Sampling Strategies for Square and Boll-Feeding Plant Bugs (Hemiptera: Miridae) Occurring on Cotton

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ABSTRACT

Sampling methods for square and boll-feeding plant bugs (Hemiptera: Miridae) occurring on cotton, Gossypium hirsutum L., were compared with the intent to assess if one approach was viable for two species occurring from early-season squaring to late bloom in 25 fields located along the coastal cotton growing region of south Texas. Cotton fleahopper, Pseudatomoscelis seriatus (Reuter), damages squares early-season and dominated collections (~99% of insects collected). A major species composition shift occurred beginning at peak bloom in coastal fields, when verde plant bug, Creontiades signatus Distant, represented 55–65% of collections. Significantly more cotton fleahoppers were captured by experienced samplers with the beat bucket and sweep net than with the other methods (30–100% more). There were more than twice as many verde plant bugs captured by experienced and inexperienced samplers with the beat bucket and sweep net than captured with the KISS and visual methods. Using a beat bucket or sweep net reduced sampling time compared with the visual method for the experienced samplers. For both species, comparing regressions of beat bucket-based counts to counts from the traditional visual method across nine cultivar and water regime combinations resulted in only one combination differing from the rest, suggesting broad applicability and ability to translate established visual-based economic thresholds to beat bucket-based thresholds. In a first look at sample size considerations, 40 plants (four 10-plant samples) per field site was no more variable than variation associated with larger sample sizes. Overall, the beat bucket is much more effective in sampling for cotton fleahopper and verde plant bug than the traditional visual method, it is more suited to cotton fleahopper sampling early-season when plants are small, it transitions well to sample for verde plant bug during bloom, and it performs well under a variety of soil moisture conditions and cultivar selections.

KEY WORDS cotton fleahopper, Pseudatomoscelis seriatus, verde plant bug, Creontiades signatus, pest sampling
stink bugs (Hemiptera: Pentatomidae) in the mid-
south and southeast (Musser et al. 2007, Reay-Jones et
al. 2009). A complex of stink bug species (Hemiptera:
Pentatomidae) injure cotton by feeding on bolls. Ex-
ternal and internal wounds of the carpel wall have
been used as indicators of stink bug feeding (Toews et
al. 2009, Reay-Jones et al. 2010). For insect density
estimation, beat cloths have been found to be more
effective in sampling nymphs (Reay-Jones et al. 2009).

In contrast, the cotton insect pest complex along the
south Texas coastal cotton growing region appears to
be composed mainly of plant bugs; the traditionally-
occurring cotton fleahopper and the more re-
cent verde plant bug, Creontiades signatus Distant
(Hemiptera: Miridae). Boll-feeding stink bugs (Hemi-
ptera: Pentatomidae) also occur, although their
abundance is variable, generally skewed toward low
densities, and greater in the upper Texas coastal areas
where soybean is grown (Hopkins et al. 2009). Adults
and nymphs of cotton fleahopper feed on squares and
very young bolls, which results in excessive abscission
(Ring et al. 1993). In investigating alternatives to vi-
sual inspection for cotton fleahopper, the beat sheet
and beat bucket were favored over the sweep net and
visual observation as measured by time required to
sample and numbers of insects caught (Pyke et al.
1980). The sweep net was preferred by Parajulee et al.
(2006) based on fixed precision cost reliability, but
when considering other operational factors the beat
bucket was recommended for commercial pest mon-
itoring use. Boll feeding by verde plant bug is con-
centrated on young bolls during peak to late bloom,
resulting in lint and seed damage (Armstrong et al.
2009). Sampling approaches included visual inspec-
tion during bloom to determine if verde plant bug was
present, if bolls showed signs of feeding, and if bolls
had reached an age when they were less prone to
damage (Armstrong et al. 2009). The situation pre-
vented a challenge in sampling one species of the
traditional complex that threatened early-season
squares (cotton fleahopper) and another species that
occurred later in plant growth and threatened bolls
(verde plant bug), because visual sampling may
change in efficiency and effectiveness as the plant
matures.

The cotton pest management industry is accus-
tomed to a one-size-fits-all sampling approach for the
traditional pest complex. We propose that a sampling
protocol for cotton fleahopper and verde plant bug
would be attractive to the industry if one method was
used for both species. To determine feasibility of this
approach, our objectives were to compare insect sam-
pling methods for these two square and boll-feeding
plant bug species from early-season squaring through
late bloom. For selected sampling methods, we also
considered relationship to an existing economic
threshold and sample size recommendations.

### Methods and Materials

**Growth Stage, Methods, and Experience Compari-
son.** Sucking bugs (Hemiptera: Miridae, and Pentato-
midae) were sampled along the coastal cotton grow-
ing regions of south Texas. In 2010, 25 cotton fields
were sampled using five sampling methods (Table 1)
during three cotton growth periods (early-season
squaring, early bloom, and peak through late bloom)
and by samplers differing in experience (with prior
years of sampling experience or no experience). All
samplers were provided 30 min of field training on
methods and given background of the project. At least
two samplers representing the two experience levels
randomly sampled groupings of at least 10 plants with
the five methods at four locations in each field. Lo-
cations were no closer than 25 m from a field edge to
avoid edge effects. The plant bugs were identified and

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**Table 1. Description of sampling procedures for six methods used to sample square and boll-feeding sucking bugs on cotton, 2010 and 2011, coastal growing region of south Texas**

<table>
<thead>
<tr>
<th>Method</th>
<th>Equipment</th>
<th>Sampling procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweep net</td>
<td>Standard 38-cm-diameter field net made from thick white fabric, 90 cm wood handle</td>
<td>Vigorous 10 pendulum sweeps across the top of the canopy along one row, down to base of small plants and into 20–25 cm of top growth of large plants$^a$</td>
</tr>
<tr>
<td>Beat cloth</td>
<td>One m²$^b$ white cloth framed with wood dowels on two parallel sides</td>
<td>Placed on soil surface with one edge at the base on one row of cotton; 3–4 plants are quickly shaken$^c$</td>
</tr>
<tr>
<td>Beat bucket</td>
<td>White 18-liter plastic bucket, 27 cm in diameter and 37 cm in depth</td>
<td>Held at a tilt toward the plants, plants’ are grasped at the stem and bent into the bucket. 2–3 plants are quickly shaken$^d$</td>
</tr>
<tr>
<td>Visual</td>
<td>None</td>
<td>Examine plant separating terminal growth and leaves to detect nymphs$^d$</td>
</tr>
<tr>
<td>KISS</td>
<td>Leaf blower with 12.7- by 40.6-cm opening of net held 30 cm from blower by a wire frame</td>
<td>The blower and net are placed on opposite sides of plant row. Insects are blown from 3.05 m of row$^{b,c}$</td>
</tr>
<tr>
<td>Cage</td>
<td>Whole plant cage made from organza fabric, 1.07 m in diameter and 1.65 m in height</td>
<td>Two people quickly cover 3–5 plants, cut plants at base, and tie cage. Keep cool, freeze cages to chill insects, shake plants, and inspect cage fabric</td>
</tr>
</tbody>
</table>

$^a$ In 2010 the sweep net, beat cloth, beat bucket, visual, and KISS (Beerwinkle et al. 1999) methods were used; in 2011 the beat bucket, visual, and cage methods were used.

$^b$ Counts adjusted to a per plant basis based on stand count.

$^c$ Sample entire plant during early-season squaring and upper 20–25 cm (terminal growth) thereafter.

$^d$ Continue to another section of row until 10 plants are sampled.
counted in the field, and counts were adjusted to a per plant basis using actual plant counts or stand count estimates (Table 1). Time to sample for all species was recorded at 22 of the fields, which consisted of time to take the sample, counting all insects, and recording the counts. For verde plant bug, nymphs and adults were counted separately to assess potential sampling method biases for this new pest. For cotton flea hopper and other species, nymphs and adults were recorded as a sum total. The fields were selected randomly from a group identified as having plant bug activity by cooperating pest consultants. Locations by Texas county and GPS coordinates were Calhoun County (28.580° N, 96.644° W, 28.551° N, 96.645° W, and 28.550° N, 96.65° W), Aransas County (28.095° N, 97.218° W), Nueces County (27.781° N, 97.561° W, 27.786° N, 97.560° W, 27.776° N, 97.562° W, 27.770° N, 97.562° W, 27.725° N, 97.665° W, 27.708° N, 97.665° W, 27.708° N, 97.665° W, 27.708° N, 97.644° W), Kleberg County (27.437° N, 97.848° W, 27.426° N, 97.875° W, and 27.446° N, 97.910° W) and Cameron County (26.210° N, 97.480° W, 26.204° N, 97.953° W, 26.243° N, 97.651° W, 26.165° N, 97.652° W, 26.289° N, 97.862° W, 26.243° N, 97.651° W, 26.191° N, 97.367° W, 26.207° N, 97.856° W, 26.242° N, 97.872° W, and 26.239° N, 97.758° W). The fields were planted to multiple cultivars adapted to the region. Insecticides were used occasionally for plant bug control, but sampling occurred before spraying or at least two weeks after an application.

Summing counts across all fields, relative number of cotton flea hopper, verde plant bug, and other square and boll-feeding species collected were compared for each method and growth stage by using a χ² test of equality (Freund and Walpole 1980). Based on this analysis, counts of predominant species and corresponding time to sample data were analyzed separately with analysis of variance (ANOVA). Data were averaged across samplers of the same experience level before analysis. These data were adjusted to a per plant basis (insect counts) and 10-plant basis (time to sample), and insect counts were transformed by the square root of (x + 0.5).

The ANOVA followed a split-split-plot design. The main plot was the plant growth stage factor (three levels), the first split was the experience of the sampler (two levels), and the second split was the sampling method (five levels). Field replication was used as a blocking factor in the analysis. The levels were considered fixed, and three error terms were used to test the main factors and their interactions (Neter et al. 1985). Because verde plant bug was only detected at 15 fields during peak to late bloom, the ANOVA was transformed to a split-plot design using two error terms (Neter et al. 1985). Comparison of the five methods was the primary interest; therefore mean separation tests (Tukey’s Honest Significant Difference (Littell et al. 1991)) were performed on the five methods by slicing data by the two experience levels and three cotton growth stages whenever a method interaction with these factors were detected. Tukey’s test also was done to separate method means when no interaction was detected. Tukey’s test was used in all subsequent means separation tests in this study.

**Comparison to a Whole Plant Caging Method.** In 2011, sampling methods chosen as the most promising used by experienced samplers (i.e., beat bucket and sweep net) were compared with a whole plant caging method (Table 1). Whole plant caging has been used to approximate an absolute count in some crop applications including cotton (Knutson et al. 2008). The whole plant caging method was of special interest to see if stink bugs were detected, because they were rarely detected with the five methods used in 2010. The sampling procedures from the 2010 methods were used with the following modification: seven fields were visited, sampling was done by experienced samplers, time to sample data were not taken, nymphs and adults were counted together, and the caged plants were taken to the laboratory and chilled before counting the insects. Fields were in the same area as those visited in 2010. Insect count adjustment to a per plant basis, count data transformation, and data averaging across samplers were done as in 2010.

The cotton flea hopper was the focus during early-season squaring, and the verde plant bug was the focus during peak to late bloom; therefore, the analyses were performed separately by species for the respective cotton growth periods. Insect counts of nymphs and adults of each species for each method were based on a 10-plant sample in each plot and adjusted to a per plant basis. Relative sampling efficiency of the visual and beat bucket methods to the whole plant caging method was calculated (mean count [visual or beat bucket] divided by mean count whole plant caging). After transformation as described in the previous section, measurements were also analyzed in a single factor (sampling methods) ANOVA replicated across seven fields (cotton flea hopper) and four fields (verde plant bug). Field was used as a blocking factor in the analysis. If the method factor was significant, numbers of collected insects using the three methods were compared using Tukey’s mean separation test.

**Relationship of Visual and Beat Bucket Methods across Growing Conditions.** In 2011 at one field, experienced samplers used the beat bucket and visual methods for cotton flea hopper and verde plant bug sampling. Sampling was done on three cultivars (i.e., PhytoGen 367 WRF [PhytoGen Seed, Dow AgroSciences, Indianapolis, IN], Deltapine 1032 B2RF [Deltapine, Monsanto, St. Louis, MO], and Stoneville 5458 B2RF [Bayer CropScience, Research Triangle Park, NC]) under three water regimes (i.e., dryland, irrigation scheduled at 75% of evapotranspiration replacement, and irrigation scheduled at 90% of evapotranspiration replacement) and planted on two dates (i.e., 1 April representing a common date for the region, and 20 April representing a late date for the region). The treatment combinations represented a broad range of moisture conditions, planting dates, and cultivar selections in the growing region. The intent was to compare the promising beat bucket method to the traditional visual method across varying conditions in a replicated experimental setting that
reflects various conditions a grower may experience but was not be experienced in our larger survey of commercial fields. Treatments were arranged in a split plot design of five replications, with water regime as the main plot and the six combinations of cultivar and planting date as the split plot. Each plot measured 30.5 m by four rows. Land cultivation, fertilization, and planting were standard for the growing region. No insecticides were used. Data were taken on the inner two rows. Drought conditions were severe: ≈7.6 cm of rainfall 1 April through 30 August compared with 45.7 cm in 2010 and a 35.5 cm average over 125 yr (National Weather Service 2011). Insect colonization was delayed; therefore insect counts were used only for the late planting.

Cotton fleahopper was the focus of three consecutive weeks of sampling from early-season squaring through early bloom, and verde plant bug was the focus of three weeks of sampling beginning at peak bloom. Insect counts of nymphs and adults of each species for each method were based on a 10-plant sample in each plot, adjusted to a per plant basis, and transformed before regression analyses. Correlation analysis was used to compare separate counts of nymphs and adults to the total count. Using transformed data across all weeks of targeted sampling periods and from the nine combinations of the cultivar and water regime factors, simple linear regression was used to regress density estimates using the beat bucket method to density estimates using the visual method. To test sensitivity of the summary regression across these nine combinations, an indicator variable was used to compare a regression line estimated from each cultivar/water regime treatment combination to a regression line estimated from the data representing the remaining cultivars and water regimes (Neter et al. 1985). As an additional analysis check, an analysis of covariance (ANCOVA) approach was taken comparing the nine treatment combinations of cultivar and irrigation regime, using transformed beat bucket counts as the dependent variable and visual counts as the covariate and disregarding the replication and observation date structure of the design (Littell et al. 1991). A cotton fleahopper economic threshold of 15 cotton fleahoppers per 100 plants using the visual method in south Texas (Benedict et al. 1989) was translated to its equivalent using the beat bucket method using a common regression or separate regressions depending upon the outcome of the analyses. This procedure was not done for verde plant bug because an economic threshold is currently not established. Use of the Verde plant bug regression still remains valuable for those using the visual method and considering adopting the beat bucket method.

Sample Size Considerations. For the beat bucket and sweep net methods, variation associated with mean estimates of cotton fleahopper and verde plant bug was explored across several fixed sample sizes and compared with variation associated with mean estimates of the visual method. Sequential sampling for classification, where sample size is a random variable and error rates are fixed, was not considered because an economic threshold for verde plant bug was not available and using multiple sequential sampling plans for different species can be problematic (Wilson 1994). Data used were from experienced samplers in 2010 focusing on cotton fleahopper at early-season squaring and focusing on verde plant bug at peak to late bloom. Means, standard errors, and coefficients of variation (CV, as a percentage of the mean) for insect counts (per plant) and time to sample (per 10 plants) were calculated across fields. These descriptive statistics were calculated for Verde plant bug using 120, 80, and 40 plants taken in groups of 10 plants and for cotton fleahopper using 80 and 40 plants taken in groups of 10 plants. Therefore, variation estimates were based on 10-plant observation units of 12, 8, and 4, drawn sequentially from the data set (i.e., each field) and taking a single draw from the beginning of the data set to have the same number of values to generate the mean estimates. For each species and sample size scenario, means and CVs of the three methods were compared using a one-way ANOVA, with field as a blocking factor, followed by Tukey’s means separation test if the methods factor was significant.

Results and Discussion

Growth Stage, Methods, and Experience Comparison. In collections from 25 coastal and inland fields in 2010, over 99% of the insects collected using all five sampling methods were cotton fleahopper during early-season squaring through early bloom. But for the 12 coastal fields during peak to late bloom, 55–65% of the insects collected were Verde plant bug for each method (Fig. 1), while Verde plant bug was not detected in inland fields. Cotton fleahopper and Verde plant bug dominated the collections, as judged by the significant \( \chi^2 \) tests of equality for the three growth stages (early-season and early bloom for all methods: \( df = 1, \chi^2 > 100, P < 0.005 \); peak/late bloom for all methods: \( df = 2, \chi^2 > 20; P < 0.005 \) ) and the large cell contributions for cotton fleahopper (all growth stages) and Verde plant bug (peak/late bloom).

Cotton Fleahopper. In comparing growth stage, experience level, and sampling method, the 3-way interaction was not significant (\( P = 0.18 \)). One two-way interaction was significant (sampling method by experience level: \( P = 0.009 \), Table 2) and one two-way interaction was nearly significant (sampling method by plant growth stage: \( P = 0.06 \), Table 2). The beat bucket and sweep net methods accounted for more captures than the other methods, especially starting at early bloom (Fig. 2A). For experienced samplers, significantly more cotton fleahoppers were captured with the beat bucket and sweep net than with the other methods (Fig. 2B). Inexperienced samplers detected fewer cotton fleahoppers, and their counts were uniformly low among the methods (Fig. 2B). This is not an uncommon result for inexperienced samplings, and points out the importance of well-trained samplers (Hoff et al. 2002).
Verde Plant Bug. The two-way interaction between sampling method and experience level was not significant \((P = 0.35)\). Averaging across experience, there were more than twice as many verde plant bugs captured with the beat bucket and sweep net than captured with the KISS and visual methods \((P = 0.0015, \text{Table 2})\) \((\text{Fig. 3})\).

Time to Sample. The three-way interaction between growth stage, experience level, and sampling method was significant \((P = 0.03, \text{Table 2})\). The greatest contributions to variation were the two-way interactions of sampling method by growth stage \((P = 0.006, \text{Table 2})\) and sampling method by experience level \((P < 0.0001, \text{Table 2})\). Even though fewer plant bugs were collected on a per plant basis, the KISS and visual methods took longer to perform than the other methods with some variation detected across sampling periods \((\text{Fig. 4A})\). It took nearly twice the time for experienced sampler to visually inspect plants, especially the older plants, compared with when experienced samplers used the beat cloth, beat bucket, and sweep net \((\text{Fig. 4B})\). Using a beat cloth, beat bucket, or sweep net was key to reducing sampling time for the experienced samplers \((\text{Fig. 4B})\). Wilson et al. \(1989\) also noted that fatigue and lack of insect knowledge may result in under-estimation of densities by inexperienced samplers.

Comparison to Whole Plant Caging Method. In 2011, severe drought limited surveys to seven fields where plant bugs were detected. When using the whole plant caging method, very few stink bugs were detected relative to verde plant bug and cotton flea-hopper \((<0.1% \text{ of total insects collected})\). This very low percentage was similar to last year’s results, suggesting an infrequent occurrence of stink bugs and not a sampling method bias. Stink bugs previously had been found in low densities in our study area, while they were more commonly found north of our study area where soybean was grown \(\text{Hopkins et al. 2009}\).

Further analyses centered on cotton flea-hopper during early-season squaring and verde plant bug during peak to late bloom. The visual method detected about half the number of cotton flea-hopper and verde plant bug than detected with the whole plant caging method \((\text{relative sampling efficiency to the absolute sampling was 0.48 and 0.45, respectively})\) \((\text{Table 3})\). In contrast, the relative sampling efficiency was 0.74 using the beat bucket method to sample for cotton flea-hopper, while the beat bucket actually captured more verde plant bugs than the whole plant caging method \((\text{relative sampling efficiency was 1.57, Table 3})\). We suspect the relative sampling efficiency would have been closer to 1.0 if the cages had been set at the base of the plant the day before and then quickly pulled up over the plant to reduce insect escapes. Despite this concern, the high sampling efficiency substantiated that the beat bucket was particularly useful in sampling verde plant bug compared with the visual method \((\text{Fig. 3})\). Parajulee et al. \(2006\) previously recommended this method in a commercial setting where ease of use and local availability of buckets make it especially attractive. The methods factor in the ANOVA was not significant, likely because of high variation in the counts \((\text{Table 3})\).

Visual/Beat Bucket Regressions and Relationship to a Cotton Flea-hopper Economic Threshold. Strong correlations of cotton flea-hopper nymphs and adults to the total count were seen for visual and beat bucket sampling methods \((n \geq 540, r > 0.86, P < 0.001 \text{ for all four comparisons})\). The counts of verde plant bug nymphs and adults to the total count were significantly correlated when using the beat bucket \((n = 270; \text{correlation between nymphs and total counts: } r = 0.90,\)
P < 0.001; correlation between adult and total counts: n = 270, r = 0.82, P < 0.001) and when using the visual method (correlation between nymphs and total counts: n = 270, r = 0.51, P < 0.001; adult/total: n = 270, r = 0.62, P < 0.001). For insect density estimation, Reay-Jones et al. (2009) found differences in catch efficiencies for nymphs and adults of stink bugs when using beat cloths and sweep nets. Based on our correlations, adults were under-represented using the visual method in comparison to using the beat bucket method. A likely explanation is that adult cotton fleahoppers readily fly when disturbed as the plant is visually inspected, whereas an experienced sampler will sample the plant and count captured bugs quickly with the beat bucket resulting in fewer escapes.

Total counts were used in the regression analyses comparing insect counts using the beat bucket and visual sampling methods. For both species, regressing beat bucket-based counts on visual-based counts was fairly robust across the nine combinations of cultivar and water regime. Only the regression using data from the Deltapine cultivar/ high irrigation treatment differed from the composite regression using data from the remaining eight cultivar/ water regime treatments.
(regression line comparison: $P < 0.02$ for cotton flea-hopper and verde plant bug) (Table 4). This regression was confirmed using the ANCOVA approach. The visual count covariate was significant for both cotton flea-hopper and verde plant bug ($F > 59; df = 1, 260; P < 0.0001$). And as in the regression approach, only the beat bucket and visual count parameter estimate from the Deltapine cultivar/ high irrigation treatment differed from the hypothesis of common relationship among the nine treatment combinations (cotton flea-hopper: $t = -2.86, df = 260, P = 0.005$; verde plant bug: $t = 2.10; df = 260; P = 0.04$).

An established economic threshold of 15 cotton flea-hoppers per 100 plants (Benedict et al. 1989) using the visual method translated to 48 cotton flea-hoppers per 100 plants using the beat bucket method using the
Table 3. Mean (± SEM) total (nymphs and adults) insect counts per plant using the visual, beat bucket, and absolute sampling methods during early-season squaring (cotton fleahopper) and peak bloom (verde plant bug).

<table>
<thead>
<tr>
<th>Method</th>
<th>Cotton fleahopper</th>
<th>Verde plant bug</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SEM</td>
<td>RE*</td>
</tr>
<tr>
<td>Visual</td>
<td>1.91 ± 0.42</td>
<td>0.48</td>
</tr>
<tr>
<td>Beat bucket</td>
<td>2.97 ± 0.55</td>
<td>0.74</td>
</tr>
<tr>
<td>Whole plant caging</td>
<td>4.01 ± 1.47</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Means differences among methods were not detected in the ANOVA and post-ANOVA contrast statements comparing the visual and beat bucket means to the absolute mean.

Data taken from seven (cotton fleahopper) and four (verde plant bugs) fields along the Texas coastal cotton growing region, 2011.

* Relative efficiency: mean count [visual or beat bucket] divided by mean count whole plant caging.

composite regression (Table 4). Our analyses support use of this relationship in most situations, but consideration of a higher threshold using the beat bucket method is appropriate in well irrigated or high soil moisture fields for some cultivars (a beat bucket economic threshold of 55 cotton fleahoppers per 100 plants is the equivalent). Given variation associated with the regression and use of the sampling methods, we propose for field application a low economic threshold of 40 cotton fleahoppers per 100 plants using the beat bucket is appropriate for producers with low pest risk and high intensity management perspective. A higher economic threshold of 55 cotton fleahoppers per 100 plants is more appropriate for producers using an IPM approach of frequent field scouting for insects and square damage, especially when the cotton field is well irrigated or experiencing good moisture conditions.

Sample Size Considerations. The sweep net and beat bucket consistently had significantly higher captures of cotton fleahopper and verde plant bug than when using the visual sampling method. There were no capture differences detected for the sweep net and beat bucket under several sample size scenarios (Table 5). Variation was high, resulting in no difference in CVs among sampling methods for each sample size scenario (Table 5). This first look at sample size considerations suggested that sampling could be reduced to 40 plants without substantial increase in variation of the estimate. The sample size of 40 plants equates to four 10-plant samples in the field when using the beat bucket and sweep net. The sample size is applicable to a location that is homogeneous with respect to plant health, planting time, irrigation, and other agronomic and environmental conditions. Sequential sampling approaches may be possible given the few species and growth stage separation of their occurrence. Sequential approaches using accepted economic thresholds may improve sampling quality (fixed error rates). But sample size reductions likely will be marginal given the practical aspects of sampling in groups (Wald 1947), such as groups of 10 plants when using a beat bucket in this study.

The general consensus in the literature was that alternative methods to visual inspection of stink bugs and plant bugs were available. Buckets and drop cloths (beat sheets) usually were identified as effective, and efficiencies were affected by factors such as crop stage and insect development stage (Pyke et al. 1980, Reay-Jones et al. 2009). The catch efficiency of the sweep net was variable across studies. Some reported poor catch efficiencies (Smith et al. 1976) while others found the sweep net efficient in sampling cotton fleahopper and stink bugs under selected conditions (e.g., Parajulee et al. 2006, Reay-Jones et al. 2009). But in our system, the sweep net was difficult to use when fleahopper sampling is critical for decision-making. The beat bucket was more flexible for early-season and bloom period sampling, and it had comparable catch efficiency to the sweep net (Figs. 2, 3). It was much more catch efficient in collecting verde plant bug during the bloom period than the visual method (Fig. 3). The beat bucket also performed well across a range of cultivars and soil moisture conditions (Table 4) and sample sizes (Table 5). Last, it is effective in sampling for natural enemies in cotton (Knutson et al. 2008) and headworms in sorghum (a rotational crop with cotton) (Parker et al. 2009).

In the literature, the shake bucket (similar to the beat bucket but shorter in depth) and beat bucket often were viewed as an acceptable sampling method for cotton insects based on a combination of catch efficiency, low time requirements to sample, and ease of use (Pyke et al. 1980, Parajulee et al. 2006, Knutson et al. 2008). The visual method generally was the least effective, either in catch efficiency, time to sample, or both. In contrast, Parajulee et al. (2006) found the visual method detected more cotton fleahopper than

Table 4. Linear regressions of density estimates of cotton fleahopper and verde plant bug by using the beat bucket method (dependent variable) to density estimates using the visual method (independent variable).

<table>
<thead>
<tr>
<th>Insect</th>
<th>Regression</th>
<th>n</th>
<th>Slope ± SE</th>
<th>Intercept ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton fleahopper</td>
<td>Composite</td>
<td>240</td>
<td>1.63 ± 0.05</td>
<td>0.24 ± 0.08</td>
</tr>
<tr>
<td>Deltapine high irrigation</td>
<td>20</td>
<td>0.86 ± 0.09</td>
<td>0.42 ± 0.17</td>
<td></td>
</tr>
<tr>
<td>Verde plant bug</td>
<td>Composite</td>
<td>114</td>
<td>0.56 ± 0.16</td>
<td>0.06 ± 0.01</td>
</tr>
<tr>
<td>Deltapine high irrigation</td>
<td>30</td>
<td>1.30 ± 0.83</td>
<td>0.14 ± 0.04</td>
<td></td>
</tr>
</tbody>
</table>

Statistical tests were done using transformed data; slope and intercept estimates are given in untransformed units. The regression of the Deltapine and high irrigation treatment differed from the composite regression from the remaining eight cultivar or water regime treatments for cotton fleahopper (t = 3.16, df = 1; P = 0.002) and verde plant bug (t = -2.27, df = 1; P = 0.02).

Data taken from one experimental field with treatment combinations representing moisture conditions and cultivar selections in the Texas coastal cotton growing region, 2011.
the beat bucket when experienced samplers used the methods, but they concluded that the beat bucket was more appropriate for pest management decision-making partly because it was much more time efficient. Wilson et al. (1989) noted that commercial crop advisors often adopted the visual method for stink and plant bug sampling because it had been successfully used as part of a plant damage and insect monitoring system for cotton boll weevil and heliothines. We interpreted this observation as matching a philosophy of method consistency from an operational, and not a sampling efficiency, perspective.

We propose that advisors may be willing to change to an alternative method if it meets field operational criteria for sampling methods: a method suitable for all species of interest, rapid and easy to use, and easily integrated into a field monitoring program (Knutson et al. 2008). From this viewpoint, our results supported use of the beat bucket method, using a common white, 18-liter, plastic pail, to sample the plant bug pest complex found along the coastal cotton growing region of Texas. Overall, the beat bucket is much more effective in sampling for cotton flea hopper and verde plant bug than the traditional visual method, it is more suited to cotton flea hopper sampling during early-season sampling than the sweep net, it transitions well to sample for verde plant bug during bloom, it performs well under conditions and has utility for sampling other insects in cotton and sorghum.

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References Cited


Table 5. Means and coefficients of variation (percentage of the mean) of total counts (nymphs and adults) per plant using the sweep net, beat bucket, and visual sampling methods under several sample size scenarios.

<table>
<thead>
<tr>
<th>Sample size</th>
<th>Sample method</th>
<th>N</th>
<th>Mean ± SEM</th>
<th>CV</th>
<th>N</th>
<th>Mean ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Sweep net</td>
<td>10</td>
<td>2.19 ± 0.69a</td>
<td>99.9a</td>
<td>4</td>
<td>10.56 ± 4.04a</td>
</tr>
<tr>
<td></td>
<td>Beat bucket</td>
<td>10</td>
<td>1.61 ± 0.45a</td>
<td>88.9a</td>
<td>4</td>
<td>5.94 ± 2.34ab</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>10</td>
<td>0.98 ± 0.25b</td>
<td>81.4a</td>
<td>4</td>
<td>2.31 ± 1.16b</td>
</tr>
<tr>
<td>80</td>
<td>Sweep net</td>
<td>10</td>
<td>2.37 ± 0.64a</td>
<td>85.6a</td>
<td>4</td>
<td>9.78 ± 3.71a</td>
</tr>
<tr>
<td></td>
<td>Beat bucket</td>
<td>10</td>
<td>1.75 ± 0.49a</td>
<td>87.9a</td>
<td>4</td>
<td>7.00 ± 3.06ab</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>10</td>
<td>0.95 ± 0.24b</td>
<td>80.4a</td>
<td>4</td>
<td>2.53 ± 1.47b</td>
</tr>
<tr>
<td>120</td>
<td>Sweep net</td>
<td>4</td>
<td>8.92 ± 3.54a</td>
<td>79.3a</td>
<td>4</td>
<td>7.46 ± 3.17a</td>
</tr>
<tr>
<td></td>
<td>Beat bucket</td>
<td>4</td>
<td>7.46 ± 3.17a</td>
<td>85.0a</td>
<td>4</td>
<td>2.58 ± 1.53b</td>
</tr>
</tbody>
</table>

N was the number of fields sampled and was kept constant across sample size scenarios. Only two fields had cotton flea hopper captures for a sample size scenario of 120; therefore it was not considered. Different letters among sampling methods within a sample size indicate significant differences at α = 0.05 using Tukey’s means separation test. Analyses based on transformed data, and descriptive statistics based on untransformed data.

Data taken from 25 fields along the Texas coastal cotton growing region, 2010.


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