MODELS FOR PREDICTING POPULATIONS OF THE WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* (PERGANDE), ON ONIONS IN THE TEXAS HIGH PLAINS

by

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CHAPTER I

INTRODUCTION

Purpose and Scope

Frankliniella occidentalis (Pergande), the western flower thrips, is the predominant thrips species of economic importance found on onions in the Texas High Plains. Although onion growers routinely apply insecticides, there is limited information available about economic thresholds or factors affecting growth of thrips populations. If thrips densities can be predicted, and if reliable economic threshold levels are known, one can determine how often the crop should be sprayed.

I shall ask two questions. First, how fast do thrips populations on onions increase after being sprayed with insecticide? Second, what environmental factors influence this growth rate? I quantify the variables affecting thrips

population growth and present a predictive model. I also draw some biological inferences from the model about the nature of thrips populations on onions in the High Plains.

In addition, I compare two sampling techniques, a visual density estimate and a plant wash density estimate, to evaluate their relative accuracies.

Literature Review

General Biology

Frankliniella occidentalis was described in the genus Euthrips by Pergande in 1895 and was later redescribed by Hinds in 1902 (Watson, 1923). The species is distributed throughout western North America and has been reported from scattered areas of the eastern United States. It has a wide host range, occurring on nearly every flowering plant from sea level to subalpine altitudes (Bailey, 1938; Bryan and Smith, 1956).

Lublinkhof (1976) summarized the life cycle of F. occidentalis in the High Plains of western Texas. After onion harvest, adults seek an overwintering site, usually provided by surrounding wheat, clover, alfalfa, or various grasses. In spring, adults migrate from these overwintering sites onto the young onion plants. The female deposits a bean-shaped egg into the onion leaf tissue. Time of hatching depends upon temperature. First and second instars feed on the leaves. When fully grown, the second instars drop to the ground seeking a protected area in the soil until they reach the adult stage. The early and the late pseudopupal stages are spent in the ground until adult emergence.

Adult female F. occidentalis are facultatively parthenogenetic and many generations are produced per year depending on locality and environmental conditions (Bryan and Smith, 1956).

Damage to the Onion

The feeding damage to the onion plant is similar to that of phytophagous thrips in general. Nymphal and adult thrips begin feeding by cutting the plant tissue with the mandible. The maxillary stylets are used to puncture cells in the deeper layers and the exuded plant fluid is sucked up in the mouthcone by force (Ananthakrishnan, 1971). The punctured cells are emptied, exposing the base of the cell walls, which in turn gives the infested area of the plant a silvery coloration. Damage to onions first appears as silvered patches along the inner angles of the leaf, followed by the appearance of whitish and yellowish patches on the leaf. As infestation of the entire onion leaf occurs, the leaves eventually curl, and necrotic areas expand and coalesce (Bailey, 1938; Ananthakrishnan, 1971). The plant may eventually die. Ananthakrishnan (1971) reported that, in general, nymphal thrips do more damage than the adults because the nymphs are gregarious and confine their feeding to limited areas.

Population Dynamics

The weather appears important in affecting thrips densities. Many authors have cited rainfall as being detrimental to thrips populations (Davidson and Andrewartha, 1948b; Wilcox et al., 1949; Bryan and Smith, 1956; Harding, 1961a; Stradling, 1968; Lewis, 1973). Harding (1961a) reported that cold, driving rain was especially damaging to F. occidentalis populations on onions in southern Texas. The influence of temperature and humidity on thrips has also been noted. Chandler (pers. comm.) found that cold, wet conditions kept thrips populations from increasing on onions in southern Texas, whereas dry conditions and daily high temperatures above 15.5° C allowed populations to increase. Harding (1961a) found that mean daily temperatures below 10° C reduced thrips movement, whereas mean daily temperatures above 14.4° C led to increased F. occidentalis densities. Shirk (1951) reported that populations of Thrips tabaci (Lindeman) on onions in Idaho do not greatly increase until mean daily temperatures are 21.1° C or more. Lublinkhof and Foster (1977) reared F. occidentalis in the laboratory and found that a constant 20 ° C was optimal for reproduction,

whereas temperatures of 15° C and 30° C inhibited reproductive potential. Kisha (1977) noted that populations of T. tabaci on onions in Sudan were reduced by extreme high temperature and low humidity.

Few people have tried to put all these weather influences together and predict how thrips density will be affected. El Shaarawy et al. (1975) studied how weather factors influenced the density of T. tabaci on cotton in Egypt. They singled out daily maximum and minimum temperatures and mean daily relative humidity as being the most important. A daily maximum temperature of 30° C, a daily minimum temperature of 17° C, and a mean relative humidity of 54% were cited as being optimal for development of T. tabaci populations. A more detailed study, and one offering a predictive model, is that of Davidson and Andrewartha (1948a, 1948b). The authors analyzed adult populations of Thrips imaginis (Bagnall) on cultivated roses in Australia over a 14 year period. They calculated a regression equation with four independent weather variables. Three of the variables were based on degree-day units, and one was

based on rainfall accumulation. Their model was designed to predict annual variation in the thrips population. However, this study has been very controversial among ecologists because it contended that density-dependent factors were not important in regulating the density of the T. imaginis population. In spite of the controversial nature of the study, Lewis (1973) stated that "it is worth stressing that thrips are delicate insects whose development and dispersal are affected greatly by temperature, rain, and wind, and superficially these appear to be the dominant factors affecting long term trends." Two papers (Stradling, 1968; Stoltz and Stern, 1978) have dealt with predation of thrips species found on onions.

Economic Importance

In the order Thysanoptera, F. occidentalis, occurring on onions in the western U.S., and T. tabaci, found on onions world-wide, are considered the two major insect pests of economic importance (Hale and Shorey, 1965). However, researchers have not been able to consistently show a correlation between reduced thrips numbers and increased

onion yields. Hibbs and Ewart (1946), Wilcox and Howland (1948), and Wene and Mayeux (1949) found yield increases associated with thrips control. Ewart et al. (1944), Ashdown and Watkins (1948), and Richardson (1953) all reported experiments where thrips control was inconsistent in increasing onion yields. Shirk and Douglass (1956), Passlow (1957), and Harding (1961b) showed that reduction of thrips populations did not significantly increase onion yields.

Why is there so much uncertainty about thrips causing yield loss? Several factors determine how much damage thrips cause on onions. One factor is onion variety. The shape of the leaves, the angle at which they diverge, and differing plant tolerences to thrips feeding damage seem to be important (Sleesman, 1943). Coudriet et al. (1979) reported that varieties with open growth and circular leaf structure support fewer thrips. Harding (1961b) and Hale and Shorey (1965) suggested that, as onion varieties have improved, thrips have had less effect on onion yields. This could be true, since many of the reports showing little

correlation of thrips density with yield have been published within the past 25 years.

Other factors affecting the severity of thrips damage are cultural practices. Passlow (1957) stated that "with adequate irrigation and sound farming methods to ensure continuous rapid growth, onions can be produced profitably despite the presence of thrips. Under these conditions the application of suitable insecticides will not appreciably increase yields in either bulb or seed crops." Other studies have shown that young onion plants seem most vulnerable to thrips damage, and insecticides would be useful only if severe infestations occurred early in the growing season (Getzin, 1973; Kisha, 1977). Kisha (1977) found that onion seedlings transplanted early in the growing season were mature enough to tolerate damage when thrips populations started to build up, making the use of insecticides unnecessary.

Another factor affecting the severity of thrips damage on onions is the weather. It is possible that weather

conditions sometimes prevent thrips populations from becoming economically important.

Economic thresholds for thrips on onions have not been experimentally determined. Ashdown and Watkins (1948) recommended that chemical control begin when populations reach an average of six thrips per plant, whereas Hibbs and Ewart (1946) gave a level of eight thrips per plant. Wilcox and Shirk (1960) advised spraying at ten thrips per plant if the plants were young. Kisha (1979) stated that late transplanted onions should be sprayed when nymphal thrips densities reach 5 to 10 per plant. However, these recommendations were considered prophylactic and offered as insurance to protect onions from damage.

CHAPTER II

MATERIALS AND METHODS

Sampling Procedure

Sampling Technique

Thrips populations were sampled during 1980 and 1981 using the plant wash method of Scott (pers. comm.) and modified from Bullock (1963). An onion plant was cut off at the base, where the foliage joined the bulb, using sheep shears. The plant was held gently and lowered into an inflated plastic bag (52 by 17 cm). The open end of the bag was then tied in a knot beyond the foliage.

Each sample, made up of bagged onion foliage, was labelled with replicate number, field locality, and date. After all samples were taken, they were brought back to the laboratory for processing. Each bag was opened in a one

gallon bucket, half-filled with 1 part water and 1 part 70% ethanol. The plant was swirled around and the leaves pulled apart to remove as many thrips as possible. The contents of the bucket were then dumped into the lower half of a Berlese funnel (i.e. a funnel with a wire-screen mesh inside) supported by a ringstand, with another bucket underneath to catch the ethanol/water solution. Before opening each sample, a double folded piece of polyester organdy cloth (having a very fine mesh) was attached to the narrow bottom of the funnel with several rubber bands. When the contents of the bucket (containing leaves, thrips, and solution) was dumped in the funnel, the wire mesh within caught the plant material, the cloth attached to the lower end of the funnel caught the thrips, and the ethanol/water solution went through the cloth into a lower bucket. The inside of the funnel was then rinsed with a pressurized spray, also of 1 part water and 1 part 70% ethanol. The solution was sprayed from a lever-operated nozzle connected by a hose to a one gallon stainless steel insecticide tank, pressurized with nitrogen gas at 4.22 kg/cm^2 . This pressurized spray rinsed down to the fine cloth mesh any thrips adhering to the inside of the funnel.

The cloth was then carefully removed from the end of the funnel, and thrips washed off with a squirt bottle into a 30 ml glass beaker. In 1980, the thrips were washed off with water into the beaker, then a layer of benzene was added. The thrips floated on top with the benzene, and methylene blue dye was injected into the lower layer of water to increase contrast. The thrips could then easily be seen, and the numbers of nymphs and adults were counted with the aid of a dissecting microscope and recorded separately. In 1981, I decided benzene was too hazardous and used another method. The thrips were washed off the cloth with 70% ethanol into the beaker. The beaker was then emptied into a labelled vial. After all samples from each sampling date were processed, each vial was emptied into a petri dish etched with a grid. The numbers of nymphal and adult thrips in each sample were counted with the aid of a dissecting microscope and recorded separately.

In 1981, visual counts were also taken to estimate the density of thrips per plant. When a plant was cut and bagged in the field (to be taken to the laboratory and

washed), the plant next to it was examined and a visual count of nymphal and adult thrips was made and the numbers recorded separately. These counts were made to determine the relationship between a visual density estimate and a plant wash density estimate.

1980 Field Season

Two commercially grown onion varieties, Spanish and Ringmaster, were sampled during the summer of 1980 on the Kenneth Gray farm. The Spanish onions were located on a 8.1 ha plot 29 km north of Lorenzo, Texas. The Ringmaster onions were in a 2.8 ha plot 1.6 km north of Lorenzo. Both plots were divided into four quadrats of equal size. Four samples, one from each quadrat, were taken from each variety on each sampling date.

.There were two periods of spray and subsequent population regrowth studied during the growing season. Both varieties were aerially sprayed with insecticide (Meta-Systox-R®) on 9 June. Thrips samples were taken 4, 11, and 18 days after the application, the last sampling date being 27 June. Both

varieties were again sprayed (this time with parathion) on 28 June. Samples were taken 6 and 13 days after the application.

1981 Field Season

During the summer of 1981, Yellow Grano onions were sampled on the Ben Holcomb farm 13 km south of Dimmitt, Texas. Two rectangular plots, each .04 ha were set up. One plot, in the southwest corner of the field, was marked off as the control plot and was to receive no aerial insecticide applications. The other plot, located approximately 50 meters east of the control area, was within a large area of sprayed onions. Each plot was divided into four quadrats of equal size. Eight samples, two from each quadrat, were taken on each sampling date from each plot. This gave a total of 16 samples per sampling date.

In the 1981 experiment, samples were taken from four periods of spray and subsequent thrips increase. Because both the control and the sprayed plots were sampled on the same dates, it was expected that the control plot would not

show the same population trends as the sprayed plot. Parathion was the insecticide used in all of the sprays. On 25 May, the treated plot was sprayed and thrips were sampled 4, 7, 10, and 16 days after the application. On 11 June, another application was made and samples were taken 3, 6, 11, and 14 days afterward. On 28 June, application was again made and sampling followed 2 and 6 days later. The last spray was on 5 July, and thrips samples were taken 4 and 9 days following it. On each of these sampling dates, samples (bagged onion plants) were taken and visual counts made at both control and treated plots.

At the end of the growing season, yield data were taken from the control and treated plots. Eight meters of double row onions were harvested from each quadrat and allowed to dry for one week. The onions were then graded and weighed.

Weather Information

A hydrothermograph inside a wooden shelter continuously recorded temperature and relative humidity. In 1980, the shelter was located in Lorenzo, and in 1981 it was placed on

the Ben Holcomb farm. Separate averages of the daily high and the daily low temperatures between sampling dates were calculated. The percent relative humidity was measured at three hour intervals, giving eight readings each day. The average of these readings between each sampling date was calculated.

A rainfall gauge with a capacity of 25 cm was placed in the field in 1981. Each sampling date, the amount of rainfall accumulated since the previous sampling date was recorded. The gauge was then emptied, and a few drops of oil placed inside to reduce evaporation of water collecting in the gauge.

Computer Analysis

The goals of this research were to determine how fast thrips populations on onions increase after being sprayed with insecticide, and what affect environmental factors have on this growth. If the population increased exponentially through time, it would follow the exponential growth curve (May, 1976):

$$N(t) = N(o) \times \exp[rt]$$

where N(t) is the density of thrips at time "t", N(o) is the initial density, "r" is the intrinsic growth rate, and "t" is time, which in this study is measured in days following insecticide application.

This can be converted to a statistical linear model by taking the natural logarithm of both sides:

$$\ln N(t) = \ln N(o) + rt$$

Using linear regression analysis, "r" (the intrinsic growth rate) can be estimated, and a test made as to whether the slope of this regression line differs significantly from zero. It is also possible to test whether or not the lnN(t) versus time relationship is curved: indicating that the thrips are encountering resource limitation. Other variables recorded between sampling dates, such as average high and low temperatures, average relative humidity, and rainfall accumulation were added to the model to see if they significantly affected population densities over time.

The objectives were to determine the best fitting model to describe the growth of the thrips population over time, and what weather factors were important in influencing this growth for each of the two years' data. Nymphal and adult densities for each sample were combined to obtain total density. All densities were logarithmically transformed to convert exponential growth to a linear form. Multiple regression analyses were performed by the computer, using the General Linear Models procedure of the Statistical Analysis System.

CHAPTER III

RESULTS AND DISCUSSION

1980 Field Season

The results of the regression analysis (Table 1) indicated that both time (measured in days after spraying) and average daily high temperature between sampling dates significantly affected thrips numbers. Average daily low temperature and the average relative humidity between sampling dates did not significantly affect thrips densities. An analysis of covariance showed that the growth rates of the population after the earlier and later periods of insecticide spray did not differ significantly. Analysis of covariance also showed that there was no significant difference in population rates of increase between the Spanish and Ringmaster onion varieties, nor were there significant differences among the sampling replicates.

Table 1. Linear regression analysis and parameter estimates of thrips density on onions, 1980 field season.

Source	df	MS	F
Time	1	4.1660	17.45**
High Temperature	1	3.9165	16.41**
Residual Sum of Sq.	37	0.2387	
Lack of Fit	3	0.2404	1.008 n.s.
Pure Error	34	0.2385	

Parameter	Estimate	Std. Error of Estimate
Intercept	7.0952	0.8288
Time 1/	0.09228	0.01701
High Temperature 2/	-0.09612	0.02373

** $p < 0.01$

n.s. $p > 0.05$

1/ Measured in days after spraying.

2/ Averaged between sampling dates, in ^{o}C.

Thus, the best model for describing how the thrips density increased in the 1980 season is one with two independent variables: time, measured in days after spraying, and the average of the daily high temperatures between consecutive sampling dates.

The non-significant lack of fit indicates that this linear model adequately describes the data, and that the population does increase exponentially through time after being sprayed with insecticide. There are no curved features implying resource limitation.

The regression analysis (Table 1) gives parameter estimates from which a regression equation can be found. The equation is:

$$\ln(dens) = 7.0952 + [(0.09230)(time)] - [(0.09612)(htemp)]$$

where ln(dens) is the natural logarithm of thrips density, 7.0952 is the y intercept, 0.09320 is the estimate of r (the intrinsic growth rate), time is the number of days after an

insecticide spray, 0.09612 is the high temperature constant, and htemp is the average of the daily high temperatures between consecutive sampling dates (in ° C). This function is a plane on the logarithmically transformed scale (Figure 1).

Using this model, it is possible to calculate the time it takes for the thrips population to double. At an arbitrary temperature, i.e. z° C, the initial equation becomes

$$\ln(\text{dens}) = 7.0952 + [(0.09230)(\text{time})] - [(0.09612)(z)].$$

When the population doubles, the log density will be equal to the initial log density plus the natural log of 2, at some unknown time:

$$7.0952 - [(0.09612)(z)] + 0.6931 = 7.0952 - [(0.09612)(z)] + [(0.09230)(\text{time})]$$

or

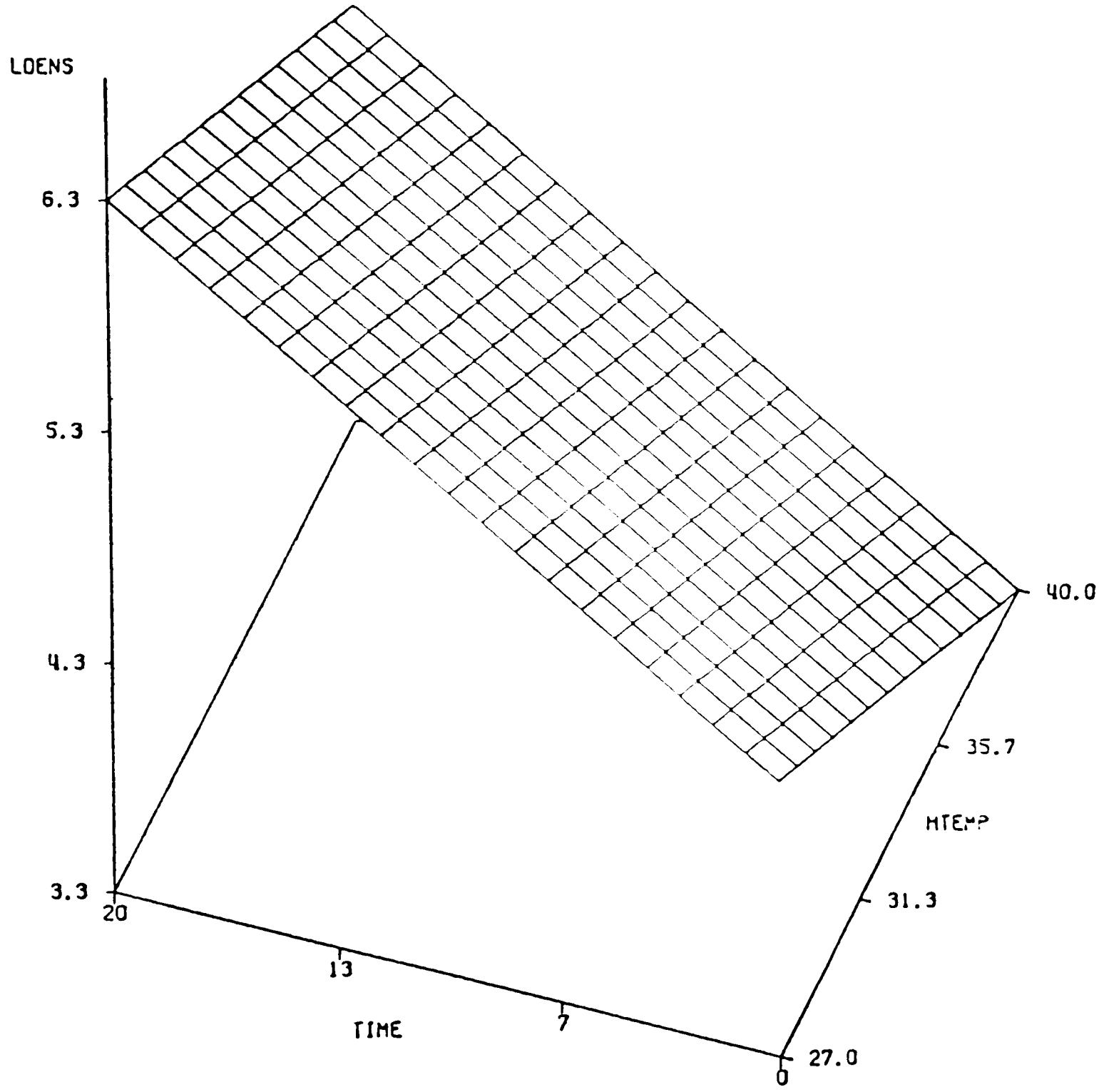

Figure 1. Three dimensional plot of logarithmically transformed thrips density per plant versus time (days after spraying) and high temperature (° C), 1980 field season.

$$0.6931 = [\,(0.09230)\,(\text{time})\,]$$

and

$$\text{time} = 7.5 \text{ days}.$$

The thrips population will double every seven and a half days. This will be true at any given temperature (within the temperature range of the model). However, the model predicts that at higher temperatures, there will tend to be fewer thrips. Even though the doubling time remains constant throughout the temperature range, at higher temperatures the initial densities are lower and thus it will take a longer time to reach a given density.

Finally, the equation for predicting the natural log of thrips densities can be transformed back into its exponential form:

$$\ln(\text{dens}) = 7.0952 + [\,(0.09230)\,(\text{time})\,] - [\,(0.0912)\,(\text{htemp})\,]$$

becomes

$$dens = exp[7.0952][exp[(0.09230)(time)]] / exp[(0.09612)(htemp)]$$

or

$$dens = 1206\{exp[(0.09230)(time) - (0.09612)(htemp)]\}.$$

This exponential form can be graphed in three dimensions, as shown in Figure 2. The inhibitory effect of increasing high temperatures on the thrips population can be seen clearly.

1981 Field Season

To improve the accuracy of a predictive model, the data from 1981 differed from those of 1980 in several ways. Thrips populations on a single onion variety (Yellow Grano) were sampled during four periods of insecticide spray and thrips regrowth. Samples were more frequently taken within each sampling period, and rainfall data were recorded. In addition, a control plot was set up to compare unsprayed population increases with sprayed population increases.

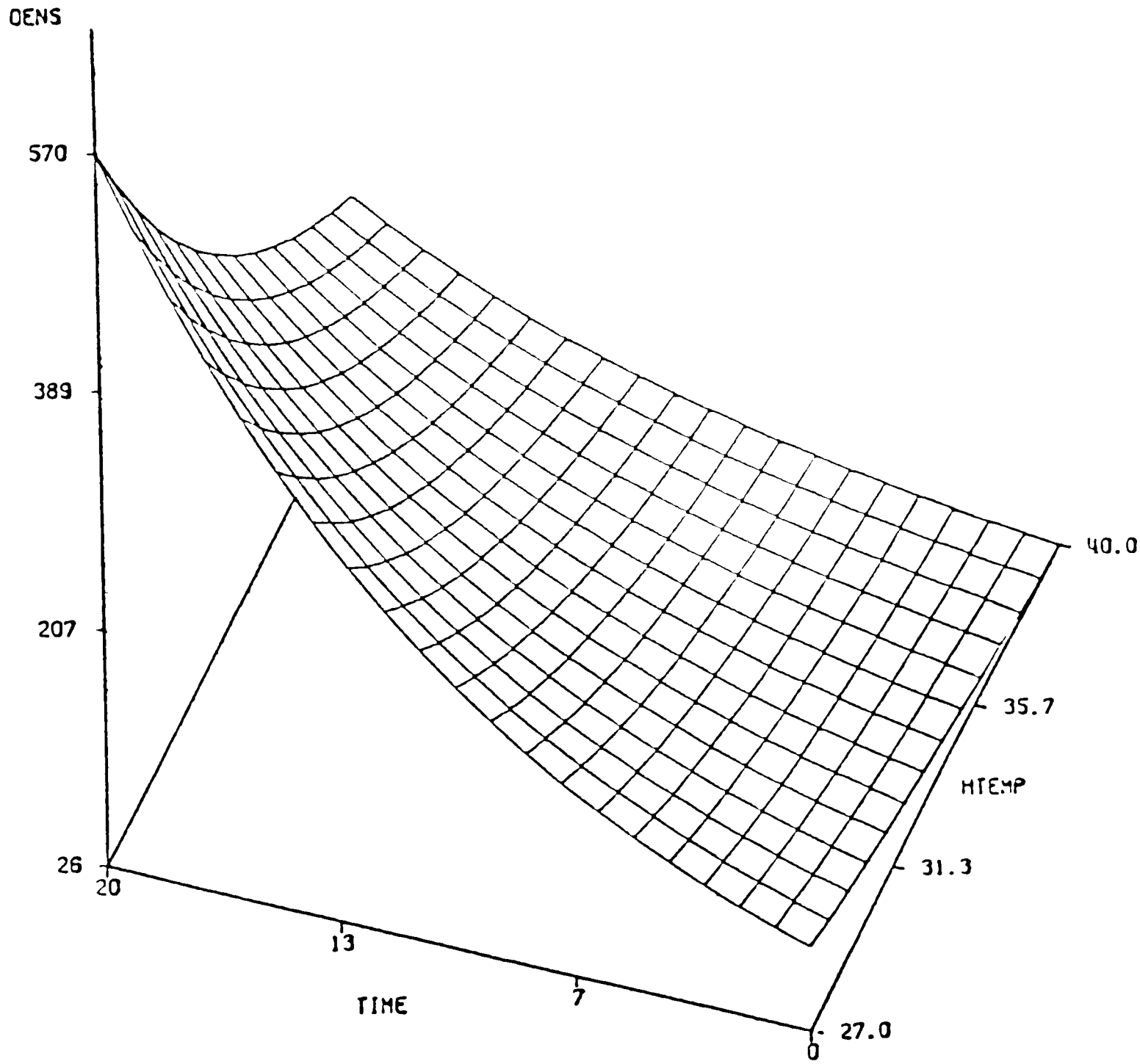

Figure 2. Three dimensional plot of thrips density per plant versus time (days after spraying) and high temperature (° C), 1980 field season.

An analysis of variance revealed that the thrips densities in the control and treated plots were not significantly different. I suspect that the control plots had been sprayed along with the treated plots, since the number of beneficial insects in both plots was also not significantly different. Separate regression models for the control and the treated plots were very similar. As the thrips densities between the two plots were statistically identical and the separate regression analyses were alike, the data were combined for further analyses.

The best fitting model appears in Table 2. As in the 1980 model, average daily high temperature between sampling dates significantly affected thrips density. Time (measured in days after spraying) was significant as an interaction term with sampling period. This meant that time did significantly affect thrips density, but its effect differed between each sampling period. Rainfall, both by itself and through its interaction with average daily high temperature, significantly affected thrips density. Relative humidity, as in 1980, was not significant in affecting the thrips

Table 2. Linear regression analysis of thrips density on onions, 1981 field season.

Source	df	MS	F
High Temperature	1	20.4542	88.34**
Rainfall	1	3.6157	15.62**
Sampling Period	3	35.8291	154.73**
Time x Sampling Period	4	0.8416	3.63**
High Temperature x Rainfall	1	1.2783	5.52*
Residual Sum of Sq.	181	0.2316	
Lack of Fit	1	0.2055	0.8869 n.s.
Pure Error	180	0.2317	

** $p < 0.01$

* $p < 0.05$

n.s. $p > 0.05$

population. There were also no significant differences among sampling replicates. The non-significant lack of fit shows that this linear model adequately describes the data, and that there are no curved features implying resource limitation.

Table 3 presents the parameter estimates for this model. Because sampling period was significant in the model, the parameter estimates actually describe four separate regression equations, one for each sampling period.

The period x time interaction was also significant, implying that each of the four equations had a different slope associated with the variable time, and had different intercepts. The other terms were the same for all four equations.

The four regression equations are:

Period 1 (25 May - 10 June):

$$\ln(\text{dens}) = 6.3204 - [(0.09734)(\text{htemp})] - [(0.3770)(\text{rnfl})] + [(0.06806)(\text{time})] + [(0.01364)(\text{htemp})(\text{rnfl})]$$

Table 3. Linear regression parameter estimates of thrips density on onions, 1981 field season.

Parameter		Estimate	Prob.>t	Std. Error of Estimate
High Temperature 1/		-0.09735	0.0001	0.02534
Rainfall 2/		-0.3770	0.00845	0.1563
Sampling Period	1	6.3204	0.00005	0.6204
	2	5.8016	0.00005	0.5784
	3	5.1513	0.00005	0.6391
	4	4.5409	0.00005	0.7030
Time x Sampling Per. 3/	1	0.06806	0.00105	0.02179
	2	0.06055	0.0348	0.03317
	3	-0.06509	0.09885	0.05034
	4	0.07949	0.02435	0.04005
High Temp. x Rainfall		0.01364	0.00995	0.00581

1/ Averaged between sampling dates, in ^{o}C.

2/ Measured in cm between sampling dates.

3/ Time measured in days after spraying.

Period 2 (11 June - 27 June):

$$\ln(\text{dens}) = 5.8016 - [(0.09734)(\text{htemp})] - [(0.3770)(\text{rnfl})] + [(0.06055)(\text{time})] + [(0.01364)(\text{htemp})(\text{rnfl})]$$

Period 3 (28 June - 4 July):

$$\ln(\text{dens}) = 5.1513 - [(0.09734)(\text{htemp})] - [(0.3770)(\text{rnfl})] + [(0.00)(\text{time})] + [(0.01364)(\text{htemp})(\text{rnfl})]$$

Period 4 (5 July - 14 July):

$$\ln(\text{dens}) = 4.5409 - [(0.09734)(\text{htemp})] - [(0.3770)(\text{rnfl})] + [(0.07949)(\text{time})] + [(0.01364)(\text{htemp})(\text{rnfl})]$$

where rnfl is centimeters of precipitation accumulated between each sampling date, and the other terms are as previously defined.

In the regression equation for Period 3, the intrinsic growth rate (the slope associated with the variable "time") was not significantly different from zero. It has, thus, been set to zero.

The four equations give estimates of the natural logarithm of thrips density given values for time (in days after spraying), an average of the daily high temperature (in ^{o} C) between sampling dates, and rainfall (in cm) accumulated since the last sampling date. Thrips densities can be determined from each equation by transforming it into its exponential form, as shown earlier for the 1980 model.

This set of four regression equations is more difficult to illustrate than the equation from the 1980 data, because there are more than two independent variables affecting thrips density and thus more than three dimensions to graph. In addition, there is an interaction occurring between high temperature and rainfall. I will use the Period 2 equation as an example.

Figures 3 through 6 show how average daily high temperature and rainfall between sampling dates affect thrips density at four time increments. (Note that density along the x axis differs with each graph.) Rainfall is detrimental to thrips populations when temperatures are cool, but it has a beneficial effect when temperatures are hot. To show how these four surfaces are related to time, I have selected an arbitrary point on each where the high temperature is 32° C and the rainfall is 10 cm. These points are labelled A, B, C, and D for the four time increments, respectively. Figure 7 is a graph of thrips density over time, with average daily high temperature held constant at 32° C and rainfall at 10 cm, for each of the sampling periods. The points A, B, C, and D on the Period 2 line illustrate how a density selected from the surfaces in Figures 3 though 6 will increase over time.

Figure 8 shows how thrips density is affected by time and high temperature in the absence of rainfall (the rainfall terms in the equation are multiplied by zero). High temperatures inhibit thrips population growth. However, Figure 9 shows an opposite effect when rainfall is held at

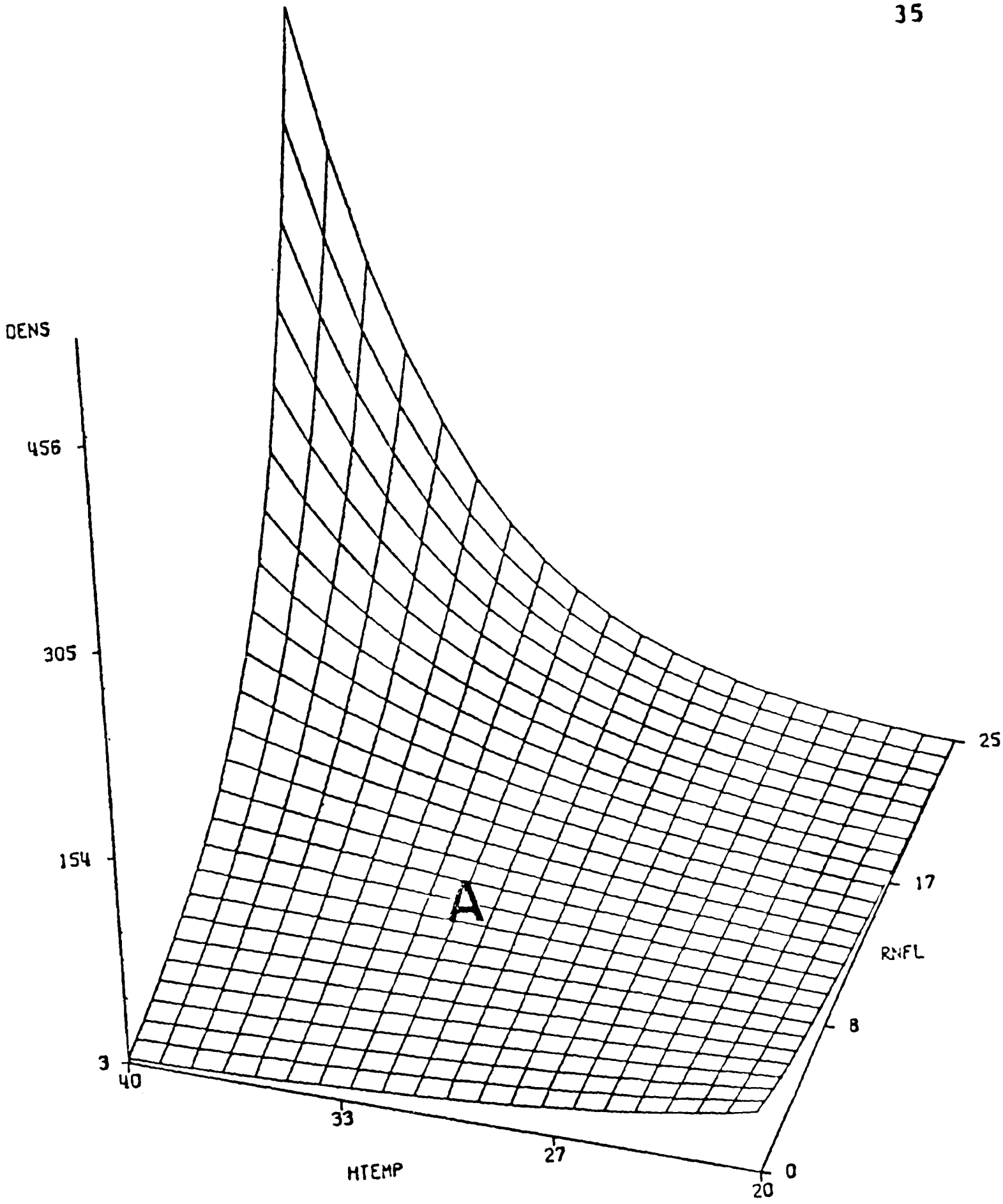

Figure 3. Three dimensional plot of thrips density per plant versus high temperature (° C) and rainfall (cm), 0 days after spraying, 1981 field season. "A" is the density when high temperature is 32° C and rainfall is 10 cm.

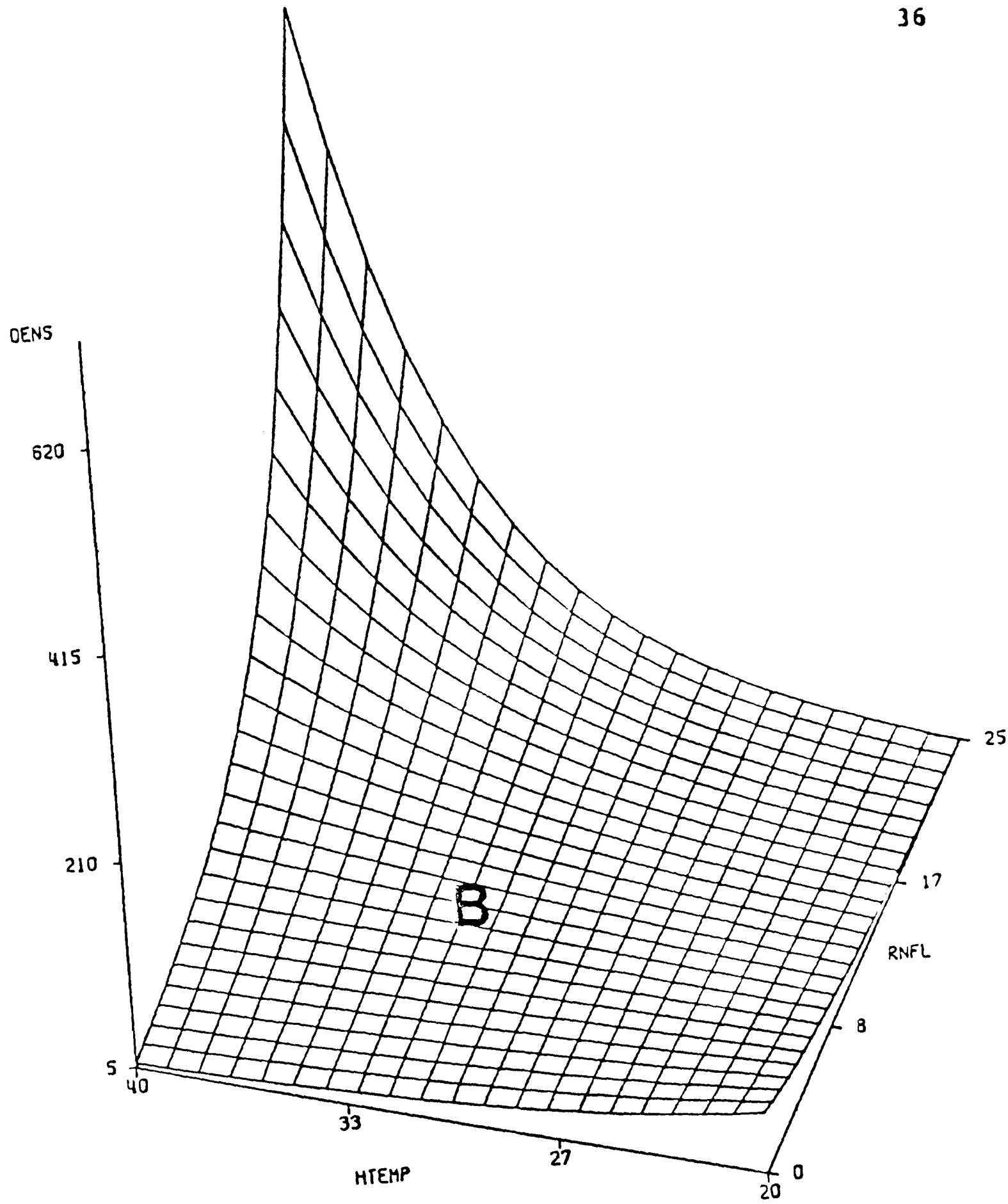

Figure 4. Three dimensional plot of thrips density per plant versus high temperature (° C) and rainfall (cm), 5 days after spraying, 1981 field season. "B" is the density when high temperature is 32° C and rainfall is 10 cm.

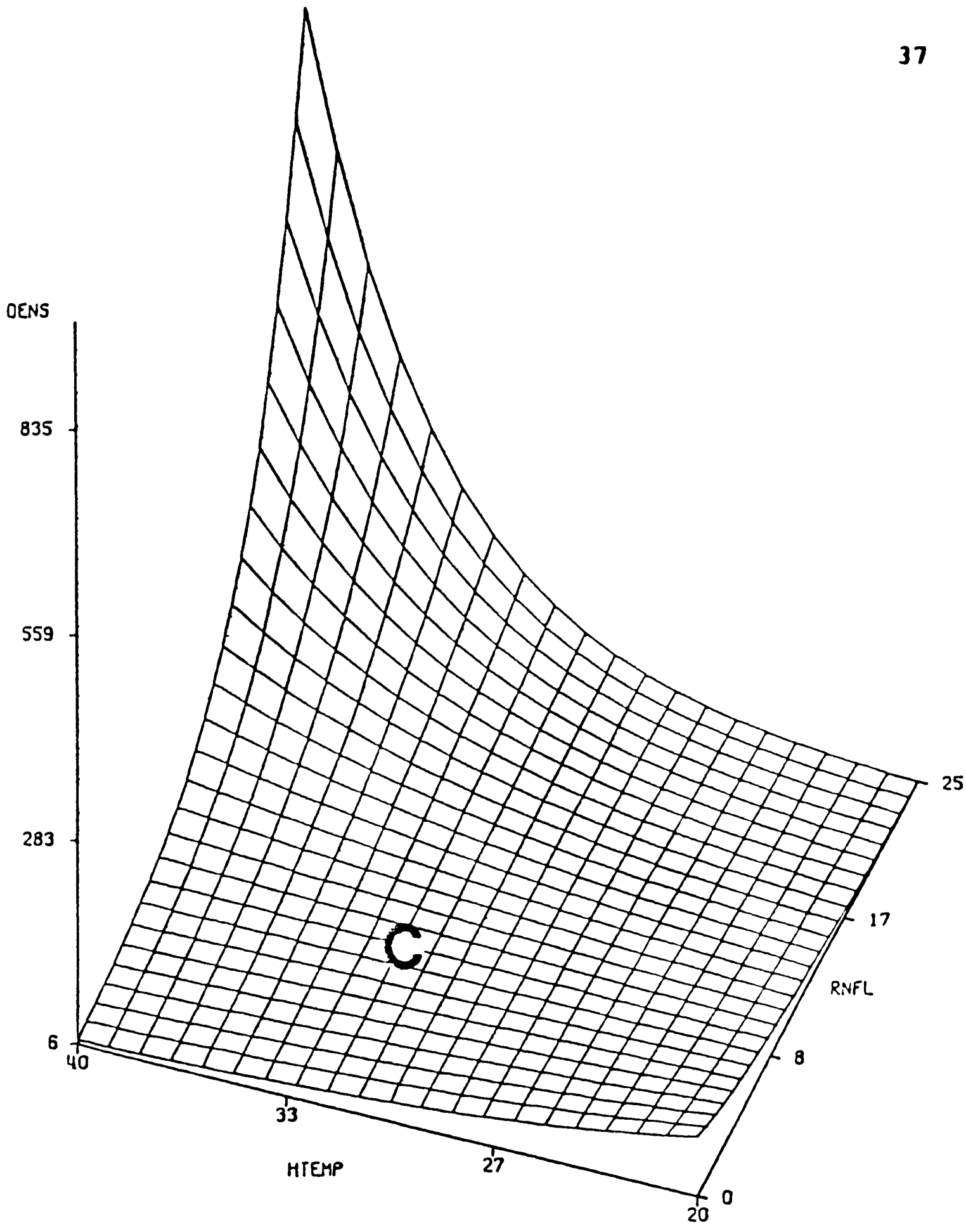

Figure 5. Three dimensional plot of thrips density per plant versus high temperature (° C) and rainfall (cm), 10 days after spraying, 1981 field season. "C" is the density when high temperature is 32° C and rainfall is 10 cm.

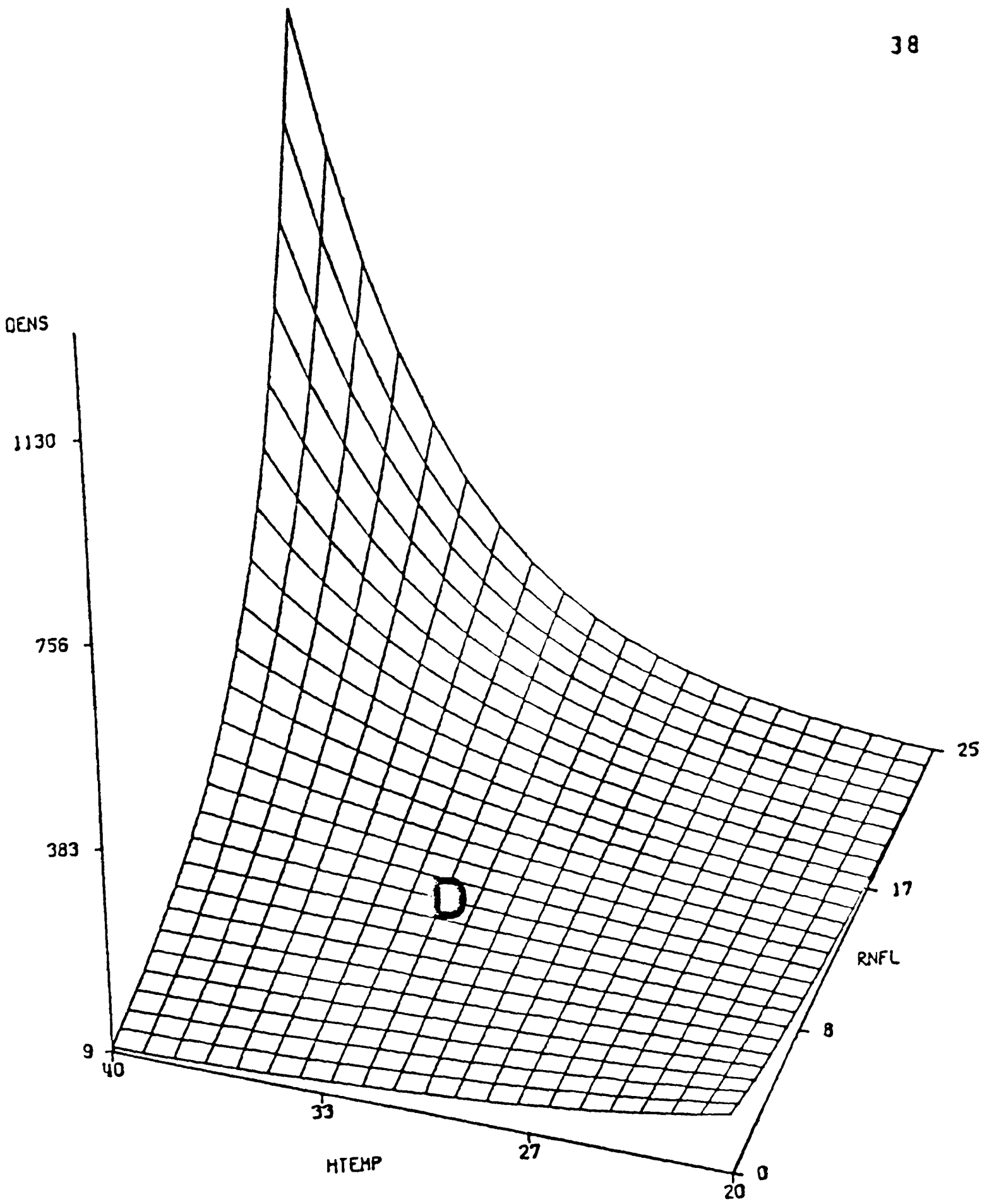

Figure 6. Three dimensional plot of thrips density per plant versus high temperature (° C) and rainfall (cm), 15 days after spraying, 1981 field season. "D" is the density when high temperature is 32° C and rainfall is 10 cm.

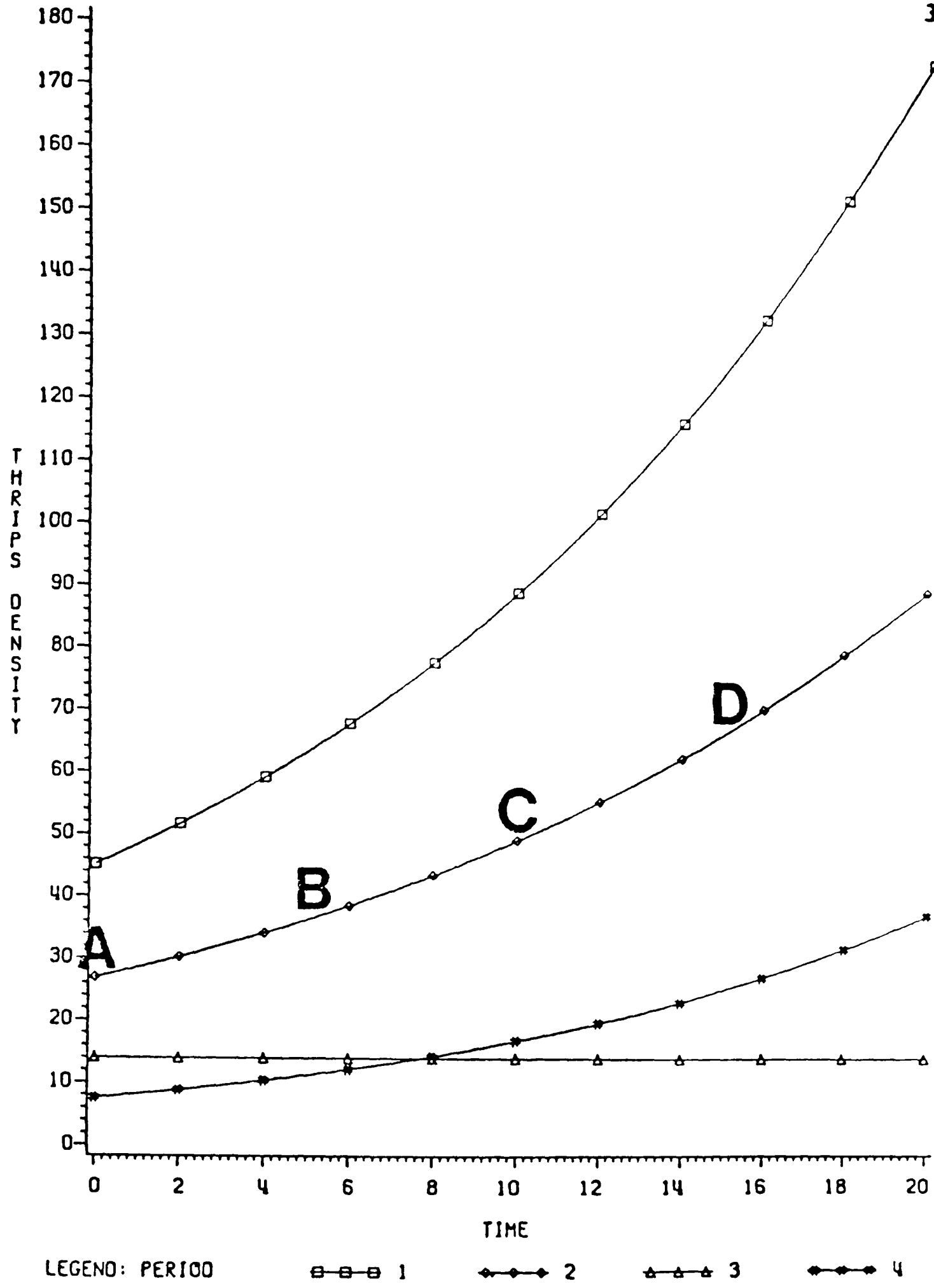

Figure 7. Plot of thrips density per plant over time (days after spraying) for each of four 1981 sampling periods, with high temperature held at 32° C and rainfall held at 10 cm. Points "A", "B", "C", and "D" on the Period 2 line are the densities selected from Figures 3 through 6.

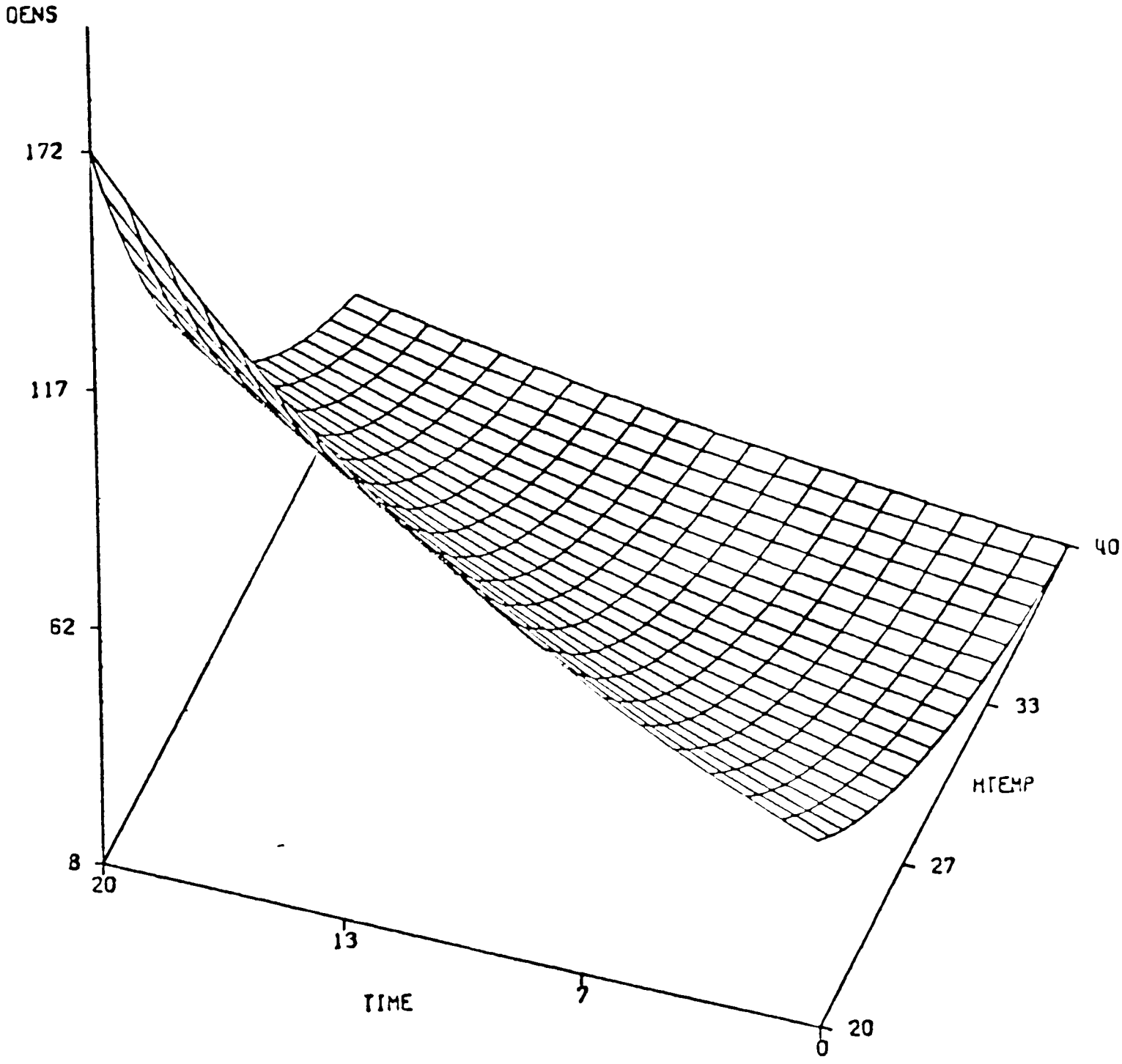

Figure 8. Three dimensional plot of thrips density per plant versus time (days after spraying) and high temperature (° C), with rainfall held at 0 cm, for 1981 field season.

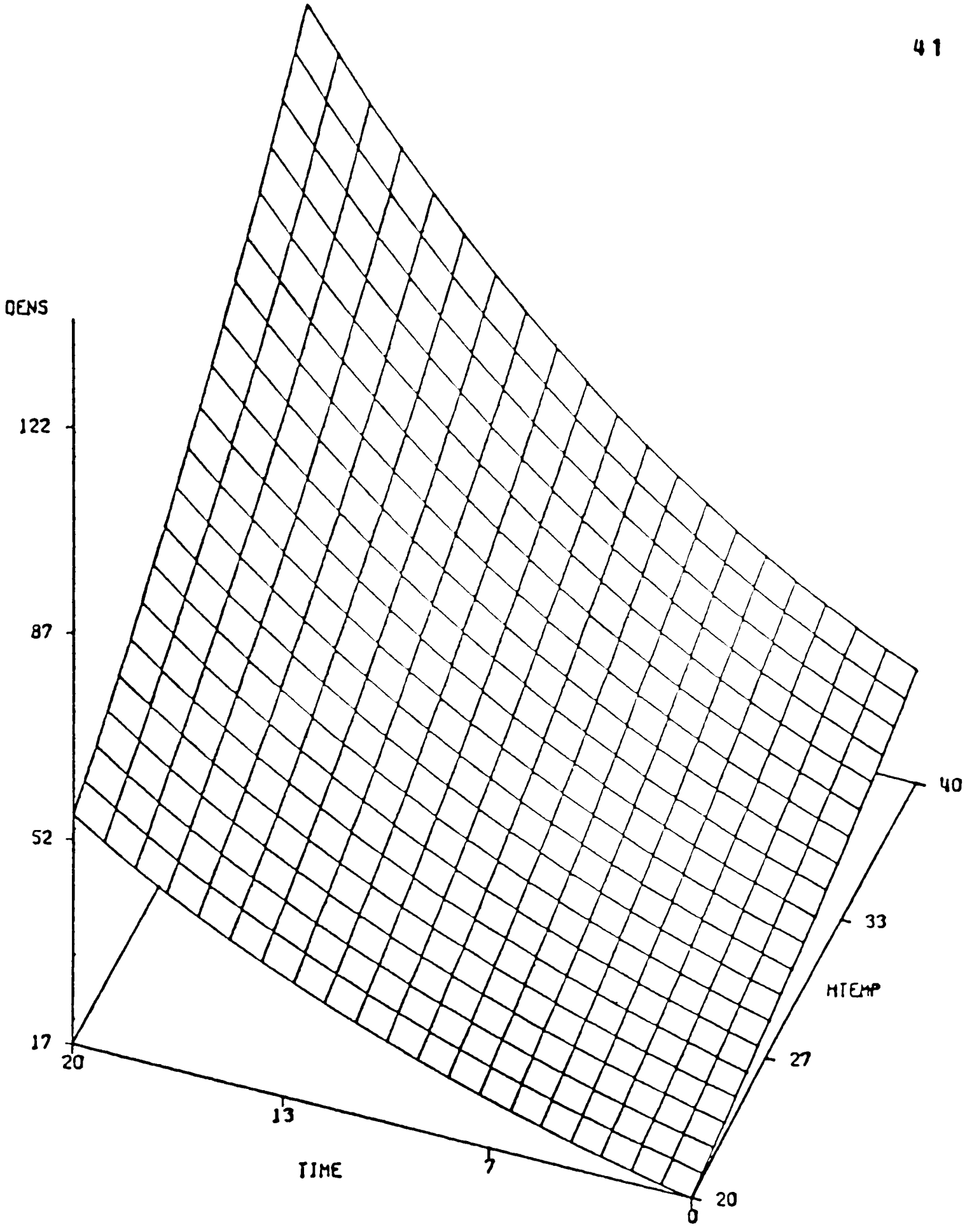

Figure 9. Three dimensional plot of thrips density per plant versus time (days after spraying) and high temperature (° C), with rainfall held at 10 cm, for 1981 field season.

10 cm: thrips densities over time increase as the high temperature increases.

These effects are based on the regression equation for the second sampling period. The effects on Periods 1 and 4 would be similar. However, in Period 3, the model shows that the density did not increase with time. Examination of the visual thrips counts indicated a similar result for Period 3, so this lack of increase probably was not due to problems with the plant wash sampling technique. This sampling period was very short, from 28 June to 4 July, and samples were taken 2 and 6 days after spraying. It is likely that more sampling dates or longer intervals between sampling dates would have revealed thrips densities increasing with time.

The doubling time for the thrips population can be calculated in the manner shown earlier for the 1980 model. For Period 1, the doubling time is 10.2 days. For Period 2, it is 11.5 days, and for Period 4 it is 8.7 days. The doubling time for Period 3 is not defined, since the slope

of the variable "time" is zero. These doubling times will be true for any given temperature (between 20° and 40° C) or rainfall (between 0 and 25 cm). However, at the higher temperatures and with little rainfall, or with lower temperatures and greater rainfall, the initial densities will be lower and it will take longer to reach a given density.

Comparison of 1980 and 1981 Models

The results from both years showed that thrips populations increased exponentially though time after being sprayed with insecticide, except in Period 3 of 1981. In 1980, the estimate of "r", the intrinsic growth rate, was 0.09230 for both sampling periods (beginning 9 June and ending 11 July). In 1981, the "r" estimate varied among the sampling periods. It was 0.06806 from 25 May to 10 June (Period 1); 0.06055 from 11 June to 27 June (Period 2); and 0.07949 from 5 July to 14 July (Period 4). The estimate for the 3rd period (28 June to 4 July) was 0, but this is probably incorrect. It is more likely that sampling over a small time interval within this period failed to detect the actual increase in density.

The predictive models from both field seasons indicate that very hot and dry conditions inhibit the growth of thrips populations. Figure 8 shows this inhibitory effect of high temperature with no rainfall on thrips densities in 1981. Although the 1980 model did not have a rainfall variable (which could be held at 0 as in Figure 8), the 1980 growing season was very dry and the effect of average high temperature shown in Figure 2 is strikingly similar to that of Figure 8. These results seem consistent with the findings of El Shaarawy et al. (1975), as well as Lublinkhof and Foster (1977) who found a constant 20° C optimal for thrips reproduction, while constant temperatures of 15° C and 30° C inhibited reproductive potential. If I had been able to measure population increases over a wider temperature range, I suspect that the curves of the surfaces in Figures 2 and 8 would decrease as the average daily high temperature decreased beyond the lower end of the scale.

The 1981 results indicated that rainfall was detrimental to thrips populations when average daily high temperatures were less than 28° C (Figures 3 through 6). This agrees

with Harding's (1961a) qualitative statement that cold rain reduces thrips populations. The 1981 results also indicated that rainfall, when average daily high temperatures were above 28° C, allowed thrips to increase at a greater rate (Figures 3 through 6). This may have been due to the cooling effect of rainfall and the increase in relative humidity, both moderating the detrimental effects of very hot temperatures. El Shaarawy *et al.* (1975) cited a mean relative humidity of 54% as being optimal for *T. tabaci* on cotton in Egypt. However, I did not find relative humidity significant in affecting thrips densities in either 1980 or 1981.

The exponential nature of both the 1980 and 1981 predictive models, which do not include terms for resource limitation, suggests that the carrying capacity of thrips on onions is much higher than the observed densities. The greatest density recorded in 1980 was 250 thrips per plant, and in 1981 it was 130 thrips per plant. Densities higher than these in the illustrations are based on the extrapolation by the models.

Analysis of variance of the 1981 yield data (Table 4) revealed that the total weight of onions harvested from the treated plot ($\bar{x}$=15.49 kg/sample) was significantly greater than that from the control plot ($\bar{x}$=13.92 kg/sample). However, analysis of variance also showed that the thrips populations were not significantly different between the control and the treated plots (Table 5). Therefore, this yield difference was not due to the effect of thrips numbers but to some other factor.

Comparison of Wash and Visual Sampling Techniques

Linear regression analysis was used to determine the relationship between plant wash and visual estimates of combined nymphal and adult thrips densities for the 1981 data (Table 6). There was a significant correlation between increasing plant wash estimates and increasing visual estimates. Sampling period was also significant, meaning that the regression estimates describe four lines, with four different y intercepts (but identical slopes) for each of the four sampling periods. These four regression equations are also listed in Table 6. Figures 10 through 13 are plots of the regression line for each of the four sampling

Table 4. Analysis of variance for total weight of Yellow Grano onions between control and treated plots, 1981 field season.

Source	df	SS	MS	F
Corrected Total	1	26581175.0000		
Treatment	1	9954025.0000	9954025.0000	8.38*
Residual Sum of Sq.	14	16627150.0000	1187653.5710	

* $p < 0.05$

Table 5. Analysis of variance for thrips populations between contol and treated plots, 1981 field season.

Source	df	SS	MS	F
Corrected Total	1	280504.6625		
Treatment	1	5.1042	5.1042	0.004331 n.s.
Residual Sum of Sq.	238	280499.5583	1178.5696	

n.s. $p > 0.05$

Table 6. Linear regression analysis and regression equations for predicting total plant wash density based on combined nymphal and adult visual estimates, 1981 field season.

Source	df	MS	F
Total Visual Density	1	34974.2960	170.85**
Sampling Period	3	16645.2564	81.31**
Residual Sum of Sq.	187	204.7051	
Lack of Fit	72	237.5734	1.2903 n.s.
Pure Error	115	184.1266	

Period 1 (25 May - 10 June):

wash density = 49.2960 + [(0.5234)(total visual density)]

Period 2 (11 June - 27 June):

wash density = 21.3400 + [(0.5234)(total visual density)]

Period 3 (28 June - 4 July):

wash density = 5.5230 + [(0.5234)(total visual density)]

Period 4 (5 July - 14 July):

wash density = 6.0484 + [(0.5234)(total visual density)]

** $p < 0.01$

n.s. $p > 0.05$

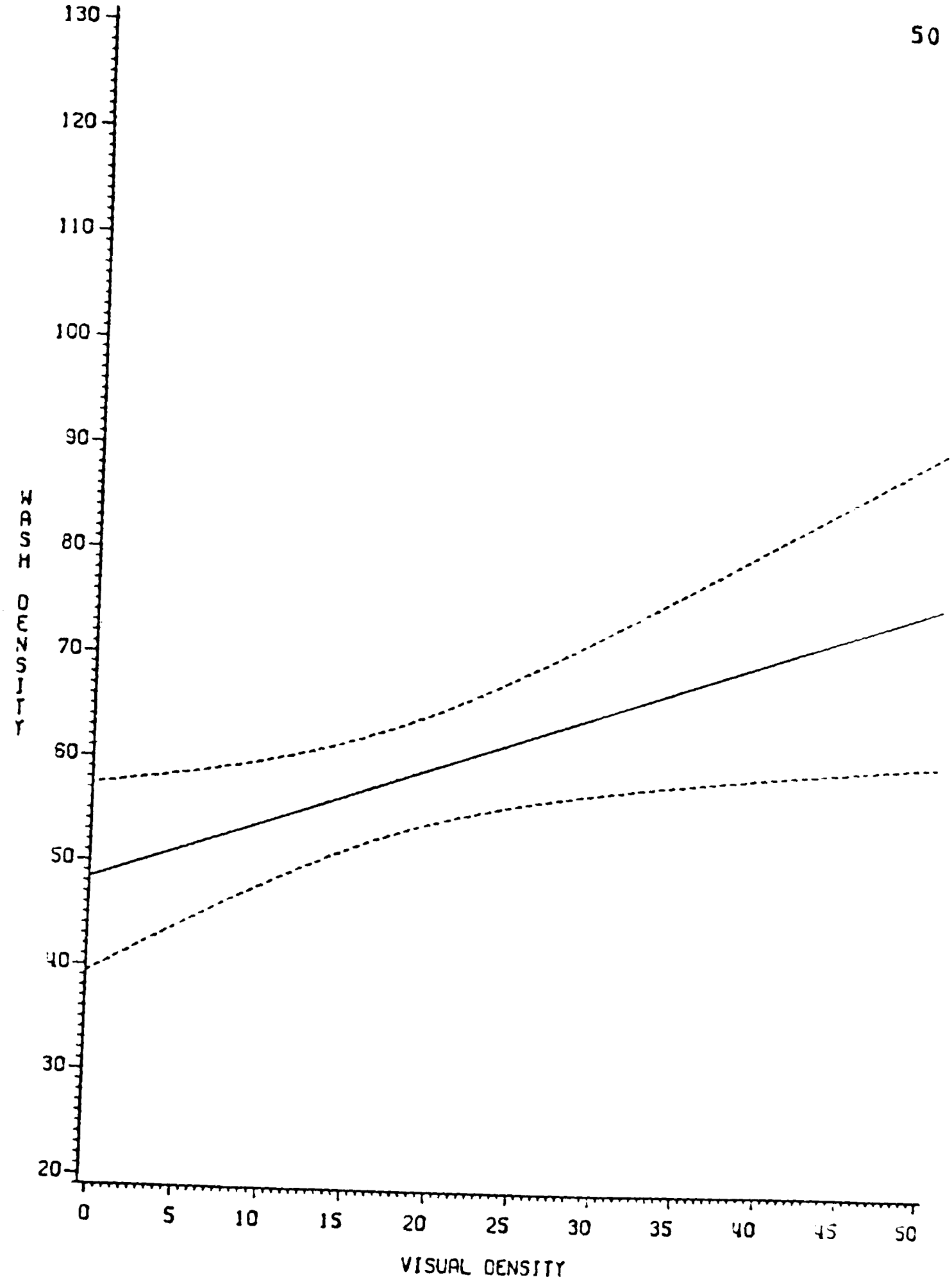

Figure 10. Plot of wash density versus visual density with 95% confidence limits, for Period 1, 1981 field season.

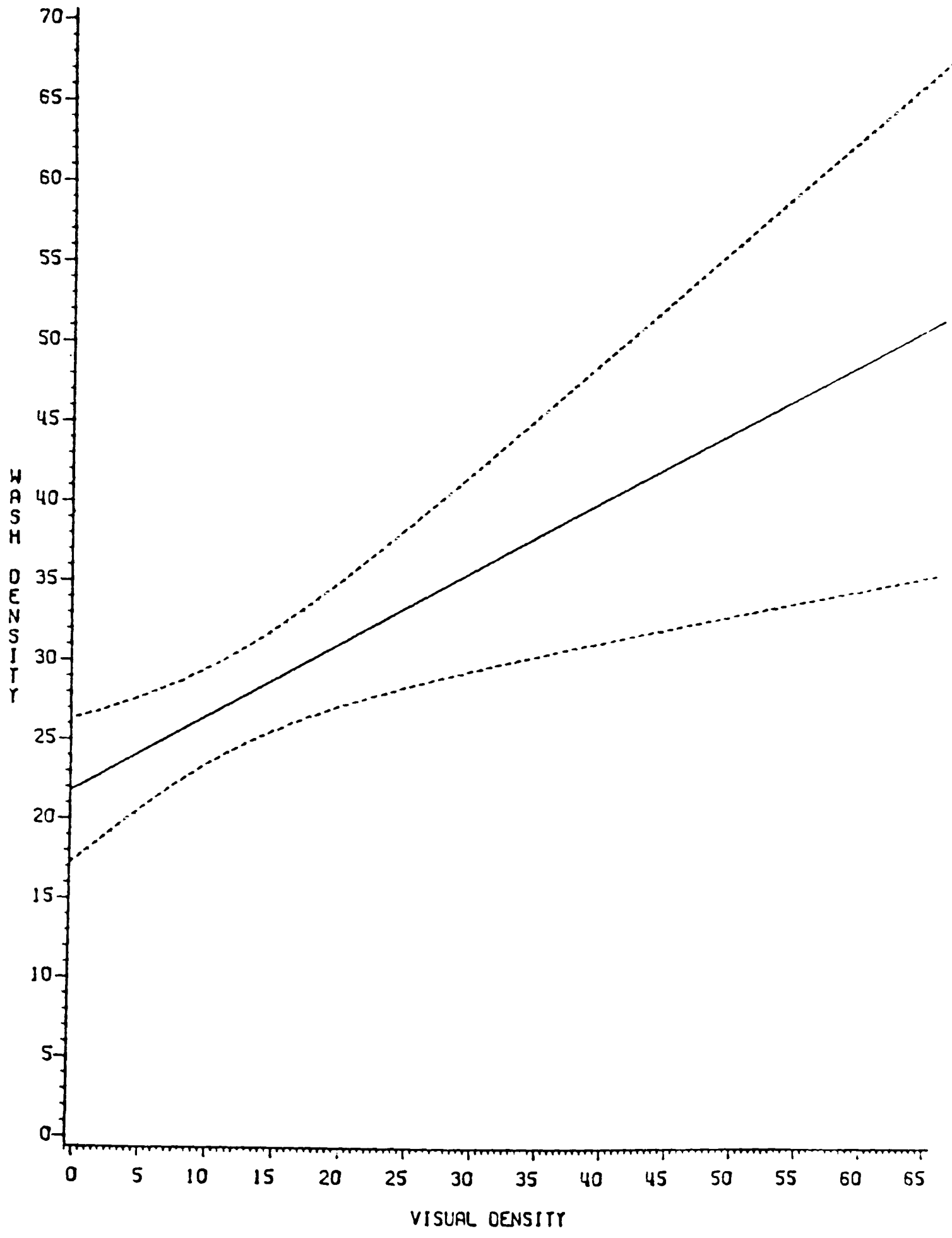

Figure 11. Plot of wash density versus visual density with 95% confidence limits, for Period 2, 1981 field season.

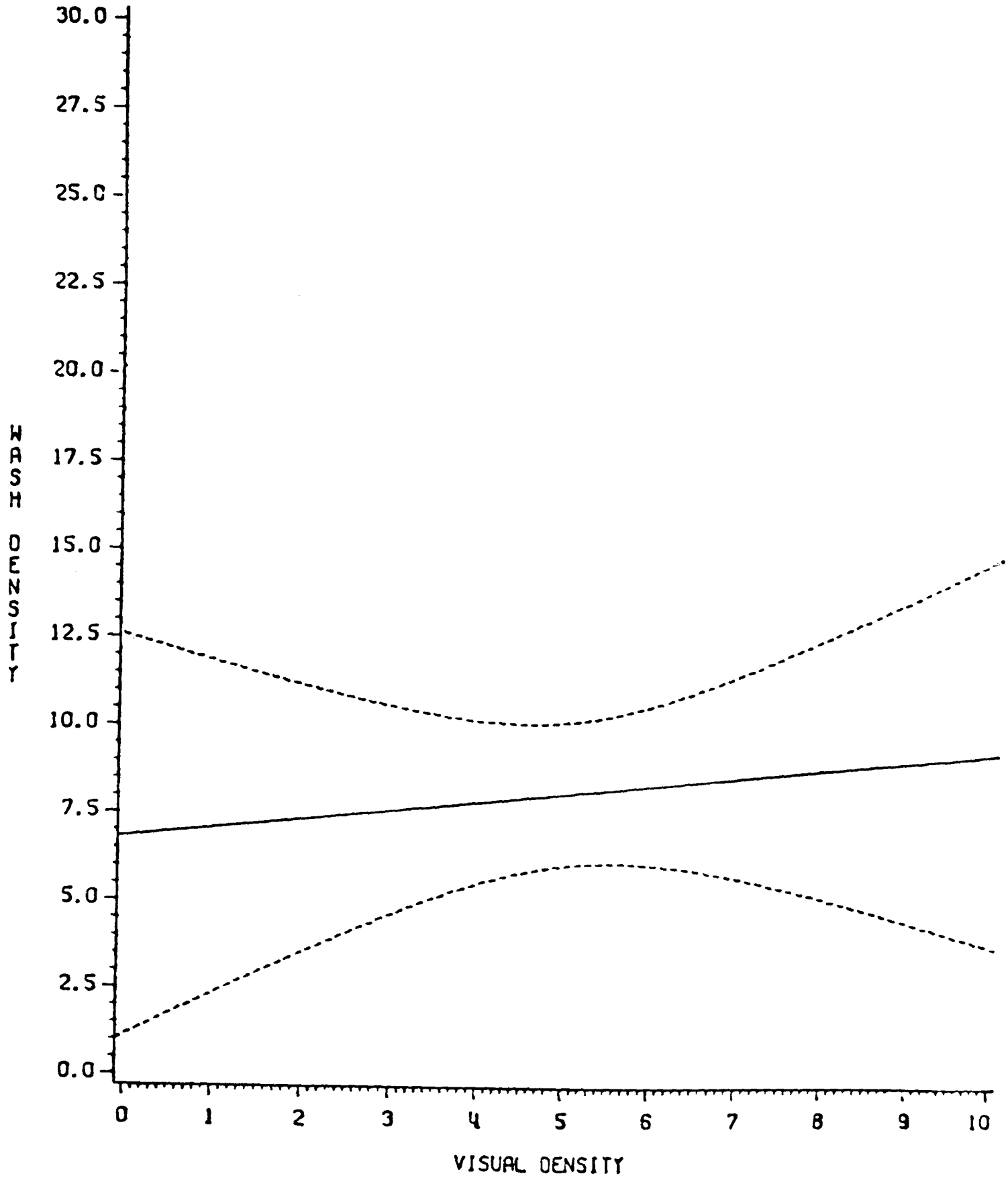

Figure 12. Plot of wash density versus visual density with 95% confidence limits, for Period 3, 1981 field season.

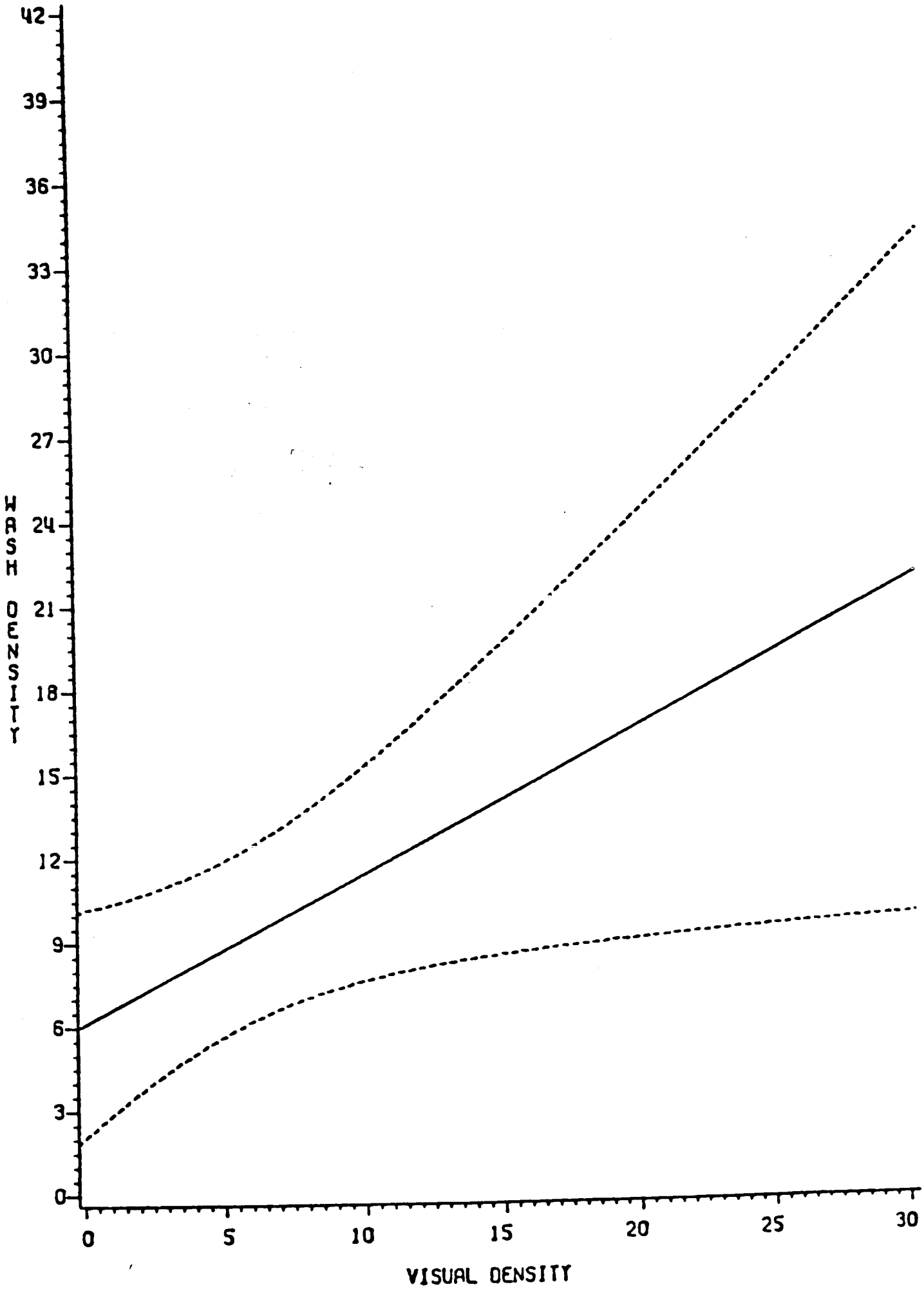

Figure 13. Plot of wash density versus visual density with 95% confidence limits, for Period 4, 1981 field season.

periods, with 95% confidence limits. (Note that the scales of both axes differ between graphs; the slopes of the four lines are the same.) A comparison of the plots shows that as the growing season progressed, visual estimates of thrips density approached the plant wash estimates. Scott (pers. comm.) found that as onion plants mature, thrips are more likely to be found near the top of the plant. If thrips are more easily seen and counted when near the top of the plant, visual estimates would be increasingly better indicators of absolute density as the growing season progresses. This may explain why the visual estimates of combined nymphal and adult densities improved with each sampling date.

Similar regression analyses were performed by separating nymphal and adult densities (Tables 7 and 8). However, the significant lack of fit of both regression analyses indicates that combining nymphal and adult visual estimates (as in Table 6) would more accurately predict absolute density than counts of nymphs or adults alone.

Table 7. Linear regression analysis for predicting nymphal wash density from nymphal visual estimates, 1981 field season.

Source	df	MS	F
Nymphal Visual Density	1	8958.7766	89.38**
Sampling Period	3	4080.4715	40.71**
Residual Sum of Sq.	187	340.8078	
Lack of Fit	55	161.6738	2.17**
Pure Error	132	74.6391	

** $p < 0.01$

Table 8. Linear regression analysis for predicting adult wash density from adult visual estimates, 1981 field season.

Source	df	MS	F
Adult Visual Density	1	8596.0749	131.79**
Sampling Period	3	4934.1366	75.65**
Residual Sum of Sq.	187	65.2233	
Lack of Fit	36	134.5400	2.76**
Pure Error	151	48.7000	

** $p < 0.01$

I had previously thought the plant wash technique would more accurately estimate the absolute density of thrips per plant than would a visual count. However, with the exception of the first sampling period, the wash and visual density estimates converge and the added labor of washing the plants was not worth the effort.

CHAPTER IV

CONCLUSION

The predictive models developed in this thesis identify and quantify variables influencing thrips population dynamics. The densities of thrips increased exponentially after being sprayed with insecticide. This exponential growth was hindered by hot, dry conditions (Figures 2 and 8) and cold, wet weather (Figures 3 through 6); whereas hot, wet conditions aided this increase (Figures 3 through 6). The density of thrips on onions can be predicted if the number of days since spraying, the average daily high temperature between sampling dates (in ^{o} C), and the amount of rain accumulated between sampling dates (in cm) are known.

If accurate economic thresholds were available for thrips on onions, these models could be used to predict when populations of thrips should be sprayed to optimize onion

yields versus the cost of insecticide applications. However, the recommended threshold levels for insecticide application that have appeared in the literature seem to be nowhere near actual economic thresholds. Determination of accurate economic thresholds will require a detailed experimental design, with thrips populations at varying levels correlated with yield (Passlow, 1957). This is very difficult to do because thrips populations are quite variable and in a given year might never build up to the high densities necessary for such an experiment. Even if thrips densities were great enough to regulate at different population levels, unpredictable weather conditions could drastically reduce thrips numbers and invalidate the experiment. Any field experiments would probably have to be done over at least several years.

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