COTTON DEVELOPMENT AND YIELD AS
AFFECTED BY INSECTICIDES

by

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CHAPTER I

INTRODUCTION

In the past several years, the use of insecticides has intensified in the production of cotton on the Texas High Plains. Although insecticide usage is essential for the control of various pests, there is a high probability that there are secondary direct effects upon growth, development, and subsequent yield of chemically-treated plants. Every chemical used to control an undesirable biological organism has a mechanism of action which is based upon its effect on certain enzymatic processes of that organism. Therefore, it is logical to assume that the chemicals may have similar physiological effects on other biological organisms, especially plants, since they are repeatedly in close contact with the insecticide.

If indeed there are differences in development and yield between plants treated with various insecticides, then these differences must be attributed to either a direct physiological effect upon the plant or an effect due to the differences in control of detrimental and/or beneficial insects.

Considering the increasing cost of producing agricultural commodities, there is a need to research all areas in which

expenditures are made and to optimize the cost/benefit ratio in each area. Although the chemical control of insects is relatively inexpensive in comparison to the probable losses incurred by insect damage, there may be added advantages or disadvantages in the use of these insecticides. An understanding of these phenomena could be of great benefit to both the chemical industry as well as the farmer.

CHAPTER II

LITERATURE REVIEW

There are numerous chemicals used to control detrimental insects found on various crop species. Although these insecticides are rather specific, they may have an effect upon growth and development of treated plants. There are variations in the chemical's effects upon plants between the various "classes" of chemicals (chlorinated hydrocarbons, organophosphates, carbamates, and synthetic pyrethroids) used for insect pest control (7). In addition, the number of applications of a chemical may alter the compound's effect upon the plant (8).

The chlorinated hydrocarbons are insecticides that contain chlorine, carbon, and hydrogen. The specifics of the mode of action are not known, but it is sufficient to say that chlorinated hydrocarbons, in some complex manner, destroy the delicate balance of sodium and potassium within the neuron and prevent it from normal impulse conduction (31).

In early studies, various chlorinated hydrocarbons (usually DDT and toxaphene) were used to determine possible phytotoxic effects. In most of these studies, no

significant differences were noted when the plants were only sprayed with a chlorinated hydrocarbon (1,14,27). When phytotoxic effects were found, the chemical had been applied to young plants at abnormally high rates (6,21). In some cases, soil applied chlorinated hydrocarbons tended to promote root growth and development (2).

The organophosphate compounds are considered to be any insecticide which contains phosphorus (31). The mode of action of this class of chemicals involves the inhibition of the enzyme cholinesterase (23) which causes an accumulation of acetylcholine at the nerve endings and ultimately disrupts the nervous system of the target insect.

In early studies, many organophosphates, primarily methyl and ethyl parathion, were used to determine effects on cotton development. In some of the studies, there were no effects upon the plants due to insecticide treatment (1,12), but for the most part, some type of effect was noted on the chemically-treated foliage. The effects upon the growth and development of cotton included morphological changes of the leaves (18), an increase in the number of vegetative branches (9), delayed plant maturity, (6,32,33,5,10,21) and ultimately, lower yields (14). Fowler (9) studied the carbon:nitrogen ratio in treated plants. He found that the increase in vegetative branches could be

attributed to the interaction between the chemical and the physiological processes of the treated plant. The treated plants had an increase in nitrogen which was negatively correlated with sugar concentration. Fowler considered that this offset promoted vegetative growth until the plant could reestablish a proper carbon:nitrogen balance. Other studies using organophosphates included the use of diazinon applied to alfalfa (34) and apple trees (11). Both the CO₂ exchange rate and the total nonstructural carbohydrate concentration were reduced in the treated plants. These effects were apparently short term since 75% of the diazinon dissipated from the soil-plant complex within six days of treatment.

In more recent studies, organophosphates have been shown to decrease photosynthetic rates and have a detrimental effect upon stomatal conductance in lettuce (29,30), citrus (13), and strawberries (15).

Another group of insecticides which are commonly used on cotton are the carbamates. Again, this is a broad term which refers to those insecticides that originate from carbonic acid (31). Carbamates are similar to the organophosphates since they both act as cholinesterase inhibitors (23) upon targeted insects.

Carbamates delay the maturity of cotton, although the effects are not as extreme as those occurring with the organophosphates. When the growing season is sufficiently long, the final yields of the plants treated with the carbamates did not significantly differ from those of the untreated plants (28).

There were instances where the application of carbamates disrupted physiological processes (3), but as with the chlorinated hydrocarbons, the chemicals were applied to young plants at abnormally high rates.

A fourth class of chemicals commonly used on cotton are the formamidines, more specifically the insecticide-ovicide chlordimeform. The poisoning symptoms of this chemical are distinctly different from those in the other chemical classes. Among the symptoms exhibited by chlordimeform-treated insects are cardiostimulation, anorexia, and an increase in water uptake (17). It is currently proposed that the possible mode of action is the inhibition of the enzyme monoamine oxidase, resulting in a buildup of compounds known as biogenic amines. The action of this chemical is not fully understood, but it appears to act as a chemical transmitter at nerve synapses, much the same as acetylcholine (31).

The research with chlordimeform indicates that it enhances yield in cotton. Various studies (25,24,16) revealed that mid- to late-season applications of chlordimeform tended to increase yield. In these studies, other chemicals were used to control insects in the field. The manufacturers have promoted this chemical as a yield enhancer. Pieters (26) reported that chlordimeform has a positive effect upon the cotton plant which caused a yield above that expected from insect control. Field trials indicated a higher yield and quality from treated plants. Higher photosynthetic rates were observed in lab studies using chlordimeform-treated plants. These studies indicated a type of enhancement, but specific data were not shown. Another study (4) indicated a yield enhancement using relatively low rates, but the chemical was applied up to 6 times at 5-7 day intervals.

The synthetic pyrethroids are a relatively old group of chemicals which have recently come to attention due to their numerous desirable traits. Some of these traits include low mammalian toxicity, a quick "knockdown" of pests, and control of insect species which have shown resistance to the carbamates and the organophosphates (31). The mode of action of the synthetic pyrethroids is somewhat of a

mystery. The symptoms of synthetic pyrethroid poisoning include hyperactivity, ataxia, convulsions, and eventual paralysis. These symptoms describe some type of effect upon nerves or muscles, but specifics are not yet known (20). The research involving the effects of synthetic pyrethroids upon plants has basically led to the conclusions that they also delay maturity and decrease yields. Toscano (30) noted that permethrin-treated plants had a greater reduction in photosynthesis and stomatal conductance than those plants which had been treated with chlorinated hydrocarbons, organophosphates or carbamates. Although permethrin had severe effects upon the plant's physiology, the ultimate yield was not significantly affected and this compound did as well or better in the control of insect pests.

A controversy presently exists concerning the "yield enhancement" aspect of insecticides. The observed yield increases have been erratic and have not been attributed to either the control of insects or an effect on plant physiology. The primary objective of this study was to determine whether certain insecticides commonly used in the production of cotton significantly alter development and yield. If development and yield are significantly altered, then separation into entomological and physiological responses will be made. An understanding of the interactions between

insecticides and plants will ultimately enhance our knowledge of the production of cotton on the Texas High Plains and elsewhere.

CHAPTER III

MATERIALS AND METHODS

Field experiments were conducted at the Texas Tech University Research Farm in Northeast Lubbock County, Texas, during the summers of 1982 and 1983 and at the Terry County Plant Stress Laboratory near Brownfield, Texas, during the summer of 1983. Additionally, greenhouse experiments were conducted in the spring and summer of 1983 at the Texas Tech University greenhouse facility located on the campus.

Field Experiments

A commercial cotton cultivar, TAMCOT SP37, was utilized for all field work at both of the locations. SP37 is a typical cotton variety grown on the High Plains. It produces a pyramidal-shaped plant with few vegetative branches, intermediate foliage and prominent fruiting branches. The vegetative growth is considered determinate, but fruiting is indeterminate. SP37 has a high resistance to bacterial blight with moderate tolerance to *Verticilium* and *Fusarium* wilt. It also exhibits root rot and seedling disease escape (19).

A randomized block design was used at both locations with treatments replicated two times in 1982 and four times in

1983. Treatments included four different insecticides and an untreated control. These treatments and their respective recommended rates are presented in Table 1. In 1982, applications were made at first bloom and thirty days later. In 1983, applications began at first flower and continued every ten days for a total of five applications. All treatments were applied with a tractor-mounted two-row sprayer which was calibrated to deliver 200 l/ha. The sprayer was constantly pressurized at 40 psi using a nitrogen gas cylinder.

TABLE 1
Insecticide treatments.

Insecticides		
Common Name	Trade Name	Rate (kg ai/ha)
Malathion	Cythion	0.65
Carbaryl	Sevin	1.12
Chlordimeform	Galecron	0.168
Flucythrinate	PayOff	0.056

Texas Tech Research Farm

The soil type was an Olton clay loam series approximately one meter deep. Three levels of soil water availability were established each year by applying irrigation water based upon water usage. The soil profile was essentially at field capacity at planting. Irrigation treatments in 1982 occurred on July 23 and August 12. The total amount of irrigation was 177.8 mm for the 100% level and 101.6 mm for the 50% level. In addition, a total of 368.3 mm of rainfall was received during the growing season. The irrigation treatments for 1983 occurred on May 20, 24, June 23, 28, July 15, 19, August 11, 23 and September 3. The total amount of irrigation was 453.2 mm for the 100% level, 277.2 mm for the 50% level, and 100 mm for the 0% level. In addition, a total of 63.3 mm of rainfall was received during the growing season.

Seeding for the two years occurred on June 1, 1982 and May 19, 1983 at a rate of 30 seed per meter of row at an approximate depth of 4.5 cm. After the seedlings were well-established, the plots were hand-thinned to a population of 12 plants per meter. Each plot measured 4 m x 15 m. All four rows were treated in each plot, but only the middle two rows were utilized for data purposes. In 1982, a preplant

herbicide, fluchloralin, was applied at the recommended rate (1 l/ha) for this soil type on March 10. In 1983, the same chemical was applied at the same rate on March 15. The pre-plant fertilizer application for 1982 consisted of 50 kg of nitrogen and 50 kg of P_2O_5 per hectare applied on March 5. In 1983, 60 kg N/ha, 60 kg P_2O_5 /ha, and 30 kg SO_4 /ha were applied preplant on March 8.

In 1982, insecticide treatments were applied twice during the growing season on August 9 and September 9. The spray schedule for 1983 consisted of five applications occurring on July 21, August 2, 10, 20, and September 4.

In 1982, growth analyses were conducted prior to an insecticide application and seven days thereafter. In 1983, growth analyses were made at thirty and sixty days after the initial application. One meter row of plants were utilized from each plot. The data taken included plant height, vegetative leaf number, reproductive leaf number, square number, boll number, and nodes per plant. Total leaf area for a meter row was measured using the Lambda LI 3000 leaf area meter.

Yield data were taken on November 9, 1982 and November 10, 1983 by counting the number of bolls per ten m^2 and

harvesting 100 open bolls. These two variables were used to determine the yield of seed cotton.

Terry County Plant Stress Laboratory

The soil type was an Amarillo loamy fine sand approximately 1.5 m deep. Two levels of soil water availability were established by applying irrigation water based upon soil water usage. A preplant irrigation treatment of 85.5 mm was applied to all plots with subsequent irrigation treatments on July 6, 28 and August 20 for a total of 385 mm of water for the 100% irrigated plots and 210 mm of water for the limited irrigation plots. In addition, there was 95.0 mm of rainfall during the growing season.

Seeding initially occurred on May 16, 1983 but due to severe weather conditions on May 31, the cotton was replanted on June 3, 1983 at a rate of 30 seed/m of row at an approximate depth of 4.5 cm. After the seedlings were well-established, the plots were hand-thinned to a population of 12 plants/m. The plots were 4 m x 15 m. Again, the middle two rows were utilized for data purposes although all four rows were treated with the insecticides. A preplant herbicide, trifluralin, was applied on March 16 at the recommended rate (1 l/ha) for this soil type. A preplant fertilizer

application of 60 kg N/ha and 60 kg P₂O₅/ha occurred on March 8, 1983.

The spray schedule for this location consisted of five applications on the following dates: July 25, August 3, 15, 24 and September 5.

Growth analyses were made thirty days after initial application. The second set of data was not taken due to an unusually early freeze which resulted in the loss of leaf tissue. The data were taken from one meter row of plants and consisted of the same parameters as those taken at the Lubbock County Research Center.

Yield data were taken October 20 by counting the number of bolls per ten m² and harvesting 100 open bolls. These two variables were used to determine the yield of seed cotton.

The physiological responses to the chemicals were measured at 24 and 48 hours after application and the methods of measurement were consistent for both locations.

Gross photosynthetic rates of single leaves were determined using the modified ¹⁴CO₂ technique as described by Naylor and Teare (22). Individual samples were

taken on the uppermost, fully-expanded mainstem leaf. Four samples were taken per treatment. The leaf discs were digested in 0.2 ml of 70% HClO_4 and 0.2 ml of 30% H_2O_2 before being counted in a Beckman LS 7000 liquid scintillation counter. The scintillation cocktail consisted of 750 ml toluene, 250 ml Triton X-100, 6 g PPO, and 75 mg POPOP per liter.

Stomatal conductance values were calculated as the reciprocal of the diffusive resistance measurements taken using the LI 1600 steady state porometer. In addition, leaf microclimate data were recorded, including air temperature, relative humidity, photon flux density, and leaf temperature.

Entomological data collection was also consistent for both field locations and consisted of making whole plant counts for a meter of row per treatment. These counts were initially taken before the first application and every ten days thereafter.

Greenhouse Experiments

A single variety of cotton, TAMCOT SP37, was utilized in all experiments. Plants were grown in 40 cm pots in a standard potting mix at a population of three plants per pot. All pots were arranged in a randomized block design. A total of three planting dates were used throughout the season. Evaluation of the material occurred from June to August 1983. Environmental conditions consisted of a day/night temperature regime of 35°C/25°C. The photoperiod ranged from 12-14 hours of natural sunlight with midday PPFD in excess of 1600 $\mu\text{E}/\text{m}^2/\text{sec}$. The relative humidity was approximately 35% at midday. The plants had an adequate amount of water supplied via an automatic watering system.

Insecticide treatments were applied to the plants at the previously noted rates (Table 1) and all treatments were replicated twice per planting date. Insecticides were applied at first square and every ten days thereafter for a total of four applications. The method used to treat the plants consisted of using a movable spray boom to simulate in-field conditions. The system was pressurized at a constant 30 psi with a nitrogen gas cylinder and was calibrated to deliver 220 l/ha.

Gross photosynthetic rates and stomatal conductances were measured as previously described.

All data were analyzed using an analysis of variance with the significance level at 5%. Duncan's multiple range test was used to test means for significance at the 5% level.

CHAPTER IV

RESULTS AND DISCUSSION

Yield and Yield Components

Individual plots were hand harvested and the components of yield, including open boll number and boll weight, were used to calculate lint yield per hectare.

Texas Tech Research Farm

The results of the analyses of variance for yield and yield components as a function of treatment at the North Lubbock County Research Farm are presented in Table 2. Irrigation treatment significantly affected yield and both yield components at this site. These results were expected since there were three distinct water regimes at this site and the yield components had adequate time to mature normally. Neither total yield nor any of the yield components were affected by the insecticide treatments. In addition, the interaction between irrigation and insecticide treatments did not significantly affect yield or yield components.

TABLE 2

Analyses of variance of yield and components of yield at the Texas Tech Research Farm, Lubbock County.

Sums of Squares				
Source	df	Yield	Boll Number	Boll Weight
Block	3	147909.07	35298.85	11653.20
Irrigation	2	1109581.86**a	280603.43**	68742.63**
Error a	6	39944.16	7227.10	28847.10
Treatments	4	14686.67	4958.73	2458.26
Trt X Irr	8	40536.96	19109.67	5038.53
Error b	36	186292.69	58519.30	28181.20

a significance at the 1% level.

The yields of the various insecticide treatments for each irrigation regime are depicted graphically in Figure 1. The yields were not statistically separable within a given water regime.

Terry County Plant Stress Laboratory

Analyses of variance for the various treatments affecting yield and yield components of cotton at the Terry County Plant Stress Laboratory are presented in Table 3. Boll weight was the only parameter significantly affected by irrigation treatments. Total lint yield and open boll number

FIGURE 1

Lint yield for each insecticide treatment within each irrigation regime at the Texas Tech Research Farm.

TABLE 3

Analyses of variance of yield and components of yield at the Terry County Plant Stress Laboratory.

Sums of Squares				
Source	df	Yield	Boll Number	Boll Weight
Block	3	43201.46	6172.20	22643.08
Irrigation	1	924.19	2250.00	23474.03 ^a
Error a	3	19198.63	3750.20	4395.88
Treatments	4	917.11	2530.85	6304.35
Trt X Irr	4	2646.50	1661.75	3677.35
Error b	24	181529.97	64586.60	105406.30

^asignificance at the 5% level.

were not affected by irrigation due to the early freeze which occurred at this location. There was not adequate time for the plants to mature normally so the difference in the irrigation treatments was not present. The insecticide treatments did not affect yield or yield components. In addition, the interaction between irrigation and insecticide treatments did not significantly affect yield or yield components.

The yield of the various treatments for each water regime are graphically depicted in Figure 2. These yields were not statistically separable from one another.

FIGURE 2

Lint yield for each insecticide treatment within each irrigation regime at the Terry County Plant Stress Laboratory.

Growth and Development

The effect of insecticides on cotton growth and development was determined by measuring various vegetative and reproductive parameters. The measurements were taken at thirty and sixty days after the initial insecticide application.

The insecticides' effects on vegetative growth components were statistically analyzed and the results of this analysis of variance are presented in Table 4. Essentially every growth parameter measured was significantly affected by the insecticide treatments at both sampling times.

Effects of insecticide treatments on plant height are presented in Table 5. Those plants treated with flucythrinate were consistently taller than plants in the other treatments while those treated with chlordimeform were consistently shorter. Only those plants treated with chlordimeform were significantly shorter from the untreated plants at the second sampling period.

Insecticide treatments significantly affected the total number of vegetative leaves per meter² (Table 4). In Table 6, the effects of the insecticides are separated with a test of the means. Carbaryl-treated plants had significantly

TABLE 4
Analyses of variance of vegetative growth parameters.

		Sums of Squares				
Daia ^a	Source	df	Height	Vegetative		LAI ^b
				Leaves/ Meter ²	Leaves/ Plant	
30	Blocks	3	46.32 ^c	29.00	8.20	81.00
	Treatments	4	289.53* ^c	2168.00** ^d	7.41	1721.38**
	Error	12	252.20	563.00	20.77	721.82
60	Blocks	3	85.14	476.20	1.25	616.48
	Treatments	4	226.67**	6086.30**	31.61**	4115.25**
	Error	12	137.77	2177.30	7.67	1638.27

^a days after initial application.

^b leaf area index.

^c significance at the 5% level.

^d significance at the 1% level.

TABLE 5
Effect of insecticides on plant height.^a

Treatments	Plant Height (cm)	
	30 daia ^b	60 daia
Flucythrinate	62.26 a	64.01 a
Chlordimeform	51.50 b	53.95 b
Carbaryl	52.23 b	59.68 a
Malathion	55.13 ab	61.95 a
Control	55.43 ab	59.54 a

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

/

more vegetative leaves per meter² than other treated plants at the first sampling period. However, carbaryl-treated plants did not differ statistically from the untreated control. At the second sampling period, the untreated plants had significantly more leaves per meter² than the treated plants. At both sampling periods, the plants treated with chlordimeform had the lowest number of vegetative leaves per meter².

TABLE 6

Effect of insecticides on vegetative leaves per meter².^a

Treatments	Total Vegetative Leaves Per Meter ²	
	30 daia ^b	60 daia
Flucythrinate	102.75 dc	95.75 b
Chlordimeform	95.75 d	71.25 c
Carbaryl	124.50 a	74.00 bc
Malathion	109.75 bc	85.80 bc
Control	118.75 ab	119.50 a

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

The number of vegetative leaves per plant was significantly affected by the insecticides only at the second sampling period (Table 4). The plants treated with flucythrinate were not statistically separable from the control (Table 7). Malathion-treated plants had significantly fewer vegetative leaves per plant than the control. Plants treated with carbaryl and chlordimeform had significantly fewer vegetative leaves per plant than the malathion-treated plants.

TABLE 7

Effect of insecticides on vegetative leaves per plant.^a

Treatments	Vegetative Leaves / Plant	
	30 daia ^b	60 daia
Flucythrinate	12.95 a	10.63 ab
Chlordimeform	12.82 a	7.92 c
Carbaryl	11.24 a	8.42 c
Malathion	12.30 a	9.70 b
Control	12.54 a	11.22 a

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

Nodes per plant were significantly affected by insecticides at both sampling periods (Table 4). At thirty days after the initial application, chlordimeform and carbaryl significantly reduced node number while the untreated plants had more nodes per plant than any of the treated plants (Table 8). At sixty days after initial application, the malathion-treated plants had more nodes per plant than the other treatments. Only chlordimeform-treated plants could be statistically separated from those treated with malathion.

TABLE 8
Effect of insecticides on nodes per plant.^a

Treatments	Nodes/Plant	
	30 daia ^b	60 daia
Flucythrinate	17.15 a	18.48 ab
Chlordimeform	13.88 b	16.38 b
Carbaryl	14.18 b	17.87 ab
Malathion	16.88 a	18.58 a
Control	17.27 a	18.02 ab

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

The leaf area index was significantly affected by insecticide treatments ($p < 0.01$) at both sampling times (Table 4). The flucythrinate-treated plants consistently had the highest leaf area index while those treated with chlordimeform consistently had a lower leaf area index (Table 9). All treatments had an increase in leaf area index between the first sampling period and the second, with the exception of those plants treated with carbaryl. This treatment exhibited a slight decrease in leaf area index between sampling periods.

TABLE 9
Effect of insecticides on leaf area index.^a

Treatments	Leaf Area Index	
	30 daia ^b	60 daia
Flucythrinate	1.60 a	1.83 a
Chlordimeform	1.35 b	1.41 c
Carbaryl	1.59 a	1.54 bc
Malathion	1.58 a	1.62 b
Control	1.53 a	1.71 ab

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

The effect of insecticides on reproductive growth parameters were analyzed and the results are presented in Table 10. The insecticide treatments had a highly significant effect on the total number of reproductive leaves per meter². The chemical effects on reproductive leaves per meter² were not statistically separable at the second sampling period.

Plants treated with flucythrinate, chlordimeform, and malathion had a significantly higher amount of total reproductive leaves per meter² than the carbaryl-treated plants and the untreated control (Table 11).

TABLE 10
Analyses of variance of reproductive growth parameters.

Sums of Squares										
Daia ^a	Source	df	Reproductive ₂ Leaves/Meter	Reproductive Leaves/Plant	Floral Byds/ Meter	Floral Buds/ Plant	Floral Bud Dry Weight	Bolls/Meter ²	Bolls/Plant	Boll Dry Weight
30	Blocks	3	197.75	51.51	342.15	13.94	5.30	205.00	10.65	124.13
	Treatments	4	14296.30** ^b	665.58**	5680.80**	244.43**	49.77	436.30	29.89	235.01
	Error	12	3554.50	236.21	1210.10	53.64	47.07	906.50	29.53	1456.44
60	Blocks	3	2771.80	2.90	-	-	-	582.40* ^c	2.72	15322.63**
	Treatments	4	4236.30	262.78	-	-	-	1062.00**	23.50*	15080.86
	Error	12	9315.70	218.12	-	-	-	559.60	15.09	4595.14

^adays after initial application.

^bsignificance at the 1% level.

^csignificance at the 5% level.

TABLE 11

Effect of insecticides on reproductive leaves per meter².^a

Treatments	Total Reproductive Leaves Per Meter ²	
	30 daia ^b	60 daia
Flucythrinate	275.75 a	297.50 a
Chlordimeform	264.50 a	283.25 a
Carbaryl	257.50 a	314.50 a
Malathion	215.25 b	294.25 a
Control	210.25 b	271.00 a

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

The chemical treatments significantly affected reproductive leaves per plant at both sampling times (Table 10). Chlordimeform and flucythrinate significantly increased reproductive leaves per plant at the first sampling period (Table 12). All treatments were significantly greater than the control at the second sampling period.

Total floral buds per meter² ground area and per plant and the dry weight of the structures were recorded only at the thirty days after initial application due to their absence at the second sampling period. Total floral buds per

TABLE 12

Effect of insecticides of reproductive leaves per plant.^a

Treatments	Reproductive Leaves / Plant	
	30 daia ^b	60 daia
Flucythrinate	34.80 a	33.28 a
Chlordimeform	35.33 a	32.45 a
Carbaryl	23.22 b	36.33 a
Malathion	24.63 b	33.61 a
Control	24.23 b	25.61 b

^ameans within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^bdays after initial application.

meter² and per plant were significantly affected by the insecticide treatments (Table 10). Flucythrinate-treated plants had significantly more floral buds per meter² than the plants treated with the other insecticides (Table 13). This treatment also had the greatest number of floral buds per plant and one of the greatest dry weights. Chlordimeform-treated plants had the second greatest number of floral buds per meter², floral buds per plant, and dry weight. Treatments of malathion, carbaryl and the control were not

TABLE 13

Effect of insecticides on floral bud development.^a

Treatments	Floral Buds/ Meter ²	Floral Buds/ Plant	Floral Bud Dry Weight (g/meter ²)
Flucythrinate	164.75 a	20.71 a	16.03 a
Chlordimeform	139.00 b	18.57 a	16.08 a
Carbaryl	131.25 bc	12.06 b	12.18 b
Malathion	120.00 c	13.55 b	14.04 ab
Control	118.25 c	12.51 b	12.97 ab

^a means within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

significantly different from one another in floral bud parameters.

The total bolls per meter², bolls per plant, and boll dry weight were recorded for the various treatments at both 30 and 60 days after initial application. All parameters were statistically nonsignificant at the first sampling period; however, at the second sampling period, all three parameters were highly significant (Table 10). The effect of the various treatments on each of these parameters is depicted in Table 14.

TABLE 14
Effect of insecticides on boll development.^a

Treatments	Bolls/Meter ²		Bolls/Plant		Boll Dry Weight (g/meter ²)	
	30 daia ^b	60 daia	30 daia	60 daia	30 daia	60 daia
Flucythrinate	78.50 a	84.75 b	9.88 a	9.45 ab	43.35 a	355.88 a
Chlordimeform	73.75 a	78.75 c	9.89 a	8.45 b	43.96 a	282.12 d
Carbaryl	78.00 a	85.50 b	7.15 b	9.77 ab	49.03 a	306.99 cd
Malathion	84.50 a	96.75 a	9.62 ab	11.09 a	53.53 a	324.25 bc
Control	70.75 a	84.25 bc	7.48 b	7.99 b	45.78 a	350.65 ab

^a means within columns followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

^b days after initial application.

Although treatments could not be statistically separated at the first sampling period for bolls per meter², there was a significant separation at the second sampling period. Carbaryl-treated plants had approximately 19% more bolls per meter² than the plants in the untreated control; however, they did not have the greatest increase in bolls per meter² between the sampling periods. Flucythrinate-treated plants had an increase of 6 bolls per meter² while those treated with chlordimeform only increased their boll number by five during the thirty days between the sampling periods. Bolls per plant were measured and treatments of flucythrinate, chlordimeform, and malathion had the greatest amount at the first sampling period. At the second sampling period, malathion-treated plants had the most bolls. Treatments of carbaryl and malathion showed an increase of 2.62 and 1.47 bolls per plant respectively for the time between sampling periods. The untreated control had a slight increase in bolls per plant while the plants treated with flucythrinate had a slight decrease. Chlordimeform-treated plants had an actual decrease of 1.44 bolls per plant during the thirty days between sampling periods.

There was no statistical separation of means for the boll dry weight at thirty days after initial application. At sixty days after initial application, flucythrinate-treated

plants had the greatest boll weight, while those treated with chlordimeform had the lowest. Although carbaryl-treated plants had the most bolls per meter² and bolls per plant, they did not have the greatest boll dry weight.

Entomological data was taken to determine whether there were differences in the insect populations of the various treatments. Due to the lack of detrimental insects in the field experiments, the statistical analysis concerns only the beneficial insect population. The insecticides did not have an effect on the insect populations found in the various treatments (Table 15).

TABLE 15

Analyses of variance of insect populations.

Source	df	Sums of Squares	
		Brownfield	New Deal
Block	1	12.01	4.13
Date	6	4.97	10.34
Error a	6	26.69	2.97
Treatments	4	6.20	8.66
Trt X Date	24	57.60	25.94
Error b	26	43.80	59.40

Flucythrinate increased plant height in treated plants, but reduced vegetative leaves per meter². All other vegetative growth parameters were unaffected by this treatment. In addition, the flucythrinate-treated plants had increased reproductive leaves per plant, floral buds per plant, and bolls per plant. Chlordimeform decreased all vegetative growth parameters, but increased virtually all reproductive growth parameters with the exception of boll weight per meter². Carbaryl and malathion reduced vegetative leaves per meter² and vegetative leaves per plant at the second sampling period. These treatments also increased reproductive leaves per meter² and reproductive leaves per plant at 30 and 60 days after initial application, respectively. Carbaryl did not affect floral bud or boll development. Malathion increased boll production, but did not affect boll weight per meter².

Physiological Data

The data for physiological processes included photosynthetic rates, stomatal conductance measurements, and subsequent photosynthesis/conductance ratios. The physiological data were analyzed using the actual data and the ratios of the treatments to the control. The purpose of using ratios

was to minimize variability due to the environmental effects on physiological responses that were measured. These data were taken from greenhouse and field-grown plants. The purpose of the greenhouse study was to carefully evaluate photosynthesis and leaf conductance characteristics under insect-free conditions and relatively controlled environmental conditions.

Greenhouse Experiments

The effects of the insecticide treatments on photosynthetic rates of greenhouse-grown plants are presented in Table 16. There were no significant differences for treatments at any of the three planting dates. In addition, the number of applications and the time after application did not affect the photosynthetic rates of greenhouse-grown plants.

The effects of the insecticides on stomatal conductance revealed no significant differences in treatments at any of the three planting dates (Table 17). Application number and time after application did not significantly affect stomatal conductance of the treated plants.

TABLE 16

Analyses of variance of the photosynthetic rates of
greenhouse-grown plants.

Source	Sums of Squares					
	df	Planting Date 1	df	Planting Date 2	df	Planting Date 3
Blocks	1	0.30	1	0.33	1	0.48
Applications	2	0.80	3	0.02	2	0.23
Error a	2	0.97	3	0.19	2	0.50
Time	1	0.005	1	0.08	1	0.002
Appl X Time	1	0.13	3	0.31	2	0.12
Error b	2	0.41	4	0.41	3	0.28
Treatments	4	0.36	4	0.15	4	0.10
Trt X Appl	8	0.73	12	0.36	8	0.13
Trt X Time	4	0.03	4	0.04	4	0.03
Trt X Appl X Time	8	0.18	12	0.47	8	0.09
Error c	20	1.13	32	0.96	24	0.49

The effects of the insecticide treatments on the photosynthesis/conductance ratios of greenhouse-grown plants are depicted in Table 18. There were no significant differences noted for treatments, application number, or time after application at any of the three planting dates.

TABLE 17

Analyses of variance of the stomatal conductance
measurements of greenhouse-grown plants.

Sums of Squares						
Source	df	Planting Date 1	df	Planting Date 2	df	Planting Date 3
Blocks	1	0.24	1	0.005	1	0.08
Applications	3	3.13	3	0.38	2	0.13
Error a	3	2.36	3	0.37	2	0.12
Time	1	0.96	1	0.05	1	0.002
Appl X Time	3	1.66	3	0.46	2	0.03
Error b	4	8.49	4	0.36	3	0.06
Treatments	4	2.75	4	0.23	4	0.04
Trt X Appl	12	4.69	12	0.92 ^a	8	0.10
Trt X Time	4	0.48	4	0.06	4	0.08
Trt X Appl X Time	12	2.78	12	0.24	8	0.11
Error c	32	11.76	32	1.15	24	0.24

^asignificance at the 5% level.

TABLE 18

Analyses of variance of the photosynthesis/conductance ratios of greenhouse-grown plants.

Source	Sums of Squares					
	df	Planting Date 1	df	Planting Date 2	df	Planting Date 3
Blocks	1	0.87	1	0.53	1	0.87
Applications	3	1.07	3	0.35	2	0.53
Error a	3	0.59	3	0.63	2	0.23
Time	1	0.02	1	0.01	1	0.002
Appl X Time	3	0.84	3	0.45	2	0.03
Error b	3	1.88	3	0.98	3	0.37
Treatments	4	0.92	4	0.24	4	0.04
Trt X Appl	12	0.79	12	1.17	8	0.18
Trt X Time	4	0.03	4	0.06	4	0.29
Trt X Appl X Time	12	0.57	12	0.63	8	0.32
Error c	32	3.35	32	1.82	24	0.76

Field Experiments

In Table 19, the effects of the insecticide treatments on the photosynthetic rates of field-grown plants are presented. The Texas Tech Research Farm and the Terry County Plant Stress Laboratory are both included in this table. No significant differences were noted for treatments, number of applications, or time after application.

TABLE 19

Analyses of variance of the photosynthetic rates of field-grown plants.

Source	df	Sums of Squares		New Deal
		Brownfield	df	
Blocks	2	0.14	3	0.11
Applications	2	0.75	1	0.03
Error a	4	0.10	3	0.33
Time	1	0.19	1	0.08
Appl X Time	2	0.48	1	0.20
Error b	6	1.57	4	0.70
Treatments	4	0.45	4	0.16
Trt X Appl	8	0.44	4	0.27
Trt X Time	4	0.31	4	0.10
Trt X Appl X Time	8	0.21	4	0.18
Error c	48	5.88	48	3.19

The effects of the insecticides on stomatal conductance measurements revealed no significant differences in treatments at either of the field locations (Table 20). The number of applications and the time after application did not affect stomatal conductance of the field-grown plants.

In Table 21, the effects of the insecticide treatments on photosynthesis/conductance ratios of the field experiments are noted. The effects of application number and time after application are also included in this table. There were no

TABLE 20

Analyses of variance of the stomatal conductance
measurements of field-grown plants.

Source	df	Sums of Squares		
		Brownfield	df	New Deal
Blocks	1	0.21	1	0.0007
Applications	2	0.14	1	0.02
Error a	2	0.58	1	0.0001
Time	1	0.13	1	0.26
Appl X Time	2	0.01	1	0.02
Error b	3	0.51	2	1.09
Treatments	4	0.16	4	0.07
Trt X Appl	8	0.47	4	0.01
Trt X Time	4	0.45	4	0.11
Trt X Appl X Time	8	0.64	4	0.06
Error c	24	1.03	16	0.59

significant differences in the effects of treatments,
application number, or time after application on photo-
synthesis/conductance ratios at either location.

TABLE 21

Analyses of variance of the photosynthesis/conductance ratios of field-grown plants.

Source	Sums of Squares			
	df	Brownfield	df	New Deal
Blocks	1	0.24	1	0.28
Applications	2	0.17	1	0.48
Error a	2	0.57	1	0.16
Time	1	0.50	1	0.07
Appl X Time	2	0.67	1	0.53
Error b	3	0.27	2	0.11
Treatments	4	0.75	4	1.34
Trt X Appl	8	0.98	4	0.64
Trt X Time	4	1.34	4	0.33
Trt X Appl X Time	8	0.98	4	0.55
Error c	24	5.87	16	3.41

CHAPTER V

SUMMARY AND CONCLUSIONS

The results of this study indicate that insecticides do not affect yield or yield components under the prevailing environmental conditions of the Texas High Plains. However, there were notable effects on growth and development of the cotton plants treated with various insecticides. Flucythrinate increased overall growth, including vegetative and reproductive parameters. Chlordimeform-treated plants reduced vegetative growth and increased reproductive growth. Carbaryl affected some of the parameters at various sampling times, but had no effect on floral bud or boll development. Malathion also affected some of the growth parameters and increased the production of bolls. The insect population had no effect on the various growth and developmental parameters.

The plant's physiological processes, including photosynthesis, stomatal conductance, and photosynthesis/conductance ratios were unaffected by the insecticides in the field and greenhouse experiments.

Due to the short growing season experienced on the Texas High Plains, the effects of the insecticides that occurred

in the growth and development of cotton did not ultimately affect yield. Given a long enough period of time, these differences may be able to express themselves as yield differences.

LITERATURE CITED

1. Adkisson, P. L., J. Hacscklayo, P. L. Hanna and J. K. Walker, Jr. 1962. Flowering rate, boll maturity, and yield of cotton treated with various insecticides. Texas Agric. Exp. Sta. Prog. Rept. No. 2245. 7 pp.
2. Anderegg, B. N., E. P. Lichtenstein and J. D. Kemp. 1977. Effects of lindane on DNA, RNA, and protein synthesis in corn roots. J. Agric. Food Chem. 25:923-28.
3. Arunachalam, K. and M. Lakshmanan. 1982. Translocation, accumulation, and persistence of carbofuran in paddy, ground nut, and cotton. Bull. Environ. Contam. Toxicol. 28:230-38.
4. Bachman, W. W. 1982. Galecron:Cotton yield enhancement. Beltwide Cotton Prod. Res. Conf. pp. 99-100.
5. Bradley, J. R. Jr. and F. T. Corbin. 1974. Effects of organophosphate insecticides, especially methyl parathion, on fruiting, maturity, and yield of cotton. Beltwide Cotton Prod. Res. Conf. pp. 133-35.
6. Brown, L. C., C. Lincoln, R. E. Frans and B. A. Waddle. 1961. Some effects of toxaphene + DDT and calcium arsenate on growth and development of cotton. J. Econ. Entomol. 54:309-11.
7. Feree, D. C. 1979. Influence of pesticides on photosynthesis of crop plants. pp. 331-41. In R. Marelle, H. Clijsters and M. Van Poucke (eds.), Photosynthesis and plant development. Dr. W. Junk, The Hague. 376 pp.
8. Feree, D. C. and F. R. Hall. 1978. Effects of growth regulators and multiple application on pesticides on net photosynthesis and transpiration of greenhouse apple trees. J. Am. Soc. Hortic. Sci. 103:61-4.
9. Fowler, H. D. 1956. Some physiological effects of attack by whitefly (Bernisia gossypiperda) and of spraying parathion on cotton in the Sudan Gezira. Empire Cotton Growing Rev. 33:288-99.

10. Gipson, J. R. 1974. Effect of temperature and methyl parathion on vegetative development and fruiting of the cotton plant. *Agron. J.* 66:337-41.
11. Heincke, D. R. and J. W. Foott. 1966. The effect of several phosphate insecticides on photosynthesis of Red Delicious apple leaves. *Can. J. Plant Sci.* 46:589-91.
12. Horst, B. L. 1973. The effect of methyl parathion on the flowering of cotton. *Beltwide Cotton Prod. Res. Conf.* pp. 74-5.
13. Jones, V. P., P. R. Youngman and M. P. Parrella. 1983. Effect of selected acaricides on photosynthetic rates of lemon and orange leaves in California. *J. Econ. Entomol.* 76:1178-80.
14. Karami, E. and J. B. Weaver, Jr. 1969. Effect of cultural practices on earliness of cotton. *Beltwide Cotton Prod. Res. Conf.* pp. 108-11.
15. LaPre, L. F., F. V. Sances, N. C. Toscano, E. R. Oatman, V. Voth and M. W. Johnson. 1982. The effects of acaricides on the physiology, growth, and yield of strawberries. *J. Econ. Entomol.* 75:616-19.
16. Lincoln, C. and G. Dean. 1976. Yield and blooming of cotton as affected by insecticides. *Ark. Farm. Res.* 25:5.
17. Matsumura, F. and R. W. Beeman. 1982. Toxic and behavioral effects oh chlordimeform on the American cockroach (*Periplaneta americana*) pp. 229-42 In J. R. Coats (ed.) *Insecticide Mode of Action*. Academic Press. New York, N. Y. 368 pp.
18. McIlrath, W. J. 1950. Cotton-leaf malformations induced by organic phosphate insecticides. *Botan. Gaz.* 112:221-25.
19. Metzger, R. B. and J. R. Supak. 1980. Characteristics of cotton varieties grown in Texas. *Texas Agric. Exp. Sta. Bull.* 1312. p. 91.
20. Miller, T. A. and M. E. Adams. 1982. Mode of action of pyrethroids. pp. 3-27. In J. R. Coats (ed.) *Insecticide Mode of Action*. Academic Press. New York, N. Y. 368 pp.

21. Mistic, W. J. Jr., B. M. Covington and F. D. Smith. 1970. Effects of methyl parathion, DDT, and toxaphene on the boll weevil, bollworm, and the cotton plant in North Carolina. *J. Econ. Entomol.* 63:596-98.
22. Naylor, D. S. and I. D. Teare. 1974. An improved rapid field method to measure photosynthesis with $^{14}\text{CO}_2$. *Agron. J.* 67:404-06.
23. O'Brien, R. D. 1967. *Insecticides Action and Metabolism.* Academic Press. New York, N. Y. 332 pp.
24. Parencia, C. R. 1981. 34th Annual Conference Report of Cotton-Insect Research and Control. New Orleans, La. p. 27.
25. Phillips, J. R., G. A. Herzog and W. F. Nicholson. 1977. Effect of chlordimeform on fruiting characteristics and yield of cotton. *Ark. Farm. Res.* 26:4.
26. Pieters, E. 1982. Fundal:Cotton yield enhancement. Beltwde Cotton Prod. Res. Conf. p. 98.
27. Roark, B., T. R. Pfrimmer and M. E. Merkel. 1963. Effects of some formulations of methyl parathion, toxaphene, and DDT on the cotton plant. *Crop Sci.* 3:338-41.
28. Roark, B., T. R. Pfrimmer and M. E. Merkel. 1964. Effects of some insecticide formulations on fruiting of the cotton plant. *Crop Sci.* 4:97-8.
29. Toscano, N. C., F. V. Sances, M. W. Johnson and L. F. LaPre. 1981. Pesticides may reduce lettuce yield. *California Agric.* 35:4-5.
30. Toscano, N. C., F. V. Sances, M. W. Johnson and L. F. LaPre. 1982. Effets of various pesticides on lettuce physiology and yield. *J. Econ. Entomol.* 75:738-41.
31. Ware, G. W. 1978. *Pesticide Book.* W. H. Freeman and Company. San Francisco, Ca. 197 pp.
32. Weaver, J. B. Jr. 1973. Effect of methyl parathion on yield and earliness of cotton. Beltwide Cotton Prod. Res. Conf. p. 73.

33. Weaver, J. B. Jr. and L. Harvey. 1963. A comparison of toxaphene + DDT with methyl parathion on 49 varieties and strains of cotton. Proc. 15th Cotton Prod. Conf. pp. 91-104.
34. Wolf, D. D., G. R. Buss and R. L. Rienkowski. 1976. Growth and physiological response of alfalfa to diazinon and methoxychlor insecticides. Crop Sci. 16:190-92.