Seasonal Periodicity of Fall Armyworm, (Lepidoptera: Noctuidae) in the Caribbean Basin and Northward to Canada[1]

E. R. Mitchell, J. N. McNeil[2], J. K. Westbrook[3], J. F. Silvain[4], B. Lalanne-Cassou[4], R. B. Chalfant[5], S. D. Pair[3], V. H. Waddill[6], A. Sotomayor-Rios[7], and F. I. Proshold[3,8]

Insect Attractants, Behavior, and Basic Biology Research Laboratory, USDA-ARS
Gainesville, FL 32604

J. Entomol. Sci. 26(1): 39-50 (January 1991)

ABSTRACT Sex pheromone traps were used to monitor the seasonal periodicity of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), moth over a 2-year period at eight locations from French Guiana northward to Canada. Results indicated a seasonal progression of movement by fall armyworm from the southern most locations in the United States into Canada. Although the fall armyworm survives throughout the year in the Caribbean Basin, analysis of moth capture and meteorological data for the region provided no direct evidence that this reservoir of continuous populations contributed significantly to the influx of this pest into the temperate regions of North America where it normally does not survive the winter. Weather disturbances along the Atlantic seaboard of the northeastern U.S. and Canada in October 1984 and an associated precipitous decline in moth captures in pheromone traps supports a previous hypothesis of a return (southward) migration by fall armyworm.

KEY WORDS Migration, Pheromone, Meteorology, Insect survey, Weather patterns, Dispersal, fall armyworm, *Spodoptera frugiperda.*

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is widely scattered throughout the Western Hemisphere (Figure 1), and it is a pest of enormous proportions on many crops including forage grasses, rice, sorghum, maize, soybean, and peanuts. The fall armyworm (FAW) survives year-round in the tropical areas of South and Central America, Mexico and in the subtropical environment of south Florida and Texas in the United States (Mitchell 1979 and 1986, Sparks 1979, Silvain and Ti-A-Hing 1985, Raulston et al. 1986, and Pair et al. 1986).

In the tropics, FAW populations tend to fluctuate with seasonal shifts in rainfall with the lowest populations recorded during the dry seasons. Unlike many insect species in the temperate regions, the FAW has no diapause mechanisms; thus, the FAW survives the winter in the southernmost areas where hosts are continually available and temperatures below 9.9° C are rare (Luginbill 1928). During spring

[1] Accepted for publication 24 September 1990.
[2] Faculte des Sciences et de Genie, Universite Laval, Quebec, Canada G1K 7P4.
[3] Insect Biology and Population Management Res. Lab., ARS USDA, P.O. Box 748, Tifton, GA 31793.
[4] INRA Station de Recherches de Lutte biologique, La Miniere, 78280, Guyancourt, France.
[5] Department of Entomology and Fisheries, Coastal Plain Exp. Sta., Tifton, GA 31793.
[6] Everglades Res. and Ed. Ctr., IFAS UF, Belle Glade, FL 33430.
[7] Tropical Agric. Res. Sta., ARS USDA, P.O. Box 70, Mayaguez, PR 00709.
[8] This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or the recommendation for its use by USDA.

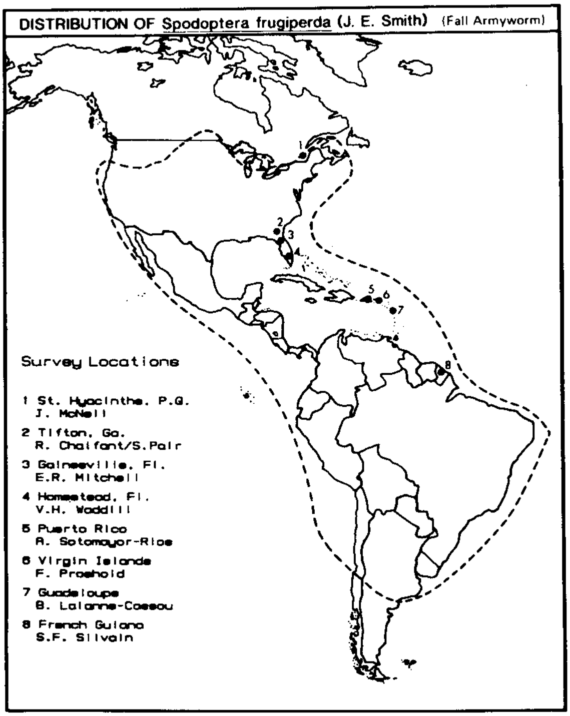


Fig. 1. Geographical distribution map of the fall armyworm (from Ashley 1986) showing the location of the adult population sampling sites and on-site cooperators.

and early summer, the FAW disperses northward into the eastern and central United States as well as into southeastern Canada (Mitchell 1979).

Prevailing winds during the spring are thought to largely determine the extent and direction of FAW adult movement. Luginbill (1928) recognized that the prevailing wind vectors in the southeastern United States consisted of south-southeasterly components during the spring months. More recently, Westbrook and Sparks (1986) compiled atmospheric data for the southern U.S., Mexico, Central America, and the Caribbean Islands for the period October 1976 - June 1977 in an attempt to explain the sudden and severe outbreak of FAW populations throughout the southeastern U.S. in 1977. Their analysis revealed atmospheric anomalies were significantly correlated with the population dynamics and dispersal of 1977 FAW populations. Retrogressive analysis of atmospheric trajectories targeted probable FAW overwintering regions — specifically southern Florida and possibly Cuba — which impacted the northerly advance of this pest into the southeastern U.S. in 1977. The present study was undertaken to determine the role of adult movement on FAW populations in overwintering areas and uninfested areas further north.

Materials and Methods

Adult sampling. Sex pheromone traps were used to monitor the seasonal periodicity of FAW at eight sites from French Guiana to Canada. Trapping commenced in April 1984 and ended in March 1986. International Pheromones Moth Traps (bucket traps; International Pheromone Systems, Merseyside, England) were baited with rubber septa containing the following blend of FAW sex pheromone (percentage by weight): (Z)-7-dodecen-1-ol acetate, 0.45%; (Z)-9-dodecen-1-ol acetate, 0.25%; (Z)-9-tetradecen-1-01 acetate, 81.61%; and (Z)-11-hexadecen-1-ol acetate, 17.69% (Mitchell et al. 1985). The baits were formulated by Terochem Laboratories, Ltd., Edmonton, Canada, and each contained 2 mg of the total blend.

Trapping sites are shown on the FAW distribution map (Figure 1). Three traps were located at each site in areas having suitable host plants, especially forage and other grass crops. Pheromone traps were operated throughout the year at all locations except Canada where they were deployed in late spring and removed in early winter. The traps were mounted ca. 1 m above ground level on metal poles. An inverted v-shaped, sheetmetal roof was mounted above each trap to protect it from rain and direct sunlight. Each trap contained a piece of Vapona® insecticide strip to kill captured moths. Traps at each site were positioned at least 1 km apart. The traps were checked and emptied on Tuesday and Friday of each week, and the pheromone baits and Vapona® strips were replaced biweekly.

Atmospheric Trajectories. Upper-air data for the stations in the southern U.S. and the Caribbean Basin during the study period were acquired from the National Climatic Data Center (NCDC). The data were available on a set of 9-track magnetic tapes as part of tape deck family TD-6201.

Upper-air soundings were recorded twice daily (0000 and 1200 UTC [Universal Coordinated Time]) as per international convention. The upper-air soundings quantified the vertical structure of temperature, humidity, wind velocity, and barometric pressure. Inter-station distances were typically 250 km. Generally, temporal changes in atmospheric variables decreased with altitude above the atmospheric boundary layer. The meteorological data (i.e., wind velocity) used in the analyses were restricted to the months of Dec. - Apr. for three consecutive years beginning in 1983.

Other noctuid moth species such as the corn earworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), have been observed flying at modal altitudes of about 500 m above ground level (AGL) (Wolf et al. 1986). A modal altitude of 500 m above sea level (MSL), which is nearly synonymous with 500 m AGL for the Florida Peninsula and the Caribben Basin, was used for calculating atmospheric trajectories representing FAW displacements.

Horizontal wind velocity components (i.e., westerly - easterly [zonal] and southerly - northerly [meridional]) were linearly interpolated at 500 m MSL from each vertical upper-air sounding. Wind velocity components were then statistically summarized for each station to note average and variability. Because wind velocity is a vector quantity (i.e., possessing magnitude and direction), it is necessary to analyze the (scalar) wind velocity components independently. Mean wind velocity components were added vectorially to produce a vector-mean wind velocity for each station.

It is important to note that a vector-mean is most meaningful when the directional variability of the wind remains relatively small (e.g., tradewinds). The vector-mean wind speed will always be less than or equal to the arithmetic mean wind speed. Missing data were common for many stations in the Caribbean Basin; no attempt was made to normalize the incomplete data records with respect to complete data records from adjacent stations.

Results

Results of the 1984 - 86 FAW pheromone trapping survey are summarized in Figure 2. In 1984, the trap capture data indicated a seasonal progression of peak moth captures from North Florida to Canada. At the time the study was initiated in April 1984, the trap catch data indicated that the FAW population in Homestead, FL (location 4), was low, a typical situation for spring and summer months (Pair et al. 1986).

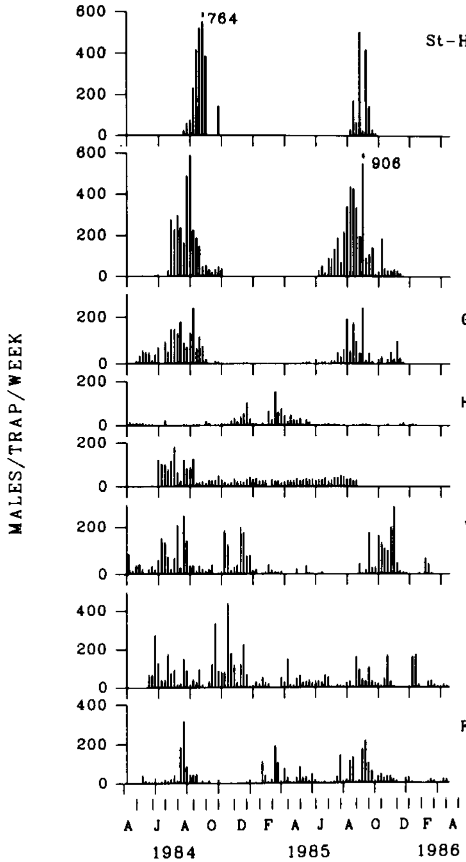


Fig. 2. Mean weekly captures of male fall armyworm moths in pheromone-baited bucket traps at selected survey sites in the Caribbean Basin, southeastern United States, and Canada (Apr. - Dec. 1984; Jan. - Dec. 1985; Jan. - Apr. 1986). Pheromone traps were not operated in Puerto Rico during week of February 17, 1985.

A substantial number of FAW adults was recorded at Gainesville, FL (location 3), during spring (April - May) 1984, but few FAW were captured at Tifton, GA (location 2), during the same time period. Large numbers of FAW were captured at Gainesville and Tifton during the ensuing summer months (July through mid-September). Captures of FAW moths at St. Hyacinthe, Canada (location 1) increased greatly during September 1984 correspondent with trap catches at Tifton and Gainesville (Figure 2).

During the winter of 1984 - 1985, the FAW population at Homestead, FL (location 4), followed the typical trend of discrete generations with increasing numbers of moth captures December through mid-March. Thereafter, the FAW moth population remained relatively low thoughout the late spring, summer and fall. However, the northward seasonal progression of FAW captures noted for Gainesville, Tifton, and St. Hyacinthe in 1984 was not evident in the 1985 trapping data.

There was no clear indication that FAW populations developing in areas of the Caribbean where survey traps were maintained contributed to the influx of FAW into north-central Florida, Georgia, and Canada in 1984 or 1985. For example, the 1984 trap catch data for Puerto Rico (location 5) and Gainesville, FL (location 3), suggested the presence of established FAW populations at both locations during April through October. Also, there were no sudden increases in FAW moth captures in traps at Homestead, FL (location 4), during this time period which might be attributed to an influx of migrant FAW moths from Puerto Rico or other survey sites in the Caribbean. However, survey traps were not located in Cuba, a potential source for migrant FAW moths entering the United States on favorable wind currents (Luginbill 1928, Westbrook and Sparks 1986).

Trap catch data in the tropical environments of Puerto Rico (location 5), the U.S. Virgin Islands (location 6), Guadeloupe (location 7), and French Guiana (location 8) indicate that the FAW survives year-round in these locations. The cyclic peaks in trap captures also indicate that Fall populations in the Caribbean region are controlled by seasonal shifts in rainfall with the highest catches occurring during the "rainy" or "wet" seasons, a characteristic of subtropical and tropical environments. Although inter-island movement probably does occur, the presence of resident populations could mask the sudden influx of moths that is so evident in areas where the FAW does not survive year-round, i.e., the temperate regions of the U.S. and Canada (Figure 2).

Vector-mean wind velocities (Figure 3) illustrate the circulation across the Caribbean basin and the southeastern U.S. One notes the persistently strong (6 - 12 m/s) easterly wind across the Caribbean Basin. However, the inter-annual wind velocity variability increased northward into the mid-latitude westerly wind regime. The inter-annual variability of vector-mean wind velocity was especially apparent at Key West, FL, where the winds were easterly at 4 m/s, easterly at 7 m/s, and northeasterly at 3 m/s for the winter of 1983-84, 1984-85, and 1985-86, respectively. One prominent difference between the vector-mean maps of 1983-84 and 1984-85 and that of 1985-86 is the pronounced lack of southerly (beneficial transport) wind across the southeastern U.S. in 1985-86.

Wind direction frequency plots (Figure 4) were documented along a line passing west-northwest from San Juan, Puerto Rico, through Santo Domingo, Dominican Republic, and Guantanamo Bay, Cuba, to Key West, FL. The purpose of this analysis was to clarify the significance of transport wind direction between

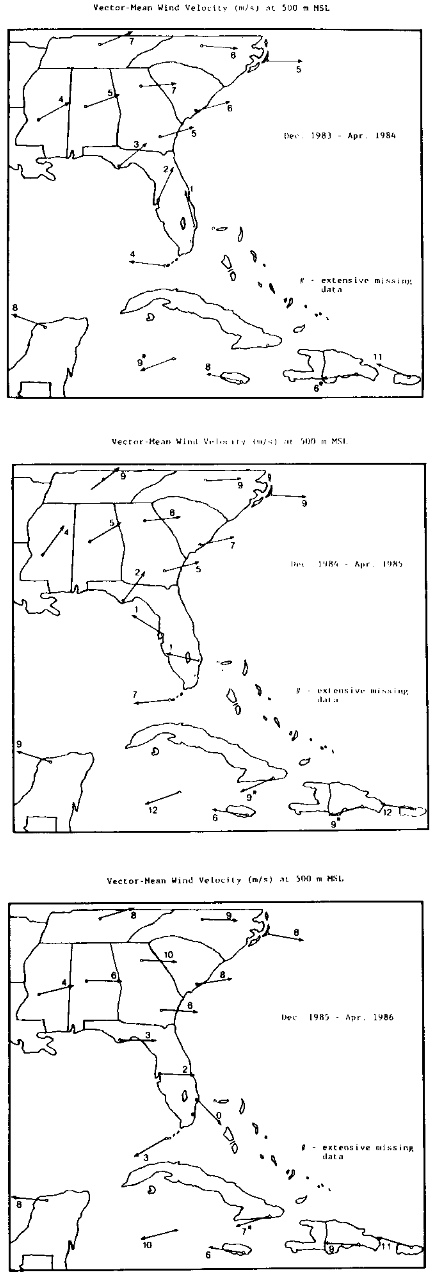
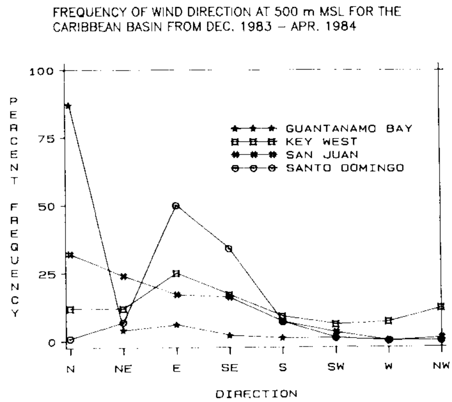
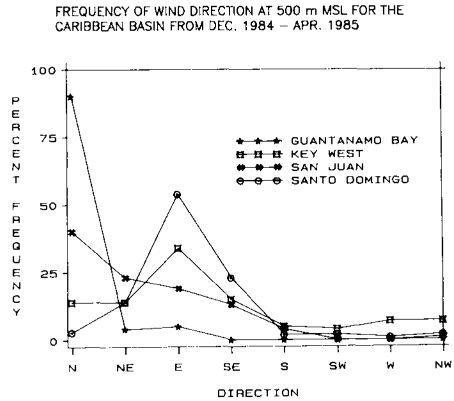


Fig. 3. Vector-mean wind velocity (m/s) for the southeastern U.S. and the Caribbean Basin (Top) Dec. 1983 - Apr. 1984, (Middle) Dec. 1984 - Apr. 1985, and (bottom) Dec. 1985 - Apr. 1986.





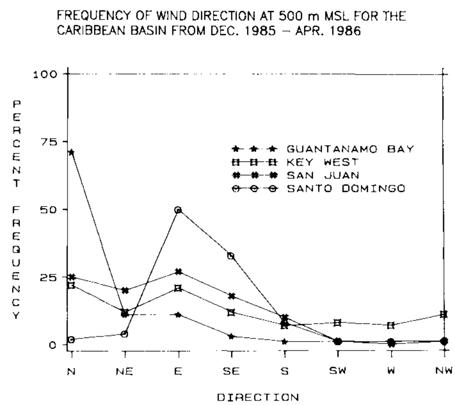


Fig. 4. Wind direction frequency (%) for the southeastern U.S. and the Caribbean Basin (Top) Dec. 1983 - Apr. 1984, (Middle) Dec. 1984 - Apr. 1985, and (bottom) Dec. 1985 - Apr. 1986.

documented perennial FAW habitats and the southeastern U.S. The modal wind direction frequency at Key West shifted from easterly (1983 - 84 and 1984 - 85) to northerly in 1985 - 86 (Figure 4). Otherwise no significant inter-annual differences appeared in the wind direction frequencies.

Close scrutiny of synoptic weather maps for October, 1984, revealed substantial atmospheric transport opportunities for northward and southward migration of FAW moths. Weekly trap captures at St. Hyacinthe, Canada (location 1), decreased from 386 moths during the week of September 30 to <2 moths per trap the weeks of October 7 and 14, 1984. The decreased trap capture corresponded with the northward movement of Hurricane Josephine along the North Atlantic coast of the U.S. from Oct. 12 - 14, 1984 (Figures 5 and 6). Strong northerly winds from Quebec southward along the Atlantic seaboard were forced several days prior, during, and after the hurricane passage and enhanced opportunities for return (southward) migration of FAW. Pair et al. (1987) described similar atmospheric transport observations and associated trap capture data to corrobrate the hypothesis of return migration of FAW from the Texas High Plains in September, 1984.

A smaller but definite late-season spike in trap captures of FAW at St. Hyacinthe occurred during the week of October 29, 1984. A deep low pressure system in the Hudson Bay, Canada, strongly forced warm air northward ahead of a cold front which briefly provided excellent northward atmospheric transport potential for fall armyworm migration into Quebec (Figures 7 and 8).

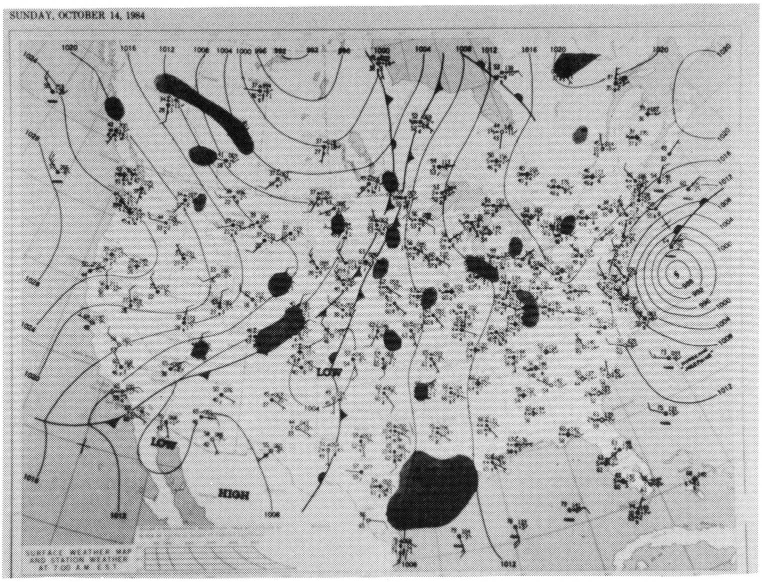


Fig. 5. Surface synoptic weather map of the U.S. for Oct. 14, 1984, valid at 7:00 EST (USDC-NOAA 1984).

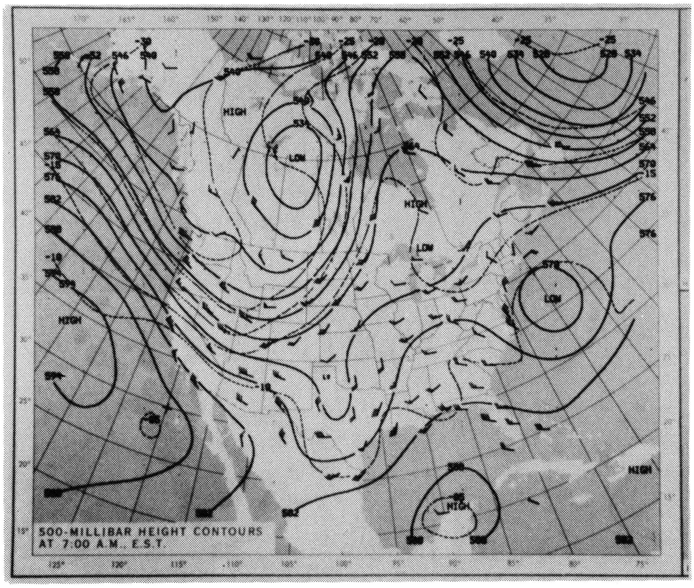


Fig. 6. Height contours, wind, and temperature at 500 mb of the U.S. for Oct. 14, 1984, valid at 7:00 EST (USDC-NOAA 1984).

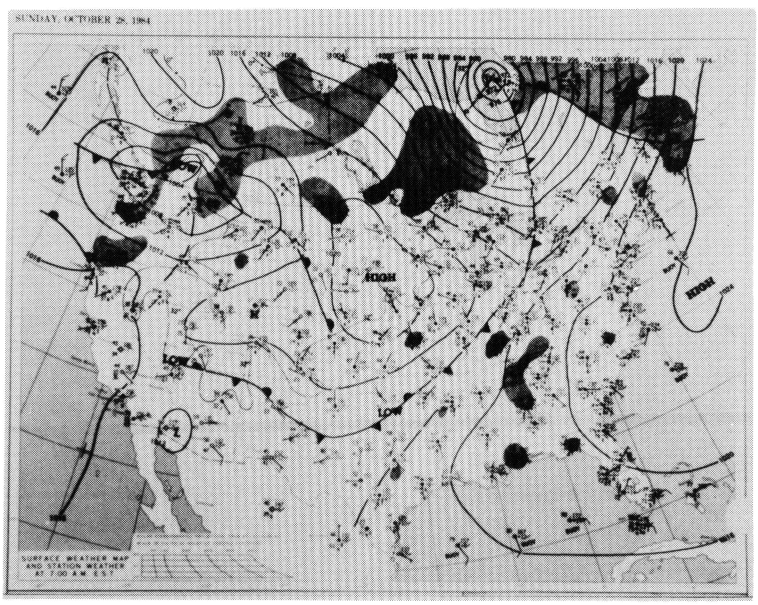


Fig. 7. Surface synoptic weather map of the U.S. for Oct. 28, 1984, valid at 7:00 EST (USDC-NOAA 1984).

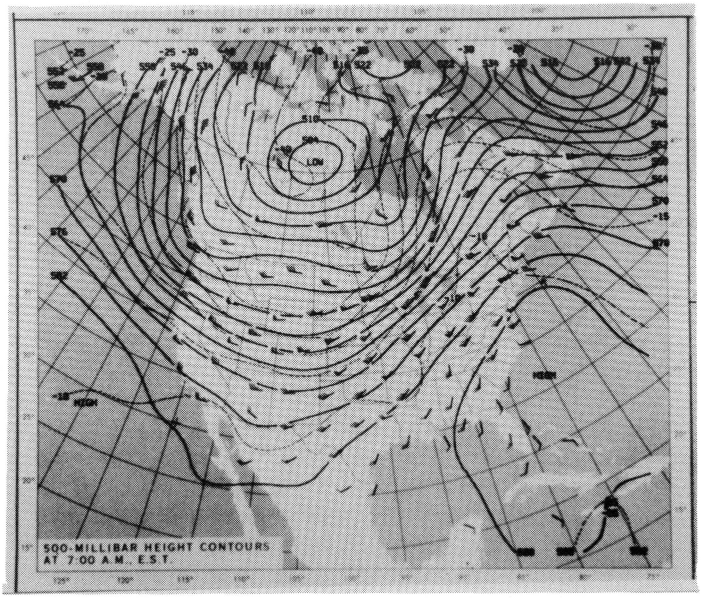


Fig. 8. Height contours, wind, and temperatures at 500 mb of the U.S. for Oct. 28, 1984, valid at 7:00 EST (USDC-NOAA 1984).

Discussion

Although the trapping data generated during the 2-year survey failed to establish any particular site as the "parental source" of FAW migrants entering uninfested areas of the U.S. and Canada, there appears to be no question that favorable wind currents are conducive to the spread of the FAW into and from these areas.

Meteorological analyses show that there are at least three distinct areas in terms of mean wind direction: continental North America with westerly or southwesterly winds; Antilles south of Cuba with easterly winds; and the Florida area with variable winds. Corresponding with these areas are three different types of seasonal phenology for FAW populations. Theoretically, movement of migrant moths can be oriented from the Lesser Antilles to Puerto Rico, Santo Domingo, Jamaica, and the Yucatan Peninsula on the south and from southwest U.S. (including northern Florida) to the northeast U.S. and Canada on the north. Movements to and from south Florida and the relative importance of beneficial atmospheric transport conditions from the south depends on the direction of winds in the Bahamas-south Florida-Cuba area.

The meteorological analyses presented here indicate a significant change in atmospheric circulation in the Bahamas-south Florida-Cuba area between the periods Dec. - Apr. for 1983-84 and 1984-85 and the period of Dec. - Apr., 1985-86. Atmospheric circulation provided less northward transport potential to enhance movement of migrating FAW moths in Dec. - Apr. 1985-86 than for the same periods in the preceding two years. However, isolated episodes of beneficial atmospheric transport conditions frequently are imbedded within the record of otherwise persistent non-beneficial (i.e., westerly or northerly) atmospheric transport conditions (Westbrook and Sparks 1986).

In this study, moth captures in pheromone traps plus analysis of wind currents provided circumstantial evidence of movement by FAW between the Antilles and the continental U.S. and between the U.S. and Canada. Nevertheless, pheromone trapping alone does not appear sufficient to detect migratory FAW moths. Future studies on the migration of FAW — and probably other migrant insect pests — would be enhanced greatly through use of multiple detection techniques including pheromone traps, light traps, mark and recapture, radar, and characterization studies such as flight capacities, and genetic analyses.

Acknowledgments

We gratefully acknowledge the support of the various governmental agencies who encouraged this cooperative effort and the many technical personnel who serviced the traps and recorded the data. A special thanks is extended to R. Hines for keying the records into a computer data bank, and to P. Therrien for preparing Figure 2. Part of the work was funded by an EXERC grant to J. N. McNeil.

References Cited

Ashley, T. R. 1986. Geographical distributions and parasitization levels for parasitoids of the fall armyworm, *Spodoptera frugiperdia.* Fla. Entomol. 69: 516-524.

Luginbill, P. 1928. The fall armyworm, USDA Tech. Bull. 34. 92 pp.

Mitchell, E. R. 1979. Migration by *Spodoptera exigua* and *S. frugiperda,* North American style. pp. 386-393. R. L. Rabb and G. G. Kennedy, (Eds). Movement of highly mobile insects: concepts and methology in research. NCSU, Raleigh, NC.

Mitchell, E. R. 1986. USDA Technical Bulletin No. 34 — The legacy of Philip Luginbill. Fla. Entomol. 69: 452-455.

Mitchell, E. R., J. H. Tumlinson, and J. N. McNeil. 1985. Field evaluation of commercial pheromone formulations and traps using a more effective sex pheromone blend for the fall armyworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 78: 1364-1369.

Pair, S. D., J. R. Raulston, D. R. Rummel, J. K. Westbrook, W. W. Wolf, A. N. Sparks, and M. F. Schuster. 1987. Development and production of corn earworm and fall armyworm in the Texas High Plains: Evidence for reverse fall migration. Southwest. Entomol. 12: 89-99.

Pair, S. D., J. R. Raulston, A. N. Sparks, J. K. Westbrook, and G. K. Douce. 1986. Fall armyworm distribution and population dynamics in the southeastern States. Fla. Entomol. 69: 468-487.

Raulston, J. R., and Coworkers. 1986. Fall armyworm distribution and population dynamics in the Texas-Mexico Gulf Coast area. Fla. Entomol. 69: 455-468.

Silvain, J. F., and J. Ti-A-Hing. 1985. Prediction of larval infestation in pasture grasses by *Spodoptera frugiperda* (Lepidoptera: Noctuidae) from estimates of adult abundance. Fla. Entomol. 68: 686-691.

Sparks, A. N. 1979. A review of the biology of the fall armyworm. Fla. Entomol. 62: 82-87.

USDC-NOAA. 1984. Daily weather maps, weekly series, Misc. issues.

Westbrook, J. K., and A. N. Sparks. 1986. The role of atmospheric transport in the economic fall armyworm (Lepidoptera: Noctuidae) infestations in the southeastern United States in 1977. Fla. Entomol. 69: 492-502.

Wolf, W. W., J. K. Westbrook, and A. N. Sparks. 1986. Relationship between radar entomological measurements and atmospheric structure in south Texas during March and April 1982. pp. 84-97. A. N. Sparks (Ed). Long-range migration of moths of agronomic importance to the United States and Canada: Specific examples of occurrence and synoptic weather patterns conducive to migration. USDA-ARS-43. 104 pp.