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SEASONAL MIGRATION OF THE BLACK CUTWORM[1]

William B. Showers, Armon J. Keaster[2], Jimmy R. Raulston[3], John L. Goodenough[4], William H. Hendrix, III[5], Michael O. Way[6], and John F. Robinson[7]
Corn Insects Research Unit, USDA-ARS and Department of Entomology, Iowa State University, Ames, Iowa 50011

ABSTRACT

Adult populations of black cutworm, *Agrotis ipsilon* (Hufnagel), males were monitored 1 June to 31 December 1985-1987. Texas 70-50-cm cone traps baited with sex pheromone were located north to south, 41°45'N to 25°45'N latitude, at Ankeny, Iowa; Columbia, Missouri; Crowley, Louisiana; and Beaumont, College Station, and Brownsville, Texas. Forecasts of nightly near-surface (100-300 m) airflow were recorded from 18 weather stations in the midcontinental United States. Average moth capture summed per 2-week interval for each Gulf Coast location was regressed upon nights of near surface northerly flow (southward displacement) summed per 2-week interval and also on average moth capture summed per 2-week interval at Ankeny or Columbia. Near-surface northerly flow was not a limiting factor at Crowley or Beaumont. Increased moth capture at Crowley was associated with decreased moth capture at Ankeny and Columbia during 1987. Although not significant, there was a consistent relationship between increased capture

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[1]Lepidoptera: Noctuidae

[2]Department of Entomology, University of Missouri, Columbia , MO 65201
[3]Subtropical Agricultural Research Laboratory, USDA-ARS, 509 W. 4th St., Weslaco, TX 78596
[4]Engineering Equipment and Methods Research Unit, USDA-ARS, Agric. Eng. Bldg., Texas A&M University, College Station, TX 77843
[5]Current address; Dow Elanco, 9410 Zionzville Road, Indianapolis, IN 46268
[6]Texas A&M University, Agricultural Research and Extension Center, Rt. 7, Box 999, Beaumont, TX 77713
[7]Current address; University of Arkansas Agricultural Research and Extension Center, P.O. Box 351, Stuttgart, AR 72160

at Beaumont and decreased capture at Ankeny. Farther west, in south-central Texas, there was strong evidence for moths captured at College Station to be related to near-surface northerly flow (one of three years) and to source moths (two of three years) from Ankeny. Farther south and west, capture at Brownsville was also associated with near-surface northerly flow two of three years of the study. During 1987, similar to moth capture at Crowley, moth capture at Brownsville was related to source moths from Ankeny. These results suggest that near-surface (100-300 m) northerly winds may be responsible for autumnal southward migration of black cutworm moths.

INTRODUCTION

In temperate regions, changes in environmental conditions are generally predictable. Insects approach the consequences of these climatic changes by entering dormancy (diapause or aestivation) essentially without changing geographic location, or they migrate to sites more conducive to dormancy. These sites may occur at different longitudes and elevations but usually are at the same or a similar latitude (Tauber et al. 1986). There is mounting evidence, however, that some insect species undertake long-distance migrations to higher or lower latitudes where they may diapause or resume breeding when environmental conditions allow (Gatehouse 1989). A classic study of long-range movement by the oriental armyworm, *Mythimna separata* (Walker) (Lepidoptera: Noctuidae), was conducted in China by Li et al. (1964). Externally dyed moths were released during the spring, and some were recaptured 600-1,000 km to the north. Equally important, one moth that had been released in the north during autumn was recaptured in Anhui Province 800 km to the south. Major long-range movement from northern Australia to southern Australia and across Bass strait to Tasmania of several noctuids [*Heliothis punctigera* Wallengren, *Persectania ewingii* (Westwood), *Agrotis munda* Walker, and *A. infusa* (Boisduval)] were defined by radar echoes (Drake et al. 1981). These spring movements allow these species to escape the seasonal high temperatures of northern Australia for the more hospitable climate of Tasmania.

Strong circumstantial evidence suggests that corn earworm, *Helicoverpa zea* (Boddie), move on upper-level airflow from plant hosts in northeastern Mexico and the Lower Rio Grande Valley of Texas into more northerly regions of the United States (Hartstack et al. 1982, 1986, Raulston et al. 1986a, 1986b). Some *H. zea* moths captured during spring in Arkansas were found to have exotic grains of pollen attached to eyes or mouth parts. These pollens indicated that these moths could only have come from the Lower Rio Grande Valley or farther south in Mexico (Hendrix et al. 1987).

Mark-release recapture of black cutworm, *A. ipsilon* (Hufnagel), by Showers et al. (1989a,b) proved that during spring or early summer, this species can, in just three or four nights, immigrate to Iowa, Kansas, and Missouri from southern Louisiana or south-central Texas. Similar to *H. zea*, feral individuals of this species captured in central Iowa and northern Missouri had exotic pollen grains on the proboscis and eye. This suggests that these moths were transported from Mexico or the Lower Rio Grande Valley (Hendrix and Showers 1992).

A possible mechanism for the rapid transport north for *H. zea; A. ipsilon;* armyworm, *Pseudaletia unipuncta* (Haworth); variegated cutworm, *Peridroma saucia* (Hübner); (McNeil 1987, Buntin et al. 1990), and other noctuids is provided by the nocturnal Great Plains low-level jet (McCorcle and Fast 1989). The largest percentage of observed wind maxima occurs nearest the 500-m elevation (Bonner 1968). During spring, it is not uncommon for wind maxima within these nocturnal jets to attain 83 km per h (Beckman 1973).

It would be advantageous in the evolution of migrating insect species for them to fully exploit potential geographic ranges. Therefore, in temperate regions, species that disperse northward should also be predisposed to disperse southward (Northern Hemisphere, the reverse in the Southern Hemisphere). Recall that during September, Li et al. (1964) recaptured a marked moth in southern China. Trap captures and radar echoes recorded by Pair et al. (1987) indicate that long-range movement from Lubbock, in the north, to Brownsville, Texas, in the south, by *H. zea* and fall armyworm, *Spodoptera frugiperda* (J.E. Smith), occurred between 15-25 September 1984. Trajectories calculated at 5-h intervals at 500 m elevation suggest that winds were predominantly southerly (northward displacement). Radar, however, indicated that large profiles of airborne insects were at lower elevation and that displacement was southerly. A recent study (Showers et al. 1993) conducted during autumn in which black cutworm moths were marked-released and recaptured indicates that moths from Ankeny, Iowa could have arrived in the College Station, Texas area within 10 to 14 nights and a recovered marked moth at Brownsville, Texas would have arrived there eight nights after release.

We hypothesize that, during autumn, black cutworm moths implement long-range transport from the central and southern Corn Belt and proceed southward to the Gulf of Mexico coastal regions of Louisiana and Texas. We also suggest that this species accomplishes this transport on near-surface northerly (southward displacement) winds. The present study was conducted to test these hypotheses.

MATERIALS AND METHODS

Adult populations of black cutworm males were monitored 1 June to 31 December 1985-1987 with Texas 70-50-cm cone traps (Hartstack et al. 1979). Each trap was baited with a rubber septum impregnated with 40 μg of a 3:1 ratio of Z-7-dodecanyl acetate:Z-9-tetradecanyl acetate (Hill et al. 1977). Traps were located north to south, two traps, Ankeny, Iowa, (93°38'N longitude, 41°45'N latitude); two traps, Columbia, Missouri, (92°15'W, 39°00'N); eight traps, College Station, Texas (96°30'W, 30°45'N); two traps, Crowley, Louisiana (92°30'W, 30°30'N); two traps, Beaumont, Texas (94°15'W, 30°10'N); and five traps, Brownsville, Texas (97°30'W, 25°45'N). Traps were observed daily at Ankeny and 5 days a week at all other sites except Columbia, where they were observed once every 7 to 10 days. Also, black cutworm adults were captured in two blacklight traps at Ankeny. Moths were sexed, and females were classified as mated or nonmated (Clement et al. 1985).

Several assumptions were made pertaining to autumn migration of *A. ipsilon*: 1) moths migrated only when there was a northerly component of airflow (Pair et al. 1987); 2) black cutworm flight was nocturnal; therefore, flight was assumed to begin at dusk and terminate 12 h later at dawn; and 3) low-level jets (approximately 500-800 m) would not promote southward transport (McCorcle and Fast 1989); height of migrational flight, therefore, was assumed to be between 100-300 m above ground level.

Nightly near surface air-flow at 100-300 m was recorded from 18 weather stations in the midcontinental United States (U.S. Dep. Commer. 1985, 1986, 1987). Nights with northerly flow and moth captures at each location were grouped into 2-week intervals over years (1985-1987), from 1 June to 31 December. Because of the reduction in calling behavior of females and the relative unattractiveness of traps baited with sex pheromone to males in central Iowa during mid-August to early-November (Kaster and Showers 1982, Clement et al. 1985, Mulder et al. 1989), capture of males in blacklight traps from 16 July to 31 October was averaged nightly and added to the average nightly capture of males in sex-pheromone-baited traps at Ankeny and summed over 2-week intervals. A large interaction between 2-week intervals and moth captures per location was expected; therefore, analyses of variance (SAS 1985) were conducted within time periods (1-15 June, 16-30 June, etc.) with trap locations (n = 6) as treatments and years (n = 3) as replicates. Mean moth captures, transformed to natural logs, were separated by a revised Ryan's Q Test (Einot and Gabriel 1975).

Further, for each year, nightly average moth capture for each Gulf Coast location summed per 2-week period was regressed upon nights of northerly flow per 2-week period. Average nightly moth capture at these locations summed per 2-week period was also regressed upon average nightly moth capture at Ankeny, Iowa, or Columbia, Missouri, summed per 2-week period. Slopes (b), t-values, and probabilities (P) greater than t were estimated. Appropriate models were developed from these regressions.

RESULTS AND DISCUSSION

Moth capture, averaged over years, during selected 2-week intervals is presented in Table 1. During late June and late July, capture at Ankeny, Iowa was significantly greater than moth capture at the other locations (df = 5, 10, F = 15.20, P = 0.0002 and df = 5, 10, F = 10.85, P = 0.0009, respectively). By late August, however, the capture at Ankeny had decreased while the capture at Crowley had increased so that at these two sites capture was similar but significantly different (df = 5, 10, F = 8.49, P = 0.002) from captures at Columbia, College Station, and Brownsville. By late September, captures of black cutworm males at all four Gulf Coast sites had increased substantially (Table 1), and those at Crowley, Beaumont, and College Station were significantly greater (df = 5, 10, F = 8.01, P = 0.003) than captures during this period at Ankeny (41°45'N) or Columbia (39°00'N). Captures at Crowley (30°30'N) and Beaumont (30°10'N) were also greater than moth capture approximately 600 km southwest at Brownsville (25°45'N).

If black cutworm moths are emigrating from the Corn Belt on near-surface winds, this phenomenon would most likely occur between 16 July to 31 October. After that date, declining temperatures usually would preclude further long-range movement. Figure 1 presents evidence that, throughout this portion of the season, Crowley has many nights with near-surface northerly flow. Northerly flow, approximately 160 km farther west at Beaumont (94°15'W), usually displays a pattern similar to northerly flow of Crowley. The two more western locations, however, do not achieve equality in near-surface northerly flow until September. These results suggest that, during this portion of the year, a transport vehicle for immigrating moths is always present at Crowley and usually present at Beaumont (Fig. 1). But adequate transport would not be available at College Station or Brownsville until later

TABLE 1. Average Capture of Black Cutworm Males at Six Geographic Locations, Transformed to Natural Log, for Selected 2-week Intervals, Summer and Autumn 1985-1987.

Location	Selected Intervals[a]							
	16-30 June		16-31 July		16-31 August		15-30 September	
	mean	log(n+1)	mean	log(n+1)	mean	log (n+1)	mean	log(n+1)
Ankeny, IA	987.0	6.45 A	430.0	6.06 A	48.7	3.91 A	4.7	1.74 C
Columbia, MO	14.3	2.75 B	15.0	2.77 B	4.3	1.67 BC	1.3	0.85 C
Crowley, LA	2.7	1.31 B	10.0	2.39 B	45.7	3.84 A	153.0	5.04 A
Beaumont, TX	6.0	1.95 B	3.3	1.45 B	12.3	2.59 ABC	79.0	4.38 A
College Station, TX	6.0	1.95 B	0.6	0.47 B	2.3	1.06 C	48.0	3.89 AB
Brownsville,TX	1.7	0.99 B	1.0	0.69 B	0.7	0.46 C	12.0	2.57 BC

[a]Transformed means within columns followed by the same letter are not significantly different ($P > 0.05$, Ryan's Q Test [Einot and Gabriel 1975]).

in the season. This may partially explain why captures at College Station and Brownsville do not increase until autumn (Table 1).

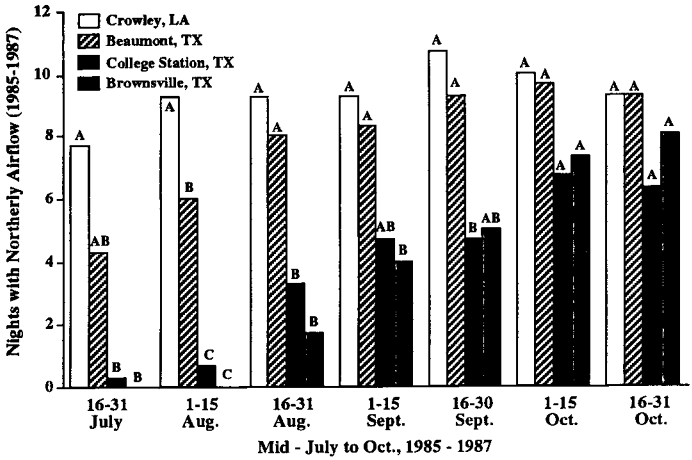

FIG.1 Nights of near-surface northerly flow, mid-July to late October, 1985-1987, at four locations near the Gulf of Mexico. Means, within time intervals, followed by the same letter are not significantly different ($P > 0.05$, Ryan's Q Test [Einot and Gabriel 1975]).

Average nightly capture of black cutworm males summed per 2-week interval, 16 July to 31 October, was separated by year, transformed to natural logs, and regressed on nights of northerly flow for each 2-week interval. The only year that moth capture at Crowley was dependent on northerly flow ($b = 0.379$, $t = 2.75$, $P = 0.04$) was 1985 (Fig. 2A). That year, there were increasing moth captures for each period until 31 October. Natural log of moth capture at Crowley was also regressed on natural log of moth capture at Ankeny or Columbia (Fig. 2B, Ankeny only). Increased captures of moths at Crowley were associated with decreased captures of moths at Ankeny and Columbia during 1987 (Ankeny, $b = -0.766$, $t = -5.19$, $P = 0.003$; Columbia, $b = -0.821$, $t = -4.17$, $P = 0.0008$). These results (Figs. 1, 2A,B) suggest that, annually, there is adequate near-surface northerly flow at Crowley during 16 July to 31 October and that moths might immigrate to this site from the central and southern Corn Belt. But with source moths from Ankeny and Columbia being significant for just one year (1987), moth capture at Crowley may also be associated with more eastern portions of the Corn Belt (*i.e.*, Illinois, Indiana, Ohio, Kentucky).

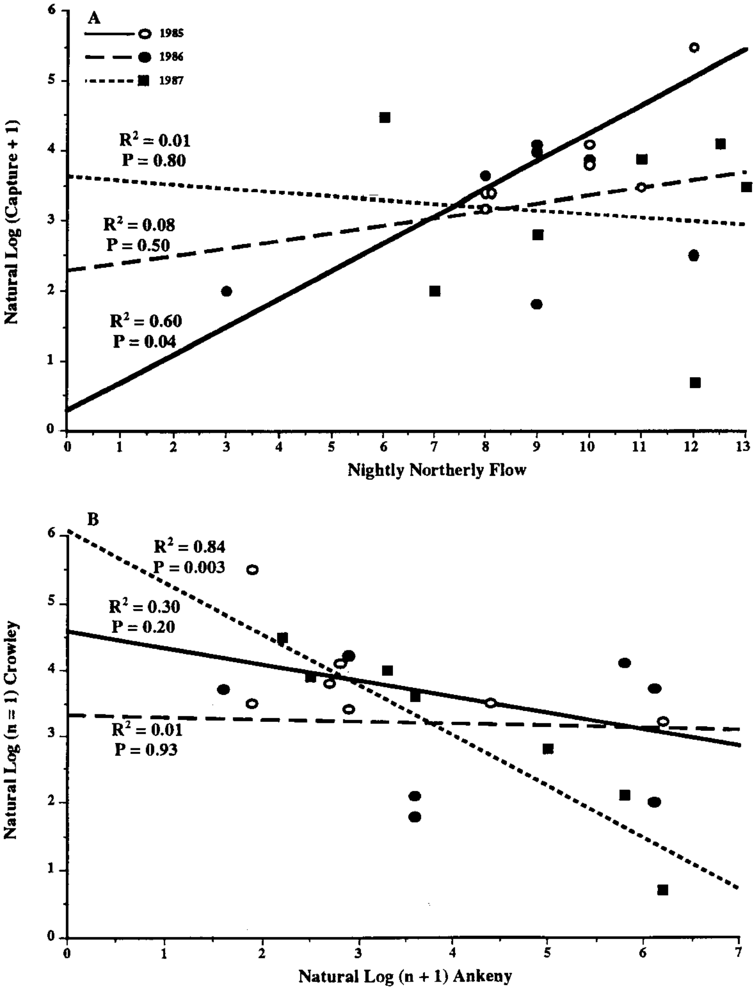

FIG. 2 (A) Natural log (n + 1) of moth capture regressed on nights with near-surface northerly flow, 2-week intervals, 15 July to 31 October, 1985 - 1987, Crowley, Louisiana. (B) Natural log (n + 1) of moth capture, Crowley, Louisiana regressed on natural log (n +1) of moth capture, Ankeny, Iowa, 2-week intervals, 15 July to 31 October, 1985 - 1987.

An indication that the Crowley site might contribute to moth immigration to more eastern areas of the Corn Belt came during a spring-summer mark-release recapture study conducted with releases from Crowley (Showers et al. 1989a, b). The investigators uniformly recaptured black cutworm moths in east-central and eastern Iowa. When the release site was moved westward to College Station, however, they regularly recaptured moths in western Missouri, eastern Kansas, and western and central Iowa (Showers et al. 1989a, b). It is conceivable, therefore, that autumn immigration to Crowley could come from areas east of Ankeny or Columbia.

Moth capture at Beaumont was not dependent on nightly northerly air flow (Fig. 3A). Again, however, there were adequate numbers of nights with near-surface northerly flow during the portion of the season being investigated (Fig. 1).

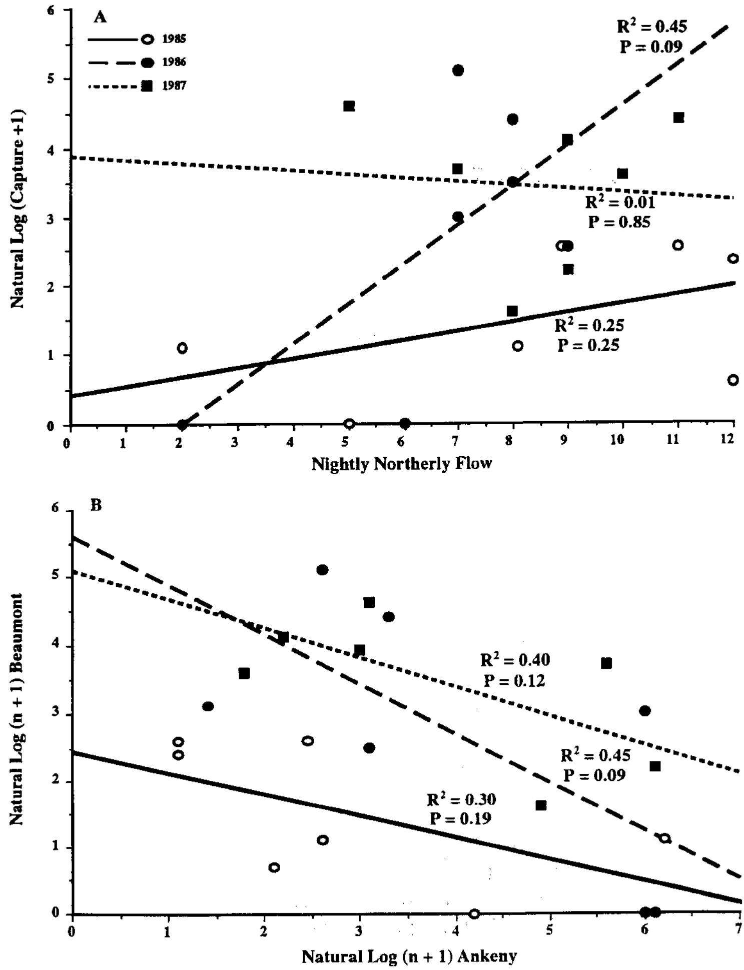

FIG. 3 (A) Natural log (n + 1) of moth capture regressed on nights with near-surface northerly flow, 2-week intervals, 15 July to 31 October, 1985 - 1987, Beaumont, Texas. (B) Natural log (n + 1) of moth capture, Beaumont, Texas regressed on natural log (n +1) of moth capture, Ankeny, Iowa, 2-week intervals, 15 July to 31 October, 1985 - 1987.

Although not significant, the relationship of high moth capture at Beaumont to low moth capture at Ankeny (Fig. 3B) is more consistent over years than at Crowley. A clearer picture begins to emerge farther west with the less maritime environment of College Station (96°30'W).

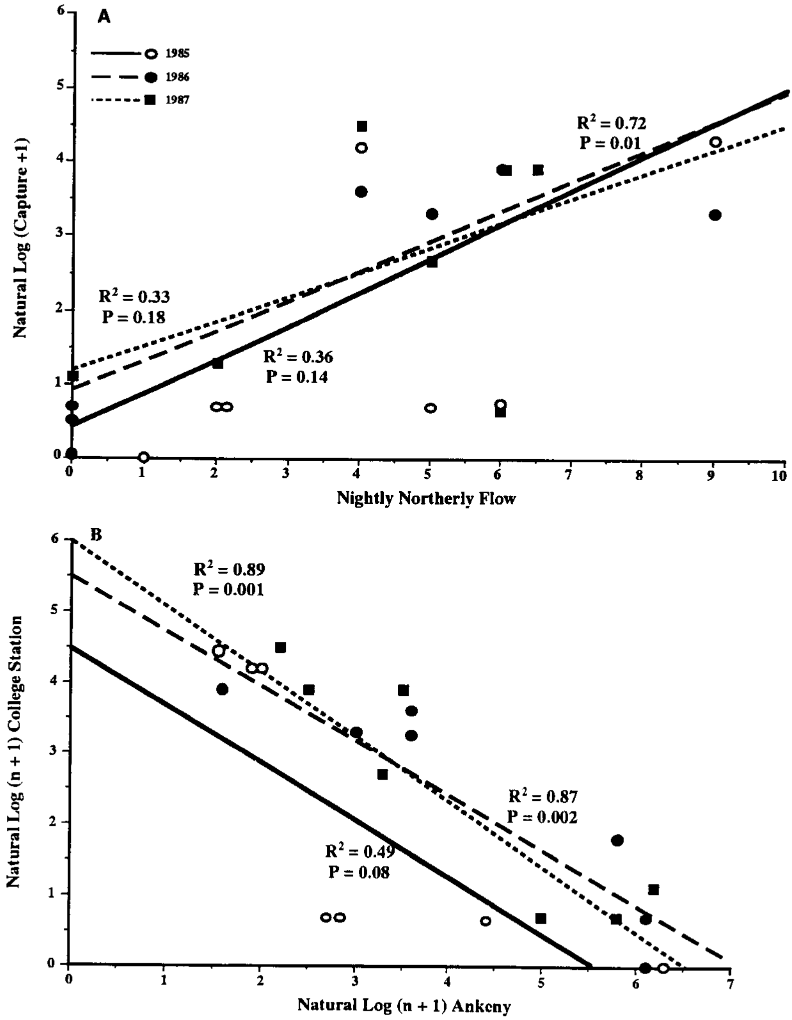

FIG. 4 (A) Natural log (n + 1) of moth capture regressed on nights with near-surface northerly flow, 2-week intervals, 15 July to 31 October, 1985 - 1987, College Station, Texas. (B) Natural log (n + 1) of moth capture, College Station, Texas regressed on natural log (n +1) of moth capture, Ankeny, Iowa, 2-week intervals, 15 July to 31 October, 1985 - 1987.

Near-surface northerly flow is rare until late August but increases through autumn (Fig. 1). Black cutworm moth capture is relatively sparse during hot, dry summer months, but captures begin to increase significantly (df = 5, 10, F = 8.01, P = 0.003) during autumn (Table 1). Although significant (b = 0.399, t = 3.647, P = 0.01) only for 1986, a trend exists for natural log of moths captured at College Station to be associated with near-surface northerly flow (Fig. 4A). When considered in conjunction with evidence that moth capture at College Station is associated with a moth source from Ankeny (Fig. 4B), northerly airflow takes on greater importance. Autumn moth capture at College Station was significantly associated with a decline in moth capture at Ankeny during 1986 (b = -0.784, t = -5.683, P = 0.002), 1987 (b = -0.939, t = -6.273, P = 0.001) and nearly significant (P = 0.05) during 1985 (b = -0.816, t = -2.205, P = 0.08).

More evidence of the importance of near-surface northerly flow enhancing populations of black cutworm much farther west and south at Brownsville (97°30'W, 25°45'N) is presented in Fig. 5A. These results suggest that, from 16 July to 31 October, capture of black cutworm moths is greatly dependent on near-surface northerly flow (1985, b = 0.175, t = 1.864, P = 0.12; 1986, b = 0.202, t = 3.014, P = 0.02; 1987, b = 0.353, t = 2.924, P = 0.03). A trend for moth capture at Brownsville to be dependent on a moth source from the central Corn Belt was not evident during autumn 1985. But in 1987, increased captures at Brownsville were associated (b = -0.824, t = -3.128, P = 0.03) with decreased captures of moths at Ankeny (Fig. 5B).

A general model was developed based on the trap capture results at College Station, Brownsville, and Ankeny. This model consists of a = intercept, b_1 = slope for airflow (x_1), and b_2 = slope for Ankeny moth capture (x_2), and $b_1b_2{*}x_1x_2$ = interaction:

$$\hat{y} = a + (-b_1x_1) + (-b_2x_2) + (b_1b_2{*}x_1x_2) \qquad (1)$$

R^2 for near-surface northerly airflow (0.72) and relationship to Ankeny moths (0.89) increased to 0.96 at College Station. R^2 for near surface northerly airflow (0.63) and relationship to Ankeny moths (0.66) increased to 0.93 at Brownsville. Because both of these variables (near-surface airflow and moth source) were not significant every autumn at both locations, it might be imprudent to use this equation until more years of airflow and moth capture are collected and analyzed. The simpler regression model ($\hat{y} = a + bx_1$) for airflow might best serve to predict moth capture at Brownsville, and the simple regression model ($\hat{y} = a + bx_2$) for moth source (Ankeny) might better describe moth capture at College Station.

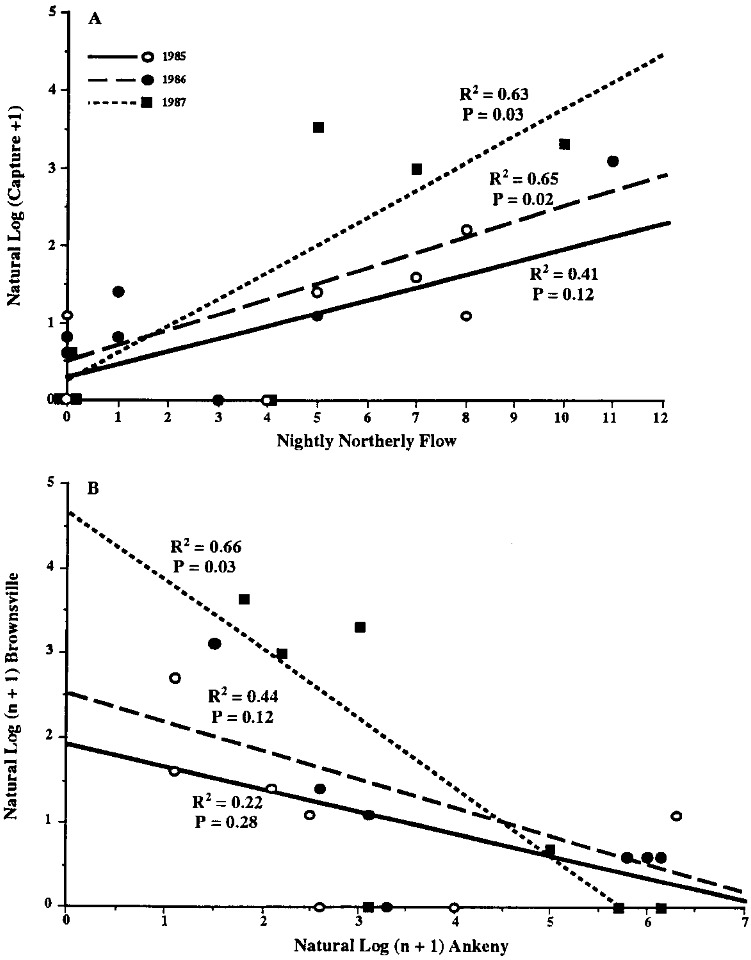

FIG. 5 (A) Natural log (n + 1) of moth capture regressed on nights with near-surface northerly flow, 2-week intervals, 15 July to 31 October, 1985 - 1987, Brownsville, Texas. (B) Natural log (n + 1) of moth capture, Brownsville, Texas regressed on natural log (n +1) of moth capture, Ankeny, Iowa, 2-week intervals, 15 July to 31 October, 1985 - 1987.

CONCLUSIONS

We conclude that near-surface northerly flow is the vehicle necessary to transport moths to College Station during autumn, but until moths leave the western Corn Belt, relatively few moths will be captured near College Station (Fig. 4B). Near-surface northerly flow is critical for increased capture of moths at the southern tip of Texas (Fig.

5A). Moths captured at Brownsville, however, might not consistently come from the western Corn Belt (Fig. 5B, and Showers et al. 1993).

Along the upper Gulf Coast the importance of near-surface northerly flow in replenishing autumn populations of black cutworm is less evident. From July to October, Crowley and Beaumont seemingly have adequate numbers of nights with near-surface northerly flow (Fig. 1). Therefore, a transport vehicle is not limiting. Arrival of moths is usually earlier, *e.g.*, late summer (Table 1), and more often emigration might be from the eastern Corn Belt. Our evidence and the recapture of a marked moth at Brownsville, suggesting that it was transported southward past Crowley and Beaumont (Showers et al. 1993) indicate, however, that moths can and do immigrate into these areas from the western Corn Belt (Figs. 2B, 3B).

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