap and the plastic Pherocon CRW kairomone trap were not effective for trapping sweetpotato weevils. In separate experiments in 2005 and 2006, a trap made from a recycled plastic (PET) soft drink bottle was significantly less effective than the universal trap. Universal traps and PET bottle traps with soapy water were as effective as traps with a dichlorvos insecticide strip for a killing agent. Captures of male sweetpotato weevils in universal traps ranged 0.0–6.0 adults per trap per day during a 6-year period, 2001–2006 at the U.S. Vegetable Laboratory. Except for 2005, when population levels were unusually low, weevil captures increased rapidly during August and continued at high levels until freezing weather in November or December each year. Peak captures were generally from mid-September to mid-October.

KEY WORDS *Cylas formicarius*, Brentidae, pheromones, sweetpotato, *Ipomoea*, population dynamics, traps

The sweetpotato, *Ipomoea batatas* (L.) Lam. (Convolvulaceae), is one of the world’s most important food crops, especially in developing countries, where it is a major source of sustenance and food security (Woolfe 1992, CIP 2004). The sweetpotato is also an important commercial crop in the United States (LaBonte & Cannon 1998). Throughout the world, production of the sweetpotato is severely limited by several insect pests, and improved pest management approaches for this crop are needed (Cuthbert 1967, Chalfant et al. 1990). The sweetpotato weevil, *Cylas formicarius* (F.) (=*Cylas formicarius elegantulus* [Summers]) (Coleoptera: Brentidae) (Anderson & Kissinger 2002), is the most important worldwide insect pest of the sweetpotato (Sutherland 1986a). This species is

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2Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.
widely distributed throughout much of the tropical and subtropical regions of the world, including coastal areas of the southeastern United States (Wolfe 1991). Losses inflicted by this pest can be severe both in storage facilities (Ray & Ravi 2005) and in the field, where yield losses can be as great as 60–97% (Mullen 1984, Sutherland 1986a, 1986b, Jansson et al. 1987).

Sweetpotato weevils damage sweetpotatoes by feeding on storage roots or in the crown of the plant (Sutherland 1986a, Jansson et al. 1990a). Adults are capable of flying at least 1 mile, they are nocturnal, and they are seldom seen on the plants during the daytime (Sakuratani et al. 1994, Shimizu & Moriya 1996). Jansson et al. (1990a) reported that approximately 80–90% of the weevil population is below the soil surface. Thus, it is difficult to determine infestation levels or root damage. The severity of infestations can only be accurately determined by digging up and dissecting the storage roots (Sutherland 1986b). This is not only a difficult process, but it also destroys a portion of the crop. Therefore, monitoring adult populations with pheromone traps has become an important component of integrated pest management (IPM) programs in many countries in Asia (Talekar 1991, Hwang & Hung 1991, Palaniswamy et al. 1992, Chiranjeevi & Reddy 2003), Africa (Smit et al. 1997, 2001), and the Caribbean (Alvarez et al., 1996, Alcázar et al. 1997, Jackson et al. 2002).

Coffelt et al. (1978) isolated and bioassayed the female-produced sex pheromone of *C. formicarius* in the laboratory. Heath et al. (1986) later purified, identified, and synthesized the active component as (Z)-3-dodecen-1-ol (E)-2-butenoate. Subsequent studies have reported on new synthesis procedures or formulations that improve safety, reduce costs, or enhance efficacy of this material (Yen & Hwang 1990, Lo et al. 1992, Pawar et al. 1993, Mithran & Subbaraman 1999, Sureda & Quero 2006). A synthetic sex pheromone has been evaluated in field experiments in the United States (Jansson et al. 1989, Heath et al. 1991), St. Croix, U. S. Virgin Islands (Proshold et al. 1986), Taiwan (Talekar & Lee 1989), Japan (Yasuda et al. 1992), India (Teli & Salunkhe 1993), Venezuela (Marchano et al. 1994), Indonesia (Braun & van de Fliert 1999), and Vietnam (Hao et al. 1996). Several studies have shown a positive relationship between trap captures and pheromone dosage between 10 ng and 1 mg (Proshold et al. 1986, Mason et al. 1990, Jansson et al. 1990b, 1992, Hao et al. 1996), but trap counts were not consistently correlated with pheromone dosage at low population densities of weevils (Jansson et al. 1991, 1992). Sugimoto et al. (1994a) reported that the average attractive distance for a lure with 100 or 400 μg of pheromone was 55 and 64 m, respectively. Jansson et al. (1991) suggested that a dosage of 10 μg was adequate for monitoring traps, but that higher dosages might be required for mass trapping or mating disruption applications. Pheromone lures for sweetpotato weevils have been used up to 3 months in the field (Pillai et al. 1993) and, in Florida, 2-month-old rubber septa with 10 μg of pheromone performed as well as new lures (Mason et al. 1990). Jansson et al. (1991) reported that the sweetpotato weevil sex pheromone is relatively stable on rubber septa and that lures remain active for at least 30–64 days. However, Hwang (2000) showed that the effectiveness of 2-month-old lures was reduced. Thus, it is often recommended that lures be changed monthly (Hwang 2000).

The sweetpotato weevil sex pheromone has several IPM applications, including quarantine pest detection (Hammond et al. 1989, Anonymous 2006a), population monitoring (Jansson et al. 1990a, Teli & Salunkhe 1993, Sugimoto et al.
mass trapping (male annihilation) (Setokuchi et al. 1991, Yasuda 1995, Smit et al. 2001), mating disruption (Mason & Jansson 1991), and eradication efforts (Komi 2000). This pheromone can also be used in attracticide formulations (Yasuda et al. 2004) or as the attractant for an auto-infection (autodissemination) device for distributing entomopathogens, such as the fungus Beauveria bassiana (Balsamo) Vuillemin (Deuteromycotina) (Yasuda 1999). Continuous trapping can significantly reduce male weevil populations and potentially protect storage roots (Talekar & Lee 1989, Jansson et al. 1991). Trapping has been shown to reduce the proportion of roots damaged by sweetpotato weevils in the Caribbean (Alvarez et al. 1996, Alcázar et al. 1997). Hwang (2000) estimated that use of pheromone-baited traps as part of an IPM program for sweetpotato weevils could eliminate one to three insecticide applications.

Several states in the southern United States have quarantine programs for limiting the spread of sweetpotato weevils (Nilakhe 1991, Anonymous 2006a, 2006b). Through quarantine detection and suppression efforts, sweetpotato weevils have been eradicated several times from the weevil-free zones of states with sweetpotato production (Jackai et al. 2006). The North Carolina Department of Agriculture (NCDA) uses screen-cone boll weevil traps with the sex pheromone at a density of one trap per 4.1 ha (10 acres), with a minimum of two traps per field (Anonymous 2006a). A commercial boll weevil trap is also listed for monitoring sweetpotato weevils by the National Agricultural Pest Information System (NAPIS) (Anonymous 2002). Hammond et al. (1989) showed that a screen-cone boll weevil trap was more effective than one with a solid cone at relatively low sweetpotato weevil populations. In a study from Louisiana and North Carolina, where there were low population densities of sweetpotato weevils, trap captures for funnel traps, universal traps, and boll weevil traps could not be differentiated (Jansson et al. 1992). However, Jansson et al. (1989, 1992) reported that the boll weevil trap was much less effective than universal traps or funnel traps at higher population levels of sweetpotato weevils.

Proshold et al. (1986) tested several trap designs in St. Croix and found that aluminum and plastic funnel traps were the most effective for capturing adult males. Jansson et al. (1989) reported that a modification of this trap with a plastic funnel was 85% efficient, compared with 49% efficiency for a plastic boll weevil trap in south Florida. Subsequently, hand-made variations of the funnel trap design have been evaluated in several countries (Talekar & Lee 1989, Yasuda et al. 1992, Sugiyama et al. 1996, Smit et al. 1997). Under high population densities in southern Florida, Jansson et al. (1992) found that the funnel trap worked better than the universal traps, partly because the lip of the universal trap impeded movement of weevils into this trap. Most weevils are captured within one meter of the ground (Sugimoto et al. 1994a), and it has been reported that the optimum height of the openings into the funnel trap is just above the height of the plant canopy (Proshold et al. 1986, Jansson et al. 1992). Because the nocturnal male weevils often crawl to the uppermost leaves of sweetpotato plants (Proshold et al. 1986), pheromone traps surrounded by foliage capture more insects than those not surrounded by plants (Jansson et al. 1992, Marcano et al. 1994). It also has been suggested that trap efficiency is increased if a wire-mesh “ladder” is provided for weevils to crawl up into the funnel trap (Proshold et al. 1986, Jansson et al. 1989, Heath et al. 1991).

Setokuchi et al. (1991) developed a square funnel-plastic box trap that was a
modification of the original funnel trap of Proshold et al. (1986). This design was used by Sugimoto et al. (1994a, 1994b) to estimate the attractive area of the pheromone and to estimate weevil population sizes in Japan. Sugiyama et al. (1996) developed a cylindrical trap from polyvinyl chloride (PVC) pipe, which was as effective as the funnel trap, captured fewer nontarget organisms, and cost less to construct.

Simple water-pan traps are often used in developing countries (Talekar & Lee 1989, Islam et al. 1992, Pillai et al. 1993, Braun & van de Fliert 1999). Talekar (1988) illustrated a simple, inexpensive trap with a water-pan supported in the middle of a truncated woven-wire cone 25 cm from the soil surface, and he recommended that the pheromone lure be suspended from the trap cover above the water pan so that it is 10–20 cm above the crop canopy. Other researchers have used a trap made from a pan or other open container filled with soapy water and with the pheromone lure suspended above it (Marcano et al. 1994, Alvarez et al. 1996, Braun & van de Fliert 1999). Although soapy water has been used most often as the killing agent for trapping sweetpotato weevils (Pillai et al. 1993, Smit et al. 1997), dichlorvos strips have also been used in traps with closed collection chambers (Proshold et al. 1986, Sugiyama et al. 1996, Hwang 2000). Pillai et al. (1993) illustrated a metal water-pan trap similar to the one Talekar (1988) used, and they reported that traps made from empty oil tins were used by farmers in Kerala, India. A similar trap was illustrated by Ray & Ravi (2005). Islam et al. (1992) described a new water pan trap for use in mass trapping sweetpotato weevils in Bangladesh.

Sticky traps of various designs have been tested for monitoring sweetpotato weevils (Proshold et al. 1986, Talekar & Lee 1989, Setokuchi et al. 1991, Yasuda et al. 1992, Smit et al. 1997, Sureda & Quero 2006). The pheromone-baited sticky trap tested by Yasuda et al. (1992) caught as many weevils as water-pan traps. When set on the ground, these sticky traps caught more weevils than traps at heights up to 300 cm (Yasuda et al. 1992). Disk-shaped sticky traps worked better than homemade traps constructed from 1-L soft drink bottles, 5-L jerry cans, or 4-L oil cans in Africa (Smit et al. 1997). However, because they were inexpensive, easy to construct, robust, and effective, 5-L jerry can traps were the best design for trapping African Cylas species (Smit et al. 1997). The 5-L jerry can traps were later used in mass-trapping studies (Smit et al. 2001). These traps had the added advantage of being larger than other designs so the trapped weevils did not have to be removed and the soapy water did not have to be replenished as often as in smaller traps.

Several variations of weevil traps made from recycled plastic containers have been tested (Talekar & Lee 1989, Hwang & Hung 1991, Alvarez et al. 1996, Smit et al. 1997, Downham et al. 1999, Lawrence & Meyers 1999). Hwang et al. (1989) developed a double funnel trap from discarded 1-L polyethylene terephthalate (PET) soft drink bottles. Clear bottles worked better than green ones, and there was no significant difference in trapping efficiency for traps with funnel diameters between 8.8 and 12 cm (Hwang 2000). Lo et al. (1992) illustrated a double-funnel version of this PET-bottle trap that they used for field evaluations of the formulation of C. formicarius sex pheromone they had synthesized. A commercial variation of this trap is now produced in China and Taiwan at a low cost (Hwang 2000). A slight modification of this trap was a good design for capturing C. puncticolis in Africa, but it was difficult to construct and not sturdy (Smit et al. 1997).
PET-bottle traps of similar designs have also been used to trap cutworms, *Spodoptera litura* (F.) (Lepidoptera: Noctuidae), in Korea (Anonymous 2001), *Agriotes brevis* Candeze (Coleoptera: Elateridae) in Europe (Tóth et al. 2002), and wasps and bees (Baxendale et al. 2002). Many other examples of home-made bottle traps of similar design can be found on the Internet.

For their IPM project in the Dominican Republic, Alvarez et al. (1996) used pheromone traps made from recycled plastic gallon containers with windows cut into them. This trap is similar to the one illustrated by Lawrence & Meyers (1999) for use in IPM of sweetpotato in the Caribbean. While visiting a grower’s field in Antigua in November 2000, we were shown a new sweetpotato weevil trap that had been constructed by a grower from a five-gallon pail. This design has several advantages over the milk-jug trap (Lawrence & Meyers 1999), which has been recommended for use in Jamaica.

Although some current trap designs are effective, they may be cumbersome, difficult to maintain, or expensive. Thus, simple, cost-effective, and efficient traps are needed for monitoring sweetpotato weevils in the United States and in developing countries. The purpose of the research described herein was to evaluate commercially available and home-made pheromone traps for monitoring sweetpotato weevils.

**Materials and Methods**

**U.S. Vegetable Laboratory (USVL) survey traps, 2001–2006.** As part of the sweetpotato weevil reduction protocols at the USVL, Charleston, South Carolina, universal traps (Great Lakes IPM, Vestaburg, Michigan) were monitored continuously from April 2001 to December 2006. Each year, a single universal trap was placed on the ground near the edge of each of three to six fields (0.7–1.1 ha.) at the USVL. Traps were baited with rubber septa lures containing 12 µg of synthetically produced sex pheromone of the sweetpotato weevil (Product no. AGS-SPW, Great Lakes IPM, Vestaburg, Michigan). Traps were checked and emptied at least weekly during the sweetpotato growing season, but were checked less frequently (every 2–4 weeks) during the winter months. During this 6-year period (2050 days), traps were monitored 362 times, and pheromone lures were changed monthly.

**Evaluation of different trap types, 2001–2002.** Ten types of pheromone-baited traps were evaluated for their effectiveness in trapping male sweetpotato weevils at the USVL in 2001–2002. Each year, two fields (0.7–1.1 ha.) that had been planted to sweetpotato genotypes from the USDA-ARS sweetpotato breeding program (Jackson & Bohac 2006) were used. Local production practices were followed, except that no insecticides were used. When rainfall was not adequate during the growing season, supplemental irrigation was applied.

Seven types of traps were evaluated in the two field replications in 2001: 1) modified water-pan trap (Talekar 1988) constructed by us; 2) modified funnel trap (Proshold et al. 1986) constructed by us; 3) universal trap with yellow funnel, white bottom, and green cover (Great Lakes IPM, Vestaburg, Michigan); 4) prototype 5-gallon (18.9-L) plastic-pail trap constructed by us; 5) modified 1-gallon (3.8-L) plastic milk-jug trap (Lawrence & Meyers 1999) constructed by us; 6) Japanese beetle trap (Great Lakes IPM, Vestaburg, Michigan); and 7) Pherocon® CRW (corn rootworm) kairomone trap (Trécé, Inc., Salinas, California) (Lingren...
2000, 2002; Trécé Inc. 2006). Eight types of traps were evaluated in the two field replications in 2002: 1) modified water-pan trap, 2) modified funnel trap, 3) universal trap, 4) plastic-pail trap, 5) milk-jug trap, 6) Pherocon 1C sticky trap (Trécé, Inc., Salinas, California), 7) Multipher 3 trap (Les Services Bio-Contrôle, Inc., Quebec, Canada), and 8) screen-cone boll weevil trap (Great Lakes IPM, Vestaburg, Michigan) (Dickerson et al. 1981). Photographs of these traps in the field were shown by Jackson (2003).

Within a field, traps were randomly assigned to flagged locations in two rows that were at least 20 m apart and at least 20 m from the edge of the field. Within rows, traps were evenly spaced at least 20 m apart. In 2001, baited traps were put into sweetpotato fields on 29 June, and they were monitored twice a week (each Tuesday and Friday) until 29 November. There were 43 sampling dates over the course of 22 weeks in 2001. In 2002, baited traps were put into sweetpotato fields on 7 June, and they were monitored as in 2001 until 13 November. There were 44 sampling dates over the course of 23 weeks in 2002.

All traps were baited with rubber septa lures containing 12 µg of pheromone. Lures were changed monthly, and traps were rotated to a new field position each week (Tuesday). A pheromone lure was hung by a thin wire in the center of each funnel trap so that the septum was centered in the holes in the funnel. For the water-pan trap, a pheromone lure was hung from the cover by a thin wire so that the septum was suspended just above the water reservoir. A pheromone lure was hung inside the Japanese beetle trap near the bottom of the funnel. For the milk jug trap and plastic-pail trap, pheromone lures were hung inside the trap by a thin wire so that the septum was centered with the openings into the trap. A pheromone lure was placed inside the collection chamber of the CRW kairomone trap above the soapy water. The universal and Multipher 3 traps have a small plastic holder with slits to hold a pheromone lure. A pheromone lure was placed in the center of the bottom panel of the sticky trap.

Modifications to the funnel trap (Proshold et al. 1986) included a plastic funnel (17 cm diameter × 17 cm long), a plywood cover (40 cm square), and a cylindrical support (35 cm diameter × 50 cm tall) made from galvanized hardware cloth (1.27 cm × 1.27 cm mesh) (The Home Depot, Atlanta, Georgia). This trap design is similar to the one illustrated by Heath et al. (1991) and Jansson et al. (1991). We modified the water-pan trap after the design of Talekar (1988). We used the bottom portion of a universal trap (15 cm diam. × 12 cm deep), to which four wooden dowels (6-mm diameter × 15 cm long) were attached vertically with clear hot-melt glue (Glue Stix®, Model AP10–4, Arrow Fastener Co., Inc., Saddle Brook, New Jersey). These dowels were then pushed into the existing sockets on the green cover (16-cm diameter) of the universal trap (the yellow funnel portion of the universal trap was not used). In the field, this trap was seated tightly into the top end of a truncated cone (60 cm tall × 60-cm diameter) constructed with galvanized hardware cloth (0.32 cm × 0.32 cm mesh; The Home Depot, Atlanta, Georgia). The plastic-pail trap was constructed from a round 3.8-L plastic pail (37 cm tall × 30 cm diam., 0.070 mil high-density polyethylene) with a lid (Leaktite, Leominster, Massachusetts). Two rectangular holes (5 cm × 29 cm) were cut into the side of the pail 15 cm from the bottom. The milk-jug trap was made from recycled white plastic (high-density polyethylene) milk containers that had been purchased from a local supermarket. Large rectangular holes were cut into the front and back of the milk jug to allow entrance of weevils.
Soapy water was placed in the collection reservoirs of the water-pan trap, funnel trap, milk-jug trap, plastic pail-trap, universal trap, CRW kairomone trap, and Multipher trap. The soapy water contained 5 ml of liquid Ultra Palmolive® Antibacterial Hand Soap (Colgate-Palmolive Company, New York, New York) per liter of tap water. Small holes in the water reservoirs of the universal trap and the modified Talekar trap were plugged with clear hot-melt glue. The boll weevil trap, Japanese beetle trap, and sticky trap do not have reservoirs for water.

The universal trap, milk-jug trap, Japanese beetle trap, Multipher, and sticky trap were suspended by a wire attached to a conduit-pipe support that was bent at a right angle. The boll weevil trap was supported by a 50 cm-long wooden dowel that was attached to the bottom of the trap at one end and pushed into the soil at the other end. The CRW kairomone trap was supported by a 45-cm long piece of 1/2-inch (1.27-cm) PVC pipe (Schedule 40 rigid conduit, Cantex, Mineral Wells, Texas). One end of the PVC pipe was inserted into a socket on the bottom of the collection chamber and the other end was pushed into the soil. The plastic-pail trap was set directly on the soil within the plant canopy. A wire-mesh cylinder supported the collection funnel of the modified funnel trap and was part of its design. The water-pan trap was supported by a hardware-cloth cone as discussed above. The height of each trap was positioned so that the pheromone lure was located about the same height as the top of the plant canopy (approximately 45–60 cm above the soil).

Current prices for the commercially available traps from Great Lakes IPM (Vestaburg, Michigan) are 1) $2.21 for the Pherocon 1C sticky trap, 2) $3.25 for the boll weevil trap, 3) $3.68 for the CRW trap, 4) $8.95 for the universal trap, and 5) $10.50 for the Japanese beetle trap. The primary cost of the plastic-pail trap is for the pail, which can be purchased for $4.00–$7.00 (various internet sources) depending on quality of the plastic and the quantity purchased. There was essentially no cost for the recycled materials and minimal costs for labor to construct the milk-jug traps (Lawrence & Meyers 1999). On the other hand, construction times and material costs are substantial for the water-pan trap ($12.00 plus labor costs) and funnel trap ($6.50 plus labor costs). The water-pan trap would be much less expensive if a cheaper pan were used instead of the bottom portion of a universal trap, which contributed $8.95 of the cost.

**Evaluation of PET-bottle trap, 2005–2006.** In 2005 and 2006, a separate experiment was set up to evaluate a trap made from recycled 2-L PET soft drink bottles, which were compared with the universal trap. The PET-bottle traps were similar in design to those illustrated by Hwang (2000). Each type of trap was filled about half full with soapy water. In 2005, two replications were evaluated in two sweetpotato fields (0.7 ha. each) at the USVL. Traps were monitored approximately weekly for the entire year (6 January to 23 December 2005), which resulted in 45 trap collections. In 2006, there were six replications in six different sweetpotato fields at the USVL. Traps were monitored weekly for 20 weeks (13 July to 22 November 2006). Pheromone lures were changed monthly during each year.

**Evaluation of killing agents, 2006.** In 2006, a separate experiment was set up to determine the effectiveness of the killing agent in pheromone-baited universal traps. For this experiment, there were three treatments: 1) universal trap with 3–5 cm of soapy water, 2) universal trap with a 2.5-cm × 5-cm strip impregnated with 10% dichlorvos (2,2-dichlorovinyl dimethyl phosphate) (Hercon
Vaportape® II, Hercon Environmental Co., Emigsville, Pennsylvania), and 3) universal trap with both soapy water and dichlorvos strip. Vaportape II is labeled for use as a toxicant strip in insect traps for sweetpotato weevil (Anonymous 2006c). The dichlorvos strips were taped to the inside of the universal trap above the soapy water. Three replications were set up about 25 m apart within a 0.7 ha sweetpotato field at the USVL. Each replication had three trap locations that were 8 m apart. Three times per week, traps were monitored, emptied of trapped weevils, and rotated to a new within-replication trap location. This experiment was conducted for 7 weeks (28 July to 18 September 2006), during which time traps were monitored for sweetpotato weevils 21 times. New pheromone lures and dichlorvos strips were put in the traps on 28 July, 9 August, and 21 August.

In another experiment, the PET-bottle trap was tested with and without a dichlorvos strip, but soapy water was used in both treatments. The dichlorvos strips were taped to the inside of the PET-bottle trap above the soapy water. This experiment was conducted in four sweetpotato fields (four replications) for three months (28 July to 26 October 2006). Traps were monitored for sweetpotato weevils 11 times at weekly intervals. New pheromone lures and dichlorvos strips were put in the traps on 28 July, 19 August, and 21 September.

**Data analyses.** Data sets were analyzed by Bartlett’s test for homogeneity of variance (Steel & Torrie 1960) using HOVTEST in PROC GLM (SAS Institute 1999). Where appropriate, data were transformed by log$_{10}$ (x + 1.0) to correct for nonnormal distributions. Transformed data were subjected to repeated measures analysis using PROC MIXED with an autoregressive covariance structure, which effectively handles missing data points (SAS Institute 1999, Littell et al. 1996, 1998). The repeated measures were dates that traps were checked. Treatment means were separated by Tukey’s $\omega$-procedure ($P < 0.05$) (Steel & Torrie 1960). Untransformed data are presented in the tables.

**Results**

**USVL survey traps 2001–2006.** Sweetpotato weevil trap captures varied widely among collection dates (Fig. 1). Few individuals were captured until about June of each year. Trap captures typically peaked in mid-September through mid-October each year, and populations remained high until sustained cold winter weather. Because of continued warm weather, weevils were collected well into the new year of 2002, 2003, and 2005.

**Evaluation of different trap types, 2001–2002.** The 2001 experiment showed highly significant effects for trap type ($F = 15.88$, df = 6, 301, $P < 0.0001$); thus, treatment means were separated by Tukey’s $\omega$-procedure ($P < 0.05$) (Table 1). Analysis also revealed that there were significant effects of sampling date ($F = 1.51$, df = 42, 301, $P = 0.029$), but trap type by sampling date interactions were not significant ($F = 0.39$, df = 252, 301, $P = 1.000$). In 2001, the water-pan trap, funnel trap, and plastic-pail trap worked significantly better than the other trap designs for collecting sweetpotato weevils (Table 1). The CRW kairomone trap and the Japanese beetle trap performed poorly in 2001, and they were dropped from the study for 2002.

The data showed highly significant effects for trap type in 2002 ($F = 29.37$, df = 7, 352, $P < 0.0001$). Because of significant treatment effects, means were separated by Tukey’s $\omega$-procedure ($P < 0.05$) (Table 1). Analysis also revealed that
there were significant effects of sampling date ($F = 9.15, df = 43, 352, P < 0.0001$), but trap type by sampling date interactions were not significant ($F = 1.11, df = 301, 352, P = 0.181$).

In 2002, the water-pan trap, funnel trap, sticky trap, and universal trap worked significantly better than the other trap designs (Table 1). The Multipher trap was more effective than the milk-jug trap, plastic-pail trap, and boll weevil trap, which were the least effective traps in 2002. Interestingly, the plastic-pail trap did not work as well in 2002 as it did in 2001.

**Evaluation of PET-bottle trap, 2005–2006.** For the evaluation of the PET-bottle trap, repeated measures analysis showed highly significant effects for trap type in 2005 ($F = 15.95, df = 1, 101, P < 0.0001$) and 2006 ($F = 10.11, df = 1, 192, P = 0.0017$). Each year, the universal trap captured significantly more male sweetpotato weevils than did the PET-bottle trap (Table 2). This analysis also revealed that there were significant effects of sampling date (2005, $F = 9.15, df = 44, 101, P < 0.0001$; 2006, $F = 2.98, df = 19, 193, P < 0.0001$), but trap type by sampling date interactions were not significant (2005, $F = 1.18, df = 44, 101, P = 0.243$; 2006, $F = 0.45, df = 19, 192, P = 0.9783$).

**Evaluation of killing agents, 2006.** There were no significant differences in the average numbers of male sweetpotato weevils captured in universal traps containing different killing agents ($F = 2.49, df = 2, 4, P = 0.198$). Although the traps with a dichlorvos strip alone tended to capture higher numbers of weevils ($3.07 \pm 0.37 \text{ [± SE] weevils/trap/day}$) than the traps with soapy water ($2.16 \pm 0.26$.)
Table 1. Mean number (±SE) of adult male sweetpotato weevils captured in 10 types of pheromone-baited traps at Charleston, SC, 2001 and 2002.\(^a\)

<table>
<thead>
<tr>
<th>Trap type</th>
<th>Mean number of weevils per trap per day (±SE)</th>
<th>Total number of weevils captured</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2001(^b)</td>
<td>2002(^b)</td>
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<tr>
<td>Water-pan trap</td>
<td>3.52 ± 0.70 a</td>
<td>2.28 ± 0.34 a</td>
</tr>
<tr>
<td>Funnel trap</td>
<td>3.21 ± 0.53 a</td>
<td>2.09 ± 0.34 ab</td>
</tr>
<tr>
<td>Sticky trap</td>
<td>—(^c)</td>
<td>1.86 ± 0.22 ab</td>
</tr>
<tr>
<td>Plastic-pail trap</td>
<td>2.29 ± 0.42 a</td>
<td>0.56 ± 0.11 d</td>
</tr>
<tr>
<td>Universal trap</td>
<td>0.95 ± 0.18 b</td>
<td>1.45 ± 0.17 b</td>
</tr>
<tr>
<td>Multipler 3 trap</td>
<td>—(^c)</td>
<td>.89 ± 0.11 c</td>
</tr>
<tr>
<td>Milk-jug trap</td>
<td>0.66 ± 0.16 bc</td>
<td>0.54 ± 0.13 d</td>
</tr>
<tr>
<td>Boll weevil trap</td>
<td>—(^c)</td>
<td>49 ± 0.08 d</td>
</tr>
<tr>
<td>CRW kairomone trap</td>
<td>0.32 ± 0.11 bc</td>
<td>—(^c)</td>
</tr>
<tr>
<td>Japanese beetle trap</td>
<td>0.17 ± 0.04 c</td>
<td>—(^c)</td>
</tr>
</tbody>
</table>

\(^a\)For each year, means followed by a common letter are not significantly different as determined by Tukey’s \(q\)-procedure (\(P < 0.05\)) (Steel & Torrie 1960).

\(^b\)In 2001, traps were monitored 43 times over 22 weeks (29 June–29 November), and in 2002, traps were monitored 44 times over 23 weeks (7 June–13 November); thus each mean was calculated from 86 data points in 2001 and 88 data points in 2002.

\(^c\)Trap not evaluated this year.

weevils/trap/day) or the soapy water-dichlorvos combination (2.48 ± 0.33 weevils/trap/day), these results were not significantly different.

The addition of a dichlorvos strip also did not affect captures of male sweetpotato weevils in the PET-bottle traps (\(F = 0.24\), df = 1, 63, \(P = 0.625\)). A total of 328 male weevils were trapped in the PET-bottle traps without insecticide (1.06

Table 2. Mean number (±SE) of adult male sweetpotato weevils captured in two types of pheromone-baited traps at Charleston, South Carolina, 2005 and 2006.

<table>
<thead>
<tr>
<th>Trap type</th>
<th>Mean number of weevils per trap per day (±SE)</th>
<th>Total number of weevils captured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005(^a)</td>
<td>2006(^a)</td>
</tr>
<tr>
<td>Universal moth trap</td>
<td>0.51 ± 0.05(^b)</td>
<td>1.47 ± 0.25(^b)</td>
</tr>
<tr>
<td>PET-bottle trap</td>
<td>0.15 ± 0.12</td>
<td>0.86 ± 0.12</td>
</tr>
</tbody>
</table>

\(^a\)In 2005, 2 replications of traps were monitored 45 times over the entire year (6 January–23 December), and in 2006, 6 replications of traps were monitored weekly for 20 weeks (13 July–22 November).

\(^b\)Significant treatment differences (\(P < 0.01\)) as determined by analysis of variance with repeated measures.
± 0.24 [± SE] weevils/trap/day) and 265 male weevils were trapped in PET-bottles with the dichlorvos strips (0.85 ± 0.20 weevils/trap/day).

Discussion

Several of the trap designs evaluated in this study were effective and could be used in the management of sweetpotato weevils. However, when choosing a pheromone trap, its primary purpose must be considered first. Traps for mass trapping, eradication, or autodissemination are likely to have different designs than those for population monitoring (Sugiyama et al. 1996, Yasuda 1999, Komi 2000, Smit et al. 2001). Also, a trap for quarantine detection (low population levels) might have a different design than a trap used to determine spray thresholds in production fields. The trap user must consider effectiveness, convenience, and cost. Certain traps, such as the Japanese beetle trap, CRW kairomone trap, and Multipher 3 trap, simply were not effective enough for trapping sweetpotato weevils to merit use. Other traps were effective, but inconvenient. For example, sticky traps are messy and the sticky panel must be replaced often as it quickly becomes covered with weevils, nontarget organisms, or soil and other debris (Talekar & Lee 1989, Smit et al. 1997). Some traps may be effective but relatively expensive to purchase (universal trap) or construct (funnel trap), especially for sweetpotato growers in developing countries (Jansson et al. 1991, Smit et al. 1997, Hwang 2000). Even in the United States, the cost of traps is not insignificant, as some states use large numbers of them in their monitoring programs. For example, in 2004 NCDA used 10,438 boll weevil traps to monitor 17,983 ha of sweetpotatoes in 4,954 fields (Anonymous 2006a).

No insect trap is perfect; each has its deficiencies. For example, the southern black widow spider, *Latrodectus mactans* (F.) (Araneae: Theridiidae) (Garb et al. 2004), was a frequent problem in funnel traps as the spiders often placed webbing over the entrance of the plastic funnel, thus preventing weevils from entering the collection bottle. Sugiyama et al. (1996) reported other disadvantages with the funnel trap were that it is expensive to construct, it catches many nontarget arthropods, it is bulky and hard to use, and it is sometimes dislodged by the wind.

The water-pan trap had the disadvantage of overflowing during heavy rain events, as the small cover allowed enough rain to enter and wash out trapped weevils. Conversely, during sunny periods, evaporation of water from the reservoir could be a problem; therefore, routine maintenance of water-pan traps is needed. These problems also affected the milk-jug trap, plastic-pail trap, and PET-bottle trap that had exposed water reservoirs. Another problem with these traps was the growth of mold and bacteria in the soapy water, which occasionally made accurate counting of weevils difficult. This was especially problematic when large numbers of nontarget organisms contaminated the water and when traps were monitored less frequently. The problem could be partially mitigated by the addition of a few drops of 6% sodium hypochlorite (Clorox Germicidal Bleach, Clorox Professional Products Company, Oakland, California). However, we observed that excessive sodium hypochlorite negatively affects trap captures, so researchers should use this product with caution.

Although the PET-bottle trap caught fewer total sweetpotato weevils than the universal trap over the course of the experiments in 2005 and 2006, there were several dates in which the PET-bottle trap caught more insects. A closer inspec-
tion of the data indicates that on certain dates the PET-bottle trap worked poorly compared with the universal trap. These poor trapping dates correspond to periods of high rainfall when weevils were apparently washed out of the uncovered PET-bottle traps. Interestingly, the PET double-funnel bottle-trap illustrated by Hwang et al. (1989) also was uncovered, but the authors did not report problems caused by excessive rain. We now construct our PET-bottle traps with small drain holes on the side to allow rain to drain without washing out the insects. Unfortunately, heavy downpours still can overflow the traps, so we are exploring ways of providing inexpensive covers for the traps.

Interestingly, some of the sweetpotato weevil traps commonly used are less effective than the water-pan trap and funnel trap. For example, the milk jug trap that is recommended for use in the Caribbean (Lawrence 1999) was relatively ineffective in our study. The larger, plastic-pail trap, first observed in Antigua, worked somewhat better in our study in 2001, but it was no better than the milk-jug trap in 2002. Because the milk-jug trap and other traps made from recycled containers are economical and easy to produce, their use in developing countries is understandable.

As previously reported (Jansson et al. 1989, 1992) and as shown in the present study (Table 1), the boll weevil trap is less effective than other trap designs for capturing adult male sweetpotato weevils. Nevertheless, commercial boll weevil traps are used in sweetpotato weevil quarantine programs in several states (Anonymous 2006b, Hammond et al. 1989). Their general availability, low cost, and ease of maintenance make them attractive for large-scale employment (Anonymous 2006a). Because there is no soapy water to replenish, traps can be left for long periods of time between monitoring without loss of data. The boll weevil trap has worked sufficiently well to detect sweetpotato weevil infestations into weevil-free areas of several states, and regulators are familiar with how to effectively use them in their monitoring programs (Anonymous 2006a, 2006b).

After being attracted by the pheromone lure, but before being captured, a sweetpotato weevil may leave the area and not be trapped. Also, weevils may escape from a trap, especially if no killing agent is used (Proshold et al. 1986, Jansson et al. 1992). This problem was not specifically addressed in this study, but it could potentially be a problem for certain trap designs like the boll weevil and Japanese beetle traps that did not have killing agents. Our study showed that the type of killing agent was not important, as soapy water worked as well as the insecticide pest strip in the universal and PET-bottle traps. Also, a combination of both soapy water and insecticide pest strip did not increase trap captures in universal traps. Hwang (2000) also reported that dichlorvos-impregnated strips did not affect capture of weevils in double-funnel PET-bottle traps with soapy water. These data indicate that once a weevil enters a trap, it is equally likely to be killed by falling into the soapy water as it is from dying from the insecticide. Researchers, extension personnel, and growers can use either technique, depending on which method best suits their circumstances.

The population levels of sweetpotato weevils at the USVL (maximum of 6 insects per trap day, Fig. 1) were much lower than reported for some tropical locations, where trap counts in the thousands of weevils per trap per day have been reported (Jansson et al. 1989, Talekar & Lee 1989). Jansson et al. (1991) reported that 20 traps in Florida averaged more than 2500 weevils per plastic-funnel trap per night during a 4-night period, and as many as 10,277 weevils have
been caught in one trap in one night. Even greater numbers have been reported outside the United States (Jansson et al. 1991). We suspect that pheromone traps perform differently at high population densities than they do at low population densities. We observed highly fluctuating trap counts from one sample period to the next (Fig. 1), which has also been reported in other studies (Jansson et al. 1989). It is not uncommon to have large fluctuations in trap counts from one sample (weekly or biweekly) to another (Proshold et al. 1986, Jansson et al. 1989). Jansson et al. (1989) attributed these fluctuations to environmental conditions, such as temperature, wind speed and direction, and rainfall. However, no significant correlations could be found between local temperature data and trap counts in our study.

Although pheromone traps may be effective in capturing male sweetpotato weevils, traps alone are usually not effective at controlling weevil populations (Talekar 1988, 1991). Current comprehensive IPM programs for the sweetpotato weevil recommend a combination of several cultural, biological, and chemical control practices, including the use of pheromone traps (Talekar 1988, 1991, Talekar & Lee 1989, Chalfant et al. 1990, Palaniswamy et al. 1992, Alvarez et al. 1996, Smit et al. 1997, Alcázar et al. 1997, Hwang 2000, Lagnaoui et al. 2000, Jackson et al. 2002). The best trap to integrate into a particular IPM program is a decision that must be based on a balance of trap efficacy, cost, availability, ease of use, and the economic situation of the country where it will be used. Thus, it is likely that some of the traps tested in this study may find use in sweetpotato IPM programs worldwide.

A sweetpotato weevil trap kit that is marketed commercially (Great Lakes IPM, Vestaburg, Michigan) uses the yellow and white universal trap. At the USVL, we also have chosen the universal trap as our standard for surveying sweetpotato weevils. Although this trap caught fewer sweetpotato weevils than some other trap designs in this study, it has several advantages that make it appropriate for our application. For instance, the universal trap can be used in buildings, greenhouses, and other locations not suitable for the sticky, funnel, or water-pan traps. Also, trap catches were less variable than for other traps as indicated by low standard error of the mean (Table 1) than some of the other designs. Data from this study are useful for establishing the efficacy of various trap designs for capturing male sweetpotato weevils, however, choice of a trap for a particular application must also take into account other considerations such as maintenance, cost, availability, and utility.

Acknowledgments

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