Comparison of Sweep Net, D-Vac, and Absolute Sampling, and Diel Variation of Sweep Net Sampling Estimates in Lentils for Pea Aphid (Homoptera: Aphididae), Nabids (Hemiptera: Nabidae), Lady Beetles (Coleoptera: Coccinellidae), and Lacewings (Neuroptera: Chrysopidae)

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J. Econ. Entomol. 82(2): 491–506 (1989)

ABSTRACT Relative accuracy of sweep net sampling was compared with D-vac (D-vac, Riverside, Calif.) and absolute sampling methods for determining population densities of pea aphid, *Acyrthosiphon pisum* (Harris), *Nabis* spp., *Hippodamia* spp., and *Chrysopa* spp. in lentils (*Lens culinaris* Medikus). Relative effects of the abiotic environment, predators, and time of sampling on population estimates also were determined during 2 yr. Original counts, area, and volume adjustments were used to evaluate accuracy of the sampling method. Volume adjustment was most accurate and was used in all subsequent evaluations. Sweep net estimates of pea aphid, *Nabis* spp., and *Hippodamia* spp. densities were similar to those obtained with absolute and D-vac sampling methods, although sweep net sampling consistently gave lower population estimates than those found for absolute sampling. In these experiments, the sweep net did not adequately sample the *Chrysopa* spp. in lentils. The time of sampling was significant when sampling for pea aphid; however, it was not as important for sampling of the three insect predators. Each year, sweep net samples were taken randomly at two locations in two fields every hour for 72 consecutive hours. The abiotic factors studied were light intensity, temperature, relative humidity, and wind velocity; *Nabis* spp., *Hippodamia* spp., and *Chrysopa* spp. were the predator groups studied. Light intensity was the only abiotic factor that was significantly correlated with pea aphid numbers over both years, whereas all four abiotic factors had significant correlations at low aphid densities in 1983. The diurnal sine of hour was significantly and positively correlated with number of aphids collected by sweep net each hour, whereas predator densities were significantly and negatively correlated with aphid densities over both years. Optimum sampling time for pea aphids in lentils can depend on the dominant predator group being sampled; however, for pea aphids and all predator groups, a sample taken in late morning is preferable when sweep net samples are taken.

KEY WORDS Insecta, sampling comparison, sweep nets, lentils

PEA APHID, *Acyrthosiphon pisum* (Harris), is a widely distributed pest of many leguminous crops including peas, *Pisum sativum* (L.), alfalfa, *Medicago sativa* (L.), and lentils, *Lens culinaris* Medikus (Maiteki et al. 1986). The potential for economic injury by the pea aphid already has been established for peas (Maiteki & Lamb 1985, Yencho et al. 1986) and alfalfa (Cuperus et al. 1982, Wilson & Quisenberry 1986). Although this aphid is known to reduce lentil yield (Murray et al. 1987), sampling procedures and economic injury levels have not been developed.

The choice of a sampling method should maximize precision, and minimize sampling time and sampling costs (Gomez & Gomez 1984). Relative sampling methods are most commonly used, because absolute sampling is laborious and cumbersome. A sweep net is the most frequently used relative sampling device for making insect counts from vegetation (Southwood 1978). Absolute density values are required to validate the accuracy of sweep net sampling (Southwood 1978, Bechinski & Pedigo 1982). Abiotic and biotic effects on sweep net sampling also should be considered when a sampling method is validated for a specific insect species and crop.

The sweep net is the most frequently used tool for deriving insect population estimates from herbaceous vegetation (Southwood 1978). The low cost per sample, speed, and simplicity of the sweep net sampling method are primary reasons for its use. However, accuracy of sweep net estimates is influenced by abiotic and biotic factors. The effects of these factors vary among insects and the crops being sampled.

Population estimates of pea aphids, potato leafhoppers, *Empoasca fabae* (Harris), and meadow spittlebugs, *Philaenus spumarius* (L.) in alfalfa are significantly affected by weather, time of day, and the person sweeping, but sweep net estimates of aphids and potato leafhoppers seemed to be affected most by plant height (Saugstad et al. 1967). Wind and temperature were important factors in determining sweep net population estimates of potato leafhopper adults in alfalfa (Cherry et al. 1977). The precision of sweep net sampling is reduced by the inability of the sweep net to penetrate the plant canopy effectively in cotton (Byerly et al. 1978, Ellington et al. 1984) and by the location of the insect being sampled within that canopy. Sweep net population estimates for most insect species were low when compared with other sampling methods in soybeans (Shepard et al. 1974, Bechinski & Pedigo 1982), cotton (Byerly et al. 1978, Ellington et al. 1984), and alfalfa (Pruess et al. 1977). Nymphal sweep net population estimates of *Lygus hesperus* Knight were correlated with relative humidity, temperature, and light intensity in lentils, whereas estimates of numbers of *L. hesperus* adults were not significantly correlated with any of the abiotic factors monitored when sampled early in the growing season (Schotzko & O'Keeffe 1986a). Sweep net sampling for *L. hesperus* is similar to other sampling methods in lentils (Schotzko & O'Keeffe 1986a).

Insect distribution, density and activity, plant height and density, and the location of the insect within the canopy influenced the effectiveness of sweep net sampling in cotton (Byerly et al. 1978, Ellington et al. 1984). Because many factors affect sweep net accuracy, a regression analysis that incorporates abiotic and biotic conditions is required to develop satisfactory models of the variation in sampling (Ruesink 1980).

As described in an earlier publication (Schotzko & O'Keeffe 1986a), either of two major types of cycles are present in a 24-h period: crepuscular or diurnal. The crepuscular sine of hour {sine[0.5239(hour)]} describes a 24-h cycle that has two peaks. The crepuscular peaks commonly occur at dawn and dusk. The diurnal sine of hour {sine[0.21679(hour)]} describes a 24-h cycle that has a single peak every 24 h. These sine functions can be used to determine if there is a significant cyclic variation within a 24-h period and whether that variation is diurnal or crepuscular (Schotzko & O'Keeffe 1986a). They also provide a useful, simple function that can be included in the modeling of the variation over a 24-h period when the interactions between the biotic and abiotic factors are complex.

Lentils are a food legume that grows to a height of about 60 cm. The lentil plant canopy is less dense than those of soybeans, cotton, or alfalfa and is therefore more easily penetrated by a sweep net. The pea aphid is commonly found in lentil fields when the plants are barely high enough to sweep. The aphid populations can develop to very high levels in less than 4 wk and often require treatment with insecticides. Aphid population development is partly dependent on the abundance of natural enemies (Hagen & Van den Bosch 1968, Neuenschwander et al. 1975). Three of the predominant predator groups in lentils in northern Idaho and eastern Washington are nabids, *Nabis* spp., lady beetles, *Hippodamia* spp., and lacewings, *Chrysopa* spp. These predaceous insects are important in determining the rate of aphid population development and should therefore be considered when evaluating a sampling method.

Our objectives were to evaluate the relative accuracy of sweep net sampling when compared with D-vac (D-vac, Riverside, Calif.) and absolute sampling methods for determining pea aphid, nabid, lady beetle, and lacewing densities in lentils. The effects of sampling period (morning versus afternoon) and insect density on estimates of insect population levels were evaluated. The effects of relative humidity, temperature, light intensity, wind velocity, and time of sampling on population estimates of the pea aphid and three of its predator groups were examined when a sweep net was used to collect hourly samples in lentils for a 24-h period. We also determined variation of sweep net sampling estimates because of insect density.

Materials and Methods

Sampling Comparison. Three sampling methods (sweep net, D-vac, and absolute) were evaluated concurrently during two periods of the day (morning, 0800–1200 hours, and afternoon, 1300–1700 hours) at two locations (Kendrick, Idaho, and Palouse, Wash.) during 2 yr (1983 and 1984). Each sampling method was used to determine insect density (adults and nymphs) at 25 sampling sites that were randomly selected in each lentil field.

The absolute sample was taken by placing a fumigation cage (Pedigo et al. 1972, Kogan & Pitre 1980), consisting of a plastic container (33 cm deep, 23 cm wide, 61 cm high) with six dichlorvos strips, over undisturbed lentil plants at each sample site for 3–5 min. Plant material was removed and examined for insects, as was the soil surface. Actual numbers of insects in each sample unit were counted when the field was sampled.

The sweep net and D-vac samples were taken in undisturbed lentils within 2 m of the absolute sample during the interval between placement of the absolute sample and the counting of insects. The sweep net sample was always taken by the same person and consisted of a single 180° sweep with a sweep net (38 cm diameter) in the top 30 cm of plant canopy. The D-vac sample was taken using a backpack D-vac (Dietrick 1961) by placing the suction cone (33 cm diameter) over the plants and quickly lowering the cone until it touched the ground. All insect counts were made in the field. Pea aphid counts were taken in 1983 and 1984, and the insect predator groups were counted in 1984.

Morning (0800–1200 hours) and afternoon (1300–1700 hours) weather conditions were similar on all sampling days. Air temperatures were higher and humidity was lower in the afternoons.

The three techniques used to compare the sampling methods were insect counts, insects per area covered by a sampling method, and insects per volume of plant canopy sampled. The original counts were not transformed or adjusted. The area covered by the absolute sample was 759 cm^2; all sweep net (area = diameter × length of arc) and D-vac (area = πr^2) area samples were adjusted to 759 cm^2 for comparison and analysis. The absolute sample unit equaled a volume of 45,540 cm^3. All sweep net and D-vac data were adjusted to equal that volume for comparison and analysis. The sweep net volume was calculated by determining the area of the opening (πr^2) multiplied by a constant, which accounted for using only the bottom 30 cm of the sweep net (0.7895), multiplied by the length of the 180° arc (168 cm). The D-vac volume was calculated by determining the area of the opening multiplied by the estimated height of the lentil plants (60 cm). Two hundred replications were taken over the two sampling periods, two dates, and two locations in 1984. One hundred replications were taken over the two sampling periods, one date, and two locations in 1983. Data were analyzed using correlation regression and analysis of variance. The F test was used in all comparisons of two means, and the Duncan option from the SAS procedure (SAS Institute 1985b) was used in all comparisons of three or more means.

Diel Variation. The relative effects of abiotic environment and time of sampling on population estimates of all stages of the pea aphid and three of its predator groups in lentils were determined during 1983 and 1984 by taking sweep net samples randomly at two locations in two fields every hour for 72 consecutive h. In 1983, the two fields were located near Kendrick and Palouse. In 1984, the two fields were located near Kendrick. Three samplers were used in each 72-h study; each person sampled a different 8-h period each day, thereby minimizing sampler effect. The sweep net sample consisted of a single 180° sweep in the top 30 cm of the lentil canopy with a standard sweep net (38 cm diameter). Five random subsamples were taken at each of two randomly selected sampling sites every hour. The stage of the crop was flower-full pods, with approximately 16 h of light.

When samples were taken, relative humidity, temperature, light intensity, and wind velocity were measured at the top of the plant canopy. Relative humidity was measured with a psychrometer (Bendix Psychron, Bendix Corporation, Baltimore). A thermometer (Weksler Max-Min, Weksler, Freeport, N.Y.) was used to measure the temperature at the time of sampling and the range of temperature during the preceding hour. Light intensity was measured with a light meter (Lunasix, Woodside, N.Y.), and wind velocity (recorded in 0.305 m/min) was measured with an anemometer (Taylor, Rochester, N.Y.). These environmental data, diurnal sine of hour {sine[0.26179(hour)]}, crepuscular sine of hour {sine[0.5239(hour)]}, and pea aphid and predator counts were analyzed by correlation (SAS Institute 1985a, 105–116), regression (SAS Institute 1982, 39–84; 1985b, 296–336), and analysis of variance (SAS Institute 1985b, 57–83) on the untransformed mean of the five subsamples per field. C(p) can be used as a criterion for selecting models (Mallows 1964). C(p) is a measure of total squared error; Mallows (1964) suggested that the model where C(p) first approaches P be used.

Results and Discussion

Sampling Comparison. Three techniques for equating relative accuracy among sampling methods showed differences depending on the technique used to standardize and analyze the capture data (Table 1). Use of the original counts equates the data on a per-unit-effort basis without adjustments for area covered or volume of plant canopy sampled. This technique biases data interpretation for the sweep net sampling method in these experiments, because the sweep net sampled the largest area and volume and significantly overestimated pea aphid and nabid densities (Table 1). The actual area and volume covered by the D-vac in these experiments were close to those of the absolute method and provided a more equivalent comparison when original counts were used, although D-vac sampling estimated lower populations for pea aphids and higher populations for nabids when compared with the absolute counts (Table 1). Use of the original counts creates a problem in comparing data sets from other publications and sampling procedures because the variation in the type and size of sample is not standardized, and changes in the relative performance of the methods would therefore be expected.

The use of an area adjustment probably is the most common technique for standardizing different sampling methods (Southwood 1978, Kogan & Herzog 1980). This adjustment considers the area covered by the sampling method, but it does not account for variation in the amounts of plant canopy sampled. If the plant canopy is tall, the proportion of the canopy included in the sample may be more important than the area covered by the sampling method (Byerly et al. 1978). When we applied area adjustments to our data, both relative sampling methods significantly underestimated the aphid and nabid populations compared with the absolute populations; the sweep net estimated significantly lower populations than the D-vac for both insects (Table 1). When the area adjustment was used, results for the sweep net were the reverse of those found for the original counts. This change in the estimated accuracy of the sweep net sampling method suggests potential problems when

Table 1. Three techniques (original counts, volume, and area) for comparing sampling methods (sweep net, D-vac, and absolute) in capture of pea aphids and nabids for lentils in 1984

Sampling method	Counts (unadjusted)	Vol (per 45,540 cm^3)	Area (per 759 cm^2)
Pea aphids			
Sweep net	72.91a	22.44b	8.67c
D-vac	22.19b	20.02b	19.70b
Absolute	28.19b	28.19a	28.19a
$\bar{x}$	41.10	23.55	18.85
R^2	0.7652	0.7201	0.7101
CV	106.1921	97.5202	108.0433
Nabids			
Sweep net	3.31a	0.76b	0.39c
D-vac	0.95b	0.86b	0.85b
Absolute	1.22b	1.22a	1.22a
$\bar{x}$	1.83	0.95	0.82
R^2	0.5056	0.5170	0.5372
CV	180.4015	140.1478	143.9104

Means followed by the same letter are significantly different ($P > 0.05$; Duncan's option [SAS Institute 1985b]).

Table 2. Mean numbers of pea aphids, nabids, lady beetles, and lacewings per sample unit (adjusted to 45,540 cm^3) for sampling methods within the morning and afternoon sampling periods and overall for 1983 and 1984

Sampling method	1983[a]		1984		
	Loc 1	Loc 2	Morning	Afternoon	$\bar{x}$
Pea aphids					
Sweep net	1.10ab	5.04b	29.59a	15.29b	22.44b
D-vac	0.76b	7.58a	22.07b	17.97b	20.02b
Absolute	1.33a	9.20a	29.49a	26.89a	28.19a
$\bar{x}$	1.07b	7.27a	27.05a	20.05b	—
Nabids					
Sweep net	—	—	0.90ab	0.62b	0.76b
D-vac	—	—	0.83b	0.89ab	0.86b
Absolute	—	—	1.32a	1.12a	1.22a
$\bar{x}$	—	—	1.02a	0.88b	—
Lady beetles					
Sweep net	—	—	0.08a	0.08ab	0.08ab
D-vac	—	—	0.04a	0.05b	0.04b
Absolute	—	—	0.11a	0.16a	0.13a
$\bar{x}$	—	—	0.07a	0.10a	—
Lacewings					
Sweep net	—	—	0.22c	0.22c	0.22c
D-vac	—	—	0.68b	0.67b	0.68b
Absolute	—	—	1.13a	1.37a	1.25a
$\bar{x}$	—	—	0.68a	0.75a	—

Means followed by the same letter are significantly different ($P > 0.05$; Duncan's option [SAS Institute 1985b]).
[a] Location 1 was near Palouse, Wash. and location 2 was near Kendrick, Idaho.

reports that do not use the same type of adjustment are compared.

The volume adjustment does not compensate for the location of insects within the canopy but standardizes the amount of plant canopy being sampled. The amount of plant canopy sampled is biologically important for phytophagous insects when two different crops or sampling methods are compared. Sampling only the portion of the plant canopy used by the insect at the time it is sampled would be preferable; however, such precise information is generally not available for field situations. When we applied volume adjustments to our data, we found that sweep net and D-vac sampling provided population estimates that were not significantly different; both relative sampling methods significantly underestimated populations compared with the absolute sampling method (Table 1). Overall, use of the volume adjustment in comparing sampling methods appeared to provide a more accurate biological and statistical picture of the comparative insect densities in lentil fields, with similar R^2 and lower coefficients of variation (Table 1). This shows that the method of data adjustment is important and should be considered when data for samples of insects are compared. The volume adjustment was used in all the following comparisons between sampling methods.

Sweep net sampling provided reliable estimates for pea aphid, nabid, and lady beetle densities in lentil fields compared with either the absolute or D-vac sampling methods. No significant differences ($P < 0.0196$) between sweep net and absolute or D-vac sampling methods for lady beetle density estimates were detected (Table 2). The population estimates for pea aphids ($P < 0.0071$) and nabids ($P < 0.0077$) were significantly lower for sweep net and D-vac than the absolute overall in 1984 (Table 2). The lacewing population estimates were significantly lower ($P < 0.0001$) for sweep net than for D-vac, and the D-vac estimates were significantly ($P < 0.0001$) lower than the absolute values (Table 2).

Significantly fewer pea aphids ($P < 0.0013$) and nabids ($P < 0.0001$) were collected during the afternoon sampling period when counts obtained from all sampling methods were combined. Lady beetle ($P > 0.3554$) and lacewing ($P > 0.3856$) population estimates were not significantly affected by time of day (Table 2). The significant effects of sampling time on pea aphid and nabid density estimates were the result of the reduced accuracy during the afternoon sampling period of sweep net and D-vac ($P < 0.0002$) sampling methods for pea aphids, whereas only the sweep net had reduced afternoon estimates for nabids ($P < 0.0428$) (Table 2). Sweep net sampling appeared to be less accurate for collecting aphids and nabids in the afternoon sampling periods; this reduction in accuracy should be considered when populations of these insects in lentils are estimated. The cause of the reduced accuracy of afternoon sampling warrants further investigation.

D-vac samples were significantly correlated ($P < 0.0174$) with the absolute samples at higher pea aphid densities in 1983 (Table 3). Sweep net samples were significantly correlated with D-vac ($P < 0.0036$) and absolute samples ($P < 0.0001$). D-vac samples also were significantly correlated ($P < 0.0007$) with the absolute samples at low aphid densities in 1983 (Table 3). When the high and low

Table 3. Correlation coefficients for the sampling methods and pea aphids in 1983 and pea aphids, nabids, lady beetles, and lacewings in 1984, within high and low insect densities and overall

Sampling method	1983	1984			
	Pea aphid	Pea aphid	Nabid	Lady beetle	Lacewing
High density					
Sweep net vs D-vac	0.23231	0.65780a	0.23639b	0.07046	0.34340a
Sweep net vs absolute	0.08227	0.62008a	0.51895a	0.06572	0.02511
D-vac vs absolute	0.33510b	0.62813a	0.20850	−0.03200	0.19633
Low density					
Sweep net vs D-vac	0.40002b	0.17805	0.93128a	−0.03856	0.11877
Sweep net vs absolute	0.66783a	0.02322	−0.02039	−0.04568	0.11727
D-vac vs absolute	0.45930b	−0.02638	−0.01961	0.38560a	0.11256
Overall					
Sweep net vs D-vac	0.46696a	0.78178a	0.36521a	0.02662	0.33235a
Sweep net vs absolute	0.35612a	0.75212a	0.59709a	0.08907	0.04650
D-vac vs absolute	0.59232a	0.76793a	0.34023a	0.13315	0.12586

Correlation coefficients followed by an a are significant at $P < 0.001$ and followed by a b are significant at $P < 0.01$ (SAS Institute 1985b, 296–336).

aphid densities for 1983 were combined, the sweep net ($P < 0.0003$) and D-vac ($P < 0.0001$) were significantly correlated with absolute samples (Table 3). In 1984, sweep net ($P < 0.0001$) and D-vac ($P < 0.0001$) samples were correlated with the absolute samples at the high aphid densities, whereas no significant correlations were observed at the low pea aphid densities (Table 3). The density-dependent variability in the correlations was expected; lack of significant correlations may be because of the clumped distribution of the insects at low densities (Ellington et al. 1984). However, in 1984, the correlations for combined data were significant between sweep net and the absolute samples ($P < 0.0001$), and D-vac and the absolute samples ($P < 0.0001$) (Table 3). Overall, no differences in the reliability of the relative sampling methods were apparent when they were compared with the absolute sampling method for determining pea aphid densities in lentils (Table 3).

Population estimates of the three predator groups in lentils showed considerably more variability than was found for the pea aphid (Table 3). This may be partly because of the low densities at which the predators were observed (Table 2). Significant correlations between sweep net and D-vac estimates at low ($P < 0.0001$) and high ($P < 0.0179$) nabid densities were observed; the sweep net samples also were significantly correlated with the absolute samples at high densities ($P < 0.0001$) (Table 3). When the combined nabid data were considered, population estimates obtained with all the methods were significantly correlated ($P < 0.0001$) with one another; the strongest correlation observed was between the sweep net and absolute counts (Table 3). Only one significant correlation ($P < 0.0001$), that between D-vac and absolute samples at the lower densities, was observed for lady beetles (Table 3). Neither of the relative sampling methods was significantly correlated for lady beetles. The lack of a significant correlation may be because of the effective microdistribution of this insect, which may have been so small that the individual samples were independent, and low correlations would therefore be expected. As with lady beetles, the sampling methods for the lacewings were not strongly correlated; the only significant correlation ($P < 0.0001$) was between the relative sampling methods (Table 3). The sweep net was the least accurate method used for collecting lacewings in these studies (Tables 2 and 3).

When pea aphid densities were high, significant differences ($P < 0.0007$) were observed in the number of aphids collected between morning and afternoon periods (Table 4). However, at middle ($P > 0.0942$) and low ($P > 0.3193$) pea aphid densities, no significant differences were noted between morning and afternoon population estimates, although a larger mean number of pea aphids was observed in the morning at low densities (Table 4). In addition, the relative performance of the sampling methods varied significantly ($P < 0.0018$) because of the density, with the sweep net and D-vac collecting fewer insects when pea aphid density was reduced relative to the absolute sampling method (Table 4). This reduced accuracy of sweep net estimates from 81% of the absolute samples at high aphid densities to 8% of the absolute samples at middle densities is a concern for researchers who collect samples when insects are present at less than one per sweep. However, this reduction is less important when a field sampling plan is being developed, because the insect densities at which reduced efficiency occurs are far below the expected economic thresholds for pea aphids on lentils.

No differences in the number of predators captured because of the time of sampling over the densities were observed (Table 4). For the insect densities we sampled, the relative sampling methods performed consistently when compared with the absolute sampling method (Table 4). Overall, the sweep net collected fewer nabids and lacewings

Table 4. Comparison of mean pea aphids, nabids, lady beetles, and lacewings per sample unit (adjusted to 45,540 cm^3) for the sampling methods and sampling periods between different insect densities in 1984

Method and period	Pea aphid	Nabid	Lady beetle	Lacewing
High density				
Morning	79.56a	2.89a	0.10a	1.25a
Afternoon	59.92b	2.42a	0.20a	1.50a
Sweep net	67.18b	2.23b	0.15ab	0.25c
D-vac	59.20b	2.44ab	0.07b	1.01b
Absolute	82.84a	3.30a	0.24a	2.86a
Middle density				
Morning	1.60a	0.14a	0.11a	0.72a
Afternoon	0.22a	0.21a	0.10a	0.72a
Sweep net	0.13a	0.06b	0.09a	0.41b
D-vac	0.87a	0.11b	0.05a	0.97a
Absolute	1.72a	0.36a	0.16a	0.78ab
Low density				
Morning	0.00a	0.02a	0.01a	0.08a
Afternoon	0.01a	0.01a	0.00a	0.05a
Sweep net	0.00a	0.01a	0.01a	0.01b
D-vac	0.00a	0.04a	0.00a	0.05ab
Absolute	0.02a	0.00a	0.00a	0.12a

Means followed by the same letter within the period or sampling method are not significantly different ($P < 0.05$; Duncan's option [SAS Institute 1985b]).

than the absolute and D-vac samples, whereas the sweep net collected greater numbers of lady beetles than the D-vac (Table 4).

The sweep net sampling method consistently gave population estimates closer to those of the absolute samples than did the D-vac for lady beetles (Tables 2 and 4). The D-vac sampling method consistently gave estimates closer to those of the absolute samples than did the sweep net for nabids and lacewings (Tables 2 and 4). No consistent trend was observed for either relative sampling method when sampling pea aphids; however, at the highest aphid densities, the sweep net may collect more aphids per sample (Tables 2 and 4). The correlation coefficients and R^2 were higher when comparing D-vac to the absolute than those when sweep net samples were compared with absolute samples for lady beetles and lacewings (Tables 2 and 6). Sweep net samples had higher correlation coefficients and R^2 only for the nabids (Tables 2 and 5).

At high pea aphid densities (approximately 30–60 aphids per sample), sweep net and D-vac had significant slopes (a = slope in Table 5) of 0.78 ($P < 0.0001$) for the sweep net and 0.87 ($P < 0.0001$) for the D-vac. However, at low aphid densities (about one aphid per sample), no significant regressions were obtained (Table 5). When the data were regressed by time of sampling, the R^2 and slopes were increased (Table 5). This increase in the R^2 showed that the general time of sampling provided a better predictive equation than did insect density at the time of sampling. The combined data provided significant regression with slopes which were not significantly different from 1 for both of the relative sampling methods (Table 5, overall). However, if the microhabitat variation was eliminated by comparing population estimates over all the replicates within each sampling period and date, R^2 was again increased (Table 5, summary). The regressions of the nabid data followed the same trends, with increases in the R^2 when data were considered by time of sampling (Table 5, morning and afternoon) and another increase in the R^2 when the microhabitat variation was eliminated (Table 5, summary). Regressions for the lady beetle had low R^2, except for the regression which eliminated microhabitat variation (Table 6, summary). For lady beetles, the only significant summary regression was sweep net (Table 6, summary). As with the lady beetle data, the lacewings had very low R^2 and few significant regressions. However, afternoon sampling did produce the only significant regression for both relative sampling methods (Table 6, afternoon). Overall, relative sampling with a D-vac or sweep net had similar correlation coefficients and R^2 for the pea aphid and its three major predators in lentils. The sweep net is less laborious and costly, making it the preferred sampling method for this pest at densities of more than one per sample.

The sweep net sampling method can be used in lentils for accurately predicting pea aphid, nabid, and lady beetle densities, although it will underestimate populations when compared with absolute sampling. Lacewings were not accurately sampled with the sweep net; if the sweep net is used to sample populations to estimate densities, care should be taken to equate the results with some other sampling method. The predator groups we sampled can be sampled either in the morning or afternoon, whereas pea aphids would apparently be best sampled in the morning. Our research was not intended to define diel variation. Instead, we sought to describe the performance of sampling methods within general time periods. The evaluation of hour of sampling and environmental effects will follow and are necessary before the accuracy of sampling methods can be validated adequately. However, the time of sampling and insect to be monitored must be considered when developing a sampling procedure for lentils.

Diel Variation. Estimates of pea aphid populations obtained by sweep net sampling were significantly correlated with all the abiotic factors we monitored in 1983; the highest correlation was between sweep net collections of pea aphid and the diurnal sine of hour and the lowest correlation was between pea aphids and the crepuscular sine of hour (Table 7). The lower pea aphid densities in 1983 showed higher correlations than high pea aphid densities during that year, whereas no consistent density-related effects were observed during 1984 (Table 7). The low population densities in 1983 were significantly and negatively correlated with relative humidity and significantly and positively correlated with wind velocity, light intensity, temperature, and diurnal sine of hour (Table

Table 5. Descriptive statistics and regressions of absolute, D-vac, and sweep net sampling methods for pea aphids and nabids lady beetles, and lacewings at high and low densities on lentils in 1984

Method	$\bar{x}$	SD	Range	CV	a (SE)[a]	b (SE)[b]	R^2	P
				Pea aphids				
High density (n = 100)								
Sweep net	41.2	40.86	0–153	71.01	25.05 (5.81)	0.78 (0.10)	0.3845	0.0001
D-vac	42.5	36.95	0–185	86.97	20.07 (6.18)	0.87 (0.11)	0.3945	0.0001
Absolute	57.4	51.71	0–225	90.06	—	—	—	—
Low density (n = 100)								
Sweep net	0.07	0.22	0–1	320.31	0.82 (0.64)	0.65 (2.83)	0.0005	0.8187
D-vac	0.43	1.12	0–4	258.96	0.92 (0.66)	−0.14 (0.55)	0.0007	0.7945
Absolute	0.87	6.09	0–60	699.77	—	—	—	—
Morning (n = 100)								
Sweep net	27.8	41.89	0–153	150.54	11.72 (3.90)	0.83 (0.08)	0.5347	0.0001
D-vac	27.2	35.03	0–183	128.54	6.81 (3.95)	1.02 (0.09)	0.5736	0.0001
Absolute	34.7	47.38	0–225	136.34	—	—	—	—
Afternoon (n = 100)								
Sweep net	13.5	25.84	0–108	191.52	4.28 (2.90)	1.43 (0.10)	0.6757	0.0001
D-vac	15.7	31.07	0–185	198.27	6.04 (3.21)	1.12 (0.09)	0.5975	0.0001
Absolute	23.6	44.92	0–200	190.68	—	—	—	—
Overall (n = 200)								
Sweep net	20.7	35.45	0–135	105.16	8.81 (2.51)	0.98 (0.06)	0.5657	0.0001
D-vac	21.5	33.53	0–185	102.21	6.34 (2.50)	1.06 (0.06)	0.5897	0.0001
Absolute	29.1	46.39	0–225	159.18	—	—	—	—
Summary (n = 8)								
Sweep net	20.7	31.84	0–88	154.12	6.84 (6.60)	1.08 (0.18)	0.8543	0.0010
D-vac	21.5	27.52	0–65	128.23	0.35 (2.20)	1.34 (0.06)	0.9859	0.0001
Absolute	29.1	37.18	0–85	127.59	—	—	—	—
				Nabids				
High density (n = 100)								
Sweep net	1.52	2.49	0–14	163.50	1.04 (0.25)	0.51 (0.08)	0.2693	0.0001
D-vac	1.27	1.79	0–10	140.44	1.46 (0.30)	0.29 (0.14)	0.0435	0.0374
Absolute	1.83	2.47	0–15	134.99	—	—	—	—
Low density (n = 100)								
Sweep net	0.03	0.19	0–2	690.10	0.05 (0.04)	−0.04 (0.19)	0.0004	0.8404
D-vac	0.09	0.65	0–6	717.74	0.05 (0.04)	−0.01 (0.06)	0.0004	0.8465
Absolute	0.05	0.36	0–3	717.74	—	—	—	—
Morning (n = 100)								
Sweep net	0.92	2.21	0–14	239.93	0.34 (0.18)	0.73 (0.08)	0.4946	0.0001
D-vac	0.69	1.38	0–6	198.69	0.22 (0.19)	1.14 (0.12)	0.4684	0.0001
Absolute	1.02	2.30	0–15	225.54	—	—	—	—
Afternoon (n = 100)								
Sweep net	0.63	1.57	0–9	248.28	0.44 (0.13)	0.66 (0.08)	0.4309	0.0001
D-vac	0.67	1.55	0–10	232.58	0.44 (0.14)	0.62 (0.08)	0.3684	0.0001
Absolute	0.86	1.59	0–8	184.79	—	—	—	—
Overall (n = 200)								
Sweep net	0.78	1.92	0–14	246.90	0.46 (0.12)	0.61 (0.06)	0.3565	0.0001
D-vac	0.68	1.46	0–10	215.13	0.63 (0.14)	0.45 (0.09)	0.1158	0.0001
Absolute	0.94	1.97	0–15	209.98	—	—	—	—
Summary (n = 8)								
Sweep net	0.78	1.39	0–4	179.71	0.13 (0.09)	1.05 (0.06)	0.9825	0.0001
D-vac	0.68	1.09	0–2	159.73	0.04 (0.13)	1.33 (0.11)	0.9606	0.0001
Absolute	0.94	1.47	0–4	156.90	—	—	—	—

[a] Intercept.
[b] Slope.

7). Population densities during 1984 were not correlated with wind velocity or temperature; however, a significant negative correlation was found with relative humidity, and a significant positive correlation was found for light intensity and diurnal sine of hour (Table 7). The loss of significant correlations for wind velocity and temperature, over all densities in 1984 and over years, shows the reduced effect of these factors at high densities. However, at densities close to the economic thresholds of this insect, these are important factors in sweep net estimates of pea aphid (Table 7). Over both years, only the diurnal sine of hour and light intensity were significantly correlated with pea aphid

Table 6. Descriptive statistics and regressions of absolute, D-vac, and sweep net sampling methods for lady beetles and lacewings at high and low densities on lentils in 1984

Method	$\bar{x}$	SD	Range	CV	a (SE)[a]	b (SE)[b]	R^2	P
				Lady beetles				
High density (n = 100)								
Sweep net	0.38	0.75	0–3	197.14	0.18 (0.06)	0.14 (0.21)	0.0043	0.5159
D-vac	0.07	0.26	0–1	366.33	0.20 (0.05)	−0.07 (0.21)	0.0010	0.7520
Absolute	0.20	0.49	0–2	246.18	—	—	—	—
Low density (n = 100)								
Sweep net	0.08	0.34	0–2	423.43	0.05 (0.03)	−0.11 (0.25)	0.0021	0.6518
D-vac	0.06	0.37	0–3	618.64	0.03 (0.02)	0.30 (0.07)	0.1487	0.0001
Absolute	0.05	0.26	0–2	522.23	—	—	—	—
Morning (n = 100)								
Sweep net	0.06	0.81	0–9	273.22	0.12 (0.04)	0.23 (0.22)	0.0103	0.3144
D-vac	0.07	0.36	0–3	492.37	0.11 (0.04)	0.29 (0.11)	0.0667	0.0095
Absolute	0.13	0.39	0–2	302.50	—	—	—	—
Afternoon (n = 100)								
Sweep net	0.08	0.19	0–1	250.25	0.09 (0.04)	0.34 (0.21)	0.0249	0.1166
D-vac	0.04	0.20	0–1	438.09	0.13 (0.04)	−0.14 (0.21)	0.0046	0.5036
Absolute	0.12	0.41	0–2	340.82	—	—	—	—
Overall (n = 200)								
Sweep net	0.23	0.60	0–3	260.47	0.11 (0.03)	0.19 (0.15)	0.0079	0.2097
D-vac	0.06	0.32	0–3	489.61	0.11 (0.03)	0.19 (0.10)	0.0177	0.0602
Absolute	0.12	0.40	0–2	320.18	—	—	—	—
Summary (n = 8)								
Sweep net	0.07	0.07	0–0.2	103.83	0.04 (0.04)	1.18 (0.43)	0.5545	0.0341
D-vac	0.06	0.06	0–0.2	98.34	0.05 (0.05)	1.26 (0.64)	0.3945	0.0954
Absolute	0.12	0.11	0–0.3	92.80	—	—	—	—
				Lacewings				
High density (n = 100)								
Sweep net	1.29	1.62	0–9	125.77	1.37 (0.22)	0.66 (0.57)	0.0138	0.2452
D-vac	1.48	2.09	0–1	140.97	1.36 (0.22)	0.24 (0.22)	0.0127	0.2649
Absolute	1.27	1.53	0–8	120.46	—	—	—	—
Low density (n = 100)								
Sweep net	0.58	1.10	0–6	190.11	1.24 (0.20)	0.08 (0.31)	0.0006	0.8042
D-vac	0.59	0.99	0–4	167.07	1.06 (0.18)	0.16 (0.08)	0.0385	0.0503
Absolute	1.49	1.92	0–8	128.86	—	—	—	—
Morning (n = 100)								
Sweep net	0.33	0.51	0–3	155.11	1.40 (0.22)	0.11 (0.38)	0.0009	0.7635
D-vac	1.24	1.87	0–10	151.65	1.20 (0.22)	0.19 (0.10)	0.0380	0.0518
Absolute	1.44	1.89	0–8	131.06	—	—	—	—
Afternoon (n = 100)								
Sweep net	0.25	0.36	0–2	144.38	0.97 (0.18)	1.39 (0.42)	0.1014	0.0012
D-vac	0.63	0.98	0–4	155.30	0.95 (0.18)	0.58 (0.15)	0.1320	0.0002
Absolute	1.32	1.58	0–5	119.36	—	—	—	—
Overall (n = 200)								
Sweep net	0.94	1.43	0–9	152.80	1.33 (0.15)	0.18 (0.28)	0.0022	0.5132
D-vac	1.04	1.69	0–1	163.05	1.25 (0.14)	0.14 (0.08)	0.0158	0.0758
Absolute	1.38	1.74	0–8	125.73	—	—	—	—
Summary (n = 8)								
Sweep net	0.29	0.22	0–0.6	78.45	0.83 (0.70)	1.90 (1.95)	0.1376	0.3656
D-vac	0.93	0.90	0–3	96.06	0.65 (0.53)	0.78 (0.42)	0.3678	0.1109
Absolute	1.38	1.16	0–3	84.04	—	—	—	—

[a] Intercept.
[b] Slope.

counts, making light intensity the most impartial abiotic factor that might influence the effectiveness of sweep net collection of pea aphid in lentils (Table 7).

Numbers of pea aphids collected by sweep net were significantly correlated with the numbers of the three predator groups (Table 7). As with the abiotic factors monitored, the predator groups had higher correlation coefficients at the lower pea aphid densities. Lady beetles had a significant positive correlation at low and high densities and over density within years; however, when the data were combined over years, a weak negative correlation was found (Table 7). The negative correlation be-

Table 7. Correlation coefficients (CC) and *P* values for pea aphid collected with a sweep net in lentils, and the predators, abiotic factors, diurnal and crepuscular sine of hour during sampling for 1983 and 1984

Factors[a]		1983			1984			Over yr
		High	Low	Over density	High	Low	Over density	
Wind	CC	0.1838	0.1579	0.3065	0.0487	0.1151	0.0697	0.0255
	P	0.0274	0.0587	0.0001	0.5618	0.1697	0.2383	0.5416
RH	CC	−0.2587	−0.5270	−0.1616	−0.1361	−0.2121	−0.3574	0.0250
	P	0.0017	0.0001	0.0060	0.1039	0.0107	0.0001	0.5486
Light	CC	0.3682	0.4949	0.2876	0.2667	0.2038	0.1730	0.5686
	P	0.0001	0.0001	0.0001	0.0012	0.0143	0.0032	0.0001
Temp	CC	0.3838	0.5521	0.2210	0.2943	0.2214	−0.0244	−0.0294
	P	0.0001	0.0001	0.0002	0.0003	0.0077	0.6801	0.4811
Sine 1	CC	0.3906	0.5572	0.3206	0.2746	0.2783	0.1932	0.1128
	P	0.0001	0.0001	0.0001	0.0009	0.0007	0.0010	0.0067
Sine 2	CC	0.2002	0.0303	0.1322	−0.0852	0.0373	−0.0227	−0.0048
	P	0.0162	0.7187	0.0249	0.3102	0.6575	0.7017	0.9092
Nabid	CC	0.0134	0.3298	−0.1437	0.0858	−0.0103	−0.5367	−0.2196
	P	0.8731	0.0001	0.0147	0.3067	0.9022	0.0001	0.0001
LB	CC	0.2096	0.3336	0.3737	0.3083	0.5092	0.1908	−0.2212
	P	0.0117	0.0001	0.0001	0.0002	0.0001	0.0011	0.0001
LW	CC	—	—	—	0.0252	0.0214	−0.3200	—
	P	—	—	—	0.7639	0.7992	0.0001	—
$\bar{x}$		28.9	6.6	17.8	634.7	220.3	427.5	222.6
n		144	144	288	144	144	288	576

[a] RH, relative humidity; sine 1, sine(0.21679 [hour]) (diurnal); sine 2, sine(0.5239 [hour]) (crepuscular); LB, lady beetles; LW, lacewings.

tween the predator groups and pea aphids may be partly because of the fact that the locations for these studies were selected for the high aphid densities; the presence of high predator numbers would tend to suppress the population development of the pea aphid when compared with locations where the predator populations were lower. This also can be seen in the relative densities of the lady beetles and aphids over years. In 1983, the pea aphid densities were low but the lady beetle densities were high, whereas in 1984, the pea aphid densities were higher and lady beetle densities were lower (Tables 7 and 9).

Diurnal sine of hour, predators, and all interactions were used to indicate variation in pea aphid counts collected by sweep net during a 24-h period. The best single-variable model given by the stepwise option of regression procedure for the pea aphids over both years was the diurnal sine of hour (Fig. 1A). The 24-h variation in the sweep net collections of pea aphids appears to be predicted best by the diurnal sine of hour. The predominance of the diurnal sine of hour may indicate a behavioral variation in the pea aphid controlled by a complex interaction among the abiotic factors shown in the four-variable model (once every 24 h). Light intensity is one of the primary factors affecting this variation (Table 6; Fig. 1A). The best four-variable model for the pea aphids was dominated by diurnal sine of hour, relative humidity, temperature, and light intensity (Fig. 1B). The importance of relative humidity and temperature in predicting the number of pea aphids collected by sweep net sampling was shown by their predominance in the four-variable model. The diurnal sine of hour and light intensity also were primary factors in determining the number of pea aphids collected by sweep net sampling. When 12 variables were added to the model, R^2 was improved to 0.8602 ($P < 0.0037$), and the only significant variable ($P < 0.0490$) was diurnal sine of hour. Thus, the four-variable model was about as effective a predictor of the pea aphid counts, because the C(p) increased from 3.114 for four variables to 13.000 for the 12-variable model.

The number of nabids collected by sweep net was significantly and negatively correlated with wind velocity and positively correlated with relative humidity and temperature over the 2 yr (Table 8). In 1983, wind and relative humidity were significantly and negatively correlated with nabid counts, whereas light intensity, temperature, and the diurnal sine of hour were significantly and positively correlated (Table 8). In 1984, only relative humidity had a significant positive correlation; diurnal sine of hour had a weak negative correlation (Table 8). Variation in the effect of the abiotic factors does not appear to be related to density of the nabids in 1983, but the only significant correlations were found at the high nabid densities in 1984. Significant correlations between nabid counts and the diurnal sine of hour at high densities were found during both years; however, these correlations were inconsistent, and correlation over both years was not significant (Table 8).

Overall, the nabid sweep net counts were not predicted very well by the abiotic factors that we measured. This may be partly because of the distributional effects, the ability of the sweep net sampling method to collect nabids, and dependence of the nabids on the aphid distribution. However, the best single-variable model found by the stepwise

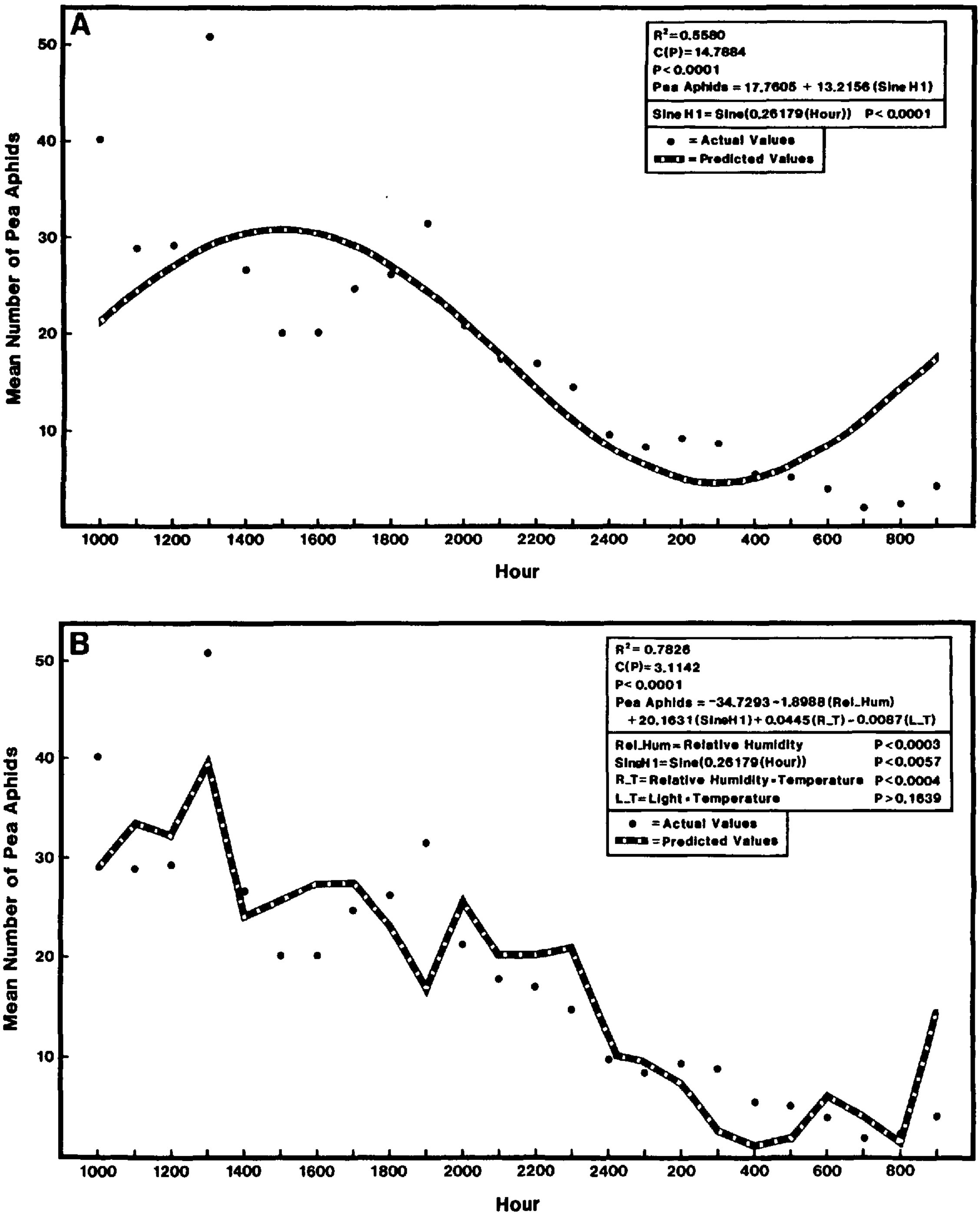

Fig. 1. Single-variable (A) and four-variable (B) models and graphs of actual and predicted values in sweep net counts for pea aphids in lentils during 1983 and 1984.

option included the diurnal sine of hour to predict the nabid count variation (Fig. 2A). We expected this result because the best single-variable model for the pea aphid also used the diurnal sine of hour (Fig. 1A). The best four-variable model given by the stepwise option in the regression procedure was dominated by wind velocity, diurnal sine of hour, and light intensity (Fig. 2B). Two of these are the same abiotic factors that were the best predictors of the pea aphid sample variation (Fig. 1B). The predominance of the same abiotic factors indicates similar effects on the ability of sweep nets to collect the prey and this predator. The number of pea aphids found in a sample also was included in this

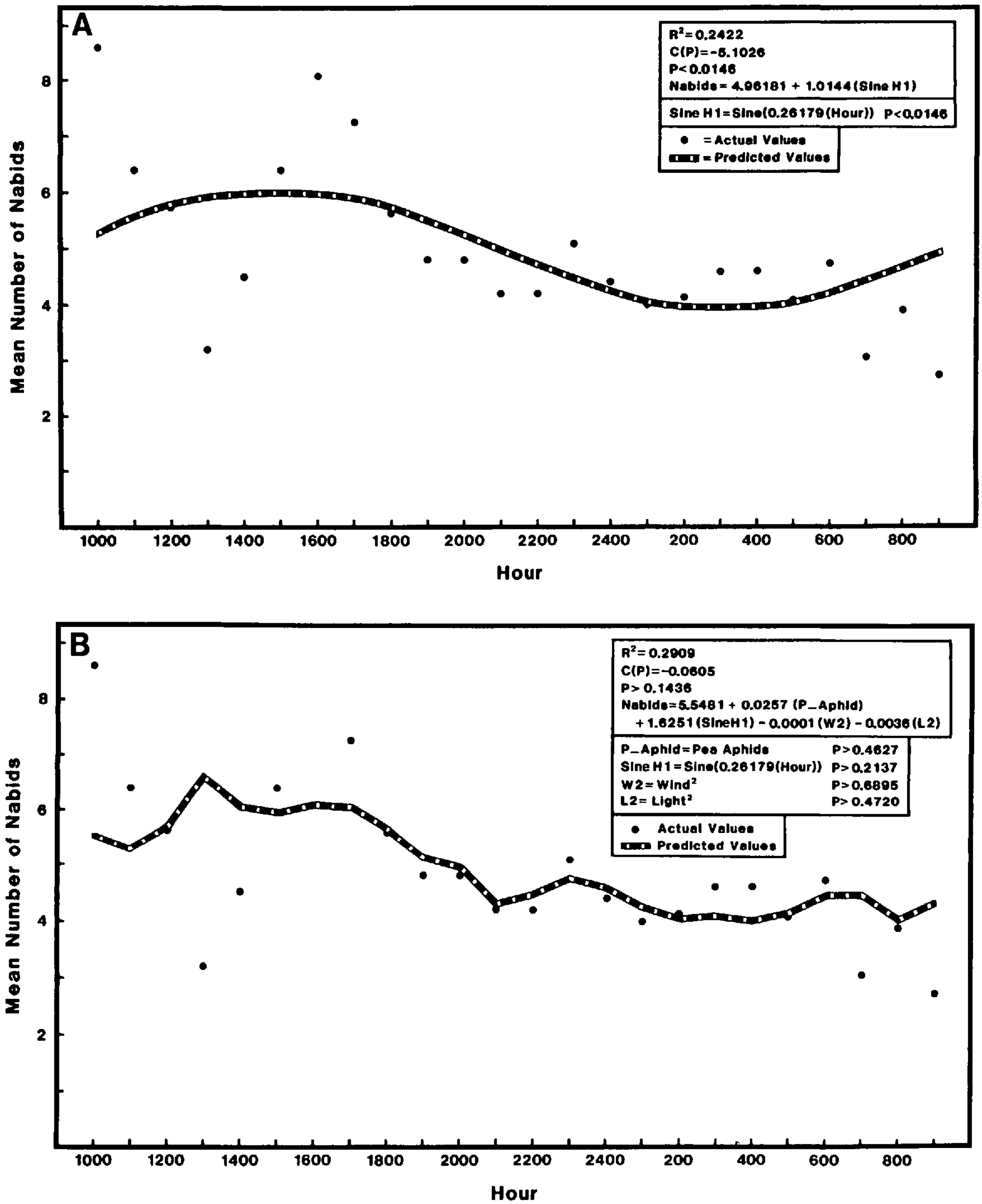

Fig. 2. Single-variable (A) and four-variable (B) models and graphs of actual and predicted values in sweep net counts for nabids in lentils during 1983 and 1984.

model; this indicates a possible relationship between pea aphid and nabid sample variation.

Numbers of lady beetles collected by sweep net had a significant positive correlation with wind velocity and the crepuscular sine of hour and a negative correlation with light intensity over both years (Table 9). These three correlations, although significant, had low correlation coefficients (0.1712, 0.1365, and −0.2354, respectively) (Table 9). Overall, there was very little correlation between numbers of lady beetles and the abiotic factors we monitored. Nonetheless, numbers of pea aphids were significantly correlated with the number of lady beetles found in samples, and the lady beetle counts

Table 8. Correlation coefficients (CC) and *P* values for nabids collected with a sweep net in lentils, and the abiotic factors, diurnal and crepuscular sine of hour, and pea aphids during sampling for 1983 and 1984

Factors[a]		1983			1984			Over yr
		High	Low	Over density	High	Low	Over density	
Wind	CC	0.1861	0.0672	−0.1277	−0.1889	−0.0985	−0.1098	−0.1138
	P	0.0255	0.4238	0.0303	0.0234	0.2401	0.0628	0.0062
RH	CC	−0.2044	−0.2511	−0.2662	0.2228	0.1201	0.3719	0.1815
	P	0.0140	0.0024	0.0001	0.0078	0.1516	0.0001	0.0001
Light	CC	0.2251	−0.0280	0.1260	−0.1353	0.0291	−0.0678	0.0757
	P	0.0067	0.7395	0.0326	0.1060	0.7294	0.2516	0.0693
Temp	CC	0.1662	0.1784	0.2216	−0.3280	−0.1278	0.0725	0.1091
	P	0.0464	0.0361	0.0002	0.0001	0.1268	0.2200	0.0088
Sine 1	CC	0.3205	0.0009	0.1728	−0.2791	−0.1307	−0.1359	−0.0292
	P	0.0001	0.9912	0.0033	0.0007	0.1185	0.0211	0.4840
Sine 2	CC	0.0416	−0.1170	−0.0112	−0.1395	−0.1321	−0.0727	−0.0486
	P	0.6207	0.1625	0.8506	0.0953	0.1145	0.2188	0.2441
Pea	CC	0.0134	0.3298	−0.1437	0.0858	−0.0103	−0.5367	−0.2196
aphid	*P*	0.8731	0.0001	0.0147	0.3067	0.9022	0.0001	0.0001
$\bar{x}$		7.1	2.9	5.0	13.3	1.0	7.2	6.1
n		144	144	288	144	144	288	576

[a] RH, relative humidity; sine 1, sine(0.21679 [hour]) (diurnal); sine 2, sine(0.5239 [hour]) (crepuscular).

appeared to have a crepuscular cycle rather than the diurnal cycle that we observed for pea aphids (Table 9).

The best single-variable model found for the lady beetle used the crepuscular sine of hour to predict the number of lady beetles collected during a given hour (Fig. 3A). As with the pea aphids, the lady beetle four-variable model was dominated by relative humidity, temperature, and light intensity (Fig. 3B). However, unlike the pea aphid and nabid models, the lady beetle model used the crepuscular sine of hour rather than the diurnal sine to predict variation in beetle collections. Although the R^2 of 0.4952 for the single-variable model was significant, the four-variable model had a larger R^2 (= 0.7933) (Fig. 3A and 3B) and contained three of the four variables used in the pea aphid four-variable model. The 10-variable model (R^2 = 0.8834; C[p] = 11.0000) did not greatly improve the predictability.

Because lacewings were at very low densities in 1983, only data for 1984 are presented. The only significant abiotic factor that was correlated with the number of lacewings collected by sweep net was relative humidity (Table 10). The number of pea aphids (which were negatively correlated) and the crepuscular sine of hour (which was positively correlated) also were significant. The lack of significance for the other correlations may be partly because of the low densities of lacewings and because the sweep net is generally not efficient in collecting lacewings in lentils (Table 2).

As was found for the lady beetles, the best single-variable model for the lacewings used the crepus-

Table 9. Correlation coefficients (CC) and *P* values for lady beetles collected with a sweep net in lentils, and the abiotic factors, diurnal and crepuscular sine of hour, and pea aphids during sampling for 1983 and 1984

Factors[a]		1983			1984			Over yr
		High	Low	Over density	High	Low	Over density	
Wind	CC	−0.0304	−0.0338	0.2142	0.0648	0.0648	0.0602	0.1712
	P	0.7180	0.6873	0.0002	0.4400	0.4404	0.3084	0.0001
RH	CC	−0.0071	−0.0475	0.0896	−0.1622	−0.0204	−0.0610	−0.0590
	P	0.9329	0.5715	0.1294	0.0521	0.8079	0.3023	0.1573
Light	CC	0.1387	0.2596	0.0762	0.2403	0.0382	0.1590	−0.2354
	P	0.0973	0.0017	0.1974	0.0037	0.6496	0.0068	0.0001
Temp	CC	−0.0164	0.0738	−0.0928	0.1923	0.0127	0.1429	−0.0306
	P	0.8458	0.3794	0.1159	0.0209	0.8798	0.0152	0.4640
Sine 1	CC	0.0361	0.2126	0.0283	0.2013	−0.0300	0.1085	0.0254
	P	0.6678	0.0105	0.6323	0.0156	0.7215	0.0660	0.5429
Sine 2	CC	0.3804	0.0304	0.2208	−0.1318	−0.1188	−0.1228	0.1365
	P	0.0001	0.7179	0.0002	0.1153	0.1561	0.0373	0.0010
Pea	CC	0.2096	0.3336	0.3737	0.3083	0.5092	0.1908	−0.2212
aphid	*P*	0.0117	0.0001	0.0001	0.0002	0.0001	0.0011	0.0001
$\bar{x}$		53.2	4.1	28.0	5.1	4.0	4.6	18.6
n		144	144	288	144	144	288	576

[a] RH, relative humidity; sine 1, sine(0.21679 [hour]) (diurnal); sine 2, sine(0.5239 [hour]) (crepuscular).

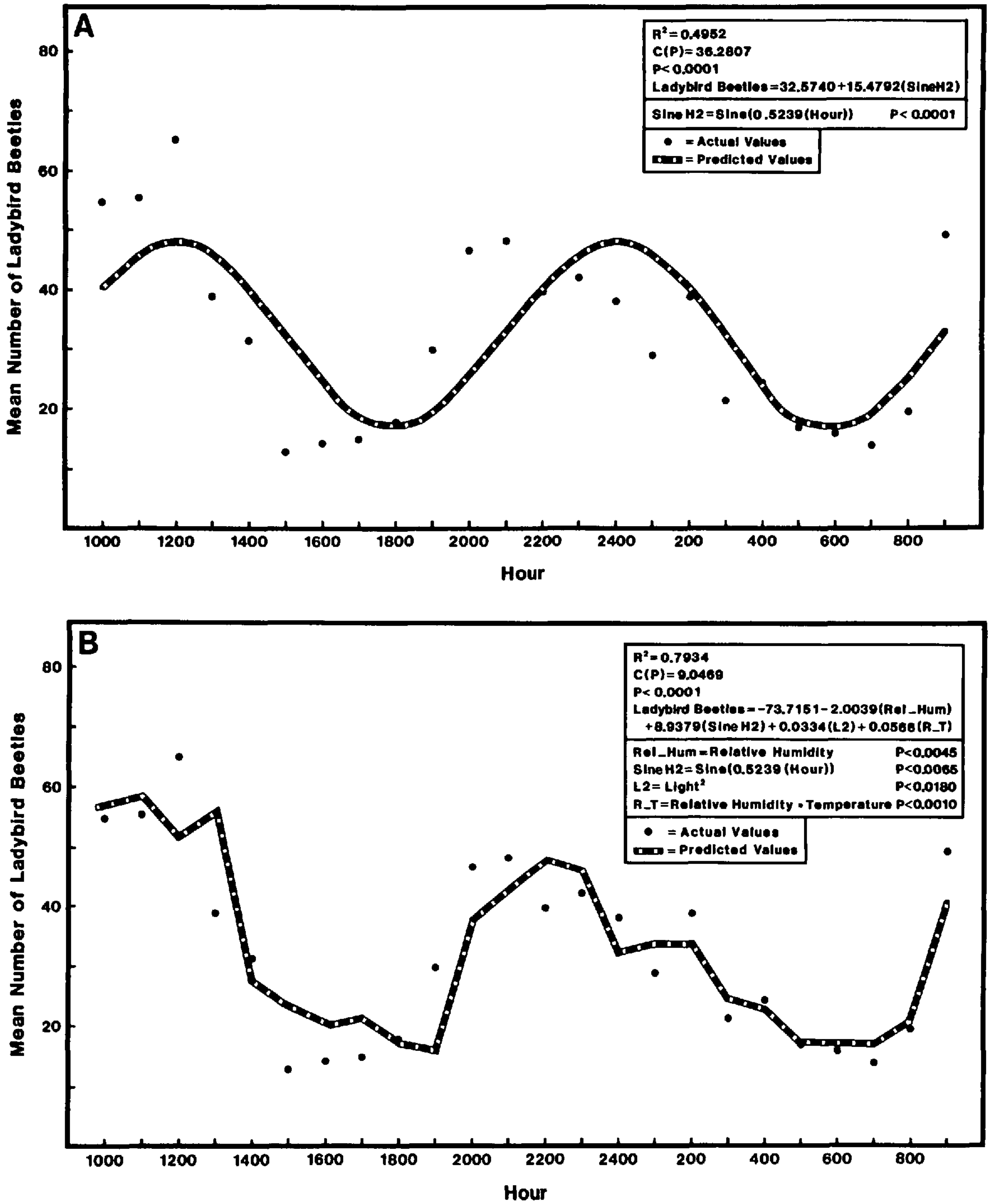

Fig. 3. Single-variable (A) and four-variable (B) models and graphs of actual and predicted values in sweep net counts for lady beetle in lentils during 1983 and 1984.

cular sine of hour to predict the number of insects in the hourly samples (Fig. 4A). The crepuscular sine of hour was a significant ($P < 0.0014$) predictor of the variation in numbers of lacewings collected by sweep net. The best four-variable model contained temperature, light intensity, and crepuscular sine of hour (Fig. 4B). Two of the same factors best described hourly variation in pea aphid numbers, and three of these four factors best described the variation in numbers of lady beetles collected by sweep net sampling. The four-variable model was a significant ($P < 0.0183$) predictor of the number of lacewings collected by sweep net. However, the only significant variable was the crepus-

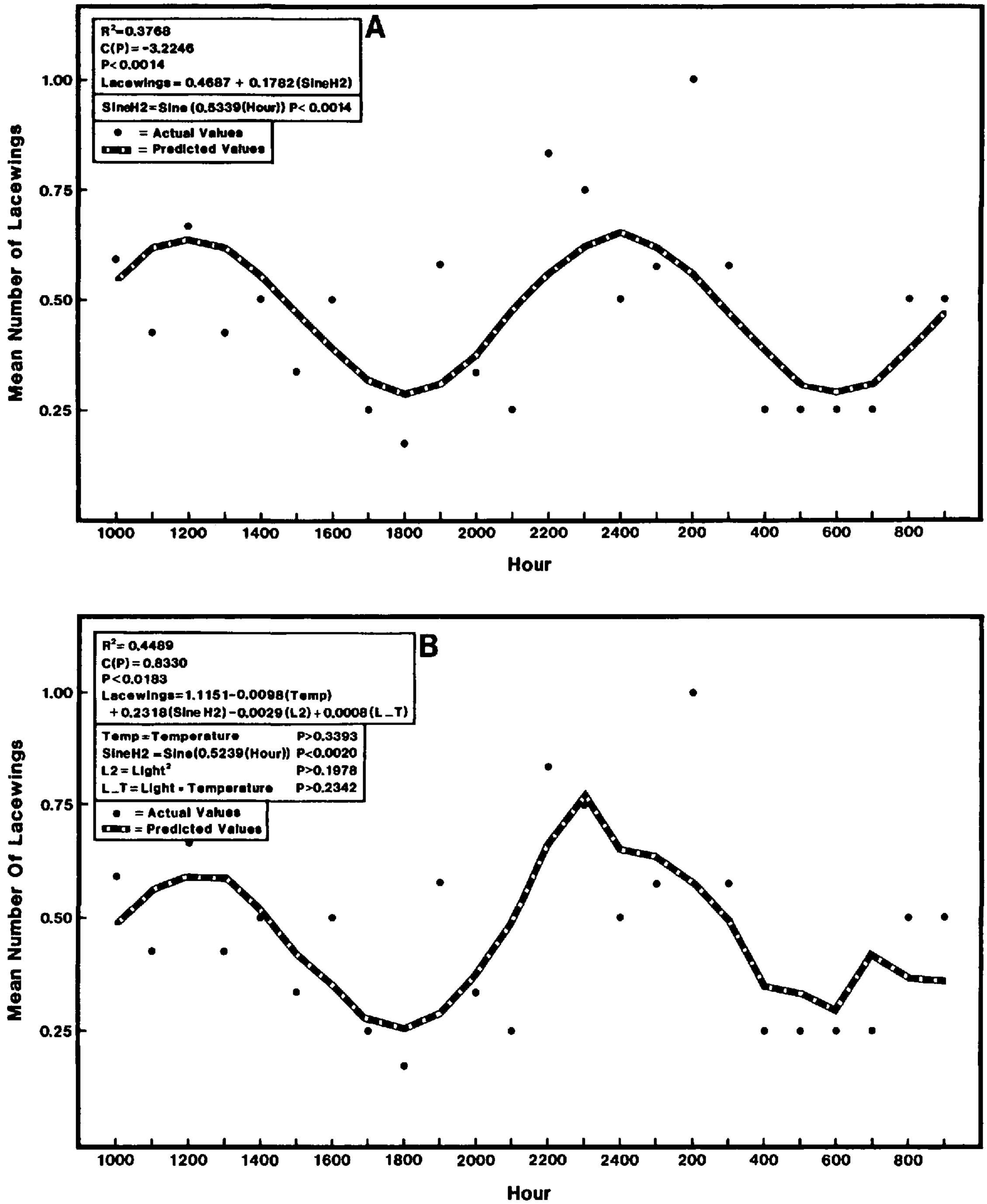

Fig. 4. Single-variable (a) and four-variable (B) models and graphs of actual and predicted values in sweep net counts for lacewings in lentils during 1983 and 1984.

cular sine of hour, but it explained little of the variation (Fig. 4B).

Understanding the effects of insect pest density and time of sampling on the efficiency of a sampling method, and the efficiency of that sampling method in collecting predators of the pest, is critical in determining the time at which sampling is most accurate. The 24-h cycle of counts shows that the sweep net collected the highest counts of pea aphids around noon, although population estimates were not appreciably reduced until dark, and counts were back to evening levels by midmorning (Fig. 1A and 1B). The preferred sampling time for lady beetles would be during late morning, whereas nabids had the largest population estimates either in late morning or midafternoon (Fig. 2B and 3B).

Table 10. Correlation coefficients (CC) and *P* values for lacewings collected with a sweep net in lentils and the abiotic factors, diurnal and crepuscular sine of hour, and pea aphids during 1984

Factors[a]		1984		
		High	Low	Over density
Wind	CC	−0.0355	−0.1356	−0.0510
	P	0.6730	0.1053	0.3887
RH	CC	0.0270	0.0587	0.1876
	P	0.7481	0.4846	0.0014
Light	CC	−0.1544	0.0451	−0.0942
	P	0.0645	0.5912	0.1106
Temp	CC	−0.0570	0.0014	0.0134
	P	0.4970	0.9868	0.0799
Sine 1	CC	−0.0758	−0.0056	−0.0468
	P	0.3666	0.9471	0.4285
Sine 2	CC	0.2442	−0.0146	0.1463
	P	0.0032	0.8619	0.0130
Pea aphid	CC	0.0252	0.0214	−0.3233
	P	0.7639	0.7992	0.0001
$\bar{x}$		0.88	0.06	0.50
n		144	144	288

[a] RH, relative humidity; sine 1, sine(0.21679 [hour]) (diurnal); sine 2, sine(0.5239 [hour]) (crepuscular).

The lacewings showed little predictability other than that found when the crepuscular sine of hour was used to predict sweep net population estimates, with highest population estimates either in late morning or late at night (Fig. 4B). Overall, if the sweep net is to be used to estimate the population densities of the pea aphid and the predators we sampled, a late-morning sample would be preferable. However, if one of the three predators is dominant, the sampling plan could be modified to maximize the collection of pest and the dominant predator. If lady beetles are the dominant predators, a late-morning sample would be preferred (Fig. 1B and 3B), but if the nabids were the dominant predators, a late-morning or midafternoon sample would be preferred (Fig. 1B and 2B). We conclude that choosing appropriate timing of sampling and using the sweep net sampling method can provide reliable estimates of pea aphid densities for determination of control actions in individual lentil fields. However, the timing of sampling is dependent on maximization of pea aphid estimates as well as the predominant predators present.

Acknowledgment

We thank G. Newberry, B. Atkinson, M. Cole, and K. O'Connor for their assistance in the field collection and identification of insects in this investigation. We also thank L. Williams III, J. P. McCaffrey, and J. P. Johnson for their helpful comments on this manuscript. This article is supported in part by USDA-ARS Grant 58-0401-0004 and the Idaho and Washington Pea and Lentil Commissions. It is published with the approval of the Director, Idaho Agricultural Experiment Station, as Research Paper No. 8872.

References Cited

Bechinski, E. H. & L. P. Pedigo. 1982. Evaluation of methods for sampling predatory arthropods in soybeans. Environ. Entomol. 11: 735–761.

Byerly, K. F., A. P. Gutierrez, R. E. Jones & R. F. Luck. 1978. A comparison of sampling methods for some arthropod populations in cotton. Hilgardia 46: 257–282.

Cherry, R. H., K. A. Wood & W. G. Ruesink. 1977. Emergence trap and sweepnet sampling for adults of the potato leafhopper from alfalfa. J. Econ. Entomol. 70: 511–513.

Cuperus, G. W., E. B. Radcliffe, D. K. Barnes & G. C. Marten. 1982. Economic injury levels and economic threshold for pea aphid, *Acyrthosiphon pisum* (Harris), on alfalfa. Crop Prot. 1: 453–463.

Dietrick, E. J. 1961. An improved backpack motor fan for suction sampling of insect populations. J. Econ. Entomol. 54: 394–395.

Ellington, J., K. Kiser, G. Ferguson & M. Cardenas. 1984. A comparison of sweepnet, absolute, and insectavac sampling methods in cotton ecosystems. J. Econ. Entomol. 77: 599–605.

Gomez, K. A. & A. A. Gomez. 1984. Statistical procedures for agricultural research. Wiley, New York.

Hagen, K. S. & R. Van den Bosch. 1968. Impact of pathogens, parasites, and predators of aphids. Annu. Rev. Entomol. 13: 325–384.

Kogan, M. & D. C. Herzog [eds.]. 1980. Sampling methods in soybean entomology. Springer, New York.

Kogan, M. & H. N. Pitre, Jr. 1980. General sampling methods for above-ground populations of soybean arthropods, pp. 30–60. *In* M. Kogan & D. C. Herzog [eds.], Sampling methods in soybean entomology. Springer, New York.

Maiteki, G. A. & R. J. Lamb. 1985. Spray timing and economic threshold for the pea aphid, *Acyrthosiphon pisum* (Homoptera: Aphididae), on field peas in Manitoba. J. Econ. Entomol. 78: 1449–1454.

Maiteki, G. A., R. J. Lamb & S. T. Ali-Khan. 1986. Seasonal abundance of the pea aphid, *Acyrthosiphon pisum* (Homoptera: Aphididae), in Manitoba field peas. Can. Entomol. 118: 601–607.

Mallows, C. L. 1964. Some comments on Cp. Technometrics 15: 661–675.

Murray, G. A., K. D. Kephart, L. E. O'Keeffe, D. L. Auld & R. H. Callihan. 1987. Dry pea, lentil, and chickpea production in northern Idaho. University of Idaho Research Bulletin 664.

Neuenschwander, P., K. S. Hagen & R. F. Smith. 1975. Predation on aphids in California's alfalfa fields. Hilgardia 43: 53–78.

Pedigo, L. P., G. L. Lentz, J. G. Stone & D. F. Cox. 1972. Green cloverworm populations in Iowa soybeans with special reference to sampling procedure. J. Econ. Entomol. 65: 414–421.

Pruess, K. P., K. M. L. Saxena & S. Koinzan. 1977. Quantitative estimation of alfalfa insect populations by removal sweeping. Environ. Entomol. 6: 705–708.

Ruesink, W. G. 1980. Introduction to sampling theory, pp. 61–78. *In* M. Kogan & D. C. Herzog [eds.], Sampling methods in soybean entomology. Springer, New York.

SAS Institute. 1982. SAS user's guide: statistics. SAS Institute, Cary, N.C.

1985a. SAS procedures guide for personal computers. SAS Institute, Cary, N.C.

1985b. SAS/STAT guide for personal computers. SAS Institute, Cary, N.C.

Saugstad, E. S., R. A. Bram & W. E. Nyquist. 1967. Factors influencing sweep-net sampling of alfalfa. J. Econ. Entomol. 60: 421–426.

Schotzko, D. J. & L. E. O'Keeffe. 1986a. Comparison of sweepnet, D-Vac, and absolute sampling for *Lygus hesperus* (Heteroptera: Miridae) in lentils. J. Econ. Entomol. 79: 224–228.

1986b. Evaluation of diurnal variation of sweepnet effectiveness in lentils for sampling *Lygus hesperus* (Heteroptera: Miridae). J. Econ. Entomol. 79: 447–451.

Shepard, M., G. R. Carner & S. G. Turnipseed. 1974. A comparison of three sampling methods for arthropods in soybeans. Environ. Entomol. 3: 227–232.

Southwood, T. R. E. 1978. Ecological methods. Chapman & Hall, London.

Wilson, H. K. & S. S. Quisenberry. 1986. Impact of feeding by alfalfa weevil larvae (Coleoptera: Curculionidae) and pea aphid (Homoptera: Aphididae) on yield and quality of first and second cutting of alfalfa. J. Econ. Entomol. 79: 785–789.

Yencho, G. C., L. W. Getzin & G. E. Long. 1986. Economic injury level, action threshold, and a yield-loss model for the pea aphid, *Acyrthosiphon pisum* (Homoptera: Aphididae), on green peas, *Pisum sativum*. J. Econ. Entomol. 79: 1681–1687.

Received for publication 9 February 1988; accepted 7 December 1988.