AGRO-ECOLOGICAL AND CLIMATOLOGICAL FACTORS POTENTIALLY INFLUENCING ARMYWORM[1] POPULATIONS AND THEIR MOVEMENT IN THE SOUTHEASTERN UNITED STATES

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ABSTRACT

Economic infestations of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), have rarely occurred in the Southeastern U.S. during the past several years. The author suggests that changes in agronomic practices (primarily the decreased corn acreages in source areas) interacting with interannual climatological variables are primary factors responsible for the decline. Precipitation appeared to be the primary factor influencing fall armyworm population levels at the overwintering site near Belle Glade, Florida. However, results of the study suggest that temperature and the availability of weather transport systems were the most important climatic factors governing fall armyworm abundance at Tifton, Georgia.

INTRODUCTION

Current knowledge of the biology, overwintering areas, host-relationships, mortality agents,and migratory behavior of fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), in the Southeastern U.S. is reviewed in detail elsewhere (Hinds and Dew 1915, Luginbill 1928, Sparks 1979, Ashley 1979, Barfield et al. 1980, Pair and Sparks 1986, Pair et al. 1986ab, Fuxa 1989). The most problematic areas of FAW bionomics are the largely unknown biotic and abiotic factors predisposing the rapid proliferation of FAW populations from low overwintering densities to outbreak proportions. Within-field or even field-to-field measurements in recipient areas outside overwintering habitats may offer little in predicting FAW occurrence over wide areas. The size and locations of primary source areas should be delineated when considering the impact of immigrants or when contemplating pest management programs due to the polyphagy and facultative migratory behavior of FAW (Barfield et al. 1980, Knipling 1980, Sparks 1986). Aside from the usual biological and climatological measurements, there are few documented studies which describe the potential impact of radical changes in agricultural practices, influenced by economics and/or weather, on FAW abundance.

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Primary source areas of FAW migrants are usually equated with overwintering areas. The northerly movement of FAW from relatively small overwintering areas of Southern Florida normally progresses at a rate of about 150 miles per generation (Luginbill 1928, Snow and Copeland 1969, Pair and Sparks 1986). Subsequently, by late-May and June, the large hectarage of corn in South Georgia and in adjacent states constitutes a relatively large nursery or "secondary" source area which may produce devastating numbers of FAW capable of invading crops throughout the Southeast and along the Atlantic Seaboard (Pair et al. 1986b). A similar situation exists in the Lower Rio Grande Valley of Texas and Mexico where a large hectarage of corn serves as a nursery crop for producing large numbers of FAW capable of migrating and infesting more northerly areas (Pair et al. 1991). Thus, the seasonal expansion of FAW populations depends upon "stepping stone" nurseries of preferred host plants such as corn, and the presence of favorable climatic conditions conducive to FAW development and northward transport.

Fall armyworm was a significant pest species in Georgia during the 1970's and caused 36.7, 16.7, and 137.3 million dollars of damage in 1975, 1976, and 1977, respectively (Suber and Todd 1980, Todd and Suber 1980). However, FAW have not been recognized as a pervasive pest in Georgia since the early 1980's except in localized areas or in late-season. Also, FAW was not listed as one of top ten economically important insect pests from 1980-1985 or as one of the top twenty from 1986-1990 in Georgia (Todd and Suber 1980, Suber and Todd 1980, 1981ab, 1982, 1984, 1985, Douce and Suber 1985, 1986, 1988, Douce and McPherson 1988, 1989, 1991). Similarly, Georgia crop losses to FAW have declined from an average of $8.0 million from 1980-1984 to $1.9 million during 1985-1989, a 76% reduction.

The impact of climatic variability on FAW populations in the southeastern U.S. has been established qualitatively (Luginbill 1928). From field surveys and general synoptic weather observations, a link was established between temperature, precipitation, and economic infestations of the fall armyworm. Early studies did not have access to upper-air wind measurements for determining even a qualitative relationship between synoptic-scale wind patterns and the timing and regional pattern of FAW infestations. Westbrook and Sparks (1986) documented a preponderance of long-distance atmospheric trajectories from southern Florida to southern Georgia in February through April, 1977 that led to severe FAW infestations in Georgia.

The relative lack of FAW infestations in corn during the late 1980's may have been due to a variety of factors. These include shifts in agricultural practices and variable climatic patterns which have occurred over the last decade in suspected overwintering areas and in potential stepping-stone nurseries. We strived to examine some of the primary factors that may potentially influence early-summer FAW populations in the Southeast. Information and data reported here are derived from field surveys, FAW trapping data, climatic data, personal observations, and from discussions with numerous individuals representing producers, consultants, state/federal researchers, and extension service personnel. The thrust of these efforts was to determine quantitative relationships between selected factors and adult male FAW populations in the southeastern U.S.

FALL ARMYWORM POPULATION TRENDS

The incidence and levels of FAW larval and adult populations in several southeastern states from 1981-1985 are reported elsewhere (Pair and Sparks 1986, Pair et al. 1986a). These studies indicate that although outbreaks did not occur, moderate levels of FAW larval infestations were present in northwestern Florida and southern Georgia by late May to early June annually. Catches of FAW in pheromone traps using Z-9-DDA (Mitchell 1979) as a bait and larval surveys in corn indicated the presence of large late-summer FAW populations in Georgia.

Since 1985, we have monitored FAW infestations in ten commercial corn fields in Tift Co., Georgia. Each field was sampled weekly by examining 50 corn plants selected at random and counting the number of FAW infested plants. These studies suggest that peak infestations of FAW in both whorl and ear-stage corn were very low in number during 1985-1990 (Table 1). In two of the five years, FAW were not detected in any of the ten fields sampled, and average ear-stage infestation levels did not exceed 3.0% in any year. Persistent but very low FAW infestations were present throughout much of the 1989 season. An extremely mild winter apparently allowed early establishment of FAW populations; however, abnormally high rainfall (234 mm) and relatively cool temperatures during June may have favored the proliferation of mortality agents which suppressed damaging FAW populations.

TABLE 1. Peak Fall Armyworm Infestation Dates of Corn in Tift County, Georgia.

	Whorl		Ear	
Year	Week	% Infestation	Week	% Infestation
1985	5/16	0.9	6/14	2.5
1986	5/21	1.5	6/24	0.4
1987	--	0.0	6/21	1.0
1988	--	0.0	7/10	1.0
1989	4/30	0.8	7/16	3.0
1990	5/20	0.3	6/24	1.7

The Unitrap or IP trap baited with a 4-component pheromone has proven an effective technique for monitoring adult FAW populations (Mitchell et al. 1985, Pair et al. 1989). Since 1984, four IP pheromone traps, baited with Terochem® lures, per location were monitored continuously at Belle Glade, Florida and Tift County, Georgia. Belle Glade (Palm Beach County) is located within the area of FAW overwintering, while Tifton (ca. 580 km north) may be considered as a recipient of annual FAW immigrant populations. Trapping data for each location were summarized by calculating the average monthly capture/trap from January-July (Belle Glade) and from April-August (Tifton) for the years 1984-1990 (Table 2). Data from Belle Glade are for months having the highest probability of contributing to FAW

TABLE 2. Average Monthly Pheromone Trap Captures of Fall Armyworm Males at Belle Glade, Florida and Tifton, Georgia, 1984-1989[a].

Loc[b]	Year	Jan	Feb	March	April	May	June	July	Aug	Total
BG	1984	3,665	3,055	1,455	1,880	2,130	3,570	815		16,570
Tift					-	6	82	1,289	2,328	3,705
BG	1985	1,217	2,477	3,263	2,468	2,705	788	242		13,160
Tift					4	4	120	560	1,442	2,130
BG	1986	456	754	264	1,537	845	1,449	1,289		6,594
Tift					0	7	16	81	312	416
BG	1987	430	358	363	597	799	941	440		3,928
Tift					<1	5	7	74	42	128
BG	1988	916	303	2,541	1,082	1,004	752	414		7,012
Tift					1	14	19	99	739	872
BG	1989	2,120	1,520	3,023	888	484	848	497		9,380
Tift					0	3	10	28	72	118
BG	1990	743	349	1,561	742	277	521	167		4,360
Tift					1	4	39	426	1,026	1,496

[a]All trap capture data were from IP traps baited with Terochem except at Belle Glade, FL, 1984 when 75-50 Hartstack traps baited with 25 mg of Z-9-DDA were used; captures at this location were multiplied by a factor of five to approximate actual capture rates of IP traps baited with Terochem.
[b]BG = Belle Glade, Florida and Tift = Tift County, Georgia.

populations in more northerly areas. At Tifton, data are shown which encompass the periods most likely to receive FAW migrants from either overwintering areas or from "stepping-stone" nurseries in northern Florida. These data reveal a relationship between the number of FAW males captured at Belle Glade and populations subsequently observed at Tifton in most years. The highest total catches were recorded at Belle Glade and Tifton in 1984-1985, but the magnitude of trap catches at Belle Glade during January-May do not appear to greatly influence the number of FAW males captured at Tifton during April or May of any particular year. In fact, there was little interannual variation in the number of FAW at Tifton during the months of April and May. During the summer, the only readily apparent effect of trends at Belle Glade upon populations at Tifton was in 1984. Monthly captures of FAW at Belle Glade averaged 3,570 during June and fell to 815 in July. Consequently, captures of FAW at Tifton in June averaged 82 and increased 15.7-fold to 1,289 during July.

Fall armyworm populations were lowest in 1987, a season characterized by cooler than average temperatures and higher rainfall. In terms of total captures at Belle Glade during January-February, the third highest population recorded during the study was in 1989. However, populations failed to proliferate at Tifton, possibly due either to the abnormally high rainfall at Tifton during June (234 mm) or to the lack of favorable weather transport systems. Fall armyworm numbers at Tifton during 1990 paralleled those observed in 1985, yet the populations at Belle Glade were the second lowest of the study. Furthermore, the damage caused by FAW on crops in Georgia during 1990 ($4.7 million) was also similar to the estimated damages in 1985 ($4.3 million). Damage to crops in Georgia during 1985 was due to late season infestations in hay pastures ($2.9 million) and in peanuts ($1.7 million). Fall armyworm trapping data and the lack of infestations (1.7 %) in corn at Tifton suggest that these populations were not of local origin. Since populations in 1985 were extremely low in Belle Glade, the source population for these moderately heavy infestations may have arrived from late-planted corn in north Florida.

The potential contribution of migrant FAW from South Florida to Georgia during July-August is unknown, but corn is not generally grown during these months due to high temperatures and lack of moisture. Corn generally matures by mid-July at Tifton, and FAW population increases during July and August would likely result from the local development and emergence of FAW. In addition, the highest probability of favorable weather systems that could transport FAW from southern Florida northward occurs during March-April and decreases significantly by June (Westbrook and Sparks 1986).

CORN HECTARAGE

Just as FAW populations are dynamic, so are host-habitats in constant flux within a single growing season and from year to year. The amount of available host-habitat, either in overwintering areas of southern Florida or in "stepping-stone nursery" areas in northern Florida and in southern Georgia, may have influenced the apparent decline in FAW populations observed at Tifton, GA from 1984 to 1990. Because of economic factors and shifts in land use to other crops, hectarages of corn planted in Georgia and Florida have decreased significantly from 1977 to 1990 (Fig. 1).

Hectarages of corn have declined 83% in Florida from 252,000 ha in 1977 to only 42,000 ha in 1990 (Anon. 1990). During the same period, corn hectarages declined 73% in Georgia, from 907,000 ha to 243,000 ha (Todd and Suber 1980; Douce and McPherson, 1992). In the years from 1984 to 1989, the amounts of corn in Florida and Georgia have dropped by 58 and 45%, respectively. The regions of Florida most affected were the northern counties of central Florida in District 30 and those lying within the panhandle (District 10) (Fig. 2). Collectively, 75% of the corn grown in Florida is grown in these two districts. In northern Florida, corn hectarage in District 10 and 30 has declined by 77 and 89%, respectively, from 1977 to 1990. Typically, most of the corn grown in these areas is unirrigated and intended for grain or livestock production. Over the past decade, however, lowered market prices,coupled with recurring droughts, have resulted in fewer hectares devoted for corn production in northern Florida and in adjacent states. The decline in corn hectarage in Georgia has followed a pattern similar to that observed in Florida. The major corn growing areas in Georgia are Districts 7 and 8 (55% of the state total) which are located in southeastern and south

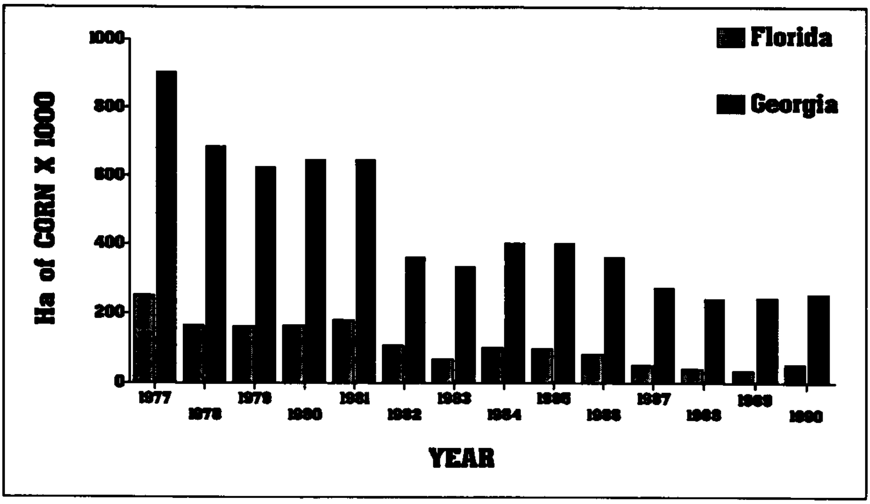

FIG. 1. Corn hectarage planted in Florida and Georgia, 1977-1980.

central portions of the state and lay adjacent to the principal corn-growing areas located in north Florida (Fig. 2). In fact, 70% of the corn grown in Georgia is produced in Districts 6-9. Indeed, when Florida Districts 10 and 30 are combined with the adjacent Georgia Districts 7-9, a total of 1.1 million ha of corn were available for an invasion of FAW during the summer of 1977. With favorable conditions for FAW development and a large nursery crop, it is understandable that a devastating FAW outbreak occurred throughout much of the eastern United States during the late summer and fall of 1977.

Much of the corn production in south Florida is devoted to sweet corn grown for fresh market. According to the Florida Livestock & Crop Reports (Anon. 1986, 1990), there are 23,000 ha of sweet corn grown annually in District 80 (Fig.2) of south Florida. Although stringent efforts are made to protect the ears from insect damage, light-to-moderate whorl-stage infestations not exceeding ca. 20% are usually tolerated. However, many producers now consider whorl-stage corn as a likely nursery for producing FAW that subsequently attack the ear-stage and are quick to spray insecticides. Only 10% damage to ears is permitted by USDA grading standards; however, most growers treat when ear damage exceeds 2% (Foster 1989). Often, severe FAW pressure necessitates applications of insecticides such as methomyl or thiodicarb on a scheduled basis in order to achieve such quality standards. As a result, the potential of ear-stage sweet corn as a primary nursery crop for FAW populations is not considered as likely as that of corn grown for either seed production or as livestock feed.

Corn grown for purposes other than sweet corn in District 80 averaged 10,500 hectares from 1977-1986. In 1987 and 1988, corn hectarage decreased to 5,600 and 3,600, respectively. There are varying hectarages of corn grown for silage intended for local livestock production in South Florida. Beginning in about 1984, silage producers began to apply carbofuran at planting (usually mid-March) to protect seedling corn from FAW damage. Thereafter, control measures are not undertaken except when infestations threaten to devour sizable portions of the crop. Consequently, under favorable conditions silage corn could potentially serve as a relatively small, yet important source crop for FAW.

Corn grown on a contract basis for seed production in District 80 varies from year-to-year depending primarily upon demand. Information from commercial seed companies indicate that, prior to 1984, there were at least 4,000 ha of seed corn grown each season in Dade County. The highest amounts planted were the 1976-1977 and 1983-1984 seasons. Interestingly, both of the ensuing summers were characterized by either massive outbreaks or higher than normal FAW populations. Since about 1984, rising production costs in the south Florida area due to land rental fees and insect control costs have prompted a shift in most of the seed corn production to either more northerly counties or to other states. However, when midwest plantings of seed corn fall short of production, the hectarage grown in south Florida may rise dramatically in order to fulfill expected seed demands. For example, according to Florida Extension Service estimates, a total of about 12,100 ha of seed corn was grown in Dade and Palm Beach Counties, Florida during the winter of 1988-1989 due to a severe drought in the Corn Belt in the summer of 1988. In the winters of 1987-1988 and 1989-1990, a total of 320 and 820 ha, respectively, of seed corn was grown in these south Florida counties.

Corn grown for seed in south Florida generally receives fewer applications of insecticide than does sweet corn unless extremely heavy FAW pressure exists. However, as the ears mature and control measures are terminated, the author has

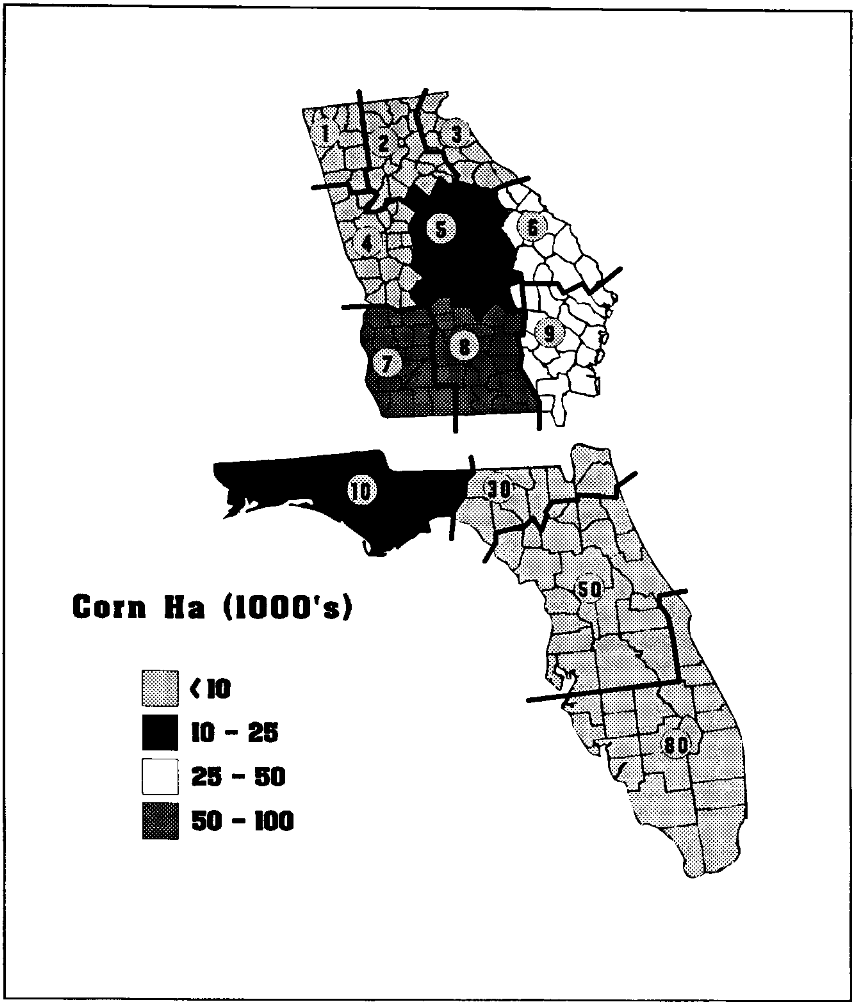

FIG. 2. Corn hectarage planted by reporting district in Georgia and Florida in 1988.

commonly observed FAW larval populations, at times in high densities, developing in these fields.

Volunteer corn, resulting primarily from harvest waste in seed corn occasionally from abandoned sweet corn fields, also serves as an important host of FAW in south Florida (Knipling 1980, Pair et al. 1986b, Pair and Sparks 1986). The amount of volunteer corn available for FAW development depends upon several factors including percentage harvest waste, planting dates, rainfall, agronomic practices, and the hectarage of seed corn originally planted. Prior to 1984, sizeable amounts of volunteer corn could be observed in the Homestead, Flordia vicinity from February through May. Pair and Sparks (1986) reported a 50-ha volunteer corn field at Homestead that contained about 88,000 plants per ha and was 100% infested by FAW larvae. Also, FAW populations arising from volunteer corn in southern Florida were produced at an opportune time for movement into more northerly areas of Florida and southern Georgia where sizeable hectarages of corn were available. Thus, volunteer corn was believed to be a primary overwintering and nursery host plant of FAW in southern Florida, which contributed significantly to the development of migratory FAW capable of invading young corn in northern Florida and adjacent states during the spring.

Pair et al.(1986b) reported that prior to 1984, seed corn was planted at varying times in the fall and winter, but usually matured in January-February. However, freezing temperatures during January 1981 and in subsequent years severely damaged corn. Consequently, growers began planting no later than late August so that corn matured in December, thus avoiding freeze damage. During the early 1980's, harvest techniques also changed; before 1984 most seed corn was harvested with snap-roll machines which left about 10% wasted seed in fields. Thereafter, producers began using a stripper-bar machine that leaves < 0.5% seed in the field. Shifted planting dates and improved harvest technology have resulted in earlier germination of seeds and a 20-fold decrease in the amount of seed left in the field. Indeed, where once numerous volunteer fields could be readily located in the Homestead vicinity, such fields are now difficult to locate and usually contain only very sparse stands of volunteer corn. There has also been a change in grower attitudes and agronomic practices. In the authors' opinion, over the last several years most growers now recognize the potential importance of volunteer corn as a FAW nursery crop and do not allow stands to persist. Another factor potentially influencing the general absence of volunteer corn in south Florida may be increased demand for tillable land because most land in the area is leased. In the early 1980's volunteer corn was generally allowed to grow unimpeded until weeds overgrew the fields. Demand for land in the Homestead area now mandates a rapid destruction of harvest residues in preparation for the production of high cash value vegetable crops such as tomatoes and pole beans.

Other host habitats exist within the overwintering range of the FAW. In the vegetable growing region surrounding much of Lake Okeechobee in southern Florida, growers may fallow fields for short periods of time following the harvest of vegetables. After removal of the crop, fields generally contain ample residual nitrogen, and consequently these fields generally produce a lush growth of crabgrass, *Digitaria sanguinalis* (L.), and goosegrass, *Eleusine indica* (L.). Both grass species are highly favored hosts of FAW, especially when well-fertilized. Occasionally, volunteer corn occurs in the area.

Another potential FAW nursery stems from the fairly common practice of using broadcast plantings of sorghum as a rotational crop with vegetables. At Belle Glade on 11 May 1988, we examined a 200-ha field of whorl-stage sorghum, about 0.8 m in height, which was 64% infested by mostly medium and large FAW larvae. Plant density counts indicated that 100 sorghum plants/m^2 (1 million/ha) or 200 million plants were present within the field. Of 60 larvae collected from the field, only 18.3% were parasitized. If, hypothetically, a total of 50% total mortality occurred as the larvae developed, this field could have potentially produced 64 million adult FAW. These FAW adults could, in the presence of favorable weather transport systems, migrate and attack susceptible crops in more northerly areas during May and June.

A more recent and potentially more serious development is a growing impetus for North Florida producers to plant tropical dent corn, usually around 1 June, following the harvest of wheat. Unfortunately, this practice provides an ideal summer nursery (in contrast to the usual spring nursery) for the production of FAW. Corn grown for silage in late season tends to harbor heavy larval infestations of FAW which produces large numbers of adult FAW capable of impacting other crops. In our opinion, such practices should not be encouraged because of their implication as a potential determinant of areawide FAW population dynamics.

CLIMATE

Monthly climate data and trap capture data were analyzed from Belle Glade, located within the overwintering range of FAW, and from Tifton, located north of the overwintering range. The climatic factors included monthly average air temperature (T), monthly total precipitation (P), and monthly atmospheric transport potential index (TPI). TPI is a frequency-weighted average southerly wind velocity component (Wolf et al. 1986). The value of TPI in this paper is actually an average of TPI values from Appalachicola, Tampa Bay, and Palm Beach, Florida, and Waycross, Georgia which encompass the Florida peninsula.

Monthly climatic and trap capture anomaly values were calculated. Precipitation and temperature anomalies (PD and TD, respectively) were calculated as departures from the respective 30-year (1951-1980) normal monthly values. Monthly TPI and fall armyworm trap capture anomalies (TPID and FAWD, respectively) were calculated as departures from the 1984-1990 monthly means. One-month lagged values of FAWD, TD, PD, and TPID (LFAWD, LTD, LPD, and LTPID, respectively) were calculated for all months except for the month of January at Belle Glade because December data were unavailable. The three climatic variables and the four lagged variables were included in stepwise linear regressions of the dependent variable FAWD using PROC REG (SAS Institute Inc. 1988).

Monthly values (mean and standard deviation) of the number of captured adult male FAW and the climatic factors are shown in Table 3 for Belle Glade and Tifton. There were trap capture peaks of FAW at Belle Glade in March (1,781) and June (1,267) with significant annual variability (SD of 1210 and 1054, respectively). The FAW peak at Tifton occurred in August (852) or later with extreme annual variability (SD = 829). Air temperature at both locations showed a minimum in January and maximum in July although the minimum at Belle Glade was 5.5°C greater than at Tifton. Precipitation showed diverse patterns at Tifton and Belle Glade; the maximum of 169 mm at Belle Glade occurred in July and 137 mm fell at Tifton in February. The atmospheric transport potential index peaked at 5.97 m/s in March and was a minimum 3.79 m/s in August.

The regression of climatic factors on the number of captured adult male fall armyworms revealed dramatic changes in the importance of climatic factors and the previous month's number of captured adult male fall armyworms. The correlation values by month at Belle Glade are shown in Table 4. PD explained 45%, 78%, 75% and 56% of the variability of FAWD in January, February, March and April, respectively; LPD explained an additional 22% of the FAWD variability in March. PD explained none of the FAWD variability in May or June and only 13% in July; LPD explained 41% of the FAWD variability in June. TD had a minor impact on FAWD except for its explanation of 38% of the FAWD variability in July. TPID and LTPID explained no more than 33% (July) of the FAWD variability. LFAWD explained 3%, 0%, 14%, 84%, 15% and 13% of the FAWD variability in February through July, respectively.

Regression statistics for the linear regression of climatic factors with the number of captured male adult fall armyworms at Tifton by month are shown in Table 5. The combination of TD and LTD explained 42% and 30% of the FAWD variation in April and May, respectively, but no more than 2%

TABLE 3. Mean and Standard Deviation of Total Fall Armyworm Trap Captures, Average Air Temperature, Total Precipitation, and Transport Potential at Belle Glade, Florida and Tifton, Georgia for 1984-1990.

		No. FAW/ trap		Air temp		Rainfall (cm)		Transport Potential Index (m/s)	
Loc.	Month	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Belle Glade	Jan.	1,364	1,167	17.4	2.18	4.42	3.25	4.49	1.03
	Feb.	1,259	1,124	18.7	1.26	3.86	2.72	5.81	1.39
	Mar.	1,781	1,210	20.3	0.90	7.77	5.16	5.97	1.12
	Apr.	1,313	680	21.0	1.37	7.24	6.35	4.11	1.85
	May	1,178	896	24.1	0.53	9.60	6.77	4.34	1.24
	Jun.	1,267	1,054	26.2	0.78	13.51	5.28	4.06	1.77
	Jul.	552	385	27.0	0.25	16.69	4.72	4.13	0.85
Tifton	Feb.	0	0	11.9	1.83	13.74	9.02	5.81	1.39
	Mar.	0	0	15.3	1.05	12.19	5.74	5.97	1.12
	Apr.	1	1	18.4	0.83	6.43	6.63	4.11	1.85
	May	6	4	22.9	0.61	8.48	3.96	4.34	1.24
	Jun.	42	43	26.4	0.72	9.73	6.45	4.06	1.77
	Jul.	365	456	27.5	1.05	9.12	3.86	4.13	0.85
	Aug.	852	829	27.4	0.89	11.07	4.37	3.79	1.22

TABLE 4. Correlation and Linear Regression Coefficients for Current One-month Lagged Departure of Precipitation (PD and LPD), Air Temperature (TD and LTD), Atmospheric Transport Potential (TPID and LTPID) and One-Month Lagged Departure of Fall Armyworm Trap Capture Regressed with the Current Departure of Fall Armyworm Trap Capture (FAWD) at Belle Glade, Florida for 1984 Through 1990.

Month	df	Int	Partial r^{2} [a]							Total r^2	F value
			LFAWD	PD	LPD	TD	LTD	TPID	LTPID		
Jan	3,3			0.45		0.24		0.20		0.89	8.09
		-97.6		-758.00		-93.80		218.50			
Feb	5,1		0.03	0.78	0.00	0.01	0.00	0.00	0.18	1.00	∞^{c}
		-354.4	-0.50	-489.50		-48.50			518.60		
Mar	5,1		0.00	0.75	0.22	0.00	0.00	0.00	0.03	1.00	∞^{c}
		-279.6	-0.10	-437.00	-559.10			-96.50	209.60		
Apr	5,1		0.14	0.56	0.00	0.05	0.14	0.04	0.00	0.94	15.67[c]
		597.4	-0.50	540.60		110.80	-352.60	-145.70			
May	5,1		0.84	0.00	0.03	0.03	0.10	0.00	0.00	1.00	∞^{c}
		-1.2	0.60		295.80	-274.40	-123.70		-14.60		
Jun	5,1		0.15	0.00	0.41	0.00	0.23	0.10	0.06	0.96	24.00[c]
		224.2	1.00		-47.60		-778.30	303.50	1063.90		
Jul	5,1		0.13	0.13	0.00	0.38	0.00	0.28	0.05	0.98	49.00[c]
		1171.6	1.10	1003.80		352.90		-790.20	1039.00		

[a]No lagged values were available for January.
[b]For each month, the first and second lines, respectively, list correlation and regression coefficients.
[c]Value significant at $P < 0.05$.

TABLE 5. Correlation and Linear Regression Coefficients for Current and One-Month Lagged Departure of Precipitation (PD and LPD), Air Temperature (TD and LTD), Atmospheric Transport Potential (TPID and LTPID) and One-Month Lagged Departure of Fall Armyworm Trap Capture Regressed with the Current Departure of Fall Armyworm Trap Capture (FAWD) at Tifton, Georgia for 1984 through 1990.

Month	df	Int	Partial r^{2} [a]							Total	F
			LFAWD	PD	LPD	TD	LTD	TPID	LTPID	r^2	value
Apr	5,1		0.00	0.03	0.19	0.24	0.18	0.07	0.00	0.71	2.45
		2.2		0.50	1.50	1.80	1.40	-1.20			
May	5,1		0.09	0.00	0.40	0.27	0.03	0.00	0.14	0.92	11.50[b]
		-8.7	-0.60		-7.10	3.00	-0.60		11.90		
Jun	5,1		0.07	0.12	0.27	0.00	0.00	0.31	0.21	0.98	24.00[b]
		43.6	-3.90	45.30	68.50			-94.40	-30.90		
Jul	5,1		0.00	0.02	0.18	0.00	0.02	0.76	0.01	0.99	99.00[b]
		365.5		265.40	-214.70		174.50	92.80	141.50		
Aug	5,1		0.92		0.00	0.01	0.00	0.04	0.03	1.00	∞[b]
				0.01							
		-107.9	0.50	107.50		339.00		242.00	1023.90		

[a]For each month the first and second lines, respectively, list correlation and regression coefficients.
[b]Value significant at $P < 0.05$.

in June, July and August. PD and LPD combined to explain 22%, 40%, 39%, 20% and 1% of the FAWD variation in April through August,respectively. TPID and LTPID combined to explain 7%, 14%, 52%, 77% and 7% of the FAWD variability in April through August, respectively. LFAWD explained 0%, 9%, 7%, 0% and 92% of the FAWD variability in April through August, respectively.

DISCUSSION

The circumstantial evidence provided here suggests that major shifts in corn hectarage and production practices in FAW overwintering and in "stepping stone" nurseries (*e.g.*, northern Florida) and influences by climate are largely responsible for the observed reduction in FAW populations and subsequent crop damage from 1985-1990. Shifts in hectarage or changes in production practices have been identified as primary factors influencing populations of other pest species as well. Leser (1981) suggested that the shift toward planting large hectarages of corn during the late 1970's and decline of grain sorghum were directly correlated with increased bollworm, *Helicoverpa zea* (Boddie), damage and control costs in cotton on the Texas High Plains, a region that previously had rarely experienced bollworm problems (Rummel et al. 1986). Currently, the large hectarage of corn planted on the Texas High Plains is capable of developing large populations of corn earworm in late summer (Pair et al. 1987). The decline of cabbage looper, *Trichoplusia ni* (Hubner), populations during early spring at Hastings, Florida was attributed to a shift in farmer attitudes whereby cabbage residue was removed within two weeks following harvest (Tingle and Mitchell 1977). Previously, cabbage was allowed to stay in the fields for long periods, thus allowing high cabbage looper populations to develop.

Kennedy and Margolies (1985) defined a nursery crop as one which subsequently increased the pest potential on one or more crops. They also cited the work of Stern (1969) that described the relationship of alfalfa and safflower with the production of enormous *Lygus hesperus* Knight populations as well as their own studies of *Tetranchynus urticae* Koch and corn as examples of nursery crops which exacerbated pest insect populations. In this case, the large hectarage of corn planted prior to 1984 in northern Florida and southwestern Georgia served as a large nursery crop for the development of substantial FAW populations in late spring and early summer. As the season progressed, these populations were capable of attacking in large numbers the corn crops at more northern locations and along the Atlantic Seaboard. We feel that our study constitutes the first reported instance where annual populations of a long-distance migrant were suppressed due to the virtual removal of a primary nursery crop. Also, our data provide strong circumstantial evidence that the loss of FAW habitat resulted in decreased losses to FAW on corn and other crops. Of course, the effects of decreased habitat are governed or overridden by climatic events.

The small number of degrees of freedom limited the statistical significance of the correlations between climatic variables and the number of adult male fall armyworms at Belle Glade (Table 4) and Tifton (Table 5). However, the magnitude and timing of the highest correlation support the hypothesis of spring migration of fall armyworms from southern Florida to Tifton.

The combination of PD and LPD most strongly influenced FAWD at Belle Glade from January through April, and in June. LFAWD explained most of the variability of FAWD in May. TD was the single highest factor in explaining the variability of FAWD in July, although it explained less than 40% of the variability of FAWD. The relative importance of these climatic factors and the previous month's FAWD seem to support the hypothesis that FAW overwintered at Belle Glade in 1984 through 1990.

The combination of TD and LTD most strongly influenced FAWD in April at Tifton. In May, LPD most strongly affected FAWD. The likelihood of migration was supported by TPID and LTPID in June and July, which explained 52% and 77% of the FAWD variation, respectively. In August, 92% of the FAWD variation was explained by LFAWD and only 7% by the combination of TPID and LTPID. Apparently moth immigration predominated at Tifton in June and July, but the local population contributed more than immigrants to the August population. These results further suggest that the number of FAW captured early during April and May contributes little to subsequent populations in later months.

Additional analyses of climatic influences on fall armyworm populations should include higher-frequency (daily or weekly) observations to better define population development patterns and significant weather events. Summaries of monthly values such as those presented in this paper may mask important atmospheric features such as extremely low minimum temperature, inundative rainfall, and strong transport wind speed. Ideally, the same normal period should be applied for all variables. More importantly, additional efforts and personnel are required to delineate and monitor seasonal FAW populations as they develop and disperse throughout the southeastern U. S.

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