Efficacies of *Rhagoletis cerasi* (Diptera: Tephritidae) Traps and Ammonium Lures for Western Cherry Fruit Fly

Wee L. Yee

United States Department of Agriculture-Agricultural Research Service, Temperate Tree Fruit & Vegetable Research Unit, 5230 Konnowac Pass Road, Wapato, WA 98951 and Corresponding author, e-mail: wee.yee@ars.usda.gov

Received 21 March 2018; Editorial decision 12 May 2018

Abstract

Western cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera: Tephritidae), is a quarantine pest of cherries (*Prunus* spp.) in western North America that can be detected using sticky yellow rectangle traps. Recently, a related invasive fly from Europe and Asia, the European cherry fruit fly, *Rhagoletis cerasi* (L.) (Diptera: Tephritidae), was detected in eastern North America, prompting surveys for it in the West. Sticky crossed-panel yellow Rebell and cylindrical-type yellow PALz traps were developed for *R. cerasi* and are effective for monitoring it, raising the question of efficacies of three-dimensional versus rectangle traps against *R. indifferens*. Here, efficacies of the Yellow Sticky Strip (YSS) rectangle, thus far the best trap for *R. indifferens*, of three-dimensional versus rectangle traps against *R. indifferens*. Here, efficacies of the Yellow Sticky Strip (YSS) rectangle, thus far the best trap for *R. indifferens*, and Rebell and PALz traps with ammonium lures were determined for *R. indifferens* in Washington State. The Rebell and YSS traps caught similar numbers of *R. indifferens* and more than the PALz trap. Ammonium carbonate (AC) released more ammonia than ammonium acetate and attracted more *R. indifferens* to all three traps. The large surface area or shape of the Rebell trap was responsible for its high efficacy relative to the YSS. Results suggest that YSS and Rebell traps with AC would be equally useful for detecting *R. indifferens*, and that a crossed-sheet YSS trap could be even more efficacious than the YSS due to greater surface area. For *R. cerasi* detection surveys in Washington, the PALz trap would be preferred over the Rebell trap if they are equally efficacious against *R. cerasi*, as fewer *R. indifferens* would clutter traps.

Key words: *Rhagoletis indifferens*, European cherry fruit fly, Yellow Sticky Strip, Rebell trap, CSALOMON PALz trap

Western cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera: Tephritidae), is a major quarantine pest of cherries (*Prunus* spp.) in western North America. Various sticky yellow rectangle traps (e.g., Madsen 1970, Burditt 1988, Yee 2014) can be used to detect its presence to determine necessary control measures. The trap that has outperformed all other sticky yellow rectangles for catching *R. indifferens* is the plastic Yellow Sticky Strip (AgriSense, Pontypridd, United Kingdom) baited with ammonium carbonate (AC) (Yee 2014, Yee and Goughnour 2017). The trap is most effective when Tanglefoot adhesive (Tangle-Trap Insect Trap Tropical Formula; Contech Enterprises, Inc., Victoria, BC, Canada) is applied on top of the thin pressure sensitive adhesive already present on the trap, as the Tanglefoot retains more flies than the pressure sensitive adhesive (Yee and Goughnour 2017). Traps that capture the most flies where flies are abundant may also be the most useful for detecting low fly populations (Reissig 1975, AliNiaze et al. 1987, Eliopoulos 2007) threatening orchards.

Recently, an invasive fly from Europe and Asia that is also a pest of cherries, European cherry fruit fly, *Rhagoletis cerasi* (L.) (Diptera: Tephritidae), was detected in eastern North America (CFIA 2017, Anonymous 2017). This prompted surveys for it in western North America. Its presence there is important because it could necessitate additional insecticide sprays in cherry orchards, especially if emergence times of *R. cerasi* differ from that of *R. indifferens* during the cherry season. In Turkey and Hungary, the flight period of *R. cerasi* is earlier than that of the eastern cherry fruit fly, *Rhagoletis cingulata* (Loew) (Diptera: Tephritidae), a North American species closely related to *R. indifferens* that was introduced into Europe (Lampe et al. 2005, Plant Protection Institute 2017).

In Europe and Asia, the sticky crossed-panel yellow Rebell trap (Remund and Boller 1978, Živanović 1978, Kovanci and Kovanci 2006, Özdem and Kiliçner 2009, Daniel and Grunder 2012, Daniel et al. 2014) and the sticky CSALOMON cylindrical-type yellow PALz trap (PALz hereafter) (Plant Protection Institute 2017) were developed for *R. cerasi* and are effective for monitoring it. It therefore seems logical to use these traps to detect *R. cerasi* in surveys in North America. While sticky yellow rectangles are attractive to *R. cerasi* (Prokopy and Boller 1971, Russ et al. 1973), the Rebell trap was more effective for monitoring *R. cerasi* than the Scentry Multigard rectangle trap (Scentry Biologicals, Inc., Billings, MT) (Katsoyannos et al. 2000) and the Pherocon AM rectangle trap (Trece, Adair, OK)
In general, results suggest that three-dimensional traps could be better than rectangle traps for detecting *R. cerasi*. This raises the question of efficacies of three-dimensional Rebell and PALz traps for *R. indifferens*. Earlier work (Burditt 1988) showed that an unbaited sticky yellow Pherocon AM rectangle trap caught more *R. indifferens* than a Rebell trap with AC applied as bait, but a Rebell trap that had ammonia + protein mixed in adhesive (Zoecon AM bait), caught more than the Pherocon AM. However, the use of different attractants with the traps prevented direct comparison of trap efficacy. When used with an AC lure, the Pherocon AM trap caught fewer *R. indifferens* than the Yellow Sticky Strip (Yee and Goughnour 2017); therefore, Rebell and PALz traps need to be compared with the Yellow Sticky Strip to best evaluate their efficacies.

The choice of attractant for *R. cerasi* has been ammonium acetate (AA; Katsoyannos et al. 2000, Molet and Moylett 2016) or a mix of it and AC (Toth et al. 2016). This raises the question of whether AA can be as or more efficacious for *R. indifferens* than AC alone, a standard for this species (Frick 1952, Frick et al. 1954). For *R. cerasi*, Rebell traps with AA-based lures captured more flies than traps with AC lures (Katsoyannos et al. 2000). However, for *R. indifferens*, sticky red spheres with AC captured more flies than spheres with AA, but vertical yellow rectangles baited with one or the other attractant captured similar numbers of flies (Mayer et al. 2000). These results suggest attraction of *R. indifferens* to different ammonia sources may be affected by a trap’s visual stimuli. This hypothesis has not been tested.

Here, efficacies of Yellow Sticky Strip (YSS), Rebell, and PALz traps baited with ammonium lures were tested for attraction of *R. indifferens* in Washington State. The five objectives were to: 1) confirm that the YSS is the best sticky rectangle for *R. indifferens*, to establish a standard for all trap comparisons; 2) determine relative efficacies of Rebell, PALz, and YSS traps; 3) verify that AA lures are attractive; 4) determine efficacies of AC versus AA lures with different traps; and 5) determine if size and amount of adhesive affect the efficacy of Rebell versus YSS traps. Implications of results are discussed primarily with respect to detecting *R. indifferens* and how results could lead to a better trap for this species and secondarily for detection surveys for *R. cerasi* in western North America.

### Materials and Methods

#### Traps and Lures

Thirteen tests were conducted using yellow sticky traps and ammonium lures (Supp Table S1 [online only] and Table 1). In Test 1, seven different traps were compared:

| Trap          | Color space values* | Shape           | Total surface area; total sticky surface area, cm² |
|---------------|---------------------|-----------------|-----------------------------------------------------|
| YSS           | L* 68.5 a* −11.5 b* | Rectangle 14 × 23 cm | 644; 644                                             |
| Rebell        | L* 75.6 a* 0.5 b*   | Crossed panelsb | 1,310; 1,225                                         |
| PALz (CSALOMON PALz) | L* 85.9 a* −43.2 b* | Cylinder (folded, ends of rectangle secured)c | 815; 607                                             |
| One Panel of Rebbeld | L* 75.6 a* 0.5 b* | Rectangle 14.8 × 20.7 cm | 653; 653                                             |

| Lure name | Amount (g) | Lure type | Hole diameter (mm) | Mean ammonia release ± SE (μg/hr) |
|-----------|------------|-----------|---------------------|-----------------------------------|
| AC        | 5          | 2.8-cm diameter × 5.5-cm high plastic vialf | 1 | 1577 ± 142g, 1462 ± 51h |
| AA 1      | 5          | Same      | 1                   | 2.9 ± 0.2h                        |
| AA 2      | 5          | Same      | 3.2                 | 14.1 ± 0.3h                       |
| AA 3      | 5          | Same      | 10                  | 66.1 ± 3.7h                       |
| AA 4      | 5          | 5.3-cm diameter × 1.2-cm high dish; parafilm wrapped around perimeter | 3.2 | 27.9 ± 1.1h               |
| AA + AC 1 | 2.5 of each| 2.8-cm diameter × 5.5-cm high plastic vialf | 3.2 | 4457 ± 126h               |
| AA + AC 2 | 5 of each  | Same      | 4                   | 7132 ± 200h                       |

Manufacturers: YSS: AgriSense BCS Ltd, Treforest Industrial Estate, Pontypridd CF37 3SU, United Kingdom; Rebell: Andermatt Biocontrol AG, Stahlematten, Grossdietwill, Switzerland; PALz: Plant Protection Institute, Budapest, Hungary; AC from Keystone Universal Corp., Melvindale, MI; AA from Acros Organics, Fair Lawn, NJ.

*Measured from traps with no adhesive.

bEach panel 14.8 × 20.7 cm.

c35.6 × 22.9 cm as unfolded rectangle.

dFrom one of two panels of Rebell trap.

eAdhesive added to top portion of panel to match sticky area of YSS trap.

fThorton Plastics, Salt Lake City, UT.

gFor AC, weight loss method (35.45% of AC is ammonia), means from two 15 and 24 d laboratory exposures at 22°C and three field exposures of 15–24 d in July 2017.

hFor AC and AA, ammonia analysis-based Nessler’s reagent method of Rana and Mastrorilli (1998) at 22°C; four replicates.
Sticky yellow rectangle (14 × 23 cm) traps were compared—the YSS and six others that showed the highest responses by *Rhagoletis indifferens* in the laboratory (data not shown). These comprised the PZ, which was a sheet of the PALz trap cut into a 14- × 23-cm rectangle to facilitate comparisons with other rectangles, the Neon Yellow Plexiglass (never-tested before: new), Yellow (new), Pherocon AM, Corrugated (new), and Neon (new). In Tests 2–13, YSS, Rebell and PALz traps (Fig. 1) were deployed (YSS alone or against one or both of the other two), as was one panel of the Rebell trap (Table 1). All traps in Test 1 and YSS traps in all tests had ~10 g of Tanglefoot adhesive spread over the surface to form an ~1-mm-thick layer. The Rebell trap had Tanglefoot applied by the manufacturer (Great Lakes IPM Inc. 2017). PALz traps had an ~1-mm-thick layer of adhesive applied by the manufacturer that was not Tanglefoot. Colors of all traps without adhesive were measured using the L*a*b* color space system (Adobe Systems 2000) with a Chroma Meter (CR-400/410, Konica Minolta Sensing, Inc., Tokyo, Japan). Traps were placed in front of the color meter with white poster board 15 cm behind the trap being measured. The purpose was to show traps differed in shades of yellow and not what colors flies perceive, as L*a*b* color approximates human vision. The reflectance curve of the YSS (with Tanglefoot) is shown in Yee and Goughnour (2017) and that of the Rebell trap (no adhesive) in Daniel et al. (2014).

One AC lure, four AA lures, and two AC + AA lures were tested (Table 1). Lures contained 5 g of AC, AA, or 5 g of a 1:1 mix, except in one test where 10 g of a 1:1 mix was used. The 1:1 mix of AC:AA is the ratio in a commercial lure developed for *R. cerasi* (Toth et al. 2016). Ammonia release rate was regulated by varying hole diameters, and determined from the AC lure by measuring weight loss as well as using Nessler’s reagent following methods of Rana and Mastrorilli (1998) (Table 1). Because AA is hygroscopic, release rates from AA lures were only determined by the Nessler’s method. The release rate from the AC lure was within the 200–26,200 μg ammonia/hr from similar lures that maximize responses of *R. indifferens* to traps in cherry trees (Yee 2016).

Design of Trapping Tests
All 13 tests were conducted in June to August 2017 in sweet cherry trees (*Prunus avium* [L.] L.) at the USDA-ARS experimental cherry orchard in Moxee (46°29’43.86″ N, 120°10’22.96″ W; 471 m elevation) in Yakima County, or in wild seedling sweet cherry trees in Roslyn (47°13’12.57″ N, 120°59’16.70″ W; 674 m elevation) in Kittitas County. There were five replicates of each trap treatment in all tests. When there were more than two trap comparisons, a randomized complete block design was used. When there were two trap comparisons, a paired design was used. Traps were hung 1.5–2 m above ground. At Moxee, trees were ~3.7 m in diameter, arranged 6.1 m apart within rows, each row of trees comprising a replicate block, with blocks 6.1 m apart. The numbers of trees within a block depended on the test. Block locations were chosen based on previous work at this site (Yee 2016) showing that differences in fly densities existed among trees. One trap was hung on the south side of each tree ~6 m apart from other traps. At Roslyn, trees ranged from ~4.6 to 7.6 m in diameter. Because these were wild seedling trees, replicate blocks were not neat rows but pairs or groups of two to seven trees growing closely together with overlapping branches. Such sets of trees were limited at the site, so there was little choice of block location, although difficult to access trees were not used. Replicate blocks were ~3–33 m apart. One or two traps were hung in each tree within a replicate block. Traps were spaced at least 2.5 m apart on south or north sides of trees. At both Moxee and Roslyn, traps were checked every 1–4 d, at which time all flies were removed and counted. Traps were rotated each time they were checked (Table 2). Flies were identified as males or females in the laboratory.

Tests to Address Specific Objectives
From one to six tests were performed to address each of the five objectives (Table 2). Objective 1 (Test 1) was to confirm that the YSS was the best rectangle trap for *R. indifferens*, so that it could be compared as the standard with *R. cerasi* traps in subsequent tests. Objective 2 (Test 2) was to determine efficacies of YSS, Rebell, PALz, and PZ traps using AC, primarily to compare the PALz with the PZ trap against the YSS. Objective 3 (Tests 3 and 4) was to verify that *R. indifferens* is attracted to YSS baited with ammonium acetate 1 (AA 1) and ammonium acetate 2 (AA 2) lures (Table 1), as AA was not used in previous tests with YSS (Yee 2014, 2015, 2016; Yee and Goughnour 2017). Objective 4 (Tests 5–10) was to determine efficacies of AC, AA, and AC + AA lures that differed in ammonia release...
Table 2. Details of 13 trapping tests for *Rhagoletis indifferens* in Washington State, 2017

| Test | Dates         | Traps                                      | Lure | No. trap rotations (service intervals) |
|------|---------------|--------------------------------------------|------|----------------------------------------|
| 1    | 7–22 June     | All 14 × 23 cm (Supp Table S1 [online only]); YSS, PZ | AC   | 4 (2–4 d)                              |
| 2    | 12 June to 5 July | YSS, Rebell, PALz | AC, AA | 8 (2–4 d)                              |
| 3    | 27 June to 19 July | YSS | Blank, AA | 8 (1–3 d)                             |
| 4    | 10–26 July | YSS | Blank, AA | 6 (2–3 d)                             |
| 5    | 22 June to 5 July | YSS, Rebell, PALz | AC, AA | 4 (2 d)                                |
| 6    | 27 June to 11 July | YSS, Rebell | AC, AA | 5 (2–3 d)                             |
| 7    | 11–31 July | YSS, Rebell | AC, AA | 8 (2–3 d)                             |
| 8    | 31 July to 7 August | YSS | AC, AA | 2 (2–3 d)                             |
| 9    | 7–14 August | YSS, Rebell, PALz | AC, AA + AC | 3 (1–3 d)                             |
| 10   | 14–31 August | YSS | AC, AA + AC | 4 (3–4 d)                             |
| 11   | 19–31 July | YSS + TF, one panel of Rebell | AC   | 4 (2–3 d)                             |
| 12   | 26 July to 4 August | YSS + TF, Rebell + additional TF | AC   | 3 (2–3 d)                             |
| 13   | 31 July–7 August | YSS + TF, one panel of Rebell + additional TF | AC   | 2 (2–3 d)                             |

Table 3. Objective 1: Mean cumulative numbers of male and female *Rhagoletis indifferens* ± SE caught on YSS versus six other yellow sticky rectangles (all 14 × 23 cm or 644 cm² sticky surface) with AC lures in Moxee, Washington, 2017, ranked from highest to lowest; description of traps in Supp Table S1 (online only)

| Trap type             | Mean flies ± SE | Percent of catch on YSS |
|-----------------------|-----------------|-------------------------|
| YSS                   | 293.8 ± 40.9a   | —                       |
| PZ                    | 237.0 ± 20.0ab  | 80.7                    |
| Neon                   | 204.4 ± 31.5bc  | 69.6                    |
| Yellow                | 195.4 ± 28.7bc  | 66.5                    |
| Pherocon AM           | 193.6 ± 26.8bc  | 65.9                    |
| Corrugated            | 171.4 ± 14.3cd  | 58.3                    |
| Neon                  | 138.2 ± 26.1d   | 47.0                    |

Five replicates. Means followed by the same letter are not significantly different (*P > 0.05*).

Results

**Objective 1: Confirm YSS Is The Best Sticky Rectangle**

In Test 1, the YSS caught significantly more *R. indifferens* than five of the other six traps (*F* = 6.21; *df* = 6, 24; *P* = 0.0005) and numerically although not statistically more than the PZ (Table 3).

**Objective 2: Determine Relative Efficacies of YSS, Rebell, and PALz Traps**

In Test 2, YSS and Rebell traps caught similar numbers of *R. indifferens* per trap (mean ± SE) at 452.6 ± 30.4a and 448.6 ± 33.1a, respectively, but 55–73% more flies than PALz and PZ traps, at 258.6 ± 23.1b and 289.6 ± 13.2b, respectively (*F* = 22.17; *df* = 3, 12; *P* < 0.0001) (means with same letters are not significantly different, *P > 0.05*).
Objective 3: Verify AA Is Attractive

In Tests 3 and 4, YSS traps with AA 2 (one 3.2-mm hole) and AA 3 (one 10-mm hole) lures caught more R. indifferens than blank YSS traps. In Test 3, the blank YSS caught 116.2 ± 25.7 flies, while the YSS + AA 2 caught 212.2 ± 42.6 flies (t = −4.69; P = 0.0094). In Test 4, the blank YSS caught 70.6 ± 15.3 flies, while the YSS + AA 3 caught 156.8 ± 38.1 flies (t = −5.18; P = 0.0066).

Objective 4: Determine Efficacies of AC versus AA Lures with Different Traps

Despite AA lures being attractive to R. indifferens, the AC lure was more attractive than all four AA lures deployed in Tests 5–8 (Table 4). In addition, in Tests 5 and 7, the YSS lures performed as well as Rebell and PALz traps combined (two-factor analysis: Test 5: trap: F = 7.98; df = 2, 20; P = 0.0028 [YSS = Rebell > PALz]; lure: F = 114.85; df = 1, 20; P < 0.0001 [AC > AA 1]; interaction: F = 1.88; df = 2, 20; P = 0.1779; Test 7: trap: F = 12.04; df = 1, 12; P = 0.0046 [YSS > Rebell]; lure: F = 36.39; df = 1, 12; P < 0.0001 [AC > AA 3]; interaction: F = 2.18; df = 1, 12; P = 0.1654).

In Test 6, there was no trap effect, but AC was more attractive than AA 2 (trap: F = 0.8; df = 1, 12; P = 0.4986 [YSS = Rebell]; lure: F = 20.76; df = 1, 12; P = 0.0007 [AC > AA 2]; interaction: F = 2.87; df = 1, 12; P = 0.1162). In Test 8 within YSS, AC was more attractive than AA 4 (Table 4) (t = −5.94; df = 4; P = 0.0040). Thus, none of the AA lures, nor even AA 3 that released the most ammonia (66.1 µg/hr) (Table 1), performed as well as the AC lure with one 1-mm hole.

In Test 9, responses to the AA + AC 1 mix versus the AC lure did not differ (Table 5). This was true for all three trap types (two-factor analysis: trap: F = 24.49; df = 2, 20; P < 0.0001 [YSS = Rebell > PALz]; lure: F = 2.64; df = 1, 20; P = 0.1196; interaction: F = 0.68; df = 2, 20; P = 0.5190). In Test 10 using the YSS, responses to the AA + AC 2 mix versus the AC lure also did not differ (Table 5) (t = −1.02; df = 4; P = 0.3655).

Objective 5: Determine if Size and Additional Tanglefoot Affect Efficacy of the Rebell Trap

In Test 11 when one panel of the Rebell trap (area approximately equal to that of YSS, Table 1) was tested, the YSS caught more flies (Table 6), compared with previous tests where the Rebell trap (two panels) caught as many as the YSS. Thus, the relatively large size of the Rebell trap was responsible for its efficacy versus the YSS. In Test 12, adding more Tanglefoot to the Rebell trap did not increase catches, so the original amount of Tanglefoot did not limit the trap’s efficacy versus that of the YSS (Table 6). Finally, in Test 13, the one panel Rebell with additional Tanglefoot caught fewer flies than the YSS (although P was not quite significant at 0.0958), as it did in Test 11 with less Tanglefoot (Table 6).

Fly Captures Adjusted for Trap Sticky Surface Area

When using flies caught/cm² of sticky trap surface, the YSS always caught more flies than Rebell and PALz traps, so the efficacy of the Rebell trap again was due at least in part to its larger surface area. In Test 2, the YSS trap caught more flies/cm² than Rebell, PALz, and PZ traps (F = 19.37; df = 3, 12; P = 0.0001). Flies/cm² on the Rebell, PALz and PZ traps did not differ. In Test 5, there was a significant trap × lure interaction (F = 4.89; df = 2, 20; P = 0.0186), so trap effects differed depending on the lure. Specifically, numerically within the AC treatment, the ranking of flies on traps were: YSS > PALz > Rebell; within AA 1, YSS > Rebell > PALz (trap: F = 19.68; df = 2, 20; P < 0.0001; lure: F = 108.70; df = 1, 20; P < 0.0001). In Test 6, more flies/cm² were caught on the YSS than Rebell trap (F = 35.53; df = 1, 12; P < 0.0001) and more on traps with AC than AA 2 (F = 9.33; df = 1, 12; P = 0.0010) (interaction: F = 0.44; df = 1, 12; P = 0.5201). In Test 7, more flies/cm² were caught on the YSS than Rebell trap (F = 85.27; df = 1, 12; P < 0.0001) and more on traps with AC than AA 3 (F = 10.76; df = 1, 12; P = 0.0066) (interaction: F = 0.08; df = 1, 12; P = 0.7792). In Test 9, more flies/cm² were caught on YSS than Rebell and PALz traps (which did not differ) (F = 23.11; df = 2, 20; P = 0.0001), while flies/cm² on traps with AC and the AC + AA 1 did not differ (F = 2.30; df = 1, 20; P = 0.1454) (interaction: F = 0.52; df = 2, 20; P = 0.6021).

Male and Female Catch Patterns

Proportions of flies that were male or female across trap treatments within tests varied (Supp Table S2 [online only]). However, except in Test 2, proportions of each sex among traps within tests where only AC was tested did not differ. In contrast, significant differences were detected in Tests 6, 7, and 8 where AC and AA lures were compared, as AC traps had higher proportions of males than AA traps, while the reverse was true for proportions of females. There were also proportionately fewer males caught within trap types with AA + AC 1 than AC alone in Test 9, although there was only one significant difference (Supp Table S2 [online only]).

Discussion

Previous work (Yee 2014, Yee and Goughnour 2017) and current work testing various commercial and experimental sticky rectangle traps confirmed that the YSS is the best rectangle trap identified for R. indifferens, justifying its use as a standard by which other traps should be compared. The closest in efficacy was the PZ trap. This trap caught similar numbers of flies as the YSS in Test 1 although statistically fewer in Test 2. There were no commonalities in L*a*b* values for the top three traps, so results suggest a complex relationship between trap efficacy and fly attractiveness.
combination of visual stimuli are responsible for the efficacy of the YSS (Yee 2014, 2015). AC-baited YSS traps also caught more R. cingulata than AC-baited Pherocon AM traps (Pochubay and Rothwell 2015). The Pherocon AM and other sticky rectangles are good or adequate traps for R. indifferens, but current results suggest they could detect low fly populations less frequently than the YSS.

The Rebell trap caught as many R. indifferens as the YSS, the first trap tested to do so. This result was not predictable based on earlier work on R. indifferens and other Ragoletis species, as this work as it relates to relative trap efficacy is unclear. Previous work with R. indifferens (Burditt 1988) indicated the Rebell trap baited with Zocone AM bait was superior to the Pherocon AM with AC mixed in adhesive, but the use of different attractants prevented direct trap comparisons. However, it is likely that even if the attractants had been the same, the Rebell trap would have outperformed the Pherocon AM trap because current results show the Pherocon AM is inferior to the YSS while the YSS and Rebell traps are equal. Also, for R. cingulata and black cherry fruit fly, Ragoletis fausta Osten Sacken, unbaited Rebell traps were superior to Pherocon AM, red sphere, and modified Ladd traps with AA mixed into adhesive (Liburd et al. 2004). In contrast, in Germany, the Rebell trap caught 16 times fewer R. cingulata than the Pherocon AM trap, but the Pherocon AM was baited with ammonia, whereas the Rebell was not (Lampe et al. 2005).

Use of the Rebell trap for detecting R. indifferens is appealing if there are disadvantages in using the YSS. Currently, one disadvantage is that the YSS requires application of Tanglefoot over the manufacturer’s adhesive to be most effective (Yee and Goughnour 2017), not needed for the Rebell trap. Also, the YSS may need to be cut down to a practical size as currently only 20.3 × 24.4 cm and 25.4 × 40.6 cm sheets of the YSS are available. Under windy conditions, YSS traps may flap and tear (Yee 2014) and need to be attached to branches using additional ties. However, the Rebell trap can be re-used, cleaning them for re-use is time consuming, so most growers (in Europe) use the traps for only one season (Daniel et al. 2014). Finally, while checking for flies on the Rebell trap is not difficult, manipulating the trap for inspection of all surfaces does take more time than checking for flies on the flat YSS. The choice of using YSS and other rectangle or Rebell traps will therefore depend on the ease of handling by users and labor costs (Neillson et al. 1981) rather than trap efficacy.

The Rebell trap is a viable alternative to the YSS with Tanglefoot for detecting or monitoring R. indifferens in Washington. The trap could be used to provide evidence that R. indifferens is absent in cherry orchards or their surroundings, in order to support Pest Free Areas or Areas of Low Pest Prevalence for fruit export. In Europe, Rebell and other traps have been used for mass-trapping R. cerasi to reduce infestations in cherries (Russ et al. 1973, Remund and Boller 1978, Boller 1982). However, as there is zero tolerance for infestations of larval R. indifferens in cherries in Washington (Smith 2017), mass-trapping has never been used for controlling R. indifferens populations because it cannot eliminate fly populations. Therefore, the main purpose of trapping R. indifferens is for detection and management decision-making.

Results verified that AA used to attract R. cerasi was also attractive to R. indifferens, with flies detecting an ammonia release rate as low as 14.1 μg/hr from vials. However, given an equal amount of AC (35.45% ammonia by weight) and AA (22.09% ammonia), the AC releases more ammonia, at least from the vials tested here (Table 1). The higher ammonia release from the AC lure was likely the reason it attracted more flies. This was especially true for male flies, which appear to require higher ammonia release rates than females for stimulation (Supp Table S2 [online only]). Mixing AA and AC in a 1:1 ratio (Toth et al. 2016) had no effect on increasing catches of R. indifferens, presumably because the threshold ammonia release rate was reached using AC alone. In another study, R. indifferens was more attracted to AC alone and AC plus putrescine than to AA, putrescine, 3-methyl-1-butanol alone, or a combination of them (Mayer et al. 2000). It is possible that other volatiles yet to be identified could enhance the attractiveness of AC. Use of the different lures did not support the hypothesis that attraction of R. indifferens to AC or AA is affected by a trap’s visual stimuli, so within any trap type, those baited with AC will catch more flies than those baited with AA.

The similar efficacies of the Rebell and YSS traps against R. indifferens were not due to the Rebell and YSS having equally attractive colors, as the color and/or translucency of the YSS appeared more attractive. In fact, the color of the Rebell trap does not appear to be as attractive. In another study, R. indifferens was also attract-
more effective than the YSS rectangle or Rebell trap, given that the YSS rectangle is more attractive than one Rebell trap panel. This assumes a crossed sheet would not interfere with attractive qualities of the YSS, e.g., by reducing or blocking light transmitted through its plastic. Because of the thin plastic of the YSS, such a trap would need sturdy edges to allow sheets to be crossed, a modification in design that would not be difficult.

In response to the *R. cerasi* detections in eastern North America, USDA-APHIS conducted detection surveys for *R. cerasi* in residential landscapes in central Washington in 2017 (no *R. cerasi* were caught). The sticky yellow Multigard AM rectangle trap with protein mixed in the adhesive and baited externally with a small polycyon dispenser containing AA (Molet and Molyett 2016) was used. Because the research in Europe indicates the Rebell trap is better to use than rectangle traps in surveys for *R. cerasi* (Katsoyannos et al. 2000), it should also be better to use in surveys for *R. cerasi* in Washington. However, the high numbers of *R. indifferens* caught there will clutter traps and make it difficult to detect *R. cerasi*, as the two species are similar in general appearance (black body; wings with three dark bands) (White and Elson-Harris 1992). The Rebell trap could be used without compromising efficiency of *R. cerasi* detection surveys where there are no *R. indifferens*, such as in California cherry-growing regions (Dowell and Penrose 2012).

The PALz trap did not catch as many *R. indifferens* as the Rebell and YSS traps. In Tests 2, 5, and 9, an average of 73% fewer *R. indifferens* were caught on PALz than Rebell traps. Thus, use of the PALz would reduce the time to process traps and make it easier to detect *R. cerasi*, as the two species are similar in general appearance (black body; wings with three dark bands) (White and Elson-Harris 1992). The Rebell trap could be used without compromising efficiency of *R. cerasi* detection surveys where there are no *R. indifferens*, such as in California cherry-growing regions (Dowell and Penrose 2012).

The PALz trap did not catch as many *R. indifferens* as the Rebell and YSS traps. In Tests 2, 5, and 9, an average of 73% fewer *R. indifferens* were caught on PALz than Rebell traps. Thus, use of the PALz trap would reduce the time to process *R. cerasi*, increasing efficiency of surveys for *R. cerasi* caught there will clutter traps. Data on *R. cerasi* contained aqueous AC or AA (Katsoyannos et al. 2000), then it should be used with PALz traps in surveys to reduce clutter by *R. indifferens*. However, that AA is more attractive to *R. indifferens* and YSS traps. In Tests 2, 5, and 9, an average of 73% fewer *R. indifferens* were caught on PALz than Rebell traps. Thus, use of the PALz trap would reduce the time to process *R. cerasi*, increasing efficiency of surveys for *R. cerasi* and making it an appealing alternative to the Rebell trap. Even if numbers of *R. indifferens* flies/cm² are similar to that on the Rebell trap, less surface area would need to be examined.

If AA is more attractive to *R. cerasi* than AC (Katsoyannos et al. 2000), then it should be used with PALz traps in surveys to reduce clutter by *R. indifferens*. However, that AA is more attractive to *R. cerasi* would first need to be confirmed. Ammonia release rates from the AC lures tested against *R. cerasi* contained aqueous AC or 1.7 g AC in a membrane system (Katsoyannos et al. 2000). It is possible ammonia release rates from these lures were too low to induce maximal responses by *R. cerasi*.

In summary, the Rebell trap is the first trap tested that catches as many *R. indifferens* as the YSS. Results suggest YSS and Rebell traps when baited with AC would be equally useful for detecting the presence of *R. indifferens*, and that a crossed-sheet YSS trap could be even more efficacious than the YSS rectangle. For *R. cerasi* detection surveys in locations with *R. indifferens*, the PALz trap would be preferred over the Rebell trap if the two are equally efficacious against *R. cerasi* because fewer *R. indifferens* would clutter traps. Data on the efficacies of YSS, Rebell, and PALz traps tested simultaneously against *R. cerasi* are needed to support this conclusion. A useful follow-up study is to measure the relative efficacy of detecting *R. indifferens* over a large area or in a sequence of orchards using the traps that performed the best in this study.

**Supplementary Data**

Supplementary Data are available at *Journal of Insect Science* online.

**Acknowledgments**

I thank Peter Chapman, Eugene Bell, Janine Jewett, and Celia Longoria (USDA-ARS, Wapato, WA) for assistance in studies; Diane Alston (Utah State University, Logan, UT); and Grant McQuate (USDA-ARS, DKIPBARC, Hilo, HI) for reviewing the manuscript, two anonymous reviewers for helpful comments on the paper, and USDA-FAS for partial funding of this research.

**References Cited**

Adobe Systems. 2000. Technical guides. Color models. CIELab. http://dbase.med. sc.edu/pruce/ri/Adobe TG/models/cielab.html (accessed 31 October 2017)

AliNizae, M. T., A. B. Mohammad, and S. R. Booth. 1987. Apple maggot (Diptera: Tephritidae) response to traps in an unsprayed orchard in Oregon. J. Econ. Entomol. 80: 1143–1148.

Anonymous. 2017. European cherry fruit fly confirmed in Niagara County, New York. Fruit Grower News. https://fruitgrowersnews.com/news/european-cherry-fruit-fly-confirmed-niagara-county-new-york/ (accessed 27 October 2017).

Boller, E. F. 1982. Biotechnical methods for the management of fruit fly populations. CE/IOBC Symposium/Athens/Nov 1982. 342–351.

Burdt, A. K., Jr. 1983. Western cherry fruit fly (Diptera: Tephritidae): efficacy of homemade and commercial traps. J. Entomol. Soc. Brit. Columbia. 85: 53–57.

CFIA. 2017. *Rhagoletis cerasi* (European Cherry Fruit Fly) - Fact sheet. http://www.inspection.gc.ca/plants/plant-pests/invasive-species/insects/european-cherry-fruit-fly-fact-sheet/eng/1467913088335/146791465410 (accessed 27 July 2017).

Daniel, C., and J. Grunder. 2012. Integrated management of European cherry fruit fly *Rhagoletis cerasi* (L.): situation in Switzerland and Europe. Insects 3: 956–988.

Daniel, C., S. Mathis, and G. Feichtinger. 2014. A new visual trap for *R. cerasi* (L.) (Diptera: Tephritidae). Insects. 5: 564–576.

Dowell, R. V., and R. L. Penrose. 2012. Distribution and phenology of *R. fausta* (Osten Sacken 1857) and *R. indifferens* Curran 1912 (Diptera: Tephritidae) in California. Pan-Pac. Entomol. 88: 130–150.

Eliopoulos, P. A. 2007. Evaluation of commercial traps of various designs for capturing the olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae). Int. J. Pest. Manage. 53: 245–252.

Elliott, A. C., and J. Reisch. 2006. Implementing a multiple comparison test for proportions in a 2 x c crosstabulation in SAS®. Paper presented at the SAS Users Group International Conference, San Francisco, CA. http://www2.sas.com/proceedings/sugi31/204-31.pdf (accessed 14 December 2017)

Frick, K. E. 1952. Determining emergence of the cherry fruit fly with ammonia carbonate bait traps. J. Econ. Entomol. 45: 262–263.

Frick, K. E., H. G. Simkover, and H. S. Telford. 1954. Bionomics of the cherry fruit flies in eastern Washington. WA Agric. Exp. Stat. Inst. Agric. Sci., State College of WA. Tech. Bull. 13: 1–66.

Great Lakes IPM Inc. 2017. Insect monitoring supplies for the professional grower. E. Rebell yellow (p. 8). 32 pp. greatlakesipm.com (accessed 11 January 2018).

Katsoyannos, B. I., N. T. Papadopoulos, and D. Stavridis. 2002. Distribution and phenology of *Rhagoletis fausta* (Osten Sacken 1857) and *Rhagoletis indifferens* Curran 1912 (Diptera: Tephritidae) in California. Pan-Pac. Entomol. 88: 130–150.

Kovanci, O. B., and B. Kovanci. 2006. Reduced-risk management of *Rhagoletis cerasi* flies (host race *Prunus*) in combination with a preliminary phenological model. J. Insect Sci. 6: 1–10.

Lampe, I., F. Burghause, and H. J. Krauthausen. 2005. Introduction and distribution of the American eastern cherry fruit fly, *Rhagoletis cingulata*, in the Rhine Valley, Germany, pp. 135–140. In Proceedings of the BCPC Symposium on ‘Introduction and Spread of Invasive Species’, Berlin, 06–09 November 2005, No. 81, Alton, UK: British Crop Protection Council.

Liburd, O. E., L. L. Stelinski, L. J. Gut, and G. Thorton. 2001. Performance of various trap types for monitoring populations of cherry fruit fly (Diptera: Tephritidae) species. Environ. Entomol. 30: 82–88.

Madsen, H. F. 1970. Observations on *Ragoletis indifferens* and related species in the Okanagan Valley of British Columbia. J. Entomol. Soc. Brit. Columbia. 67: 13–16.

Mayer, D. E., L. E. Long, T. J. Smith, J. Olsen, H. Riedl, R. R. Heath, T. C. Leskey, and R. J. Prokopy. 2000. Attraction of adult *Rhagoletis indifferens* (Diptera: Tephritidae) to unbaited and odor-baited red spheres and yellow rectangles. J. Econ. Entomol. 93: 347–351.

Molet, T., and H. Molyett. 2016. CHPST pest datasheet for *Rhagoletis cerasi*. USDA-APHIS-PPQ-CHPST, Raleigh, NC. pp. 1–15.
