THE BEAT BUCKET: A RAPID, RELIABLE METHOD FOR SAMPLING PREDATORY INSECTS AND SPIDERS IN COTTON

Allen E. Knutson
Texas Agricultural Extension Service
Dallas, TX
W. Ted Wilson
Entomology Dept, Texas A&M University
College Station, TX

Abstract

A beat bucket procedure using a five gallon, white plastic bucket was a rapid and reliable method for sampling predatory insects and spiders common in cotton in central Texas. This method was faster and more reliable than use of a sweep net, shake bucket or visual search of the plant and was less tedious than using a drop cloth for most predator groups. The beat bucket technique should be useful for determining densities of common predators of bollworm, budworms, other caterpillar pests and aphids in a cotton field scouting program.

Introduction

Predatory insects and spiders have long been recognized as important natural enemies that suppress infestations of bollworms, budworms, beet armyworms and aphids in cotton (Sterling et al 1989). The impact of these and other natural enemies on cotton insect pest populations becomes most apparent when the use of broad spectrum insecticides disrupts this natural control and leads to pest resurgence and secondary pest outbreaks (Ewing and Ivy 1943, Ridgeway et al 1967, Adkisson 1971). Insect and spiders are especially important in suppressing populations of bollworm and budworm (Sterling et al 1989). Most predators attack the egg and early larval stages of these pests before they cause economic damage (McDaniel and Sterling 1982, McDaniel et al, 1981). In central Texas, important predators of bollworms and budworms are: *Orius* including the minute pirate bug and insidious flower bug; *Chrysoperla* or lacewing larvae; *Solenopsis*, imported fire ants; *Geocoris* or big-eyed bugs; and several species of spiders, especially crab spiders (*Misumenops* spp.), striped lynx spider (*Oxyopes salticus*) and jumping spiders (*Phidippus* spp). (Sterling et al., 1989). Several of these predators and parasites are also important in suppressing beet armyworm infestation and disruption of these natural enemy populations has been implicated in outbreaks of this pest following widespread application of malathion on cotton (Ruberson et al. 1994). Predators, especially lady beetle adults and larvae (*Coccinellidae*), also suppress populations of cotton aphid (Kidd and Rummel 1997).

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1120-1125 (1999)
National Cotton Council, Memphis TN

Knowledge about natural enemies can be used in making decisions regarding treatment of pests and in developing crop management tactics that enhance the impact of natural enemies on pest densities. In the first case, densities of key predators are considered when determining if the pest has reached the economic threshold. Unfortunately, there has been little research in determining the relationship between densities of natural enemies and cotton insect pests. The number of predators capable of preventing a pest infestation from reaching the economic injury level has been termed the "inaction level " (Sterling, et al 1989). Based on studies in Central Texas, a mean density of two fire ants per terminal was sufficient to suppress boll weevil infestations below economically damaging levels (Strum and Sterling 1986). McDaniel and Sterling (1982) suggested an inaction level of one key egg predator to one bollworm/budworm egg was sufficient to control these pests.

Understanding the natural enemy complex in cotton can also be used to manage the crop to protect and enhance populations of key predators and parasites. This approach is termed conservation biological control and although the research base if very limited, this area has received some recent attention. Using selective insecticides or rates of insecticides that are least toxic to natural enemies is an important aspect of conserving beneficial insects. Other crop management practices include planting crops or cover crops that serve as sources of natural enemies which colonize cotton (Parajulee and Slosser 1997). As before, reliable sampling methods are necessary to evaluate the impact of insecticides, cropping patterns or other management practices on species composition, density and seasonal occurrence of predators.

The use of natural enemies in a cotton IPM system requires a sampling method that provides a reliable estimate of densities sufficient for making management decisions. Sampling methods should detect all key predators, be rapid and simple to use, and be easily integrated into current commercial field sampling programs which focus on pest and crop monitoring. Sampling equipment, if any, should be easy to carry in the field and be inexpensive. Sampling procedure should be simple to understand and conduct to reduce error and variation due to differences in individuals taking the samples.

Sampling methods for predatory insects and spiders include devices which vacuum or blow insects from the plant, sweep nets, various types of containers in which plants are shaken, or beaten, and beating plants over drop cloths. Methods such as the vacuum and suction samplers and whole plant bag sample are useful in research programs but because of the time to collect and process samples they have not been adopted for use in commercial field scouting program. The sweep net method is sometimes used, but recovers only about 10-12% of the predators relative to a visual search of the entire cotton plant (Wilson and Gutierrez 1980). Pyke et al. (1980) found shaking the plant

terminal into various sized buckets was about two times more efficient for sampling predators than a visual examination of the plant and required less time. Nuessly and Sterling (1984) reported the drop cloth method captured significantly fewer predators that the D-vac suction sampler. Recording predators while visually searching the cotton plant for pests is probably the most commonly used method for sampling predators in field scouting programs.

The objective of this study was to identify a sample method to assess densities of common predatory insects and spiders in cotton that was reliable and suitable for use by a consultant, field scout or producer in a cotton field scouting program.

Methods and Materials

Densities of pirate bugs and insidious flower bugs, *Orius* spp., lady beetles adults *(*Coccinellidae*)*, green lacewing larvae (Chrysopidae), big-eyed bugs, *Geocoris* spp., and spiders were estimated with a sweep net, drop cloth, beat bucket, shake bucket and by visual search of the plant. Adults and immatures were recorded separately for all predators except spiders. The sweep net method used a standard 38 cm diameter sweep net swung in a pendulum-like motion through the top of the canopy while walking down the row (Fleischer et al. 1985). A single sample consisted of five sweeps. Sweep net samples were converted to a per plant basis by dividing by 19 based upon a single sweep intercepting 3.8 plant terminals (Wilson and Gutierrez 1980). Captured predators were identified and counted in the field as the net was carefully unrolled.

The drop cloth method involved beating five adjacent cotton plants onto a 0.9 X 1.1 m white cloth placed on the soil between the rows (Nuessly and Sterling, 1984). Predators dislodged onto the cloth were identified and recorded. Densities were divided by five to estimate densities on a per plant basis.

The shake bucket was 15 cm deep and 27 cm in diameter and was cut from the bottom of a white, five gallon (18 litter) plastic pail. The upper 15-20 cm of the plant was placed inside the shake bucket and shaken five times to dislodge predators (Pyke et al. 1980). The plant was then removed and predators captured in the bucket were immediately identified and recorded.

The beat bucket method used a common white, five gallon (18 liter) plastic pail 27 cm in diameter and 37 cm (14.5 in.) deep, or more than twice as deep as the shake bucket. It was expected that the deeper bucket would slow the escape of rapidly moving predators. Also, a greater proportion of the plant could be placed inside the deeper bucket, increasing the capture of predators found lower in the plant canopy.

In using the beat bucket, the sample plant was carefully approached and grasped near the base of the stem. The bucket was held at a 45 degree angle to the ground. The terminal of the plant and as much of the plant as possible was quickly bent into the bucket. While continuing to grasp the plant stem near the base, the plant was rapidly beaten against the side of the bucket 12-16 times during a 3-4 second period. This action dislodged predators which fell into the bottom of the bucket. The plant was removed and the bucket held upright to prevent predators from escaping. Any leaves or fruit which fell into the bucket were examined for predators and discarded. Captured predators were then identified and counted.

The visual search method involved a rapid examination of the terminal and all fruiting structures beginning in the terminal and working down through the plant. Blooms and bracts were opened to expose predators hiding in these structures. Samplers were alert to predators on leaves and stems during the examination but did not specifically sample these structures.

All of the above sampling methods were compared to an absolute method which attempted to recover all of the targeted predatory insects and spiders present on the plant. Absolute sampling methods used in cotton include quickly caging plants with large plastic cages or in bags and then collecting the plants for later dissection (Smith et al. 1976, Byerly et al. 1978, Garcia et al. 1982). We developed a method where plants were exposed to a pyrethrin fog and then beaten inside a large container which funneled the insects into a collection jar with alcohol.

The absolute method used a sampler constructed from a 25 gallon capacity galvanized trash can (38 cm opening at the top and 67 cm deep) fitted with a large funnel in the bottom. The sampler was supported in the field by a five gallon plastic pail. One side of the pail was cut open to allow access to the bottom of the funnel which was fitted with a 0.5 liter glass jar containing 50% ethyl alcohol and water and a few drops of detergent. An aerosol can of 0.5% pyrethrin (PT 565 Fogger, Whitmire Labs, St. Louis, MO) was fastened to the outside of the sampler. The tip of the spray nozzle was inserted through a small hole in the side of the sampler. Exposure to the pyrethrin was expected to flush small predators (*Orius* nymphs, lacewing larvae) from behind bracts and in blooms to more exposed areas of the plant where they could then be dislodged by beating the plant.

The sample plant was quickly cut with pruning shears just below the first branch and quickly placed inside the sampler. The lid was placed on top of the sampler and the sampler was fumigated by releasing a 1 second spray of pyrethrin. After one minute, the lid was removed and the plant vigorously shaken and beaten against the side of the sampler to dislodge predators which were collected in the jar at the bottom of the funnel. All leaves and fruiting

forms were removed and examined for predators while inside the sampler. Bracts were removed from fruit, and blooms were opened to reveal predators. During this time, the plant was periodically beaten against the side of the sampler and was used to brush any predators from the sides of the sampler into the jar below. The jar was then removed from the bottom of the sampler, sealed and returned to the laboratory. A Buchner funnel was used to concentrate the predators onto a filter paper where they were identified and counted using a dissecting microscope.

In 1997, all of the above sampling methods were compared in a 3 acre field of cotton at the Texas A&M Research and Extension Center at Dallas and in two large commercial fields located near Hillsboro in central Texas. In 1998, only the sweep net, beat bucket, and visual search were compared to the absolute sample in the field at the Texas A&M Research and Extension Center at Dallas. The field at Dallas was planted to 'Delta Pine 50' cotton on 40 inch rows and was not treated with any foliar insecticides. The field was bordered by grain sorghum on one side and corn on the other side. The two commercial fields were planted to Bt cotton 'Delta Pine 33B' on 40 inch rows and both fields were bordered on one side by a field of grain sorghum. Both fields were treated with foliar insecticides for fleahoppers and boll weevils three weeks prior to the start of the trial. Also, one field received an application of endosulfan (Phaser) and oxamyl (Vydate) on July 23 and it was not sampled again until August 1.

In the two fields at Hillsboro, a block of cotton 50 rows wide by 540 feel long was divided into 30 plots each 5 rows wide and 180 feet long. Each plot was further divided into six subplots 5 rows wide by 30 feet long. Because of the smaller field size at Dallas, each subplot was 5 rows by 15 feet long. Each of the six sampling methods was randomly assigned to one of the subplots within each of the 30 plots to provide 30 samples per method on each sample date.

The Dallas field was sampled on eleven dates at weekly intervals from June 16 to August 21 in 1997 and on six dates from June 15-July 28, 1998. The Hillsboro fields were each sampled on four dates from July 3 to August 1. Sampling began in the early morning and was completed by noon since many insects readily fly or drop from the plant when the plant is disturbed once temperatures reach 25-30 C (Garcia et al 1982). Samplers worked in teams with one person sampling while the other person recorded data. Data on predator densities from all four fields and both years were pooled for analysis. The time in minutes for the team to complete each sampling method was recorded in 1997. Mean sample times for each sample method were analyzed by ANOVA and means separated by Least Significant Difference test at a=0.05.

Efficiency (% recovery) of each sample method was determined by comparing the total number of each predator group collected to the number collected in the absolute sample. The sample size necessary to estimate the mean within 35% with a 95% confidence interval was determined from Wilson (1993) as :

$$n = t^2_{a/2} D_x^{-2} a x^{b-2}$$

where $t_{a/2}$ = standard normal variate for a two-tailed confidence interval, D_X = a proportion defined as the ratio of half the desired confidence interval to the mean (D_X = [C.I./2]/x for enumerative sampling), x = sample mean, and a and b = Taylor's coefficients.

Commercial field scouting must balance the reliability of a sample, as measured by the number of samples, with the time or effort required to collect the sample. The optimal sampling method is one which provides the most reliable estimate per unit of time or effort. The cost of a sampling method is a product of the sampling time and the number of samples required for a given level of reliability. The ratio of the costs of two sampling methods is referred to as the relative cost reliability (Wilson 1993). In this analysis, the relative cost reliability (RCR) of each sampling method was compared to the visual search method as follows:

$$RCR = \frac{\text{sampling time for method } a \text{ X sample size for method } a}{\text{sampling time for visual search X sample size for visual search}}$$

As an example, a sampling method with a RCR of .25 requires 25% less time than the visual search method to estimate the mean density of a predator within 35% of the actual mean and a 95% confidence interval.

Results

The insidious flower bugs and pirate bugs (*Orius* species) and spiders were the most common predator groups collected by the absolute method, representing 78% of all predators collected (Table 1). Lady beetle adults, primarily the convergent lady beetle *(Hippodamia convergens*) and lacewing larvae each represented 3-4 % of all predators collected. Cotton aphids were not common in any of the four sample fields and this accounted for the low density of lady beetles and lacewing in this study. Big-eyed bugs (primarily *Geocoris punctipes*) were uncommon in all fields and years. Although a major pest of cotton in central Texas, fleahoppers are also an important predator of bollworm eggs and were reported in this study (McDaniel and Sterling 1982). The red imported fire ant (*Solenopsis invicta)* is an important predator of several cotton pests in central Texas (McDaniel and Sterling 1982), but numbers recovered in these study fields were too low to report.

The beat bucket and shake bucket method required significantly less time to complete than the other three sampling methods (Fig. 1). To sample with each method, the samplers walked 5,400 feet (through 30 plots each 180 feet long), or just over a mile. Since walking distance for each method was the same, differences between sampling times were a result of the sampling method.

Whole Plant Visual Examination

The efficiency of the visual search method ranged from only 17% for spiders to 112% for adult lady beetles relative to the absolute method (Table 2). The visual search required the most time to complete (Fig. 1) and required the largest sample size for four of the eight predator groups (Table 3). As a result, this method had the highest cost-reliability estimate for every predator group (Table 4).

The visual search method was particularly inefficient for sampling spiders. During the visual search, spiders were often observed dropping on silk threads or escaping to adjacent plants while the sampler was searching the plant terminal and in this way many escaped detection. Also, small predators such as lacewing larvae hidden behind bracts, in blooms or on the undersides of leaves can be missed, especially if the scout is focused on finding pest species.

Visual examination of the plant for predators was compared to an "absolute" method using a large cage quickly placed over cotton plants in Mississippi (Smith et al. 1976). They found whole plant inspection yielded similar seasonal trends in total predator densities. However, they did not investigate different predator species or adult and immature stages or determine precision of the density estimates.

The most limiting factor in whole plant sampling is time (Wilson and Gutierrez, 1980, Pyke et al, 1980,). Sampling terminals only has not been evaluated but if found to be accurate, it could reduce the time required for sampling.

Also, visual examination is especially subject to the sampler's ability to see and detect predators on plants. Garcia et al. (1982) concluded that sampler bias is the principal disadvantage of the visual sample method. It is also difficult to maintain multiple "search images" while simultaneously searching the plant for pests and predators. Thus, while visually searching plants for predators is convenient since it can be done while searching for pests, a large sample size is necessary because of sample variation due to sampler bias and low recovery (Table 2). Because of the high cost-reliability estimate (large sample size and greatest time to sample) and sampler bias, the visual search method was determined to be the least useful of the five sampling methods evaluated.

Sweep Net Results

The sweep net method was the least efficient method for all predator groups, capturing only 2-22% of each group relative to the absolute method (Table 2). The low recovery rate was due in part to the fact that only the terminal portion of the plant was sampled. While some predator species are more abundant in the terminal portion of the plant, others are more common lower in the canopy (Wilson and Gutierrez, 1980). Small predators such as *Orius* nymphs and small lacewing larvae located beneath bracts and in blooms are not readily dislodged by the sweep net.

Sample size estimates for the sweep net were favorable for sampling *Orius* adults, spiders, lady beetles, *Geocoris* adults and fleahoppers (Table 3). However, sampling time was intermediate (Fig. 1) due to the time required to carefully unfold the net to reveal captured arthropods. As a result, the cost-reliability estimate for the sweep net was lowest only for adult lady beetles, *Geocoris* adults and fleahopper adults (Table 4).

Also, individuals were observed to differ in how they used the sweep net to sample plants. Tall, strong individuals often swept deeper into the canopy and as a result may have captured a greater proportion of predators than samplers who swept higher in the canopy. Observing predators in the sweep net was also a source of error as predators could quickly fly away or escape notice while the net was being unfolded.

Wilson and Gutierrez (1980) working in California found the sweep net recovered 10-12% of the predatory arthropods, similar to the results reported here (Table 2). However significant regressions for sweep net count and whole plant visual examination were found for *Orius* adults and nymphs, *Geocoris* nymphs and adult nabids. This comparison was based on 16 fifty count sweep net samples per sample date which would require more time than available in a field scouting program. Also, these authors found that sweep net sampling was most efficient during peak square production and then declined. A second study, again in California, compared 6 fifty count sweep net samples to an absolute sample consisting of bagging plants and dissecting them to recover predators. In this study, the sweep net samples failed to reflect actual population trends of predators throughout the season (Byerly et al. 1978).

These results suggest that the sweep net is useful for sampling certain important predator groups but not *Orius* nymphs or lacewing larvae. Sweep net samples must also be calibrated to provide a per plant estimate. Other problems include the variability among samplers in using the sweep net and their ability to detect and identify predators before they escape from the net.

Drop Cloth

Efficiency of the drop cloth ranged from a low of 11% for *Orius* nymphs to 74% for *Geocoris* nymphs. Although the drop cloth required more time than the beat bucket or shake bucket (Fig. 1), sample size estimates were low for many major groups (Table 3). As a result, the drop cloth had the lowest cost-reliability estimates for spiders, lacewing larvae and *Geocoris* nymphs (Table 4).

However, this method was the most tiring of the different sampling methods as it required the sampler to get on hands and knees to beat the plants and observe and record the predators on the cloth. High soil temperatures, threat of attack by fire ants, and the still air and high humidity within the canopy e added to the discomfort of the drop cloth

method. Sampling with the drop cloth was not considered suited for use in a scouting program because it was physically tiring and did not provide a significant benefit in cost reliability relative to the beat bucket method (Table 4).

Shake Bucket

The shake bucket method required significantly less time than the other methods except the beat bucket (Fig. 1). However, sample size estimates were high for most predator groups (Table 3) and its cost-reliability estimates were higher than the beat bucket or drop cloth for all predator groups (Table 4). Fewer predators were recovered because only the terminal portion of the plant was sampled. Also, many predators were observed to quickly fly out or were blown out of the shake bucket on windy days before they could be recorded. For these reasons, the shake bucket was not considered a useful sampling method.

Beat Bucket

The beat bucket was the most efficient sampling method, capturing 40% to 100% of the total predators recovered by the absolute method (Table 2). In fact, the beat bucket captured more *Geocoris* adults and lady beetles than did the absolute method. Sample size estimates were intermediate for many predator groups and less than those for visual search and shake bucket for all predator groups (Table 3). Sampling with the beat bucket required significantly less time than the visual search, sweep net and drop cloth methods (Fig. 1). Because of this time savings, the relative cost reliability values for the beat bucket method were low for most predator groups (Table 4). Excluding the drop cloth for the reasons cited above, the beat bucket method was the most cost efficient (lowest cost reliability) method for sampling *Orius* adults and nymphs and lacewing and was equal to the sweep net for sampling lacewing larvae. These four predator groups accounted for 82% of the total predators recovered (Table 1). Also, the cost reliability of the beat bucket method was second only to the sweep net for sampling the remaining four predator groups (Table 4). These results suggest the beat bucket is an optimum sampling method for *Orius* adults and nymphs, spiders and lacewing larvae and can be used to sample *Geocoris*, lady beetles adults and fleahopper adults in cotton.

Discussion

The beat bucket method provided a rapid and reliable estimate of the number of key predatory insects and spiders present in cotton in central Texas. The five-gallon, white plastic bucket is inexpensive and readily available. The deep sides of the bucket retain predators inside the bucket until they could be counted and identified. Moving predators are also easier to identify and count because they attract the eye and the way in which different species move aides in identification. This is in contrast to sweep net samples in which the predators are often clumped in the end of the net. The bucket should be kept clean so the insects are easily seen. Samplers can quickly learn how to use the beat buck and the method is not as tiring as using the drop cloth or the visual search. Also, as discussed, individuals vary greatly in their ability to visually detect small predators on a plant. With the beat bucket, sampler bias is reduced since predators are clearly visible in the bottom of the bucket.

The large number of beat bucket samples, ranging from 40 to more than 200 (Table 3), necessary to accurately estimate predator densities would require an hour or more to collect. This time requirement would be prohibitive in most commercial scouting programs. One approach to this problem is to determine threshold densities for key predators necessary to maintain target pests below damaging levels. Sample sizes necessary to determine if a density is above or below a threshold (decision sampling) are much smaller than those necessary to estimate density (population sampling) (Wilson 1993). The exception is when the density is very near the threshold.

All sample methods provided a more reliable estimate at less cost (time) than the visual search method for every predator group. The beat bucket method provides a reliable sample estimate of common predatory insects and spiders, is convenient to use and should be suitable for use by growers, field scouts and consultants. The beat bucket method has been identified by the Texas Agricultural Extension Service as the preferred method for sampling predatory insects and spiders in cotton scouting programs (Parker et. al 1999). The value of the beat bucket method for sampling other predators not encountered in this study (Collops beetles, nabids, fire ants, etc.) will need to be determined in production areas where they are important. Research to identify action thresholds for key predators would further reduce the sample size and facilitate the use of predator information in making pest management decisions.

Acknowledgment

This project was funded in part by a grant from the Texas Pest Management Association/Texas Department of Agriculture IPM Program. We thank Marty Jungman, Extension Agent-Integrated Pest Management, Texas Agricultural Extension Service, for assistance with the field studies in Hill County and Bill Langston, Texas Agricultural Experiment Station, for his assistance at Dallas.

References

Adkisson, P.L. 1971. Objective use of insecticides in agriculture, in J. E. Swift (ed.), Agricultural Chemical-Harmony or Discord for Food, People, Environment. Univ. Calif. Div. Agric. Sci Publ. pp. 43-51.

Byerly, K.F., A.P. Gutierrez, R.E. Jones and R.F. Luck. 1978. A comparison of sampling methods for arthropod populations in cotton. Hilgardia 48: 257-282.

Ewing E.P., and E.E. Ivy. 1943. Some factors influencing bollworm populations and damage. J. Econ. Entomol. 36: 602-606.

Fleischer, S.J., M.J. Gaylor and J.V. Edelson 1985. Estimating absolute density from relative sampling of Lygus lineolaris and selected predators in early to mid-season cotton. Environ. Entomol. 14:709-717.

Garcia, A., D. Gonzalez and T.F. Leigh. 1982. Three methods for sampling arthropod numbers on California cotton. Environ. Entomol. 11:565-572.

Kidd, R.W. and D.R. Rummel. 1997. Effect of insect predators and a pyrethorid insecticide on cotton aphid, *Apis gossypii* Glover, population density. Southwest Entomol. 22:381-393.

McDaniel S.G. and W.L. Sterling. 1982. Predation of *Heliothis virescens* eggs on cotton in East Texas. Environ. Entomol. 11:60-66.

McDaniel, S.G., W.L. Sterling and D.A. Dean. 1981. Predators of tobacco budworm larvae in Texas cotton. Southwest. Entomol. 6:101-108.

Nuessly, G.S. and W.L. Sterling. 1984. Comparison of D-Vac and modified drop cloth methods for sampling arthropods in cotton. Southwest. Entomol. 9: 95-103.

Parajulee, M.N. and J.E. Slosser. 1997. Potential relay strip crops for predator enhancement in cotton. Proc. Beltwide Cotton Production Conf. 1124-1127.

Parker, R., A. Knutson, G. Moore and J. Benedict. 1999. Managing cotton insects in the southern, eastern and Blackland areas of Texas. TX. Ag. Extension Ser. Bulletin B-1204.

Pyke, B. and W.L. Sterling and A. Hartstack. 1980. Beat and shake sampling of cotton terminals for cotton fleahoppers and other pests and predators. Environ. Entomol. 9:572-576.

Ridgeway, R.L., P.D. Lingren, C.B. Cowan and J.W. Davis. 1967. Populations of arthropod predators and *Heliothis* spp. after applications of systemic insecticides to cotton. J. Econ. Entomol. 60:1012-1016.

Ruberson, H.R., G.A. Herzog, W.R. Lambert and W. .J. Lewis. 1994. Management of the beet armyworm (Lepidoptera: Noctuidae) in cotton: role of natural enemies. Fla. Entomol. 77: 440-453.

Smith, J. M., E. A. Stadelbacher and C. W. Gantt. 1976. A comparison of techniques for sampling beneficial arthropod populations associated with cotton. Environ. Entomol. 5: 435-444.

Sterling, W.L., L.M. El-Zik and L.T. Wilson. 1989. Biological control of pest populations. p. 155-189 in Frisbie, R.E., K. El-Zik and L.Ted Wilson eds. Integrated Pest Management Systems and Cotton Production. John Wiley, N.Y. 437 pp.

Strum M.M. and W.L. Sterling. 1986. Assessment of boll weevil mortality factors within flower buds of cotton. Bull. Entomol. Soc. Am. 32:239-247.

Wilson, L.T. 1993. Estimating abundance, impact, and interactions among arthropods in cotton agroecosystems. in L.P. Pedigo and G.D. Buntin eds. Handbook of Sampling Methods for Arthropods in Agriculture. CRC Press Inc. Boca Raton, FL. 714 pp.

Wilson, L.T and A.P. Gutierrez. 1980. Within-plant distribution of predators on cotton: comments on sampling and predator efficiencies. Hilgardia 48:3-11.

Table 1. Proportions of different predator groups recovered in absolute sample in four cotton fields.

Predator Group	Field				Mean
	Dallas 98	Dallas 97	Hill A 97	Hill B 97	(total number)
Orius adults	20%	28%	63%	56%	41% (937)
Orius nymphs	13%	33%	8%	20%	21% (483)
Spiders	30%	18%	9%	12%	16% (372)
Lady beetles	10%	4%	0.5%	0.2%	3% (74)
Lacewing larvae	1%	2%	11%	2.5%	4% (93)
Geocoris adults	5%	5%	2%	0.5%	3% (69)
Geocoris nymphs	3%	3%	0.2%	0.6%	2% (41)
Fleahopper adults	19%	6%	6%	8%	9% (195)

Table 2. Efficiency (% recovery) of different sample methods relative to the absolute sample method for different predator groups.

Predator Group	Beat Bucket	Drop Cloth	Shake Bucket	Sweep Net	Visual Search
Orius adults	1.03	.22	.48	.05	.36
Orius nymphs	.43	.11	.21	.02	.23
Spiders	.80	.37	.47	.06	.17
Lady beetles	1.17	.52	.63	.19	1.12
Lacewing larvae	.62	.25	.24	.02	.20
Geocoris adults	1.23	.69	.62	.22	.50
Geocoris nymphs	.82	.74	.49	.11	.55
Fleahopper adults	1.00	.24	.48	.18	.63

Table 3. Sample sizes necessary to estimate mean predator density within 35% of true mean with a 95% confidence interval for different sample methods.

Predator Group	Mean / Plant[1]	Beat Bucket	Drop Cloth	Shake Bucket	Sweep Net	Visual Search
Orius adult	0.8	40	34	79	44	110
Orius nymph	0.6	129	104	252	213	197
Spiders	0.4	95	35	163	68	427
Lady beetles	0.2	132	63	260	47	151
Lacewing larvae	0.2	221	122	644	427	749
Geocoris adults	0.2	130	54	264	38	322
Geocoris nymphs	0.2	197	34	351	69	314
Fleahopper adults	0.2	159	143	358	47	254

[1]Mean density per plant as determined by the absolute sample method during mid-June to mid-July in the unsprayed sample field at Dallas, 1997.

Table 4. Cost-reliability of different sample methods relative to the visual sample method for different predator groups and given mean density.

Predator Group	Mean/ Plant[1]	Beat Bucket	Drop Cloth	Shake Bucket	Sweep Net	Visual Search
Orius adult	0.8	.22	.25	.40	.31	1.0
Orius nymph	0.6	.38	.43	.70	.82	1.0
Spiders	0.4	.13	.07	.21	.12	1.0
Lady beetles	0.2	.53	.34	.94	.23	1.0
Lacewing larvae	0.2	.17	.13	.47	.43	1.0
Geocoris adults	0.2	.24	.14	.45	.09	1.0
Geocoris nymphs	0.2	.37	.09	.62	.17	1.0
Fleahopper adults	0.2	.37	.46	.77	.14	1.0

[1]Mean density per plant as determined by the absolute sample method during mid-June to mid-July in the unsprayed sample field at Dallas, 1997.

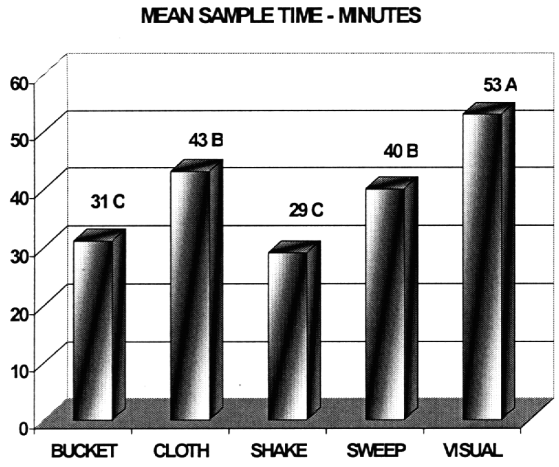

Figure 1. Mean sample time in minutes to conduct 30 sample units for each sample method.