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Research

Field and Forage Crops

Vertical Distribution of Insect Pests Using Insect Towers Placed Near Potato Fields in the Lower Columbia Basin

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Abstract

This study was conducted at the Oregon State University Hermiston Agricultural Research and Extension Center, Hermiston, Umatilla County, OR, during the 2016 and 2017 potato, *Solanum tuberosum* L. (Solanales: Solanaceae), growing seasons. The objective was to determine the vertical distribution of hemipteran (*Bactericera cockerelli* Šulc, *Circulifer tenellus* Baker, *Myzus persicae* Sulzer, *Macrosiphum euphorbiae* Thomas, and *Lygus* spp.) and thysanopteran (*Frankliniella occidentalis* Pergande and *Thrips tabaci* Lindeman) potato pests using insect towers placed near potato fields. Towers were 8 m tall and secured to the ground with metal cables. In each tower, yellow sticky cards were mounted at 1.5 m intervals up to 7.6 m aboveground. Data were collected at 7-d intervals from mid-April until mid or end of August. This study showed that *B. cockerelli*, *C. tenellus*, *M. persicae*, *Lygus* spp., and both species of thrips were captured on sticky cards placed closest to the ground; in both years, as sticky card height increased, abundances decreased. In contrast, trapped *M. euphorbiae* numbers were not affected by sticky card height. To our knowledge, this is the first study in the lower Columbia Basin of Oregon that evaluated the vertical distribution of major potato pests.

Key words: aphids, beet leafhoppers, lygus bugs, potato psyllids, thrips

In the U.S. Pacific Northwest, hemipterans such as potato psyllid, *Bactericera cockerelli* Šulc (Triozidae) (Munyaneza et al. 2009, 2010), beet leafhopper, *Circulifer tenellus* Baker (Cicadellidae) (Rondon and Murphy 2016), aphids (green peach aphid, *Myzus persicae* Sulzer and potato aphid, *Macrosiphum euphorbiae* Thomas) (Aphididae) (Klein et al. 2017), and lygus bugs (*Lygus hesperus* Knight, *L. elisus* L., and *L. keltoni* L.) (Miridae) (Antwi and Rondon 2018) are commonly found in potatoes, *Solanum tuberosum* L. (Solanales: Solanaceae). Two Thysanoptera species, the western flower thrips, *Frankliniella occidentalis* Pergande, and the onion thrips, *Thrips tabaci* Lindeman (Thripidae), also occur in commercial potato fields (Rinehold et al. 2018), but their impact on potato production has not been reported.

Economic threshold levels are important parameters on which interventions are based (Stern 1973). Current thresholds for potato pests in the Pacific Northwest include 1–2 *C. tenellus* per plant (Murphy et al. 2014), 1–5 *B. cockerelli* per plant (Butler and Trumble 2012), and 10–40 aphids per 50 leaves for *M. persicae* and *M. euphorbiae* combined (Rinehold et al. 2018). There are currently no established economic threshold levels for lygus bugs and thrips in potatoes (Rinehold et al. 2018). Because many variables are needed to develop economic thresholds, biological and ecological parameters that affect insect distribution can be valuable information for developing pest monitoring programs (Stern 1973).

Monitoring involves the use of sampling devices for obtaining data on pest activity. Traditional methods, in potatoes, include sweep-nets (Munyaneza et al. 2009), inverted leaf blowers (Rondon and Murphy 2016), beat trays (Thinakaran et al. 2017), and yellow sticky cards (Rondon et al. 2012). Yellow sticky cards are the most commonly used sampling tools recommended to potato growers in the region; they are relatively inexpensive, easy to handle, and can be used to monitor several pests simultaneously. Lewis (1967) used sticky cards to determine the horizontal and vertical distributions of flying insects. The same technique was used to study lygus bugs (Mueller and Stern 1973, Blackmer et al. 2008), aphids (Broadbent 1948), psyllids (Adams and Los 1989, Al-Jabr and Cranshaw 2007, Yen et al. 2013), leafhoppers (Meyerdirk and Oldfield 1985, Atakan and Canhilal 2004), and thrips (Beavers et al. 1971, Gillespie and Vernon 1990, Macintyre-Allen et al. 2005) in a variety of crops. Specific to potato, Broadbent (1948) and Yen et al. (2013) studied the vertical distribution of *M. persicae* in England and *B. cockerelli* in New Zealand, respectively. In the United States, little information is available regarding the vertical distribution of pest species in potatoes. Hence, the objective of this study was to evaluate the influence of height on capture of hemipteran (*B. cockerelli*, *C. tenellus*, *M. persicae*, *M. euphorbiae*, and *Lygus* spp.) and thysanopteran (*F. occidentalis* and *T. tabaci*) pests in Oregon potato systems.

Materials and Methods

Insect Towers

Two omnidirectional vertical insect towers were installed at the Oregon State University Hermiston Agricultural Research and Extension Center research farm (latitude 45.8170761, longitude 119.2846219) in Hermiston, Umatilla County, OR. Towers were made of steel tubing, cut at 1.5-m intervals and connected by threaded steel couplings. They were installed a week after potato planting on 10 and 19 April in 2016 and 2017, respectively. Each tower was secured to the ground with wire cable. This step was necessary because the Columbia Basin region is known for strong winds, particularly during spring and early summer. Each tower supported five 10 × 10 × 10 cm metal frame boxes, with each box attached at 1.5-m intervals. At least three people were needed to pivot the tower each time yellow sticky cards were changed (Fig. 1). The insect tower had a basal hinge that allowed the tower to be laid horizontally while the sticky cards were changed.

Vertical Insect Distribution

Two insect towers were installed, one at each project potato field, and located 3 m outside the potato field edges. The potato fields were 800 m apart from each other. Wheat, *Triticum aestivum*, L. (Poales: Poaceae), Kentucky bluegrass, *Poa pratensis*, L. (Poales: Poaceae), alfalfa, *Medicago sativa* L. (Fabales: Fabaceae), and bean, *Phaseolus vulgaris* L. (Fabales: Fabaceae) fields were adjacent to the potato fields. The non-potato crops were 300–1,500 m away from the insect towers. Yellow single-sided nonbaited 10.2 × 15.2 cm rectangular sticky cards (AlphaScents, Portland, OR) were mounted in the metal boxes on the towers. Each box was deployed 1.5 m apart from the other boxes on the same tower up to 7.6 m. A sticky card was placed vertically in each box, with top and bottom tightly secured to the box using large binder clips (Staple model no. 15351, The Home Depot, Hermiston, OR). Each tower had four yellow sticky cards at each height facing north, south, east, and west. Sticky cards were collected and replaced weekly for 15–19 wk, starting when the towers were erected. Trapping ended on 10 and 29 August in 2016 and 2017, respectively. Collected sticky cards were taken to the laboratory using a flat slotted wooden card holder that kept each collected sticky card separated. In the laboratory, insects on the sticky cards were identified and counted under a Leica S6E stereo microscope (Leica Microsystems GmbH, Wetzlar, Germany).

Fig. 1. Insect tower installed outside edge of potato field (Photo credit: Silvia I. Rondon).

Statistical Analysis

Data from four directions (north, south, east, west) were pooled for each height at each tower for each insect species. Thrip and lygus bug species data were also pooled separately for statistical analysis. If necessary, data were log-transformed to achieve normal distribution. A test with a normal quantile–quantile plot was performed to confirm the normality of data and equality of variance. The data of each insect species were fitted separately to a linear mixed model with sticky card height, and total insect counts per sticky card as fixed effects (categorical variables converted to factors). The variation in total insect count per tower was used as a random effect, and the insect count per sticky card height as response variable using the function 'lmer'. The model was condensed whenever possible, with stepwise removal of factors having no effect. The Kenward–Roger test was used using the function 'KRmodcomp' to compare the models (Halekoh and Højsgaard 2013). Tukey's contrast pairwise multiple comparisons were used to test for differences between means using the function 'glht' (Hothorn et al. 2008).

The nonparametric one-way ANOVA (Kruskal–Wallis test) was performed to test differences in pest species abundances between sampling dates because trap count data from each sampling date were not normally distributed. A Mann–Whitney *U*-test was used as a post hoc test for comparisons between the means. Trap counts from 1.52 m height were the only data used for analysis due to low capture rate on higher trap heights. Data were analyzed using R 2.15.1 (R Development Core Team 2012).

Results

Seasonal Abundances

In 2016, *B. cockerelli* adults were first observed in late May, and in 2017 in early August (Fig. 2A). Abundance peaked in August of both years, coinciding with the start of potato harvesting in the region. However, adult *B. cockerelli* numbers were not different between sampling dates in 2016, but adult numbers were about two times higher on traps in mid-August compared to other 2017 sampling dates ($\chi^2 = 65.53$, df = 18, $P < 0.001$) (Fig. 2A). *Circulifer tenellus* was not found in 2016. Unlike *B. cockerelli*, in 2017, *C. tenellus* adults were observed early in the season, with first detection in early May. Although numbers of *C. tenellus* were low nearly every week from early June through the end of August, peaks were observed in early July (Fig. 2B). Adult *C. tenellus* numbers were nearly two times higher on traps in early July than for other 2017 sampling dates ($\chi^2 = 58.44$, df = 18, $P < 0.001$).

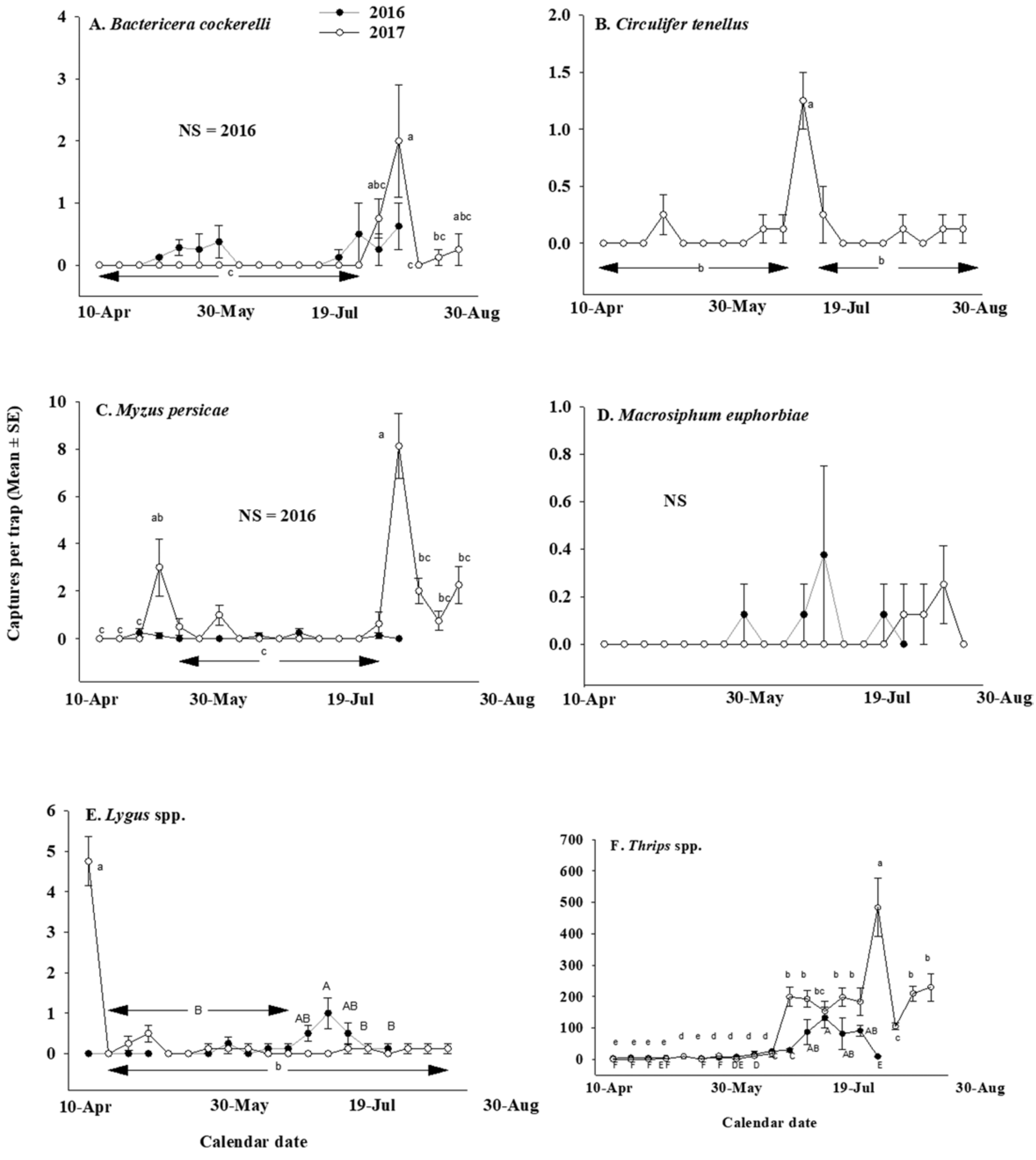

Fig. 2. Mean (± SE) weekly trap captures of hemipteran (A–E) and thysanopteran (F) insect pests on single-sided yellow sticky cards in insect collection towers 1.52 m aboveground level, 2016 and 2017. Different letters over different line graphs (capital and small letters for 2016 and 2017, respectively) indicate significant (one-way ANOVA [Kruskal–Wallis test] followed by Mann–Whitney *U*-tests, $P < 0.05$) differences. A letter between arrows represents same letter for data points within those arrows. Two insect tower data were pooled for analysis. The total numbers of replicates were 8 per sampling date.

Myzus persicae adults were initially detected in early May, while *M. euphorbiae* adults were first observed in late May during both years (Fig. 2C and D). *Myzus persicae* abundances were not affected by sampling dates and it remained relatively low without a noticeable peak in 2016 (Fig. 2C). In contrast, *M. persicae* abundances peaked in mid-August of 2017. Adult *M. persicae* numbers were two to eight times higher on traps in mid-August compared to other 2017 sampling dates ($\chi^2 = 88.10$, df = 18, $P < 0.0001$) (Fig. 2C). *Macrosiphum euphorbiae* adults were trapped in low abundances throughout the potato growing season, and adult numbers were not different between sampling dates in each year (Fig. 2D).

Lygus hesperus (97%) was the predominant lygus bug species followed by *L. elisus* (2.5%) and *L. keltoni* (0.5%). Adult lygus bug numbers varied between years. In 2016, no *Lygus* spp. were detected until late May with the greatest peak observed in mid-July (Fig. 2E). Adult lygus bug numbers were about two times higher on traps in mid-July compared to other 2016 sampling dates ($\chi^2 = 36.31$, df = 14, $P < 0.001$). In 2017, the peak was observed in early April (Fig. 2E). Lygus bug adult numbers were two to four times higher on traps in early April compared to other 2017 sampling dates ($\chi^2 = 48.48$, df = 18, $P < 0.001$) (Fig. 2E).

Thrips spp. were comprised of 91% *F. occidentalis* and 7% *T. tabaci*. *Thrips* spp. numbers were initially detected in early to mid-April during both years, and abundances generally increased as the potato growing season progressed, reaching peaks in late July and early August in 2016 and 2017, respectively (Fig. 2F). *Thrips* spp. numbers were 2–48 times higher in late July 2016 ($\chi^2 = 71.94$, df = 14, $P < 0.0001$) and 2–483 times higher in early August 2017 ($\chi^2 = 105.56$, df = 18, $P < 0.0001$) on traps compared to other sampling dates in both years.

Vertical Insect Distribution

Overall, approximately 79% of numbers of all adult insect pest combined were captured on sticky cards placed at 1.5 m compared to 10% captured on sticky cards placed at greater heights (Table 1). In both years, two to three times greater numbers of *B. cockerelli* adults were captured at 1.5 m compared to sticky cards placed at 3.0, 4.6, 6.1, and 7.6 m aboveground level (2016: $F = 12.25$; df = 4, 34; $P < 0.001$; 2017: $F = 42.52$; df = 4, 34; $P < 0.001$) (Fig. 3A).

Unlike *B. cockerelli*, adult *C. tenellus* numbers were two- to threefold greater when sticky cards were placed at 1.5 and 3.0 m compared to higher heights ($F = 10.11$; df = 4, 34; $P < 0.001$) (Fig. 3B). Abundances of *C. tenellus* adults were 29–33% greater on sticky cards placed at 1.5 and 3.0 m height levels compared to sticky cards placed at 6.1 and 7.6 m aboveground level (Table 1).

Sticky card height influenced adult *M. persicae* captures and varied from year to year (Fig. 3C). In 2016, two times greater numbers of *M. persicae* adults were captured at 1.5 and 3.0 m compared to at 4.6, 6.1, and 7.6 m ($F = 4.30$; df = 4, 34; $P < 0.010$) (Fig. 3C). In 2017, *M. persicae* adults collected at the 1.5 m sticky card height were two to eight times greater than at higher sticky card heights ($F = 9.63$; df = 4, 34; $P < 0.001$) (Fig. 3C). Adult *M. euphorbiae* numbers were not affected by sticky card height in either year of the study (Fig. 3D).

In 2016, adult *Lygus* spp. numbers captured at 1.5 and 3.0 m were two times greater than the ones found on sticky cards placed at 4.6, 6.1, and 7.6 m aboveground level ($F = 4.70$; df = 4, 34; $P < 0.01$) (Fig. 3E). In 2017, numbers of adult *Lygus* spp. caught at 1.5 m sticky card height were two to three times greater than at each of the other sticky card heights ($F = 13.65$; df = 4, 34; $P < 0.001$) (Fig. 3E).

In 2016, 4–10 times greater numbers of *Thrips* spp. were caught on sticky cards placed at 1.5 m compared to sticky cards placed at higher heights ($F = 9.66$; df = 4, 34; $P < 0.001$) (Fig. 3F). Similarly, in 2017, *Thrips* spp. numbers were 8–30 times greater at 1.5 m compared to higher heights ($F = 42.52$; df = 4, 34; $P < 0.001$) (Fig. 3F). Overall, *Thrips* spp. adults were 45–59% greater on sticky cards placed at the 1.5 m height compared to sticky cards placed at higher heights (Table 1).

Discussion

In general, insect pests are responsible for damaging crops by feeding directly on plants or indirectly by vectoring plant pathogens. Hemipteran pests (e.g., *B. cockerelli*, *C. tenellus*, *M. persicae*, *M. euphorbiae*, and *Lygus* spp.) damage potato plants by causing leaf distortion that suppresses plant growth (Munyaneza et al. 2009, Rondon and Murphy 2016, Antwi et al. 2017, Klein et al. 2017). Thysanopteran pests damage potato plants by scarring leaves, causing rib discoloration on plant green tissue (Rinehold et al. 2018). Direct feeding by both insect groups can affect potato yield; however, damage is compounded when insects vector plant pathogens. Development of an effective pest monitoring program is important to protect potatoes from hemipteran and thysonopteran potato pests.

Bactericera cockerelli has been a key potato pest in the Pacific Northwest since it was first reported in 2011. It is the only known vector of the pathogen '*Candidatus* Liberibacter solanacearum' (Rhizobiales: Phyllobacteriaceae) that causes zebra chip disease in potatoes (Crosslin et al. 2012). In New Zealand, three- to fourfold more *B. cockerelli* adults were caught using yellow sticky cards placed at 0.61, 0.63, and 0.64 m than at 0.60 m aboveground level in potato fields (Yen et al. 2013). Al-Jabr and Cranshaw (2007) found nearly twofold greater numbers of *B. cockerelli* adults on sticky cards placed at 1.5 m than on sticky cards placed 0.3 m aboveground in a greenhouse tomato, *Solanum lycopersicum* L. (Solanales: Solanaceae) production system; our results confirm their findings, suggesting that *B. cockerelli* flies above the canopy before landing on the crop.

Table 1. Height aboveground at which the adults of hemipteran and thysanopteran insect pests captured on single-sided yellow sticky cards mounted in two insect towers, Hermiston, Umatilla County, OR, 2016 and 2017

			Percentage collected at each height (m)				
Year	Insect pests	Totals captured	1.5	3.0	4.6	6.1	7.6
2016	*Bactericera cockerelli*	22	81	9	5	0	5
	Circulifer tenellus	0	0	0	0	0	0
	Myzus persicae	15	54	46	0	0	0
	Macrosiphum euphorbiae	25	24	16	28	24	8
	Lygus spp.	47	47	30	9	8	6
	Thrips spp.	6,411	63	20	9	5	3
2017	*Bactericera cockerelli*	32	78	19	3	0	0
	Circulifer tenellus	39	46	31	13	8	2
	Myzus persicae	267	49	23	17	7	4
	Macrosiphum euphorbiae	14	29	29	14	21	7
	Lygus spp.	43	70	16	5	9	0
	Thrips spp.	23,997	67	16	8	5	4

Lygus spp. include *Lygus hesperus*, *L. elisus*, and *L. keltoni*; *Thrips* spp. include *Frankliniella occidentalis* and *Thrips tabaci*.

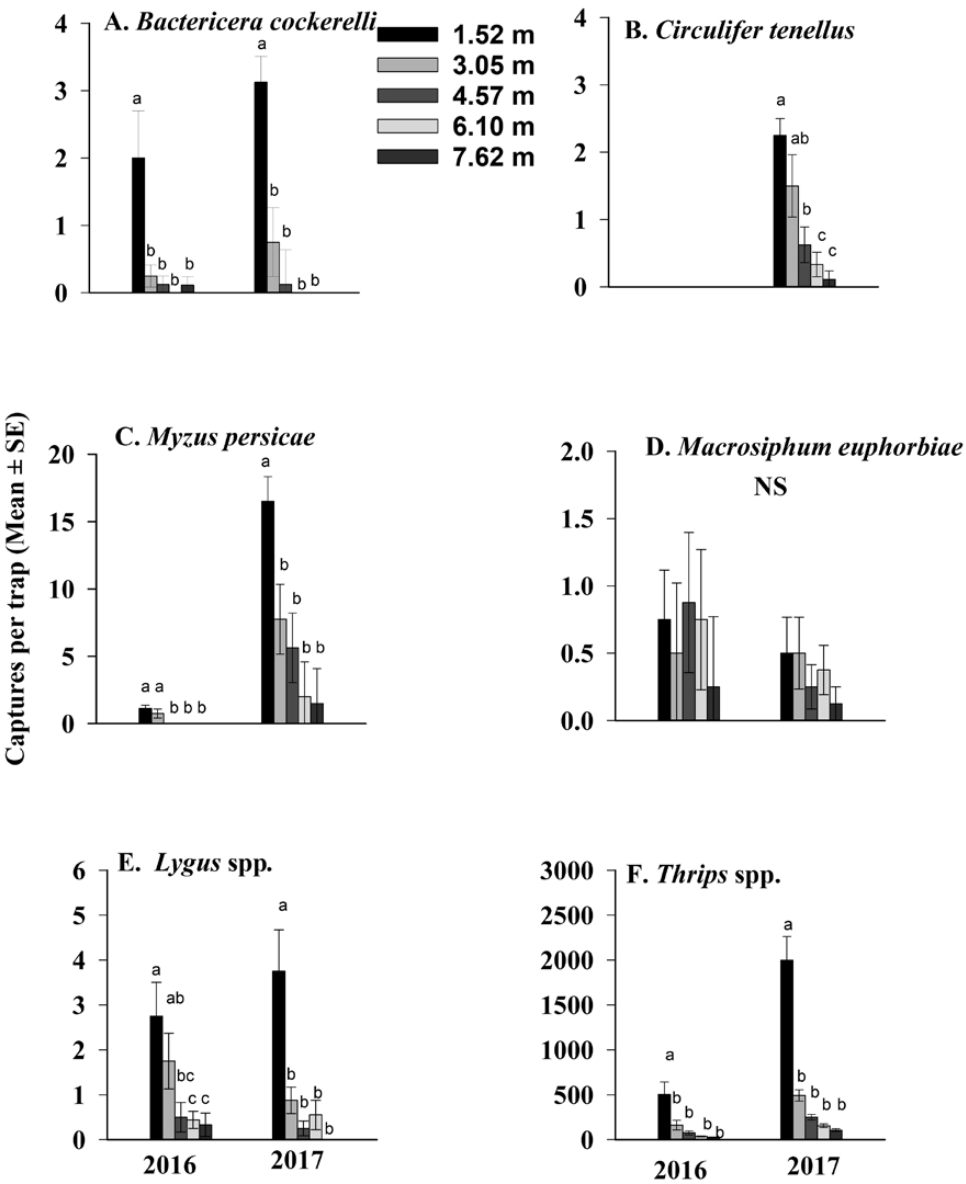

Fig. 3. Mean numbers (± SE) of hemipteran (A–E) and thysanopteran (F) insect pests captured on each single-sided yellow sticky card at five different height levels in insect towers. Different letters over different bars indicate significant (linear mixed model, Tukey's contrast pairwise, $P < 0.05$) differences.

Unlike *B. cockerelli*, *C. tenellus* has a longer history with potatoes grown in the Columbia Basin (Murphy et al. 2014, Rondon and Oppedisano 2020). Early reports of *C. tenellus* vectoring purple top disease, or Columbia purple top disease, were published in 2002 (Munyaneza et al. 2010, Rondon and Oppedisano 2020). Although *C. tenellus* does not prefer potatoes over plants in the brassica family (Rondon and Oppedisano 2020), *C. tenellus* is frequently found on potato plants (Murphy et al. 2014). Hence, *C. tenellus* is considered an important potato pest in the Pacific Northwest (Munyaneza et al. 2006). Although Meyerdirk and Oldfield (1985) found that in natural vegetation areas, they determined that 4–20 times more adult *C. tenellus* on yellow sticky cards placed on the ground than those that were 0.3, 0.6, 0.9, 1.5, 2.1, and 2.7 m aboveground level. The difference between the findings of the two studies suggests that adult *C. tenellus* flight behavior might depend on the type of ecological habitat.

Aphid trapping programs in the Pacific Northwest use 19-liter yellow buckets to monitor winged aphids, particularly *M. persicae* and *M. euphorbiae* (Klein et al. 2017). We used yellow sticky cards instead because they are routinely used for monitoring aphids by potato growers in the region. Both aphid species are known for vectoring potato virus Y (PVY) (Patatavirales: Potyviridae) (Döring et al. 2006). The virus causes millions of dollars in crop losses in potato production system. No information is available on the effect of yellow sticky card height on adult *M. euphorbiae* capture in potato fields. However, our *M. persicae* results were similar with the Broadbent (1948) finding that 67% of *M. persicae* were caught at 1.5 m, while 25–28% were collected at 0.96 m, and 5–12% at 0.2 m aboveground level on yellow sticky cards. Coon and Pepper (1968) captured 47% of *M. persicae* at the height of 1.8 m, 26% at 3.0 m, and 5–6% at 4.3–6.7 m using air traps. In contrast with the two previous studies, the greatest percentage of *M. persicae* was caught on yellow pan traps placed at ground level (66%) and lesser percentages were collected on traps placed at 1.5 (15%), 3.0 (9%), 4.6 (6%), and 6.1 (4%) m aboveground level (Moericke 1951). Also, no differences were found in numbers of

M. persicae collected on wind vane traps placed 1.5, 3.0, 4.6, 6.1, 7.6, and 9.1 m aboveground level (Shands et al. 1956). All of these differences can be explained by the different devices used. For instance, the yellow pan traps might stimulate a settling response and attract landing aphids (Shands et al. 1956). Therefore, pan traps are likely to capture the highest density of aphids at ground level because wind speed increases with elevation, and winged aphids are unable to land at wind speeds surpassing their flight speed (Shands et al. 1956). With wind vane traps, the number of airborne aphids trapped on a given elevation mainly depends on wind speed, since wind vane traps pull aphids from the passing column of air (Shands et al. 1956). In contrast, yellow sticky cards generally attract and capture aphids that are flying at certain trap heights. Our results suggest that the two aphid species we collected might have different patterns of flight.

Lygus spp. are relatively new potato pests in the Pacific Northwest. No information is available regarding optimal monitoring practices. Similarly, monitoring thrips in potato production systems is also not well understood. Nevertheless, our results are consistent with previous studies performed in other cropping systems indicating that thrips and lygus bugs can be caught on yellow sticky cards at various heights, but numbers increase at lower elevations. Mueller and Stern (1973) also used insect towers and caught the greatest numbers (three- to fourfold) of *L. hesperus* and *L. elisus* adults on yellow sticky cards placed at 0.3–1.5 m than at 1.8–3.7 m aboveground level in safflower, *Carthamus tinctorius* L. (Asterales: Asteraceae) fields. Regarding thrips, in onion, *Allium cepa* L. (Asparagales: Amaryllidaceae) and soybean, *Glycine max* L. (Fabales: Fabaceae) fields, Macintyre-Allen et al. (2005) caught the highest number of *T. tabaci* on yellow sticky cards placed at 0.7 and 0.9 m than those elevated at 2.5, 3.5, and 4.95 m aboveground level.

The ability to understand factors affecting insect vertical distribution will help to improve pest monitoring. Our study indicates yellow sticky cards placed aboveground level caught hemipteran and thysanopteran potato pests at relatively low heights. We suggest yellow sticky cards should be placed at 1.5 m aboveground to most effectively detect and monitor most potato pest species in the Pacific Northwest during the growing season.

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