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FACTORS INFLUENCING STORED OAT INSECT POPULATIONS IN EASTERN SOUTH DAKOTA

BY

JACK ADRIAN INGEMANSEN

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science
Major in Entomology

South Dakota State University
1985

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FACTORS INFLUENCING STORED OAT INSECT POPULATIONS IN EASTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dale L. Reeves
Thesis Adviser

Date

Maurice L. Horton
Head, Plant Science Department

Date

ACKNOWLEDGEMENTS

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INTRODUCTION

South Dakota has been one of the top two states in oat production over the past five years. During this time South Dakota's average production was 12,914,036 quintals (88,784,000) bushels. The eastern one-fourth of the state and western Minnesota as well are known for the production of good quality and high test weight oats. Because of the high production in this region, much of the oats is marketed for a premium to millers and race horse feed packers. It is estimated 10-15% of the total production in South Dakota is used for these two industries.

Oats delivered to the elevator containing live insects can lose this premium because of their mere presence. The Food and Drug Administration ruled that grain is unfit for human consumption if it contains two percent insect damaged kernels (Larrick 1956). Oats can be graded weevily if it contains (a) two or more live weevils per representative lot, (b) 15 or more other live insects injurious to stored grain, including Anguomois moths (Grain Inspection Handbook 1980).

In a survey of 360 elevators, 75% of the elevators are now applying a 0.2-2.9¢/quintal (1-20¢/bushel) discount for insect presence in all grains. The average discount was 0.8¢/quintal (5.2¢/bushel) (Grain Quality Newsletter 1982). This agrees with a 100 elevator unpublished survey done by myself prior to the sampling of the oat bins. Seventy-seven percent of the elevators discounted for insects specificially in oats with a range of 0.2-3.6¢/quintal

(1-25¢/bushel) and an average discount of 0.6¢/quintal (3.8¢/bushel). Milling premiums for the elevator operator were 0.4¢-3.6¢/quintal (3-25¢/bushel) and an average of 1.7¢ (11.6¢). It has been also estimated that the farmer premium could be as high as 1.5¢/quintal (10¢/bushel). Most buyers of premium oats have indicated they refuse any oats containing live insects.

The objectives of this research project were to (1) identify the major stored grain insects that infest stored oats in South Dakota, (2) to calculate insect densities over the main storage period, (3) to identify the factors that contribute to insect infestations in stored oats, and (4) to gather information that would provide for better recommendations on how to reduce insect infestations.

LITERATURE REVIEW

One of the major problems in storing grain is the infestation by stored grain insects. Many methods have been tried to control these infestations. Methods used centuries ago were to bury grain in the ground and line the holes with straw. In the mid 1800's they covered the grain with leaves from aromatic plants. Many formulations of dusts such as oil, lime, soil, sand, ashes and sulfur were mixed with the grain in order to make it unattractive to insects. One of the most effective methods was to expose the grain to direct sunlight. This killed a majority of the insects and dried the grain which made it unattractive to insects. Most of these early attempts were somewhat unsuccessful and until fumigation and modern grain handling systems came along insects were a major problem of stored grain. This problem caused a reduction of up to 10% of the grain tonnage (Cotton 1963).

Stored grain insects that currently infest oats consist mostly of secondary insects (Storey et al. 1983). These insects feed only on cracked grain or mold. They are often referred to as "bran bugs" (Cotton 1963). The secondary insects do not burrow directly into the seed like the primary insects such as the weevils and the grain borers. They do their damage by creating grain heating and mold or by their presence in grain.

The rusty grain beetle, *Cryptolestes ferrugineus* (Steph.), and the sawtoothed grain beetle, *Oryzaephilus surinamensis* (Linnaeus) were found to be the two most common insects in heated oats in

Canada. The foreign grain beetle, *Ahasverus advena* (Waltl), was also found to be a problem in some of the samples of heated oats (Sinha 1961).

Life Cycles

The sawtoothed grain beetle is the major pest of stored oats (Storey et al. 1983). It is a small, slender brown beetle about one-fourth of a centimeter long. On its thorax are six sawtooth-like projections on each side. Both the adult and larval forms attack stored grain and grain products. The adults can live up to three years, but more live from six to ten months. The female will lay 45 to 285 eggs, dropping them on foodstuff or tucking them away in kernel crevices. The eggs will hatch in three to five days.

When the larvae emerge they do not feed on a single grain, but move around and actively feed. During the summer months, the larvae will become fully grown in about two weeks. At this time it will secrete a sticky cocoon-like covering that joins small grains together. The larvae then evolve into a pupal stage that lasts about one week. Under ideal conditions it takes about four weeks to develop from egg to adult (U.S.D.A. 1978, Cotton 1963).

The flat grain beetle, *Cryptolestes pusillus* (Schoenherr), and the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), are very similar in appearance and size. Many researchers combine these two species because of their similar habits. Combined they are the second worst pest of stored oats (Storey et al.

1983). The two species differ in their antennae length. The rusty grain beetle's is about one-half the length of the body while the flat grain beetle's is about two-thirds as long as it's body (Pratt and Scott 1959). The rusty grain beetle is also more cold resistant and more commonly found in stored grain than the flat grain beetle. Both species are very small, flat, reddish brown beetles about one-eighth of a centimeter long. They act as scavangers feeding on grain that has been attacked by the primary insects.

The female lays her eggs in small grain crevices. The larvae prefer to feed on wheat germ and also other dead insects. When the larvae are fully grown they form a cocoon of a gelantinous substance to which food particles stick. They emerge into the pupal stage in the cocoons and then become adults. Under ideal conditions these insects may develop from egg to adult in five weeks but the average development is nine weeks (U.S.D.A. 1978, Cotton, 1963).

As many as 60% of the rusty grain beetle adults can survive exposure to -12^{o}C for 28 days. The eggs can also withstand very high phosphine doses. A 24-hour exposure to 4 g/m^3 of phosphine at 19^{o}C produced only 50% mortality of 0-1 day old eggs (Banks 1979).

The third most important pest of stored oats is the red flour beetle, Tribolium castaneum (Herbst). It is very similar to the confused flour beetle, Tribolium confusum Jacquelin du Val.

The last few segments of the red flour beetle's antennal segments enlarge abruptly whereas the confused flour beetle's antennal segments gradually enlarge to the antennae tip (Pratt and Scott 1959). The red flour beetle is generally found as a pest of milled products and cause a nauseous smell and taste to material it infests. It attacks only grain dust and broken grain surfaces.

The average life of the red flour beetle is about one year. The female lays an average of 450 eggs. These eggs are covered with a sticky secretion and become covered with flour or meal and stick to the sides of boxes, sacks and containers. Eggs hatch in five to 12 days. Full grown larvae are one half of a centimeter long and are a white-tinged yellow color. These larvae feed on flour, grain dust and broken kernels. The period of egg to adult is six weeks under favorable conditions (U.S.D.A., 1978, Cotton 1963).

Some of the minor species found in oats are psocids, weevils, *Dermestes spp.*, the lesser grain borer, the larger black flour beetle, cadelle, the hairy fungus beetle, *Tribolium audax* Halstead and spider beetles (Storey et al. 1983).

Recent Surveys

Very little is known about stored grain insects in South Dakota. Even less is known about the insect problem in stored oats. In the few recent surveys conducted in the midwest the processing of the grain samples was very similar. Each survey sieved the grain with a 10 or 12 mesh screen and made insect counts on the screenings. Bell et al. (1971) did their screenings at the bin sites while the others conducted their screening in the laboratory. Only Storey et al. (1982, 1983) placed the screenings and the screened grain in 0.95 liter jars for an incubation period of three to six weeks, depending on the insect species. Counts of the adults that emerged from the larval stage at sampling were added to the original count. Insect density per kilogram was used as a basis for insect population.

In 1971 and 1979-80, two farm-stored grain surveys were conducted in Kansas of all grains (Bell 1980, Bell et al. 1971). A 27 county area was surveyed from December through February. A standard grain probe was used for sampling the grain. They took three different samples; a horizontal surface, a vertical center and a south wall vertical.

In 1980, a Kansas survey of stored sorghum of 22 counties was conducted from January through May (Mills and Pedersen 1980). They sampled the top 2.5 meters of the grain with a 1.6 meter trier and a 0.9 meter extension. Sampling the lower part of the grain was found to be somewhat difficult. The samples taken were from one horizontal probe just under the surface, one vertical probe in the bin center and four vertical probes at the cardinal points one meter from the bin wall. They found some bins were peaked so high they could not be entered, thus fewer samples were taken.

In a 1977-78 Minnesota stored wheat and corn survey of four different counties was conducted during August and September

(Barak and Harein 1981). A 1.6 meter, 10 partition grain trier was used for a horizontal sample 10 cm. below the surface in an undisturbed area. Samples were also taken close to the north and south walls and half way between the center and wall. Deep cup samples were taken in the center of the bin at one meter intervals from top to the bottom of the bin.

The U.S.D.A. Grain Marketing Research Laboratory in Manhattan, Kansas conducted a 27 state survey of stored grain insect populations in wheat, corn and oats in 1980 (Storey et al. 1983). The grain samples were from the 1976, 1977, 1978 and 1979 crop years. Farm storage on loan to the ASCS was randomly sampled. Officials of the local offices of the ASCS took a representative sample from each bin using a probe to collect the sample. They sampled the wheat and oat bins in June and July and the corn in September and October.

Only two of the surveys deal with insect problems in stored oats. Bell et al. (1971) sampled nine bins in Kansas and found eight of the bins contained live insects and 12 different insect species present. The major pests included the sawtoothed grain beetle, the red flour beetle, <u>Cryptolestes</u> spp., the hairy fungus beetle, the foreign grain beetle and book lice.

Storey et al. (1983) found 56.4% of the oat samples contained one or more live stored-product insects. The average insect density per kilogram was 39 for all species in the infested samples. No constant relationship was found between the incidence of insects and the length of time each commodity had been stored on the farm. There was also no correlation of insect density and the length of time the oats was in storage. They found that in successive crop years, 90% of the same insect species were found all four years.

Nearly all of the oat samples taken were from South Dakota, North Dakota, and Minnesota. Insect incidence was almost identical in South Dakota and Minnesota, but the average densities in Minnesota (61/kg) and South Dakota (34/kg) were significantly different.

Wooden bins were found to have 10% higher insect incidences than steel circular bins. Fifty-six percent of the bins sampled were steel while 36% were wood.

Insect incidences increased with higher moisture up to the 11% range; held constant in the 12% range and declined above 13%. However, insect densities in oats containing more than 13% moisture were significantly higher.

The sawtoothed grain beetle preferred moisture levels in oats below 12% and decreased in incidence and density with moisture levels above 12%. Cryptolestes spp. incidence and density increased progressively through each higher moisture level up to 13% and then declined above that level. Tribolium spp. were most commonly found in a moisture range of 10 to 10.9%. They concluded the risk of grain becoming infested increased when grain is stored at high moisture levels. Storing grain at lower moisture levels would not necessarily eliminate infestations because many species are readily adaptable to dry grain, but it would help reduce the severity of the infestations.

Present Recommendations

The entomologists in the North Central region basically agree on what must be done by farmers to prevent insect infestations. The South Dakota Cooperative Extension Service recommends cleaning up residue in harvest equipment from the previous crop year. Spilled grain in and around the bin site along with junk piles, weeds and tall grasses should also be removed.

New grain should never be put on top of old grain. Brooms, shovels, or vacuum cleaners should be used to clean the walls and floors. False floors should be removed and cleaned because they are ideal growing areas for flour beetles.

High moisture levels and grain temperatures of above 16^{o} along with grain dockage interact to provide conditions favorable for insect reproduction and survival. If the grain temperature is above 16^{o} insects can reproduce. Bins should be checked every one or two weeks in the summer months and every four to six weeks in the winter months (Cooperative Extension Service 1980).

The Nebraska Extension Service adds to the South Dakota Extension Service recommendation by saying never to store small grains above 12% moisture (Peters n.d.).

The Purdue Extension Service suggests covering the aeration fans when not in use. This prevents rapid grain cooling in the winter and rapid heating in the summer and will help keep rodents and insects out of the duct system. When inspecting the grain, walk over it and poke your arm or a rod into the grain mass. Smell, feel and look for signs of hot spots or other problems. Also do not fill the bin to a peak. This interferes with air flow and moisture movement throughout the grain (Foster and McKenzie 1979).

The source of infestations may come from nearby sources such as feed mills and other stored grain (Cotton 1963, American Cyanamid 1981). One can obtain stored grain insects at great distances from the bin site (Future Trends 1982).

If stored grain insects are found in stored grain it should be dealt with great concern. Control must be taken if the primary pests are present or if there are enough of the seconary insects present to cause heating. If there are just a few secondary insects found at the end of the warm season and the grain is cooling there is no need for concern, but the grain should be kept under observation throughout the winter months (Cotton 1963).

MATERIALS AND METHODS

1982-1983 Study

In order to obtain a random sample of farmers that stored oats, an elevator survey was conducted in 17 high oat producing counties in eastern South Dakota. Elevator operators were asked for names of farmers who stored oats and who they thought might cooperate with this study. Approximately 850 names of farmers were collected from 93 elevators. A random sample was taken from each county on a basis of sampling one bin for every 256,000 quintals (800,000 bushels) produced. Production from each county was averaged for the 1977 through 1981 crop years. Figure 1 shows the average production of each county represented and the locations of the 58 bins that were sampled.

Much of the oats in eastern South Dakota is stored for less than one year. This oats is harvested and binned in late July and early August. A majority of the oats is marketed from January through April. The bins filled with 1982 oats were first sampled in mid August of 1982 and sampled at six week intervals until April 1, 1983. Each bin was sampled six times unless marketed prior to April 1, 1983. The sampling was started in the southern counties of Bon Homme and Yankton and continued northward until all of the bins were sampled. One complete sampling took two weeks. The next complete sampling was done in the same order and started six weeks after the first bin was sampled.

The bin sampling procedures used were very similar to

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1982-1983 Bin Sampling Locations

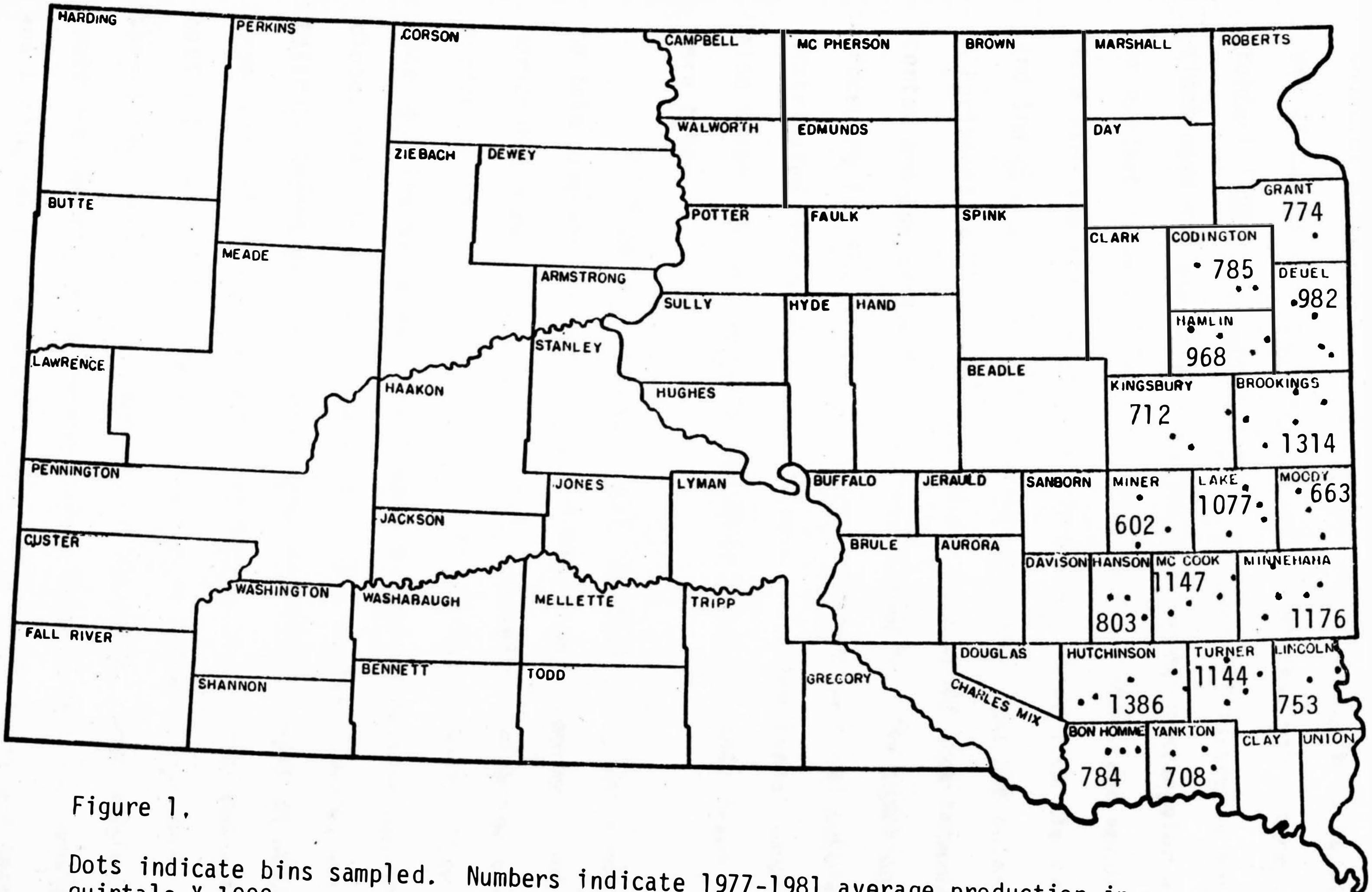

Figure 1.

Dots indicate bins sampled. Numbers indicate 1977-1981 average production in quintals X 1000.

those of Mills and Pedersen (1980). The procedure to be used was discussed in detail in personal interviews with Storey (1982), Kantack (1982) and Berndt (1982). Figure 2 illustrates the sampling sites used for the steel circular, the wooden rectangular and flat or quonset storage. The procedures for the steel and wooden bins were very similar. A vertical sample was taken from the center and the four cardinal points about one meter from the outer wall. A horizontal sample was taken in an undisturbed area between the center and one of the other vertical samples. The sampling procedure for flat storage consisted of nine vertical samples evenly distributed throughout the grain mass. Two horizontal samples were also taken. Some bins were peaked to the roof, thus fewer samples were taken.

A 1.6 meter, 10 compartment Seedburo grain probe was used to take samples. Only the top 1.6 meters were sampled. The horizontal samples were taken 10-15 centimeters below the grain surface. The probe was inserted with the compartments closed and face up. The slide was then opened to let the oats in and then closed prior to removing the probe. The vertical samples were taken by inserting the closed probe at a slight angle of about 10^o from vertical with the compartment facing to the side where the oats enter when the slide on the probe is opened. The slide was then closed prior to the removing of the probe. When removed, the probe was opened over a two meter eave trough. All the vertical and horizontal samples were bulked in the eave trough and deposited

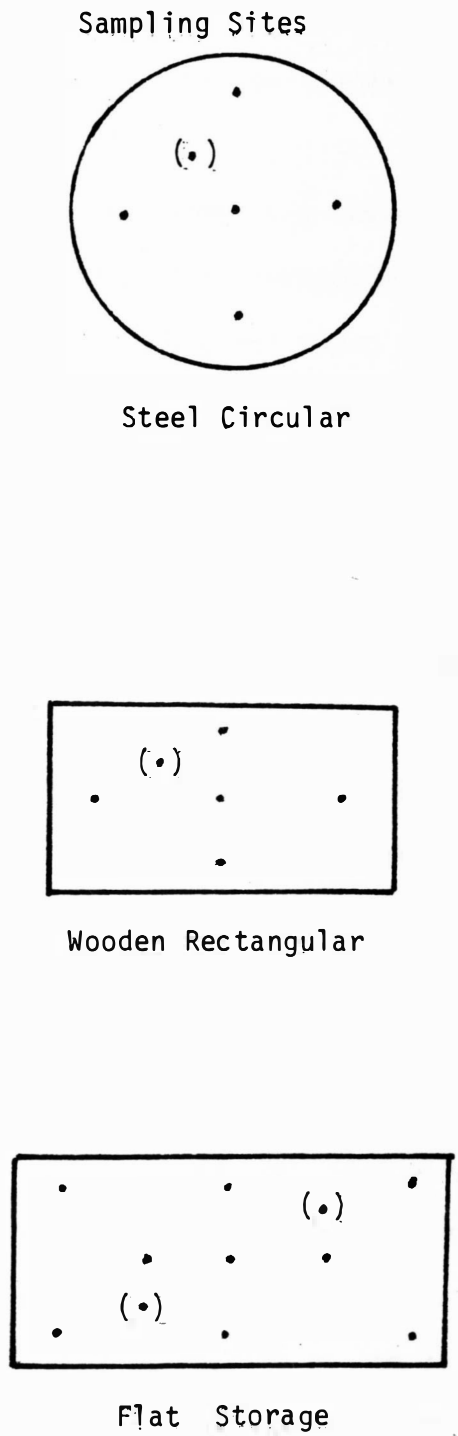

Figure 2.
• = indicates vertical samples
(•) = indicates horizontal samples

in a ziplock plastic bag. A library card with the farmer's name and the sampling date was put in the sample for identification purposes.

Temperature readings were also taken at two meter depths. A deep cup probe equipped with a thermometer was used to take readings in the center and along the south wall of the bin. The probe was left in the grain mass for five minutes before the reading was taken.

The samples were processed the day after they were obtained. They were first passed through Boerner ® Divider. From one half of the sample, 250 grams were used to determine moisture content on a Burrows 700 digital moisture computer. This sample was then discarded. From the other half of the sample, 333 grams were weighed out. This was then screened through an 8/64 triangular sieve pan. Only the live insects found in the screenings were then removed, put in petri dishes, labeled and frozen for later identification. The screenings were then weighed to determine the amount of dockage present. The screenings and the screened oats were then placed in 0.95 liter jars covered with fine wire mesh screened lids. These were stored at room temperature for four weeks and then were screened again for insects missed and adults that emerged from larvae that were present on the original sampling date. These insects were added to the original count. The insects were identified by using a stereoscope set at 10X. Final count was multiplied by three to convert to insect density per kilogram.

Many observations about the characteristics of the bin and bin site were made. Table 1 is the 1982-1983 information sheet.

In order to determine the factors that significantly caused insect infestations, the dependent variable, a process 'leaps' was used. This statistical procedure places the independent variables in order from the most to the least correlated with insect density. The best model is calculated for each subset size from one to the total number of independent variables in the data set. It also indicates the significant independent variables (Furnival and Wilson 1974).

1983-1984 Study

The 1983-1984 study was very similar to the 1982-1983 study. The 21 bins selected in 11 counties were those from the previous study. The oats from 1982-1983 had been removed and new oats from the 1983 crop were put in the same bins. Figure 3 indicates the bin locations that were sampled. The bins were sampled at two week intervals from mid August 1983 through April 1, 1984. Each bin was sampled 16 times unless marketed prior to April 1, 1984.

The sampling procedure of the bins, the sample processing and the statistical analysis were identical to the 1982-1983 study. Bins equipped with false floors and quonset storage were eliminated in order to look at the other bin and floor types more closely. Temperature readings were not taken.

Table 2 is the 1983-1984 information sheet used for data collecting.

1982-1983 Information Sheet

Producer ________________________ Directions____________

Bin Type - wood / steel / quonset

Pre binning cleaning procedure - on top of old oats / scoop shovel /

broom / vacuum

Grain mass - peaked / leveled

Bin condition - good / fair / poor

Floor type - wood / steel / cement / false

Degree of spilled grain - none / moderate / extensive

Grass length surrounding bin - grazed / mowed / unmowed

Nearby feedlot - yes / no

Residual spray used - yes / no

Grain mass quantity ____________________________

Date of sampling _____________Dockage ___________

Moisure ____________________Temperature M_____ O_____

Species	FGB	FLGB	STGB	RFB	HFB	RGB
Primary Count						
Incubation Count						
Total Count						

Table 1. FGB - Foreign grain beetle
FLGB - Flat grain beetle
STGB - Sawtoothed grain beetle
RFB - Red flour beetle
HFB - Hairy fungus beetle
RGB - Rusty grain beetle

1983-1984 Bin Sampling Locations

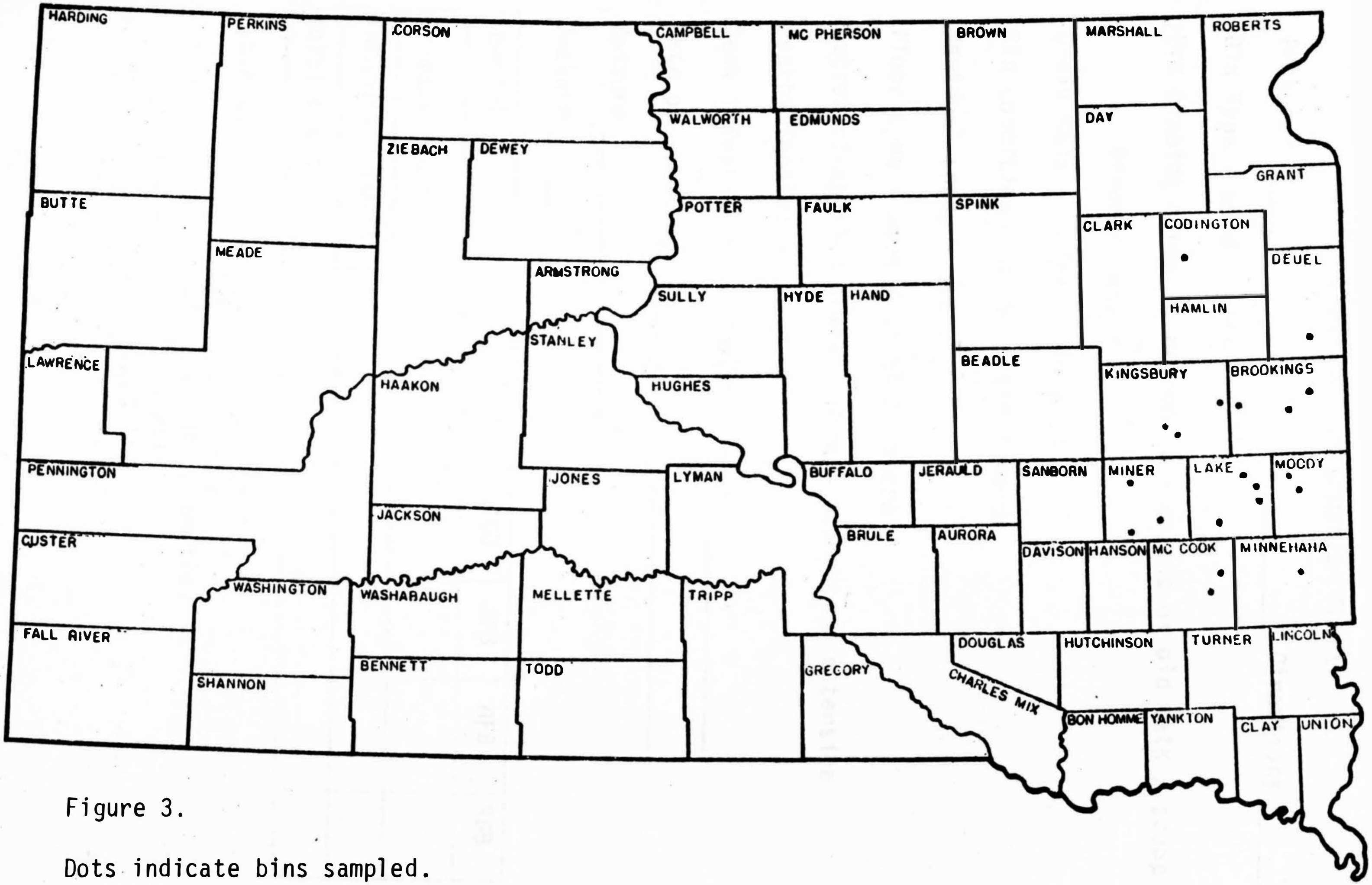

Figure 3.

Dots indicate bins sampled.

1983-1984 Information Sheet

Producer ______________________________ Directions_____________

Bin Type - wood / steel

Pre binning cleaning procedure - on top of old oats / scoop shovel /

broom / vacuum

Grain mass - peaked / leveled

Bin condition - good / fair / poor

Residual spray - yes / no

Floor type - wood / steel / concrete

Degree of spilled grain - none / moderate / extensive

Nearby feedlot - yes / no

Peak infestation of previous year _______________

Date of sampling ______________________________

Moisure ______________________

Dockage ______________________

Species	FGB	FLGB	STGB	RFB	HFB	RGB
Primary Count						
Incubation Count						
Total Count						

Table 2, FGB - Foreign grain beetle
FLGB - Flat grain beetle
STGB - Sawtoothed grain beetle
RFB - Red flour beetle
HFB - Hairy fungus beetle
RGB - Rusty grain beetle

RESULTS AND DISCUSSION

The stored grain insects found in this two year study were mostly secondary. This type generally feeds and reproduces in cracked grain and mold. The main species found were the sawtoothed grain beetle, Cryptolestes spp., the red flour beetle, the foreign grain beetle, and the hairy fungus beetle. This agrees with the 1971 study done by Bell et al. They found the same species to be the major pests of stored oats in Kansas. Storey et al. (1983) found only the sawtoothed grain beetle, Cryptolestes spp. and the red flour beetle as the major pests of stored oats in South Dakota, Minnesota and North Dakota. The reason for them not finding the foreign grain beetle and the hairy fungus beetle may be due to their sampling in June and July.

The weather for the 1982-1983 storage season consisted of above average precipitation in the fall, winter and spring. Temperatures during this time were quite mild, Conditions for insect survival and reproduction were favorable. The 1983-1984 storage period also had above average precipitation in the fall. Temperatures were normal for the fall and spring but December was extremely cold and caused great reductions in live insect populations. The two storage periods were quite different in moisture levels and climatic conditions.

Moisture

Moisture was found to be the major factor in relations to higher insect densities for the 1982-1983 storage period. Figure 4 shows the moisture content of oats going into storage in August ranged from 8.4% to 12.9% and an average of 10.5%. Frequent precipitation during harvest was the reason for oats with moisture above 11%. Average moisture content rose to a peak in January of 11.5%. This rise was the result of moisture condensation caused by the cooling of the outer walls and the movement of moisture to the upper middle portion of the oats. Since the sampling was only done on the top 1.6 meters of the oats, an increase in moisture of this area would be expected.

Figure 5 shows the relationship of moisture content and insect density. The average insect density remained constant at five per kilogram up to 11% moisture. In moisture levels above 11%, samples containing above 100 insects per kilogram were found. The average insect density increased dramatically as moisture increased from 12% to 16.5%.

In the 1983-1984 storage period, moisture content was not the major factor in relation to insect density, but was statistically significant. This was probably because of all the samples taken were below the recommended safe storage level of 13%. Figure 6 shows the moisture content going into storage in August ranged from 8.8% to 11.6% and an average of 9.8%. This was 0.7% lower than the average of the previous year. The highest moisture was 1.3% lower than the highest moisture found in the 1982-1983 storage period. Virtually no precipitation was received during harvest and this

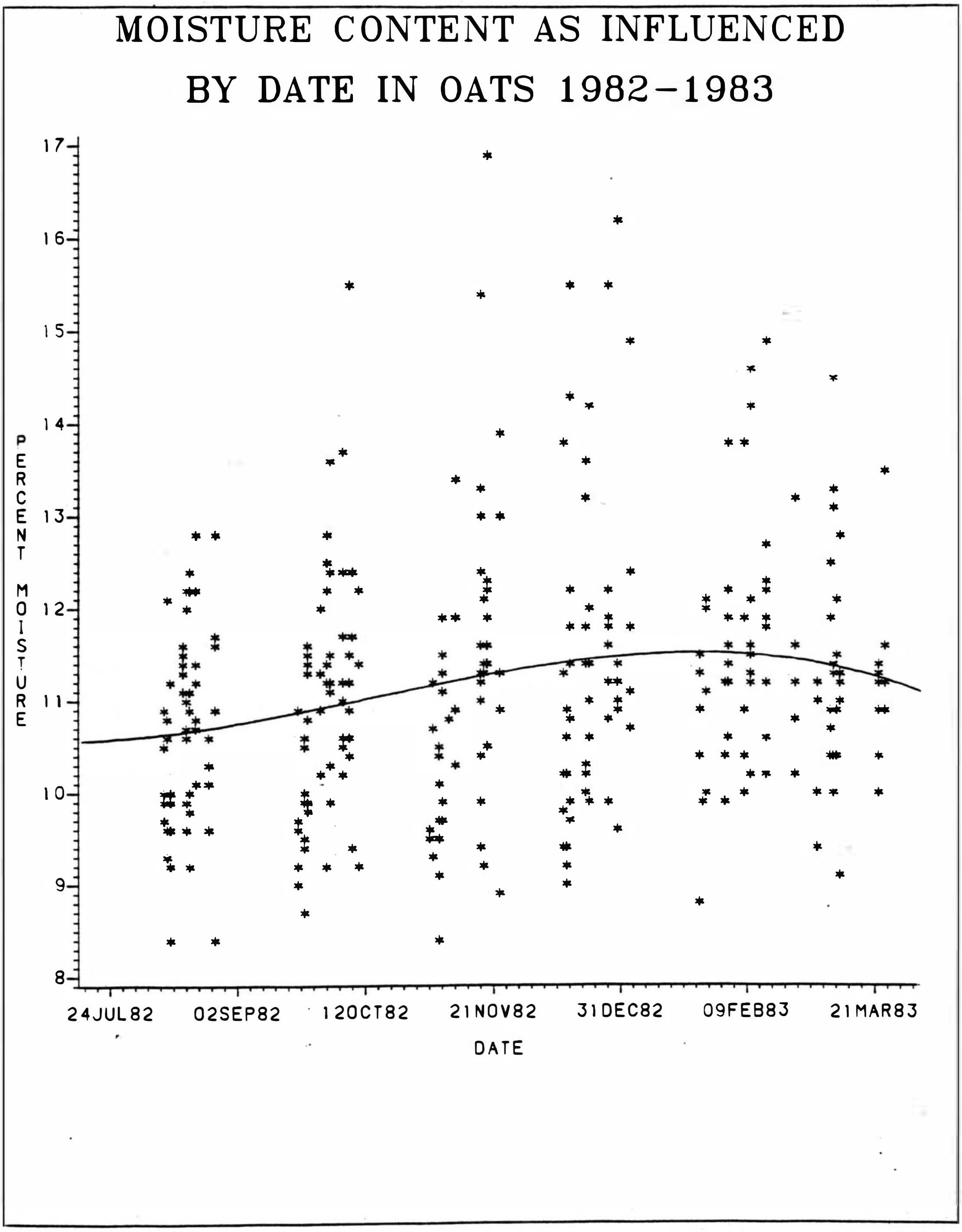

Figure 4. The line represents the average percent moisture. Each data point represents one sample.

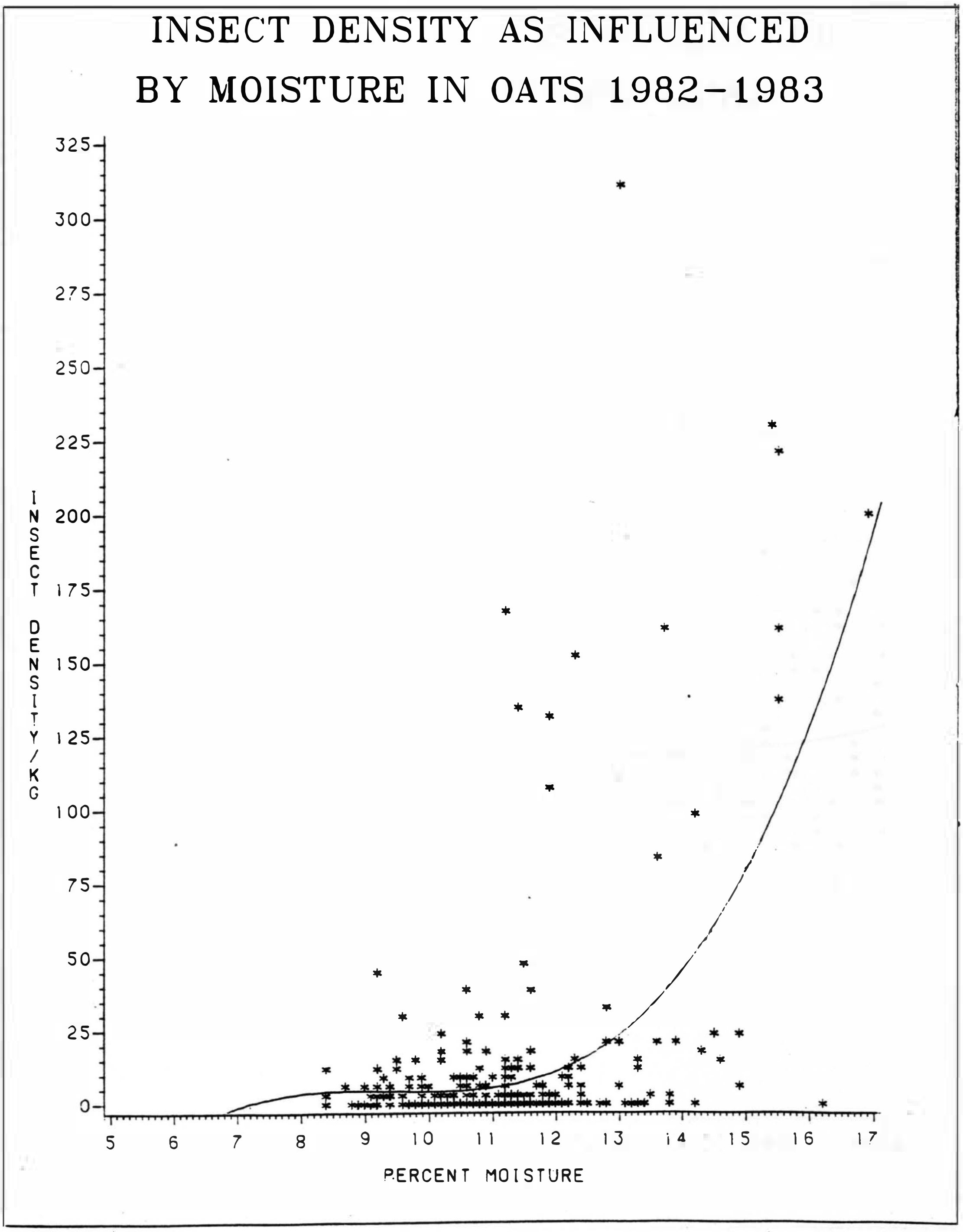

Figure 5. The line represents the average insect density per kilogram. Each data point represents one sample.

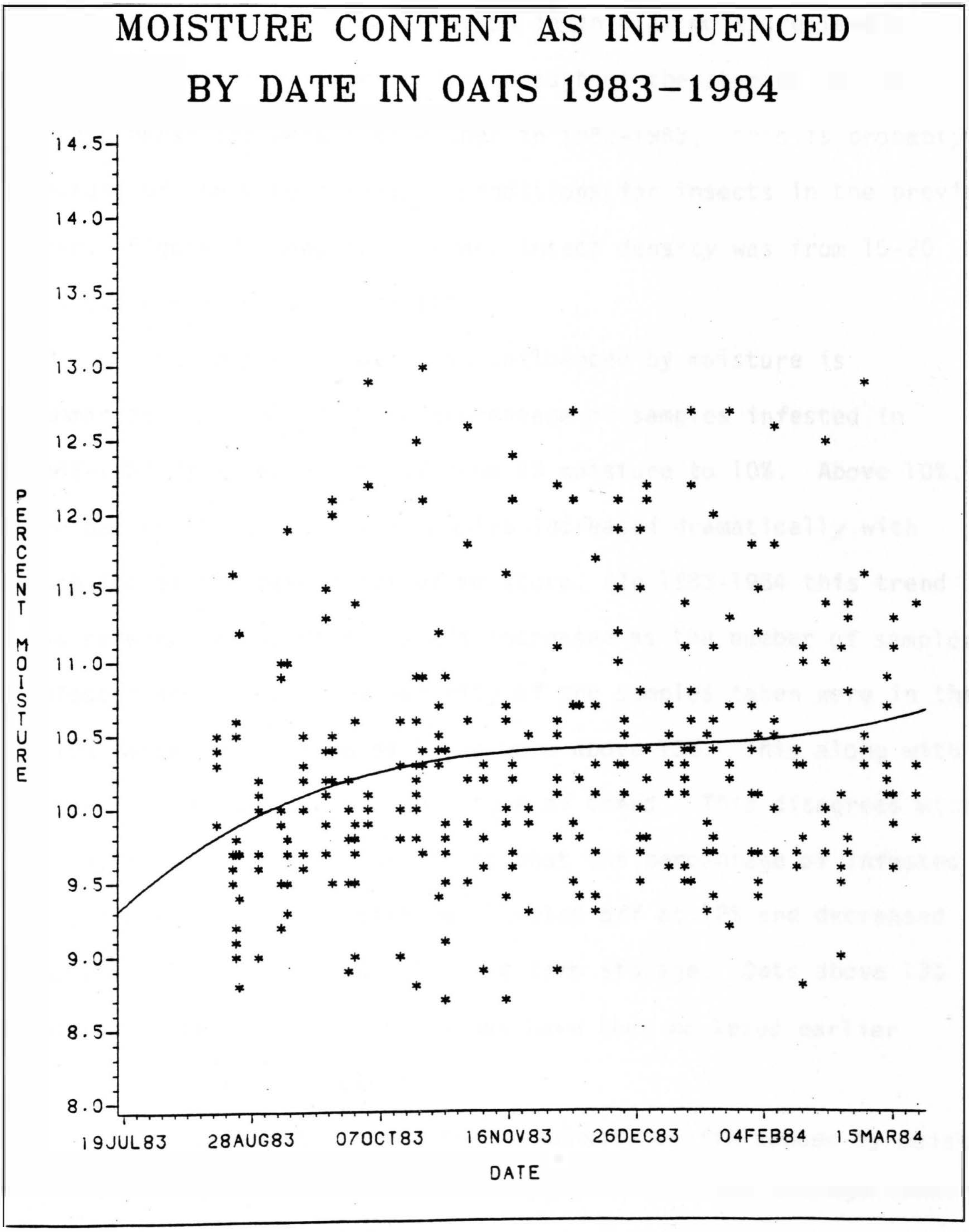

Figure 6. The line represents the average percent moisture. Each data point represents one sample.

could easily explain the reduction in initial moisture levels. Moisture content rose gradually throughout the storage period. Insect densities were much higher in 1982-1983. This is probably because of the more favorable conditions for insects in the previous year. Figure 7 shows the average insect density was from 15-20 insects per kilogram up to 12%.

The insect incidence as influenced by moisture is summarized in Table 3. The percentage of samples infested in 1982-1983 declined about 10% from 8% moisture to 10%. Above 10%, the percentage of infested samples increased dramatically with each increasing percentage of moisture. In 1983-1984 this trend was reversed as moisture levels increased as the number of samples infested decreased. The majority of the samples taken were in the 9-10% range and no samples taken were above 13%. This along with other factors may explain this type of trend. This disagrees with Storey et al. (1983). They found that the percentage of infested bins increased to 11% moisture, leveled off at 12% and decreased above 13%. They sampled only long term storage. Oats above 13% moisture infested with insects may have been marketed earlier because of storage problems.

The sawtoothed grain beetle density as finluenced by moisture is summarized in Figures 8 and 9. In 1982-1983 the average density of the sawtooth grain beetle increased with increasing moisture content. As moisture levels increased in 1983-1984, the average density level decreased. This may indicate that the sawtoothed

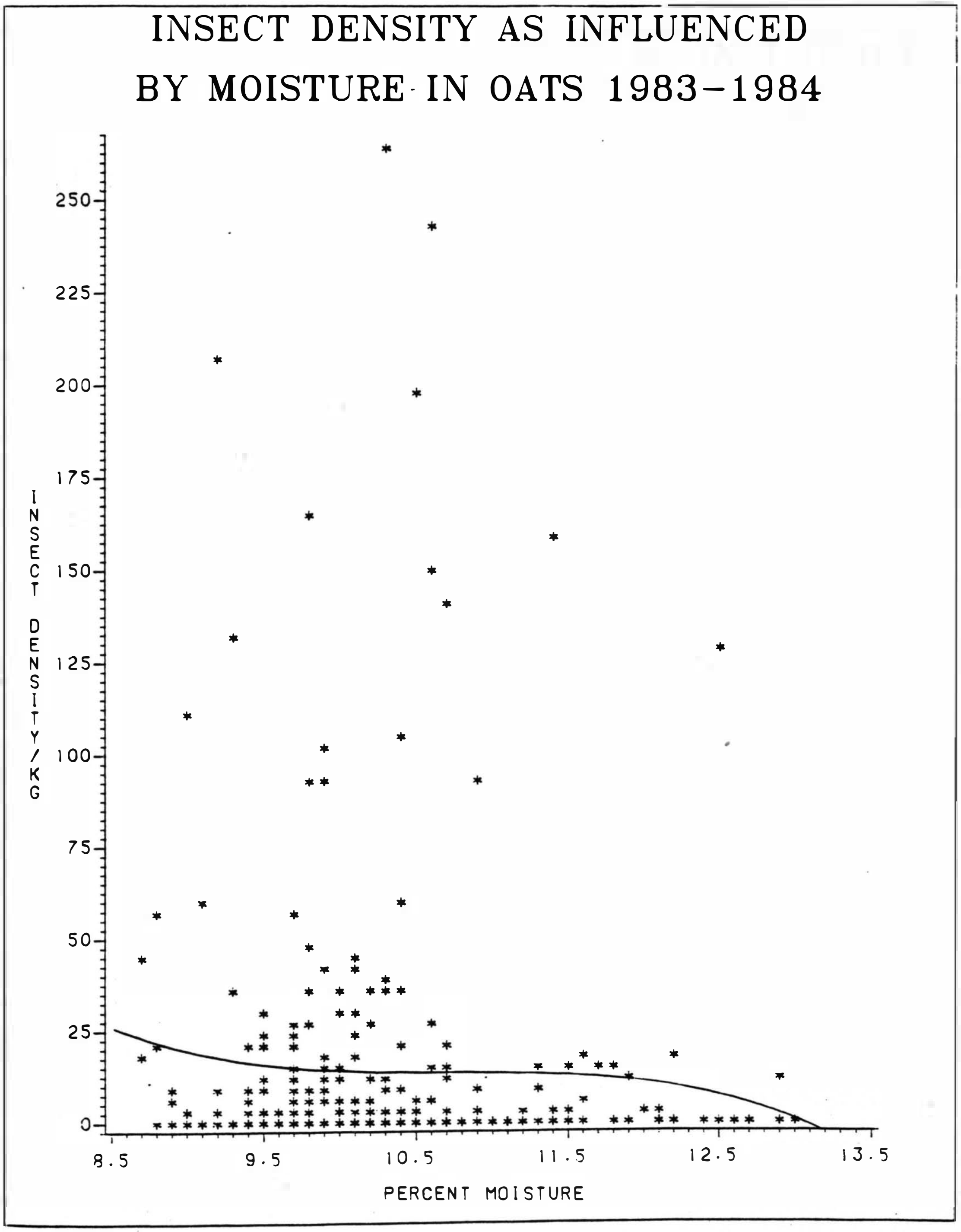

Figure 7. The line represents the average insect density per kilogram. Each data point represents one sample.

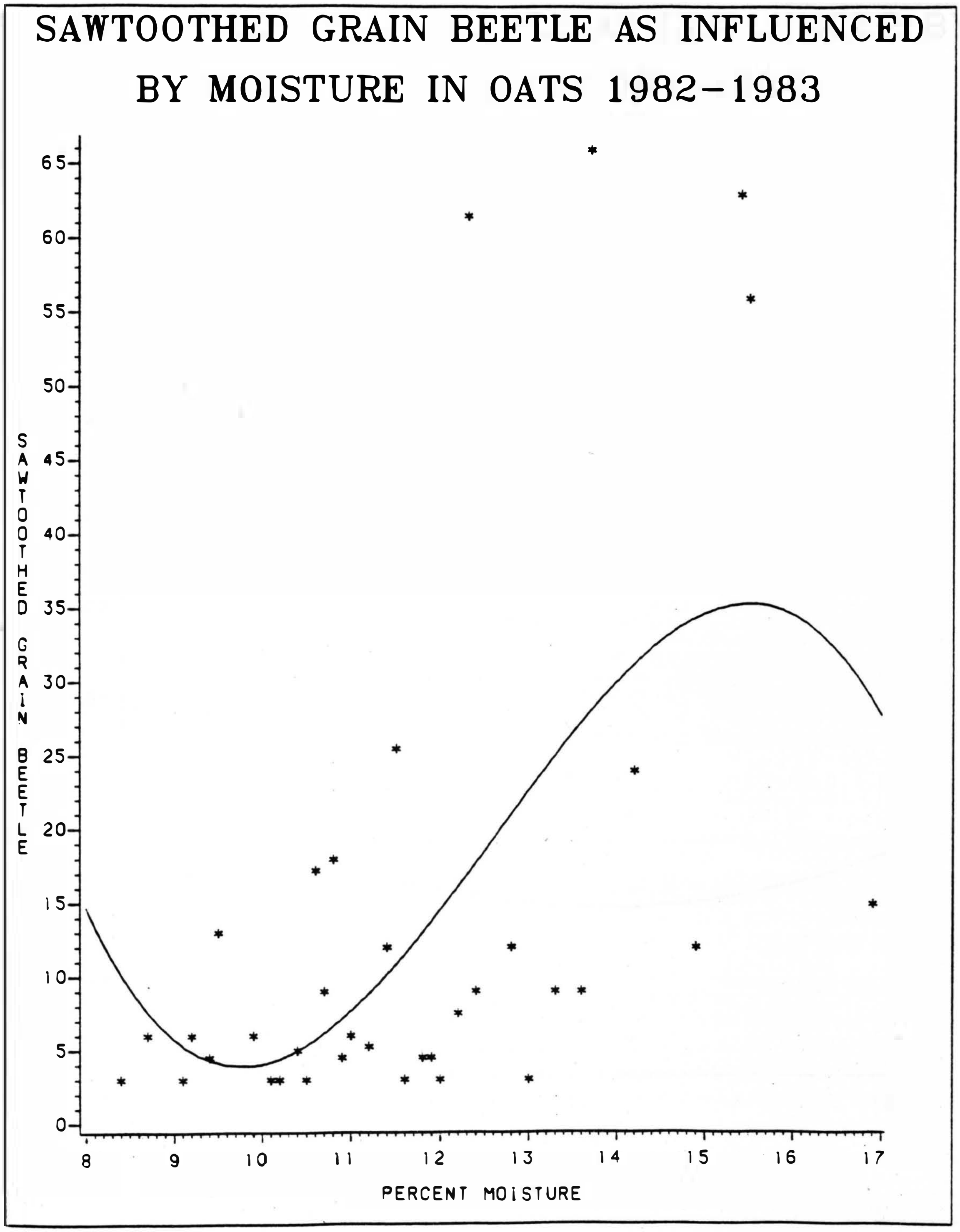

Figure 8. The line represents the average density per kilogram of the sawtoothed grain beetle in the infested samples. Each data point represents the mean for each particular moisture level.

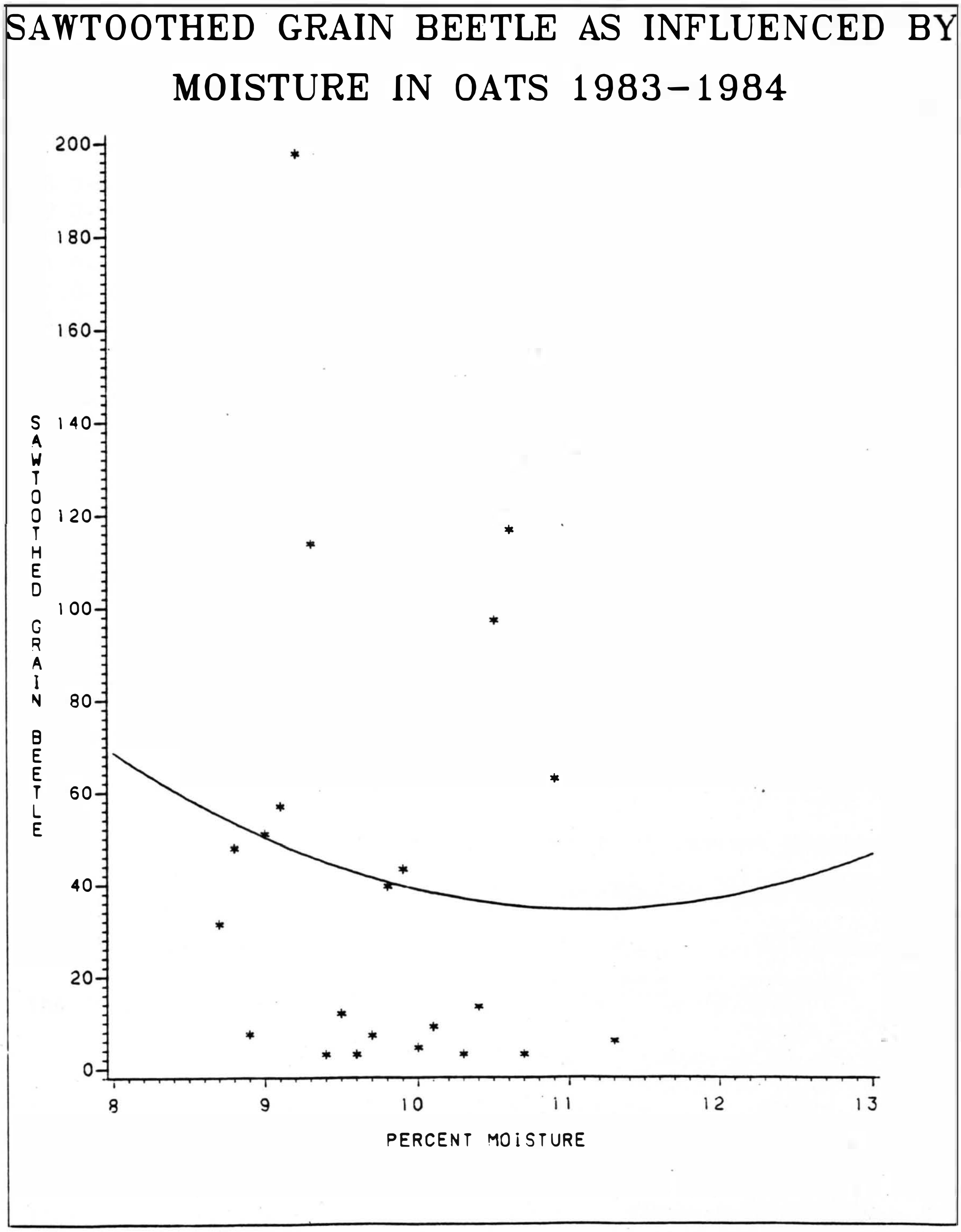

Figure 9. The line represents the average density per kilogram of the sawtoothed grain beetle in the infested samples. Each data point represents the mean for each particular moisture level.

Table 3. Insect incidence as related to moisture in all samples.

	1982-1983		1983-1984	
% Moisture	# of Samples	% Infested[A]	# of Samples	% Infested[A]
8.0-8.9	6	50	8	75
9.0-9.9	50	48	110	53
10.0-10.9	83	37	130	54
11.0-11.9	97	41	39	36
12.0-12.9	39	51	23	26
13.0-13.9	20	65	1	0
14.0-14.9	8	88	--	--
15.0-15.9	4	100	--	--
16.0-16.9	2	50	--	--
TOTAL	309	46	311	50

[A] - contained at least one live insect per kilogram

grain beetle prefers oats below 12% moisture. Density levels were much higher in 1983-1984. This agrees with Storey et al. (1983). They found the sawtoothed grain beetle to decrease in density above 12% moisture.

The *Cryptolestes* spp. density as related to moisture is shown in Figures 10 and 11. In both years the average density of the *Cryptolestes* spp. increased with increased moisture levels. Densities were much higher in 1982-1983. Figure 10 indicates that the *Cryptolestes* spp. prefers oats with moisture above 13%.

The red flour beetle density as influenced by moisture is displayed in Figures 12 and 13. The curves are very similar for both years from 9% to 12% moisture. The average density level increased from 9% to 11% moisture where it peaked and declined from 11% to 12%. In 1982-1983 very few samples were above 13% but

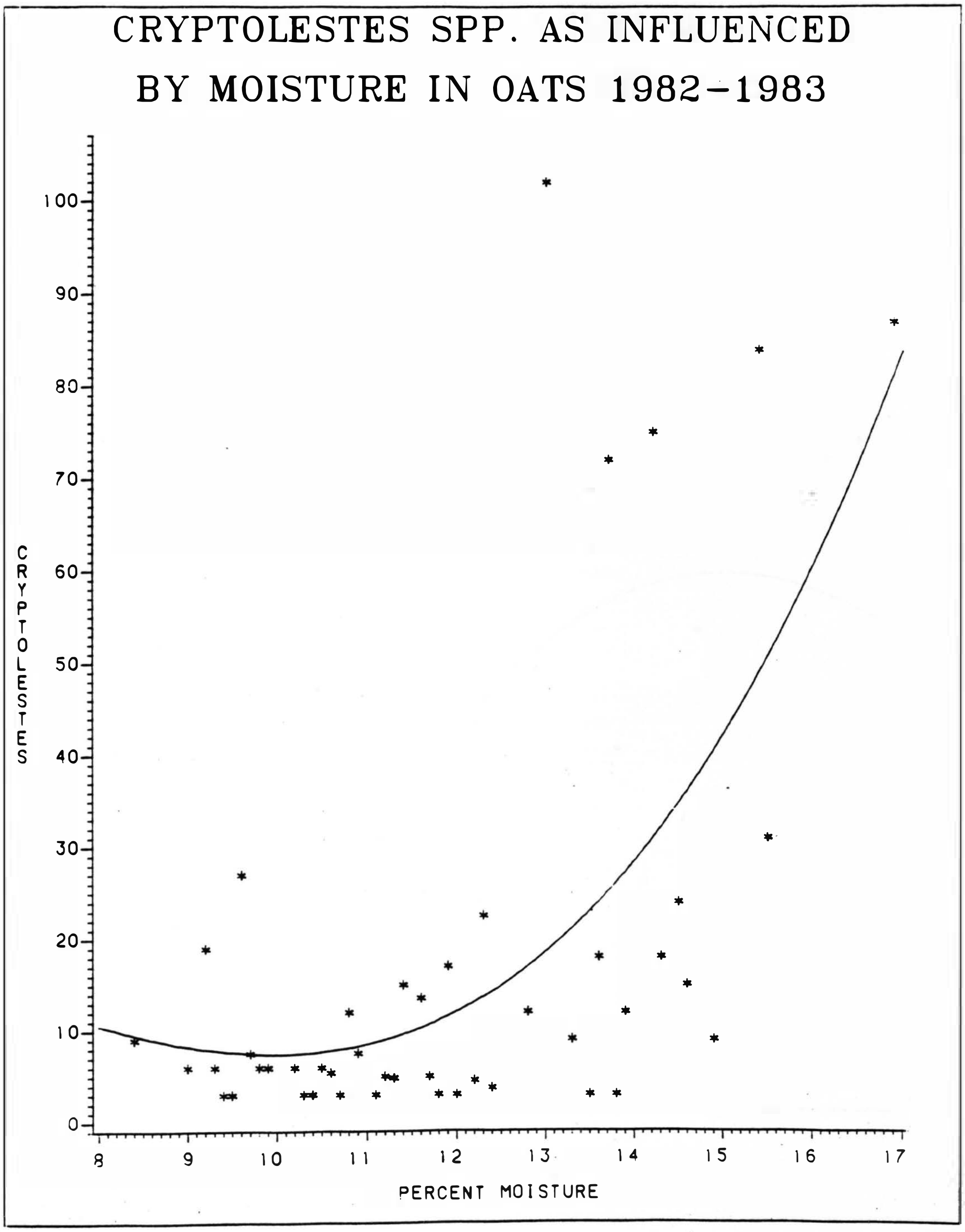

Figure 10. The line represents the average density per kilogram of Cryptolestes spp. in the infested samples. Each data point represents the mean for each particular moisture level.

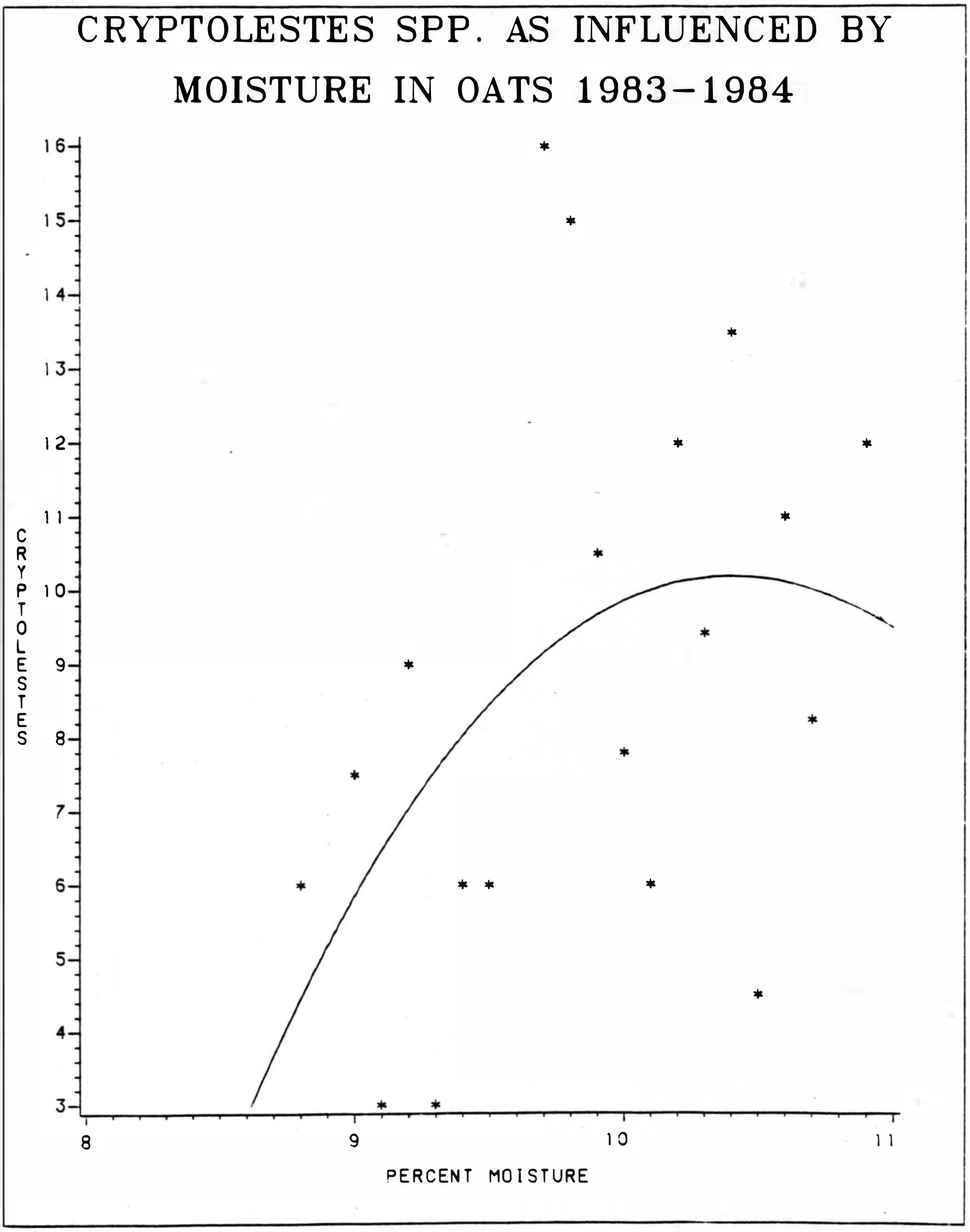

Figure 11. The line represents the average density per kilogram of <u>Cryptolestes spp.</u> in the infested samples. Each data point represents the mean for each particular moisture level.

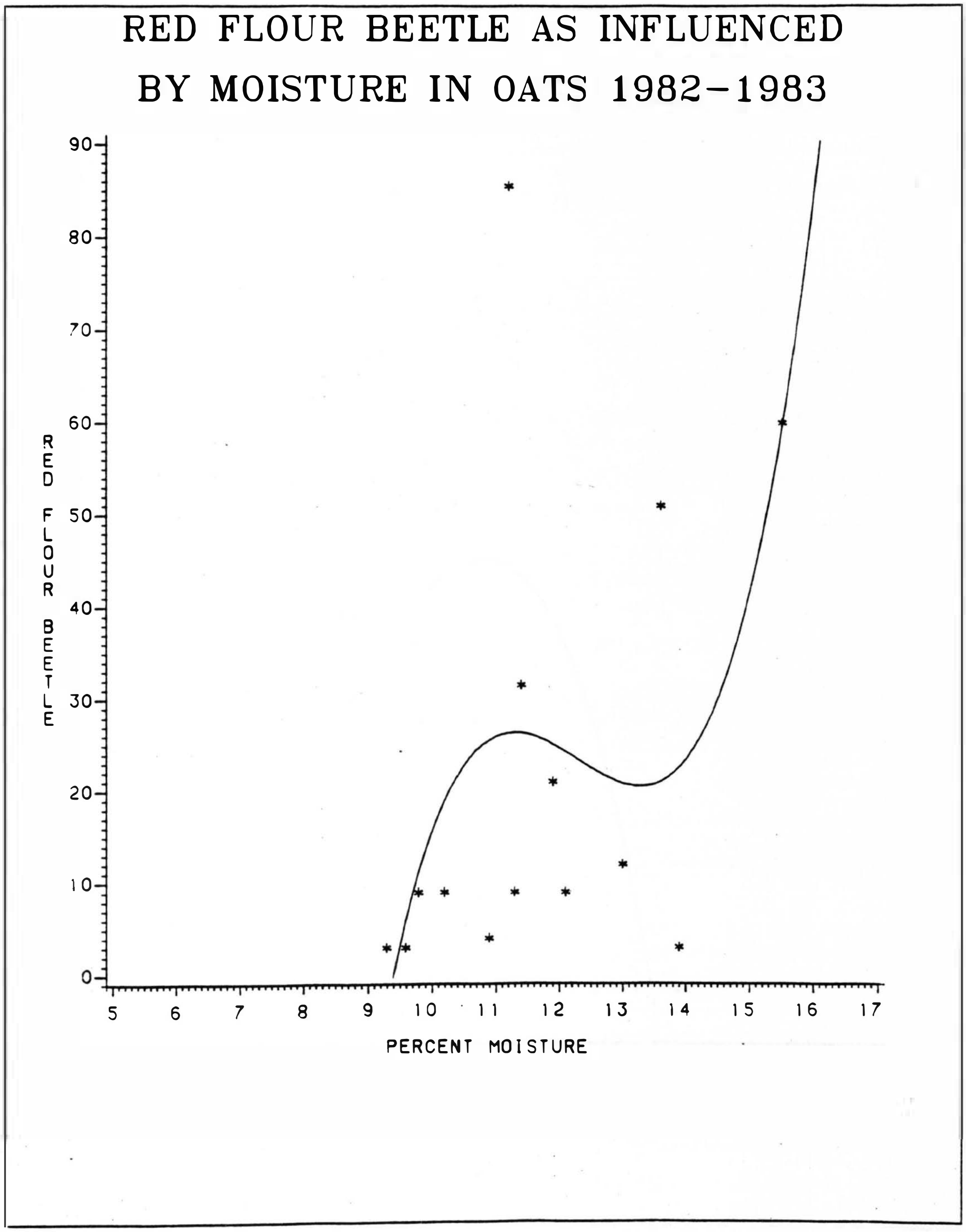

Figure 12. The line represents the average density per kilogram of the red flour beetle in the infested samples. Each data point represents the mean for each particular moisture level.

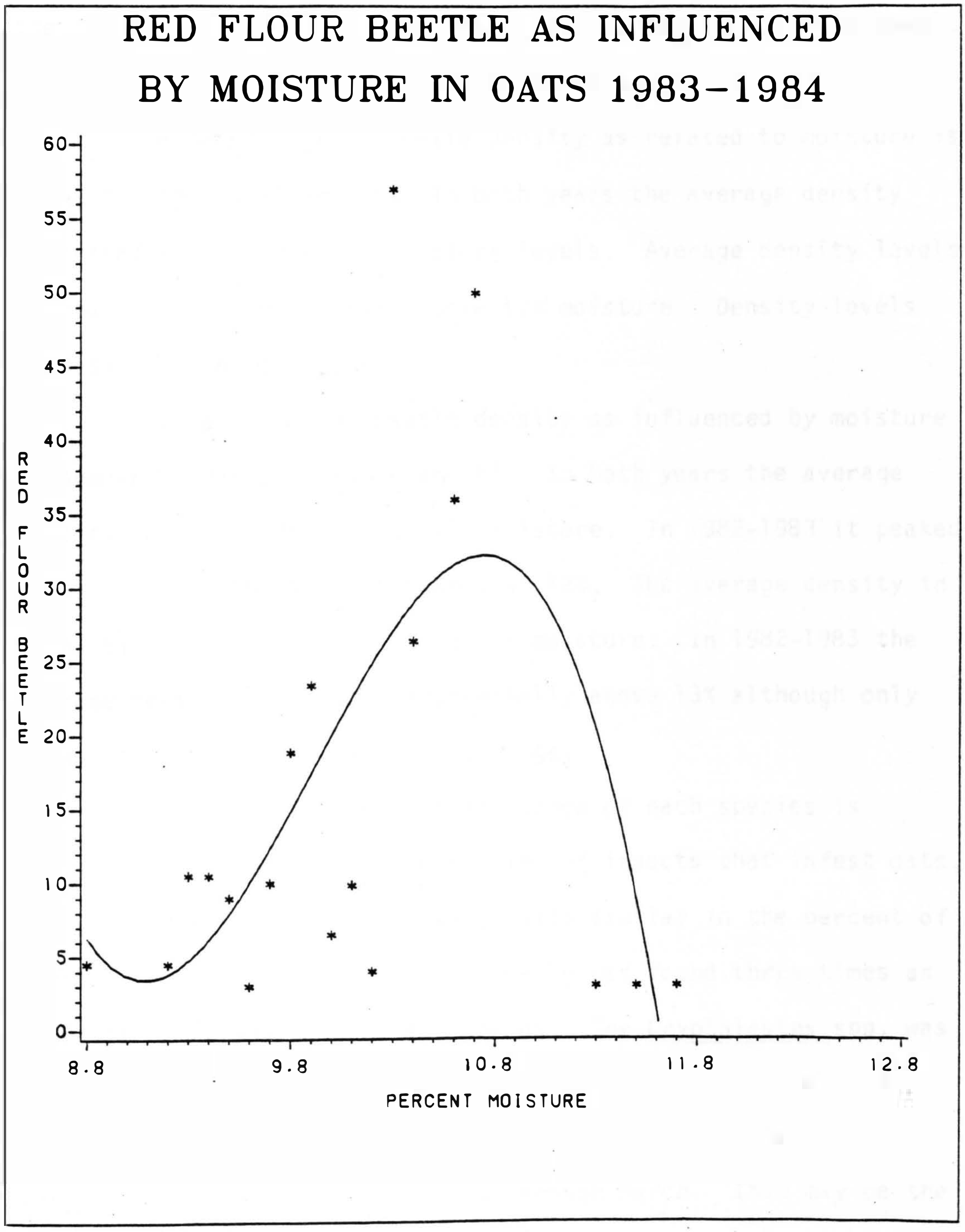

Figure 13. The line represents the average density per kilogram of the red flour beetle in the infested samples. Each data point represents the mean for each particular moisture level.

they showed an increase in density with increasing moisture level. Densities were quite similar for both years.

The foreign grain beetle density as related to moisture is shown in Figures 14 and 15. In both years the average density increased with increasing moisture levels. Average density levels increased at a greater rate above 12% moisture. Density levels were similar in both years.

The hairy fungus beetle density as influenced by moisture is summarized as Figures 16 and 17. In both years the average density increased from 9% to 11% moisture. In 1982-1983 it peaked at 11% and in 1983-1984 it peaked at 12%. The average density in both years declined from 12% to 13% moisture. In 1982-1983 the average density increased substantially above 13% although only a few samples were found in this range.

In Table 4 the percent incidence of each species is shown. In both years all the species of insects that infest oats, except the red flour beetle, were quite similar in the percent of samples infested. The red flour beetle was found three times as often in the 1983-1984 storage period. The *Cryptolestes* spp. was found in almost one third of the samples taken. Because of its resistance to cold weather, the *Cryptolestes* spp. were virtually the only species found in January through March. This may be the reason for its high percentage of infestation as compared to other species.

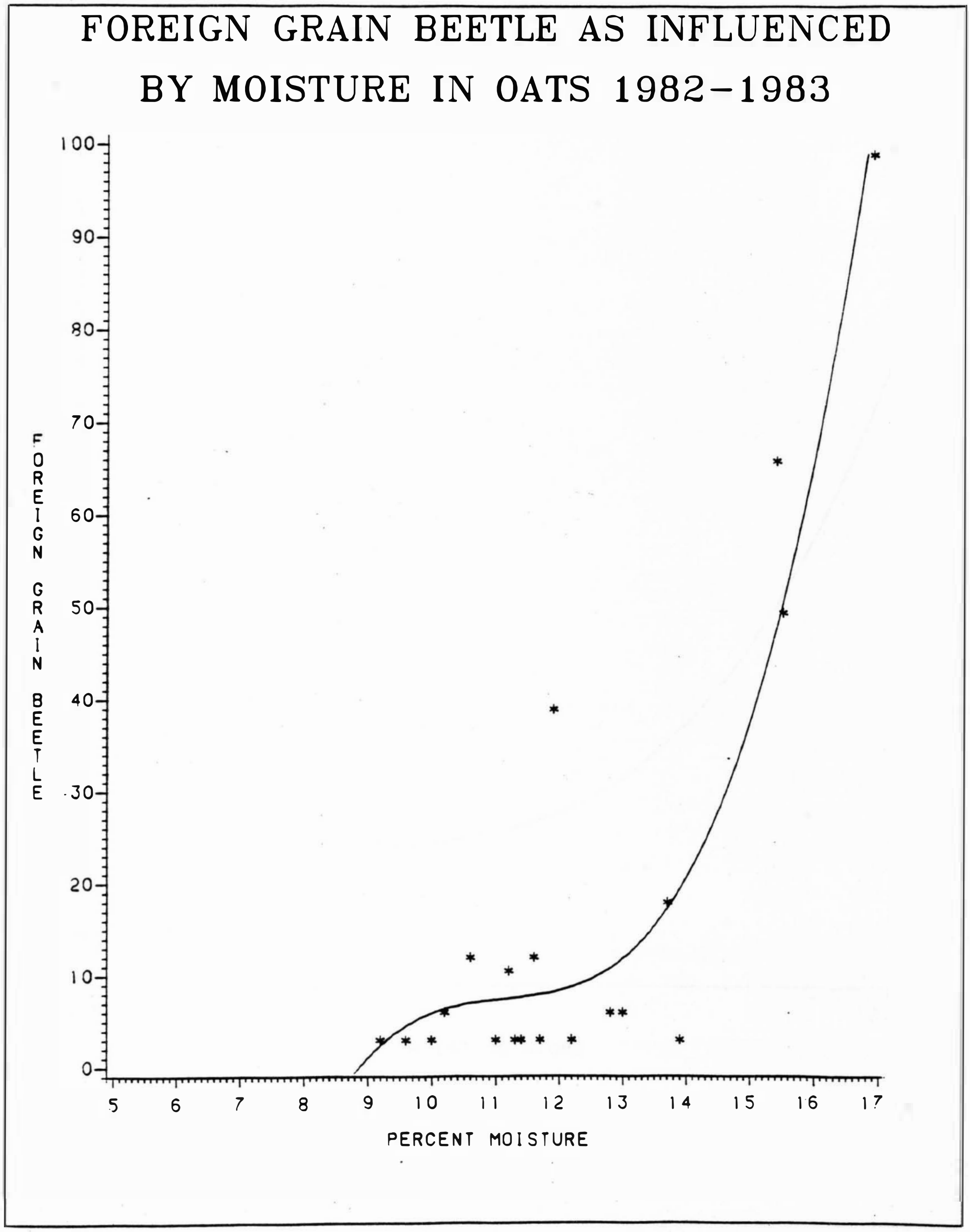

Figure 14. The line represents the average density per kilogram of the foreign grain beetle in the infested samples. Each data point represents the mean for each particular moisture level.

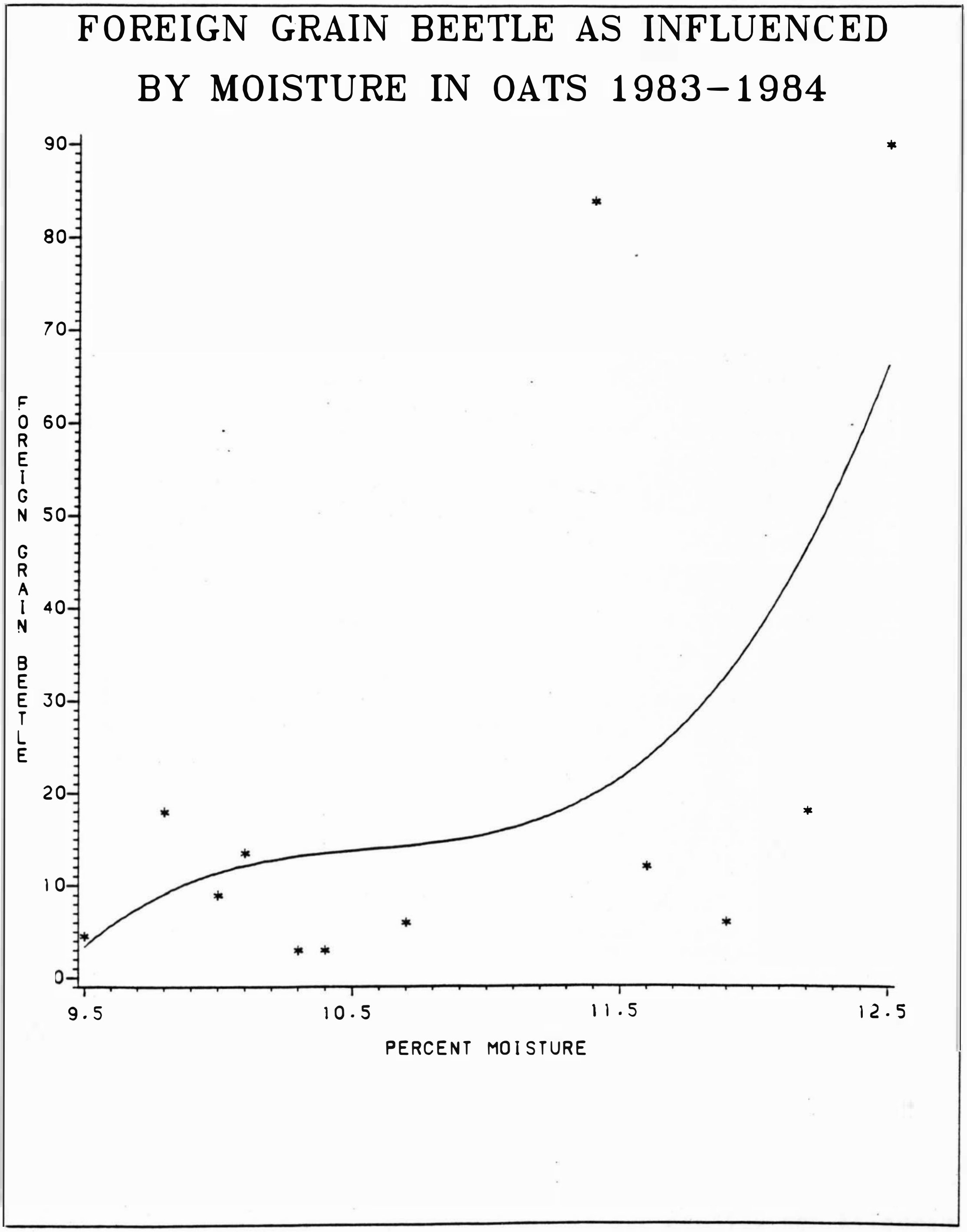

Figure 15. The line represents the average density per kilogram of the foreign grain beetle in the infested samples. Each data point represents the mean for each particular moisture level.

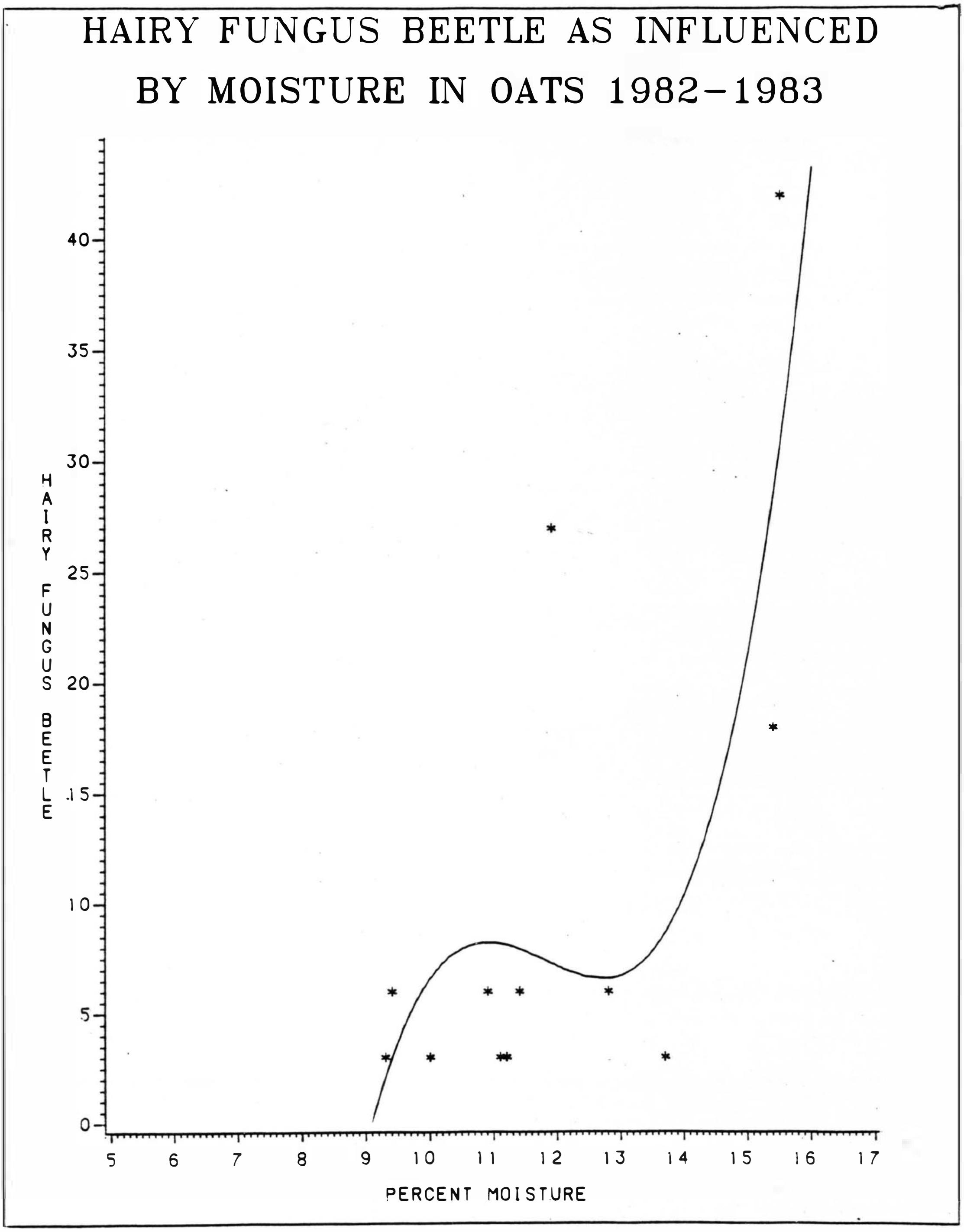

Figure 16. The line represents the average density per kilogram of the hairy fungus beetle in the infested samples. Each data point represents the mean for each particular moisture level.

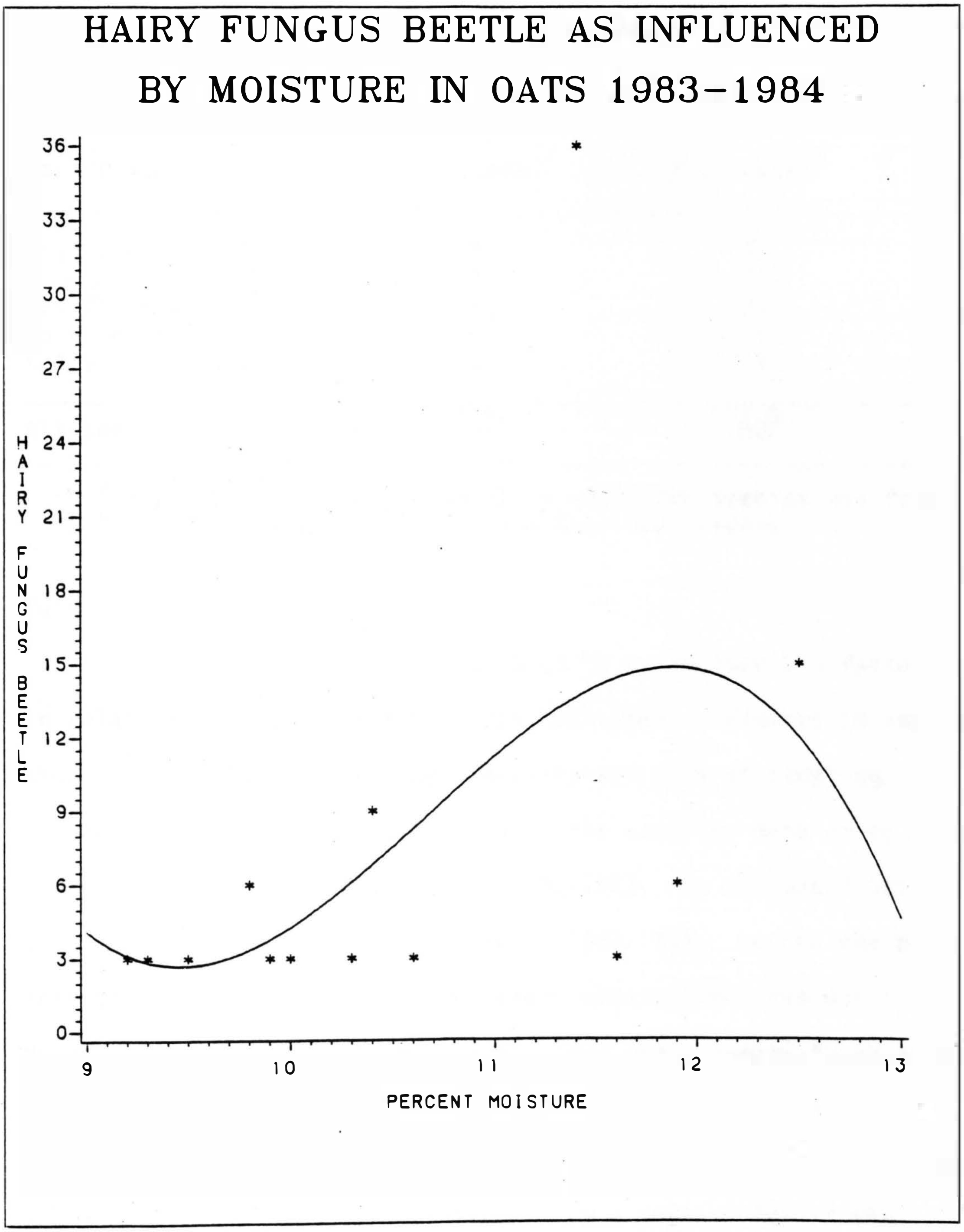

Figure 17. The line represents the average density per kilogram of the hairy fungus beetle in the infested samples. Each data point represents the mean for each particular moisture level.

Table 4. Percent incidence of each species,

	1982-1983	1983-1984
Insect Species	% Infested[A]	% Infested[A]
Cryptolestes spp.	30	32
Sawtoothed grain beetle	22	21
Red flour beetle	8	24
Foreign grain beetle	8	5
Hairy fungus beetle	5	4
All species	46[B]	50[B]

[A] - percentage of all samples in which the species was found.
[B] - some samples contained more than one species.

Date

The date of sampling was found to be another big factor in relation to insect densities for both years. Figures 18 and 19 show the relationship of insect density and date of sampling. Average insect density increased with the sampling date up to 25/kg on the first of November in 1982-1983. It increased until the first week in October to 30/kg in 1983-1984. Beyond the peak infestation levels, the average insect density declined until March. The reduction of the air and thus grain temperatures beyond November is the cause for the reduction in insect populations.

The insect incidence as related to date is shown in Table 5. In 1982-1983 the incidences increased to a peak of 74% of the samples being infested in October. There was a steady decline in incidences through January, then the incidence level held steady

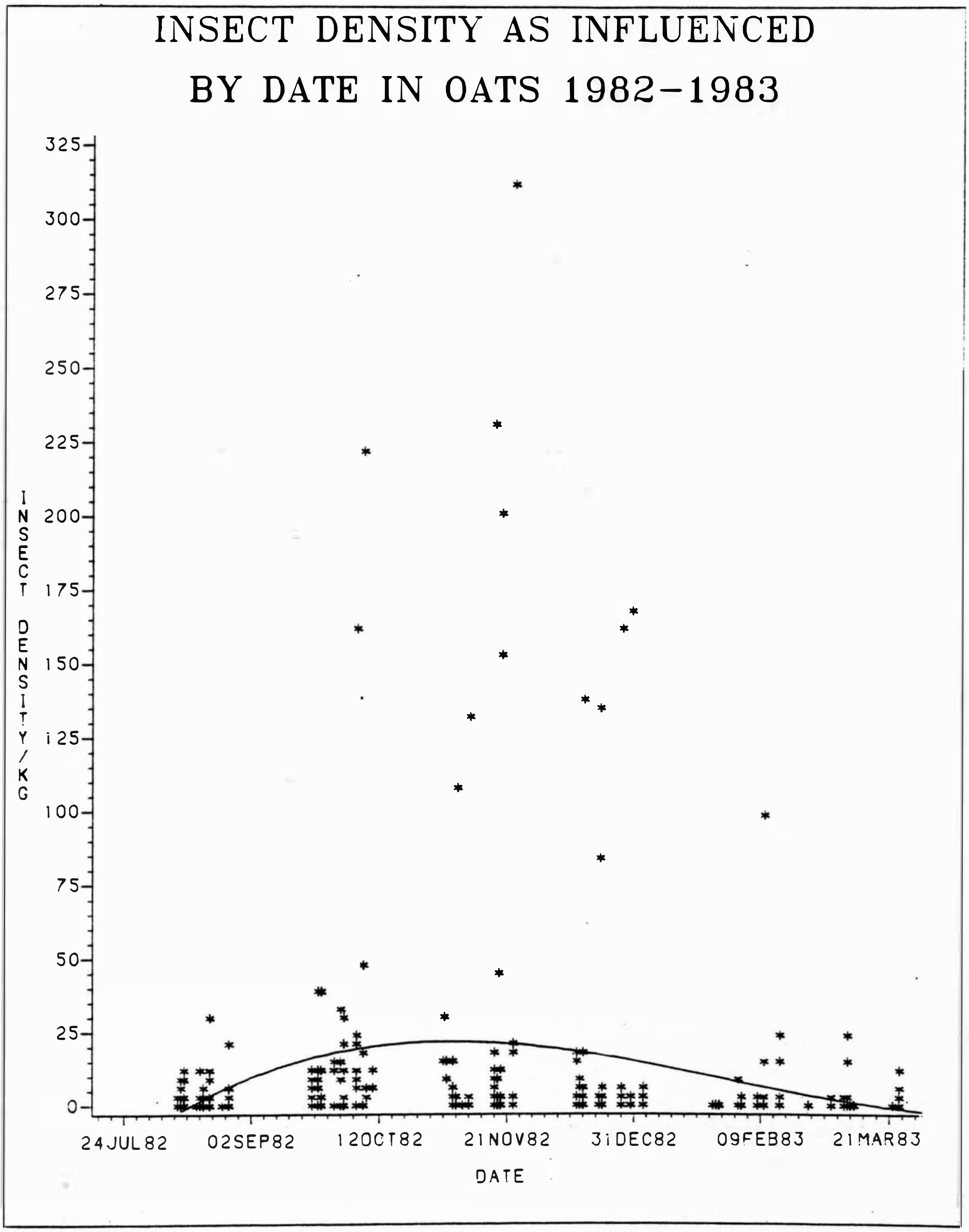

Figure 18. The line represents the average insect density per kilogram. Each data point represents one sample.

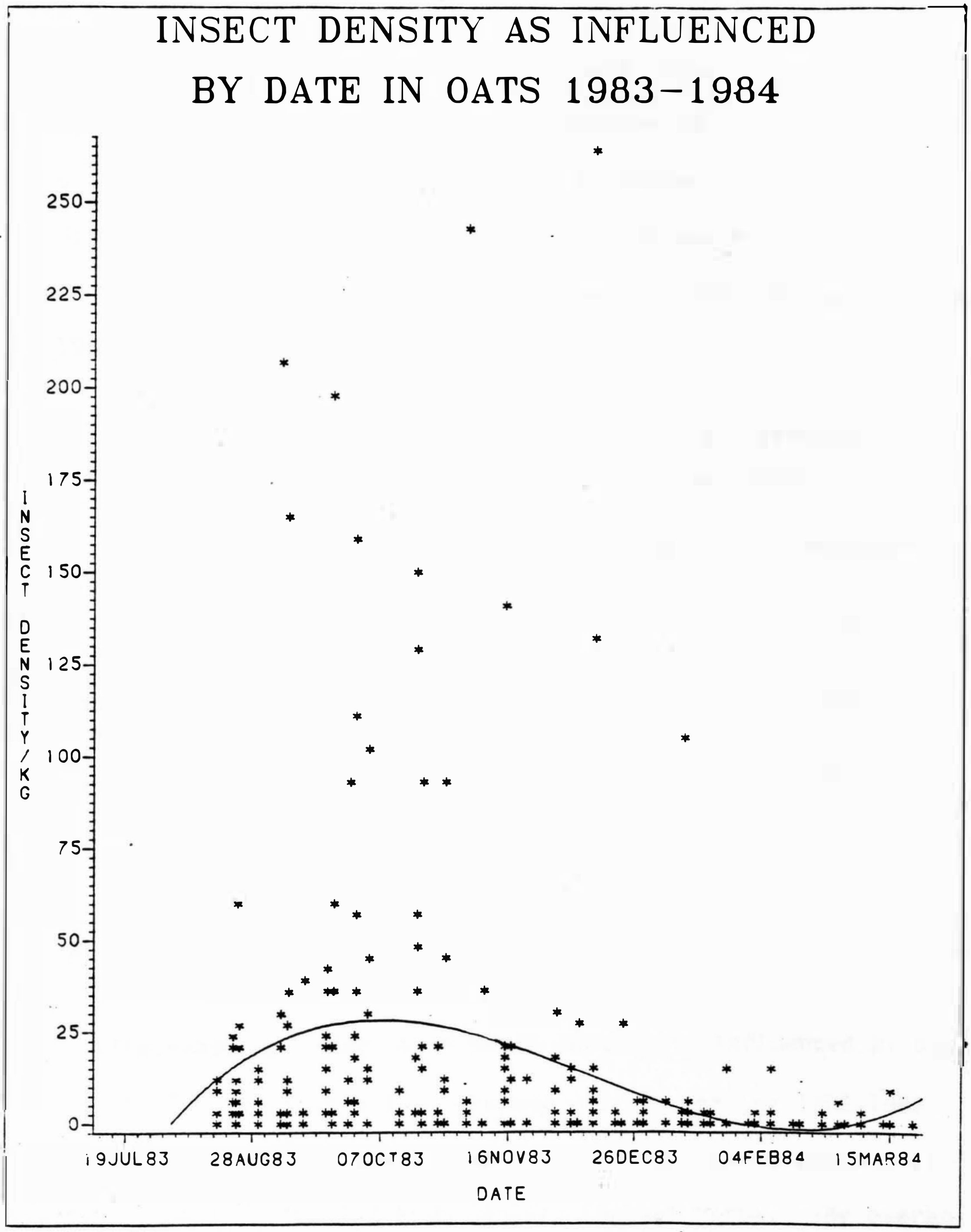

Figure 19. The line represents the average insect density per kilogram. Each data point represents one sample.

through March.

In 1983-1984 the incidence of insect infestation increased to a peak of 84% of the samples being infested in September. There was a steady decline in incidences from September through March. The difference of incidence levels in February and March is temperature related. The average incidence in 1982-1983 was 46% and for 1983-1984 was 50%.

Table 5. Insect incidence as related to date in all samples.

	1982-1983		1983-1984	
Month	# of Samples	% Infested[A]	# of Samples	% Infested[A]
August	55	36	27	78
September	29	66	51	84
October	27	74	41	71
November	56	59	32	50
December	48	54	53	45
January	18	28	44	27
February	41	32	36	17
March	35	26	27	7
Total	309	46	311	50

[A] - contained at least one live insect per kilogram.

The number of sawtoothed grain beetles as influenced by date is shown in Figures 20 and 21. Average density for the 1982-1983 storage period increased steadily to a peak of 17/kg in early December and then decreased from January through March. The average density in 1983-1984 rose sharply to a peak of 38/kg in early October and decreased gradually to zero the first of February

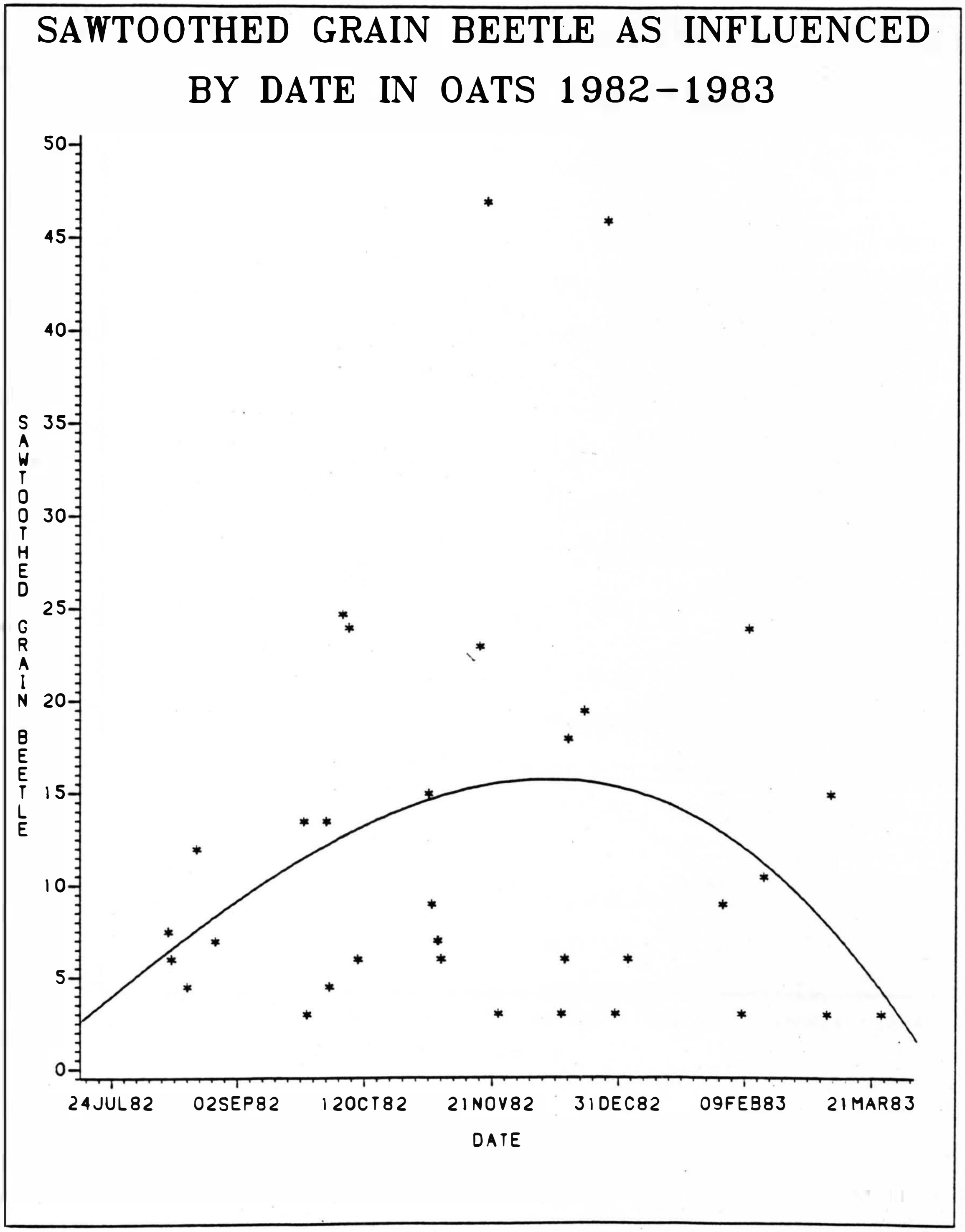

Figure 20. The line represents the average density per kilogram of the sawtoothed grain beetle for the infested samples. Each data point represents the mean for each particular date.

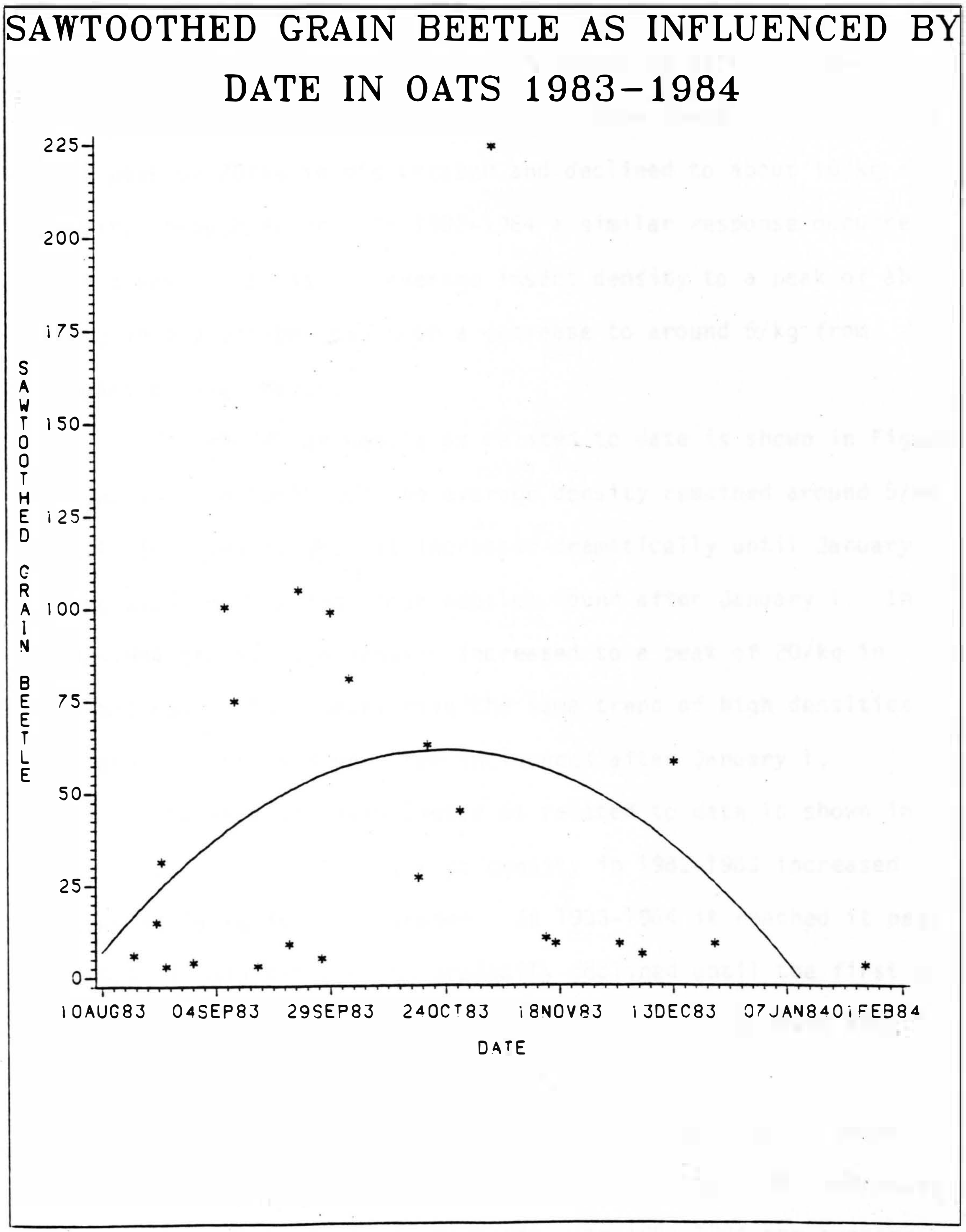

Figure 21. The line represents the average density per kilogram of the sawtoothed grain beetle for the infested samples. Each data point represents the mean for each particular date.

because of a temperature effect.

The Cryptolestes spp. as influenced by date is shown in Figures 22 and 23. The average density rose sharply in 1982-1983 to a peak of 20/kg in mid October and declined to about 10/kg from January through March. In 1983-1984 a similar response occurred with a sharp increase in average insect density to a peak of about 14/kg in mid October and then a decrease to around 6/kg from January through March.

The red flour beetle as related to date is shown in Figures 24 and 25. In 1982-1983 the average density remained around 5/kg until mid November when it increased dramatically until January 1. There were no live red flour beetles found after January 1. In 1983-1984 the average density increased to a peak of 20/kg in mid November. Both years have the same trend of high densities in late December and very few incidences after January 1.

The foreign grain beetle as related to date is shown in Figures 26 and 27. The average density in 1982-1983 increased to a peak of 45/kg in mid November. In 1983-1984 it reached it peak of 19/kg in mid October and gradually declined until the first of the year. There were no live foreign grain beetles found after January 1 in either year.

The hairy fungus beetle as influenced by date is shown in Figures 28 and 29. The average density in 1982-1983 increased to a peak of 21/kg in early November. In 1983-1984 the average density reached its peak of about 9/kg in early October. There

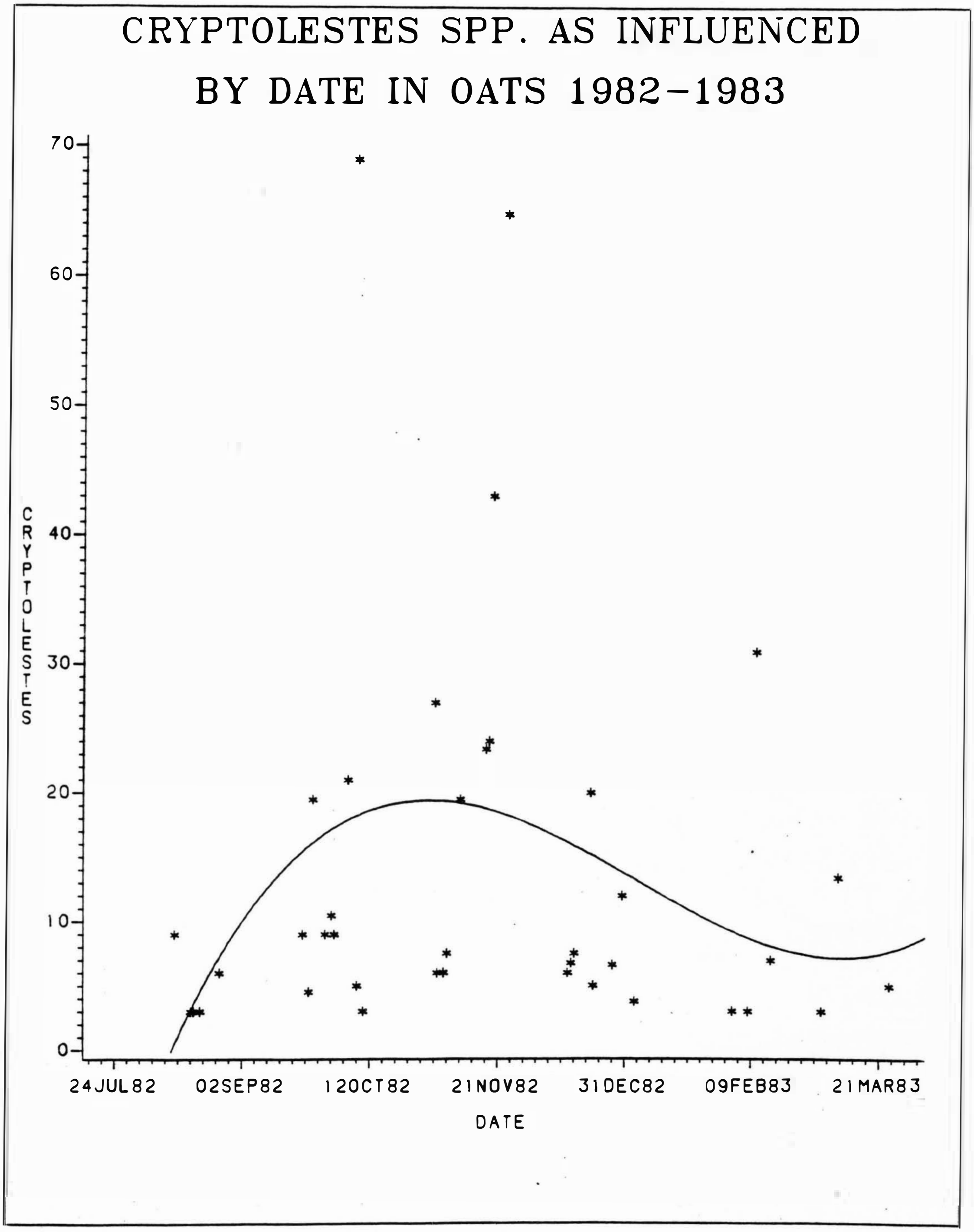

Figure 22. The line represents the average density per kilogram of Cryptolestes spp. for the infested samples. Each data point represents the mean for each particular date.

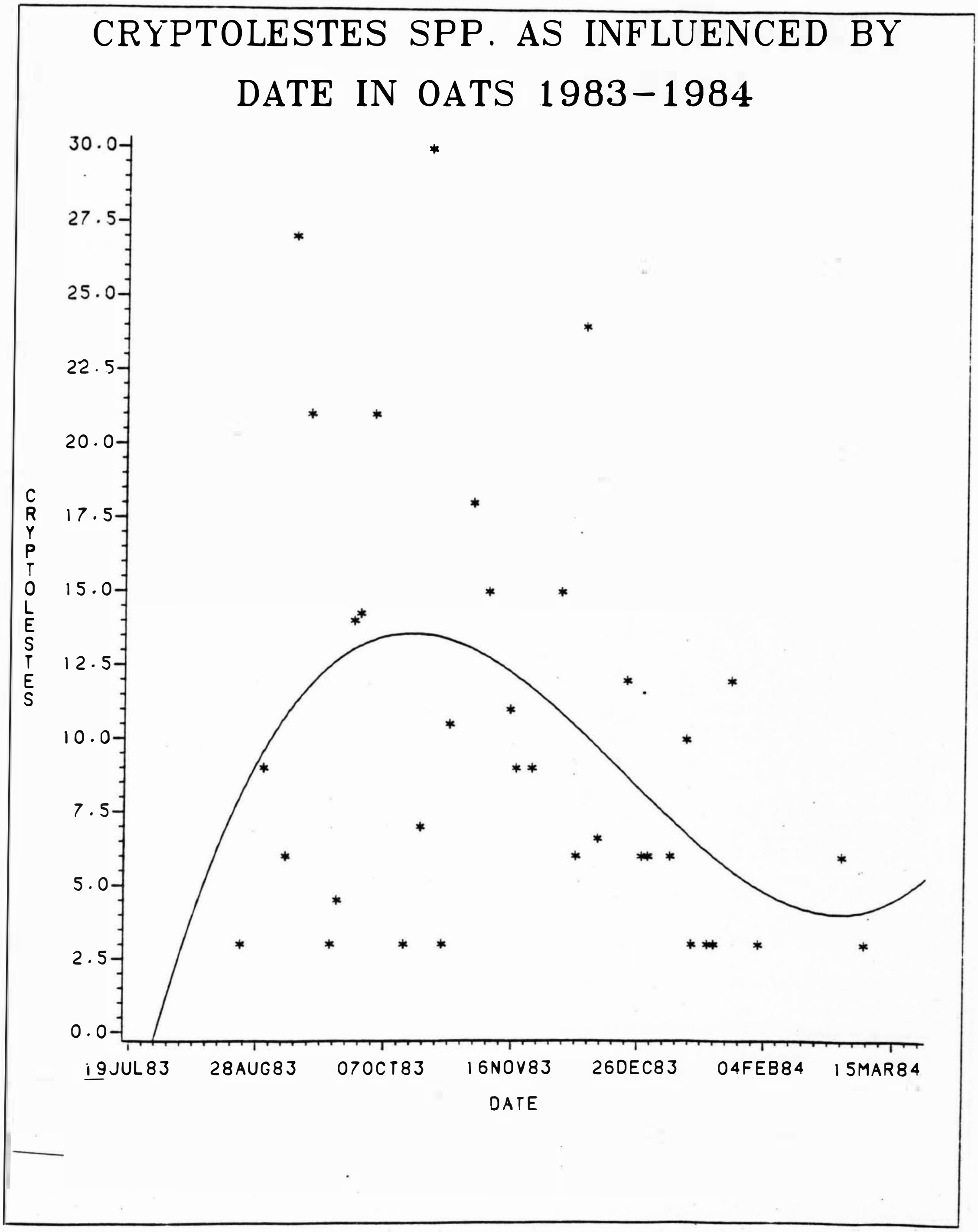

Figure 23. The line represents the average density per kilogram of Cryptolestes spp. for the infested samples. Each data point represents the mean for each particular date.

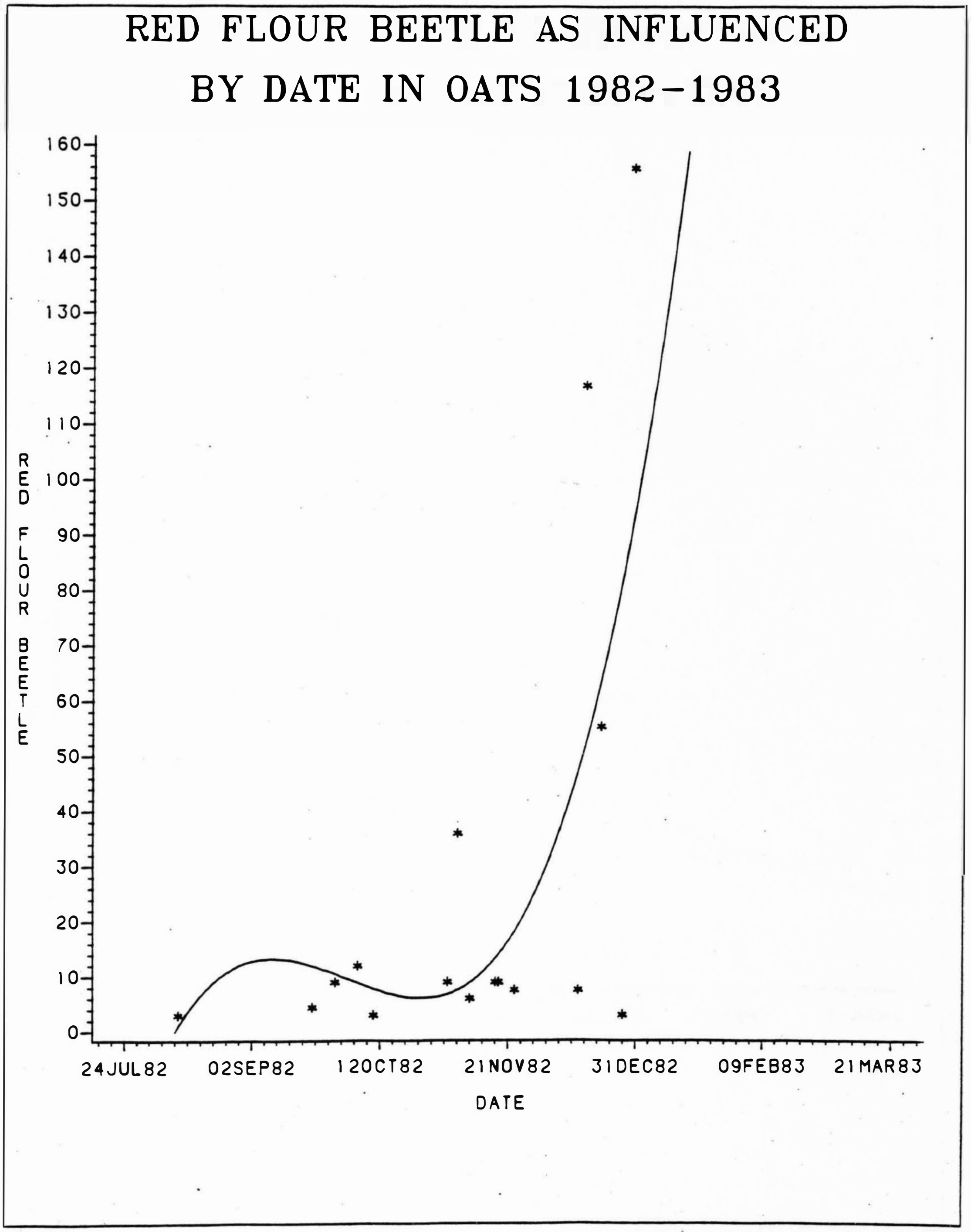

Figure 24. The line represents the average density per kilogram of the red flour beetle for the infested samples. Each data point represents the mean for each particular date.

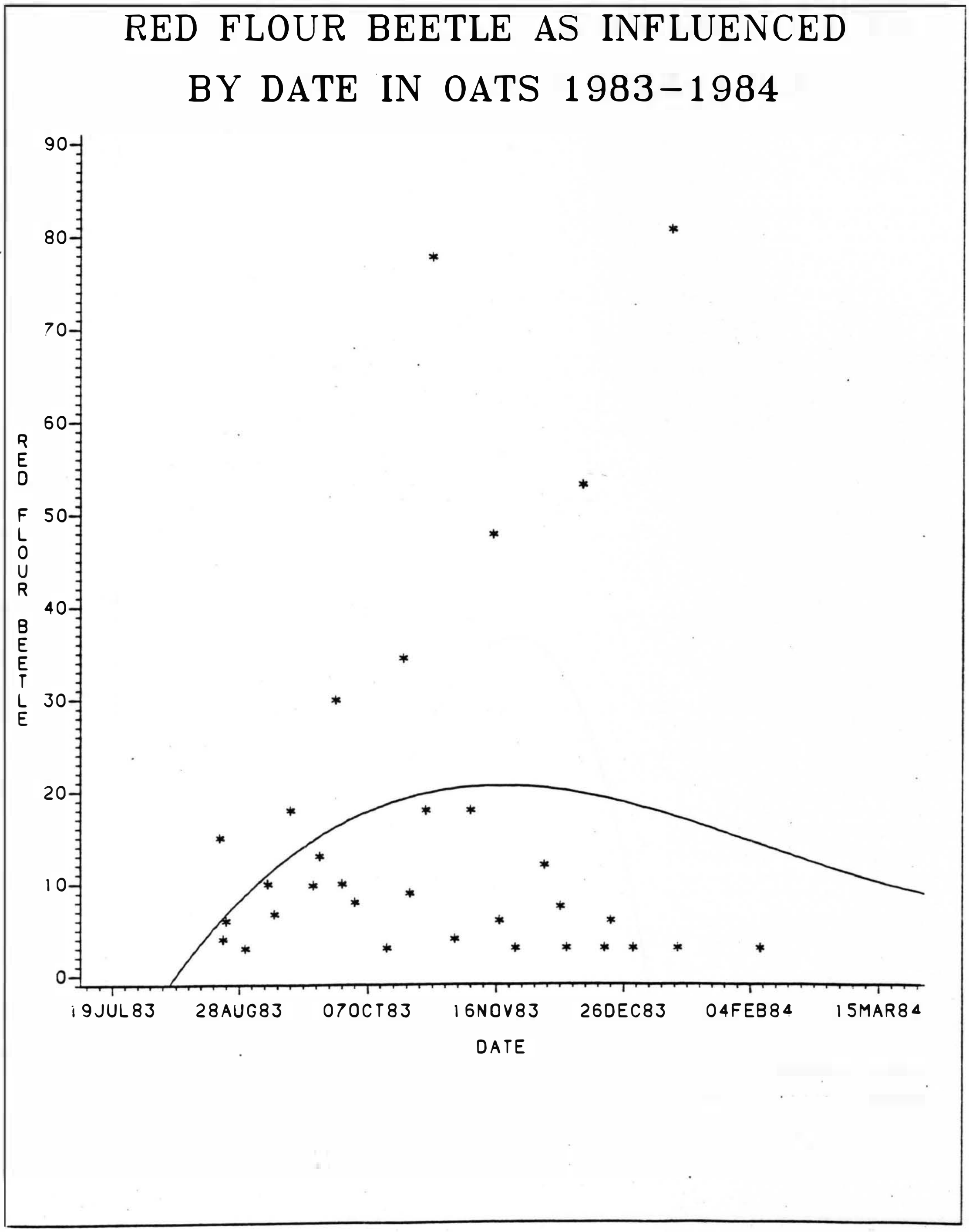

Figure 25. The line represents the average density per kilogram of the red flour beetle for the infested samples. Each data point represents the mean of each particular date.

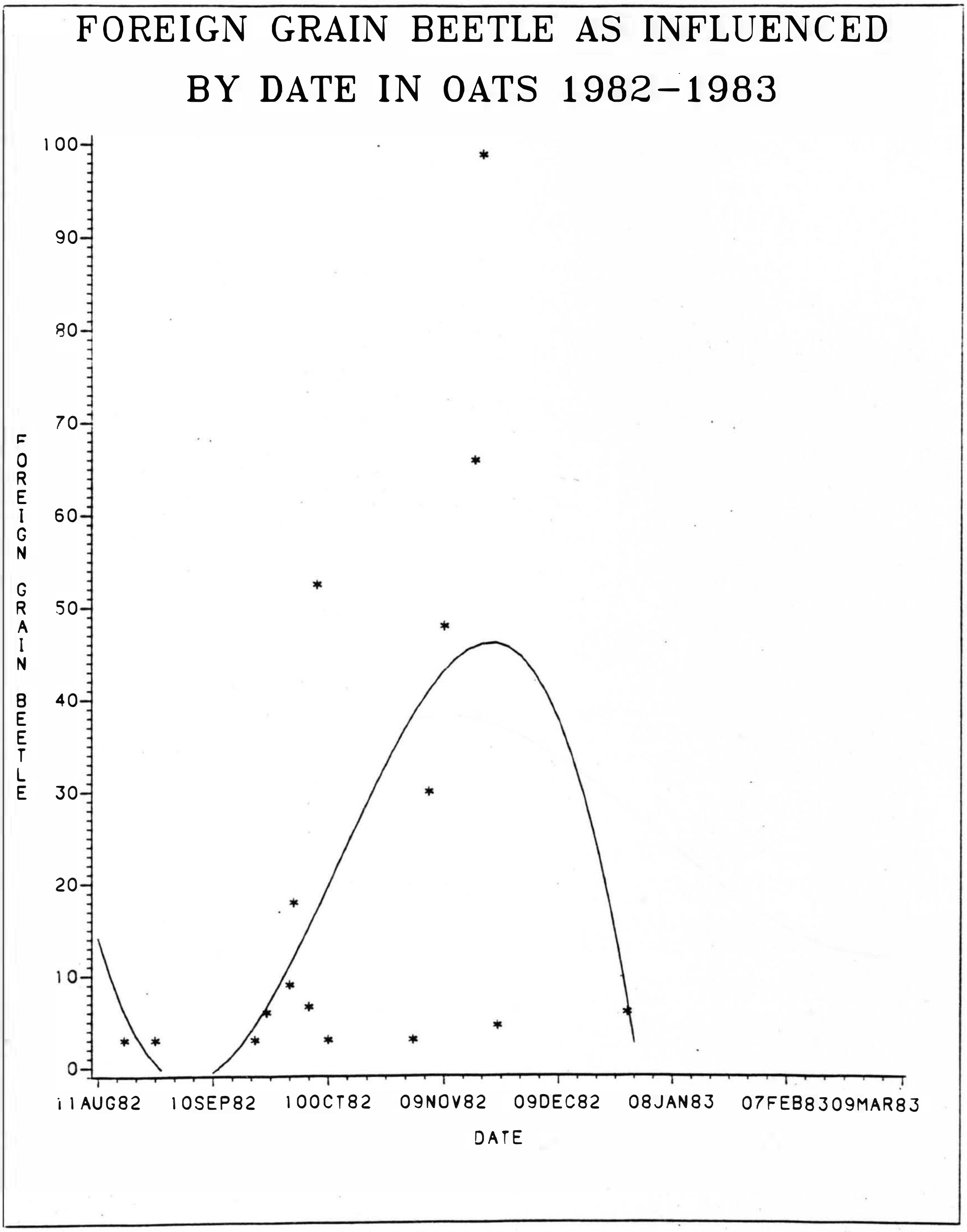

Figure 26. The line represents the average density per kilogram of the foreign grain beetle for the infested samples. Each data point represents the mean for each particular date.

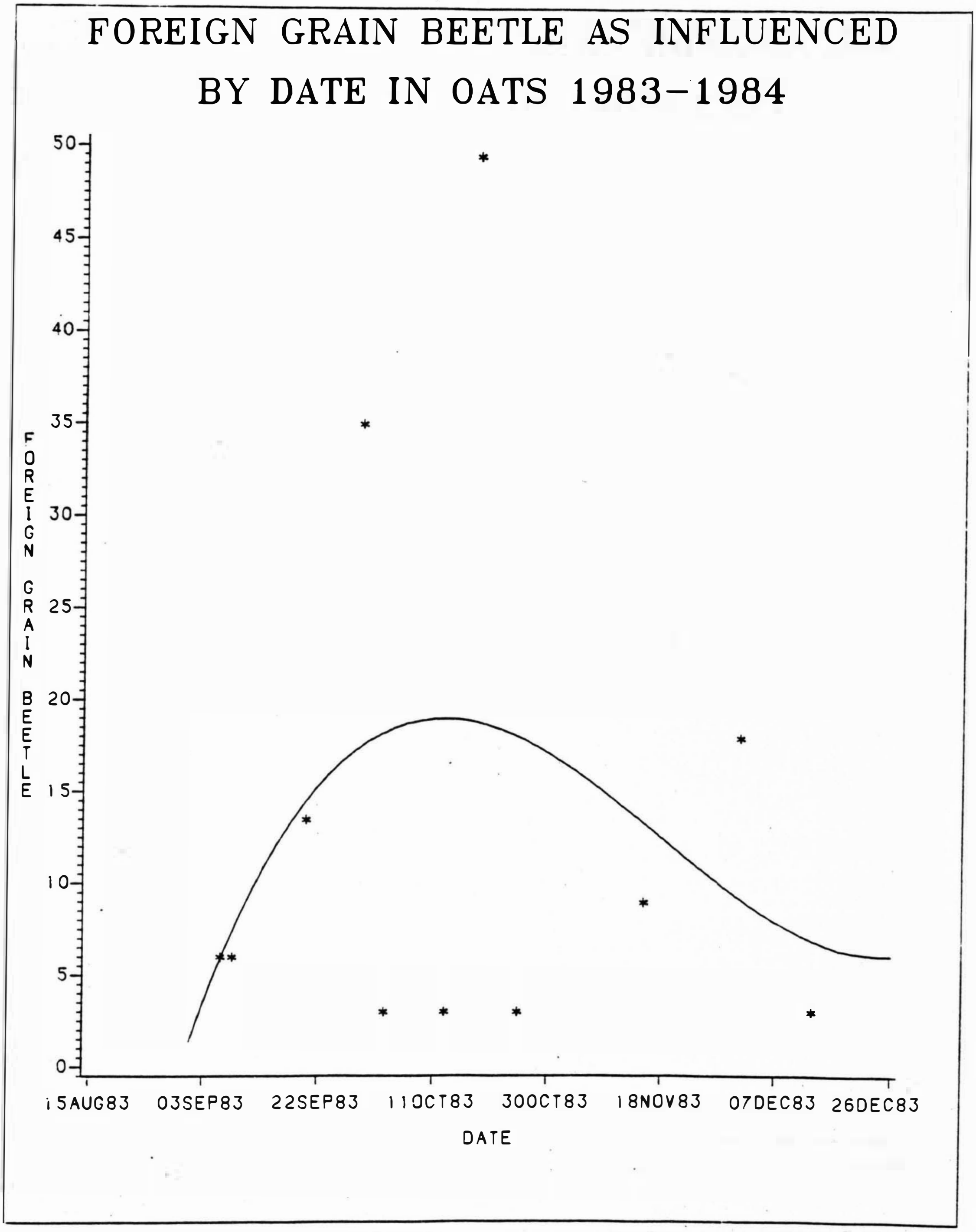

Figure 27. The line represents the average density per kilogram of the foreign grain beetle for the infested samples. Each data point represents the mean for each particular date.

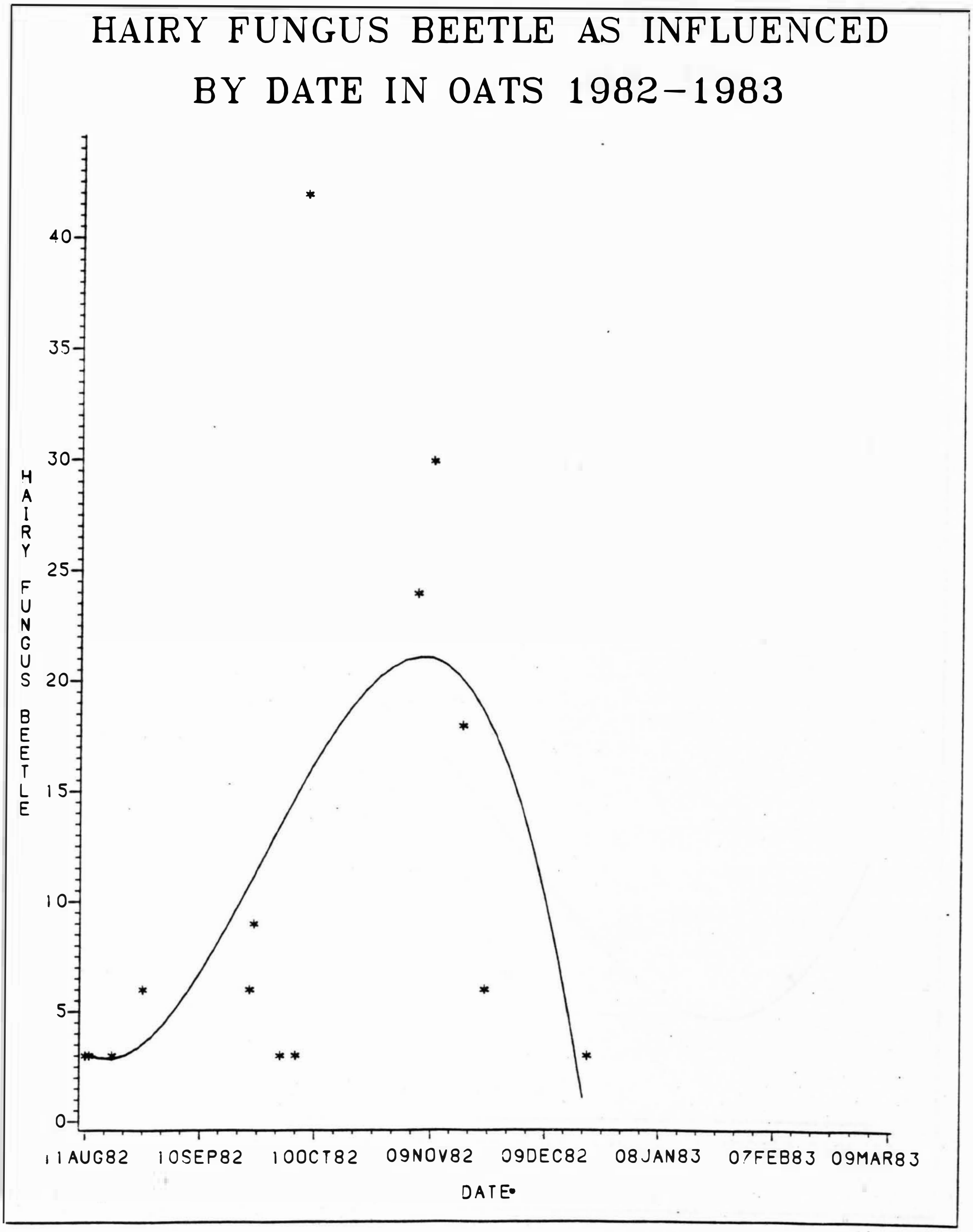

Figure 28, The line represents the average density per kilogram of the hairy fungus beetle for the infested samples. Each data point represents the mean for each particular date.

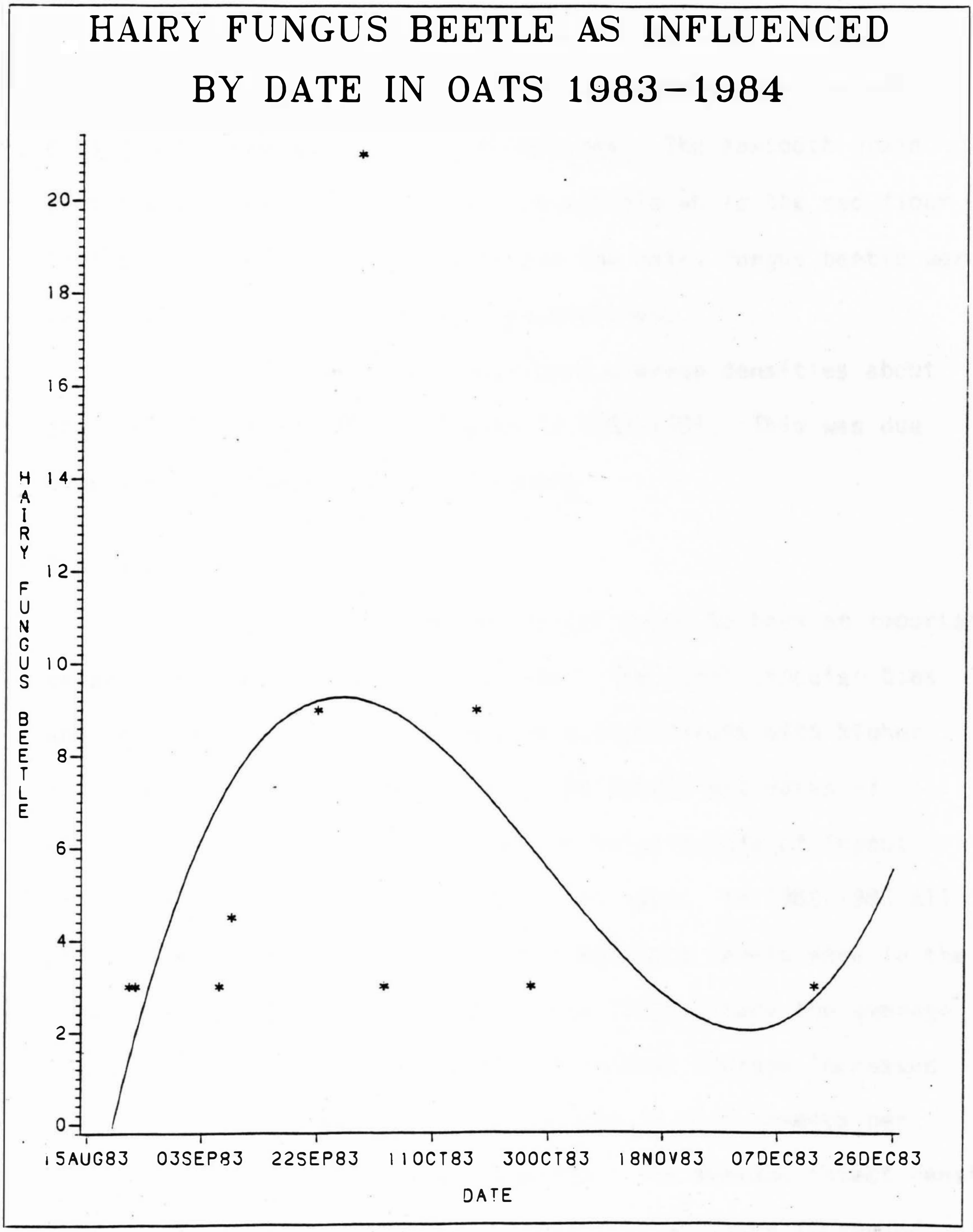

Figure 29. The line represents the average density per kilogram of the hairy fungus beetle for the infested samples. Each data point represents the mean for each particular date.

were no live hairy fungus beetles found after mid December.

The Cryptolestes spp. was found to be very resistant to cold grain temperatures below 40 degrees. The sawtooth grain beetle was found to be somewhat susceptible while the red flour beetle, the foreign grain beetle and the hairy fungus beetle were very susceptible to cold grain temperatures.

All species reached their peak average densities about one month later in 1982-1983 than in 1983-1984. This was due mainly to the temperature differences.

Bin Type

The bin type was another factor found to have an important relationship with insect populations. The steel circular bins and the flat storage in quonsets were significant with higher insect densities over various moisture levels and dates of sampling. Figures 30 and 31 show the relationship of insect density as affected by moisture and bin type. In 1982-1983 all of the high insect densities at high moisture levels were in the steel bins and quonset storage. Above 13% moisture the average insect density in the steel bins and quonset storage increased linearly. The quonset storage contained 25 more insects per kilogram than the steel bins above 13%. The average insect density in wood storage increased very slightly as moisture increased. In 1983-1984 steel bins were also found to have a significant relationship with insect density. From 9-13% moisture, the average density for steel bins was higher than wooden bins.

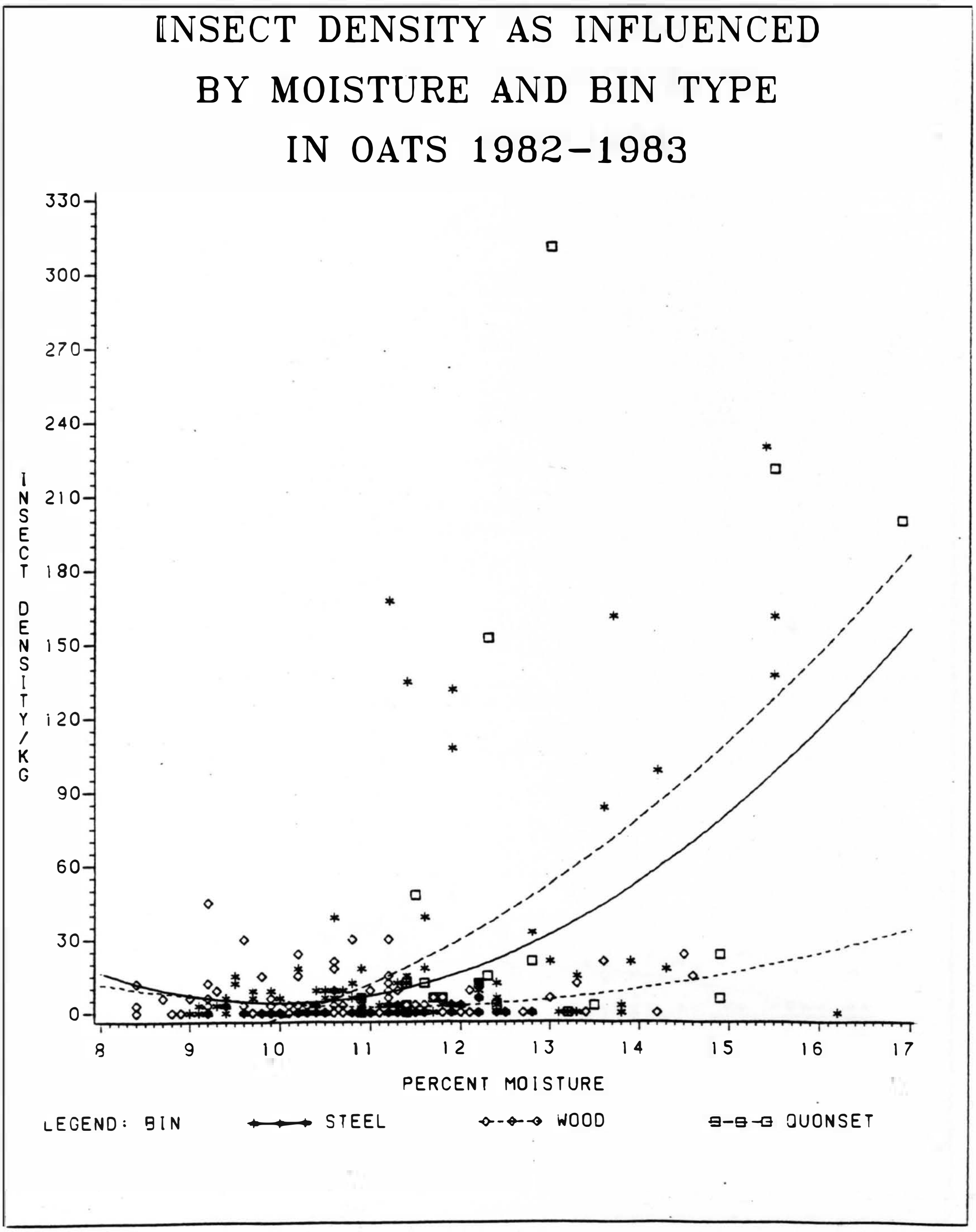

Figure 30. The line represents the average insect density per kilogram. Each data point represents one sample.

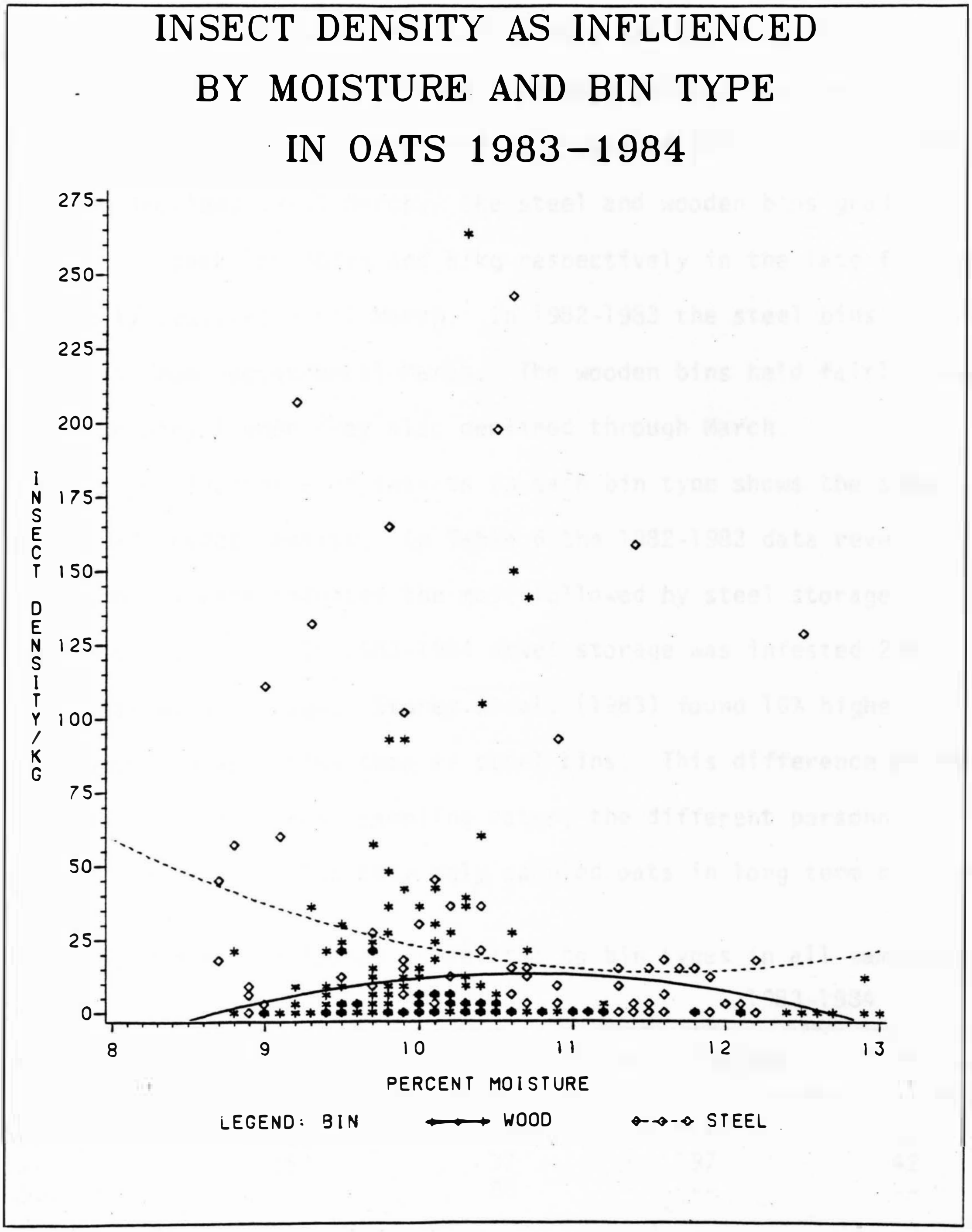

Figure 31. The lines represent the average insect density per kilogram. Each data point represents one sample.

Insect density as related to date and bin type is shown in Figures 32 and 33. From September through October the average density for the quonset storage increased to a peak of 120/kg in 1982-1983. It then declined until March. The steel and wooden bins gradually increased to peaks of 30/kg and 8/kg respectively in the late fall and gradually declined until March. In 1982-1983 the steel bins declined linearly from August until March. The wooden bins held fairly constant until January 1 when they also declined through March.

The incidence of insects in each bin type shows the same trends as insect density. In Table 6 the 1982-1983 data reveals the quonsets were infested the most followed by steel storage and then wood storage. In 1983-1984 steel storage was infested 20% more than wood storage. Storey et al. (1983) found 10% higher incidences in wood bins than in steel bins. This difference might relate to the different sampling dates, the different personnel taking the samples plus they only sampled oats in long term storage.

Table 6. Insect incidence as related to bin types in all samples.

	1982-1983		1983-1984	
Bin Type	# of Samples	% Infested[A]	# of Samples	% Infested[A]
Steel	128	51	114	62
Wood	159	37	197	42
Quonset	22	86	--	--
TOTAL	309	46	311	50

[A] - contained at least one live insect per kilogram

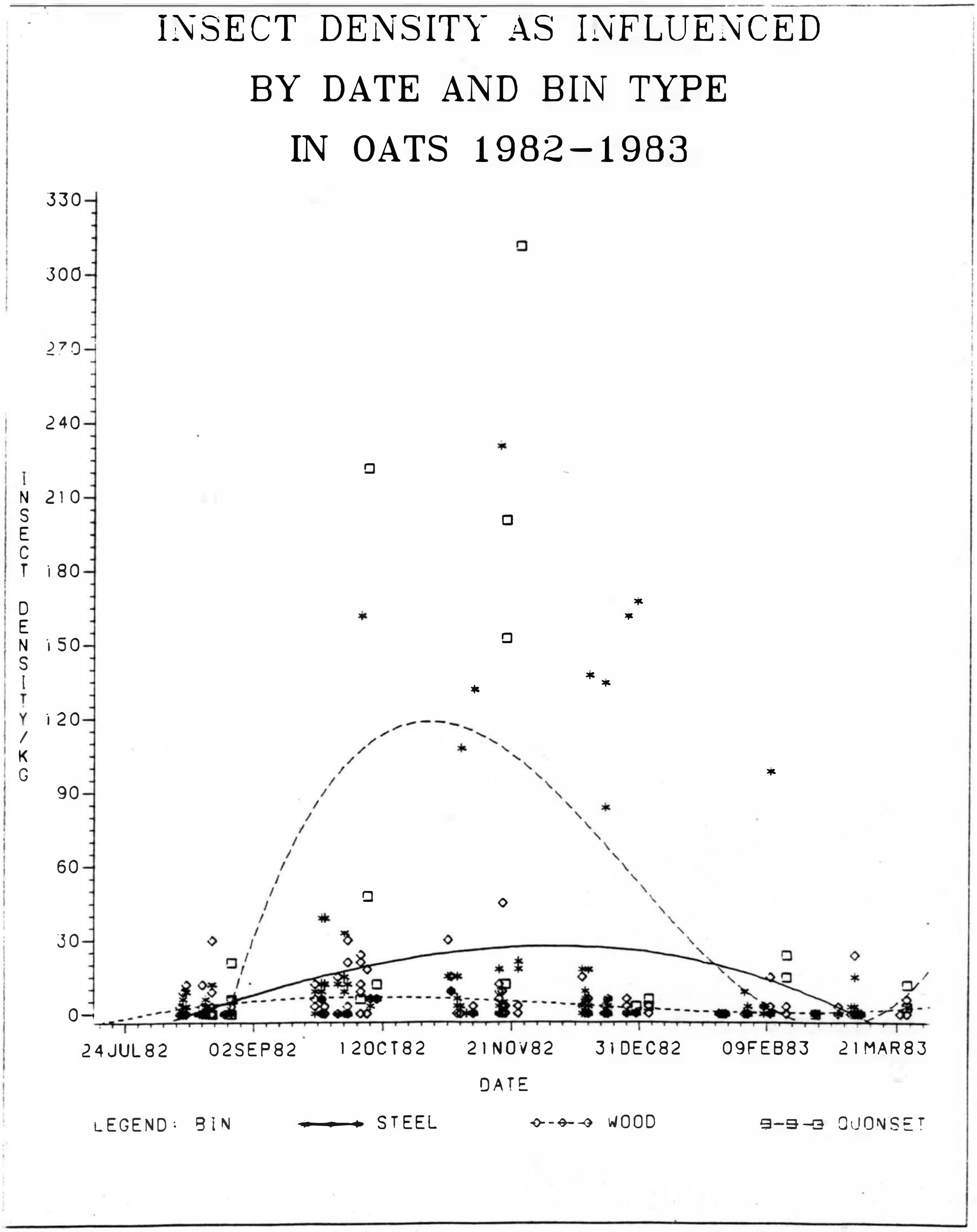

Figure 32. The lines represent the average insect density per kilogram. Each data point represents one sample.

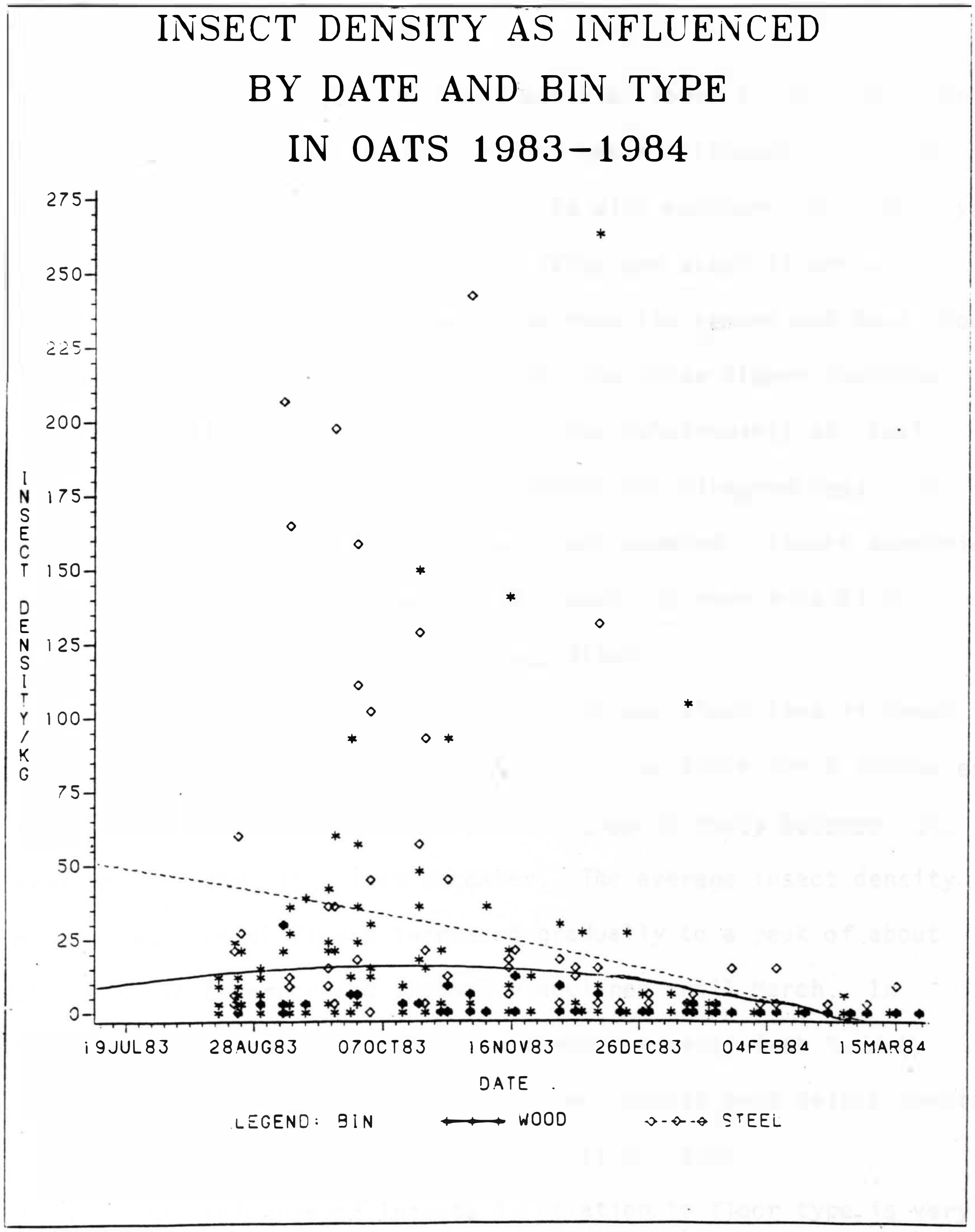

Figure 33. The lines represent the average insect density per kilogram. Each data point represents one sample.

Floor Type

The type of floor in a bin was also found to be significantly related to insect populations for both years. Figures 34 and 35 show the relationship of insect density with moisture and floor type. In 1982-1983 the bins equipped with false and steel floors were found to have higher insect densities than the cement and wood floors. The number of insects per kilogram for the false floors increased linearly from 10.5% to 17% moisture. The relationship of steel floors is similar but is about 30 insects per kilogram less. In 1983-1984 bins with false floors were not sampled. Insect densities in bins with steel floors were significantly higher from 8% to 13% moisture than the cement and wood floors.

Insect density as related to date and floor type is shown in Figures 36 and 37. In 1982-1983 the false floor curve increases to a peak of about 190 insects per kilogram in early December and were not sampled after late December. The average insect density in bins with steel floors increased gradually to a peak of about 35/kg in mid December and gradually declined until March. In 1983-1984 the steel floor curve decreased linearly from August through March. The wood and cement floor curves held fairly constant at 10-15 insects per kilogram from August to March.

The incidence of insects in relation to floor type is very similar to insect density. In Table 7 the 1982-1983 bins with false floors were found to have the highest incidence. Bins with steel floors were found in both years and found to have higher

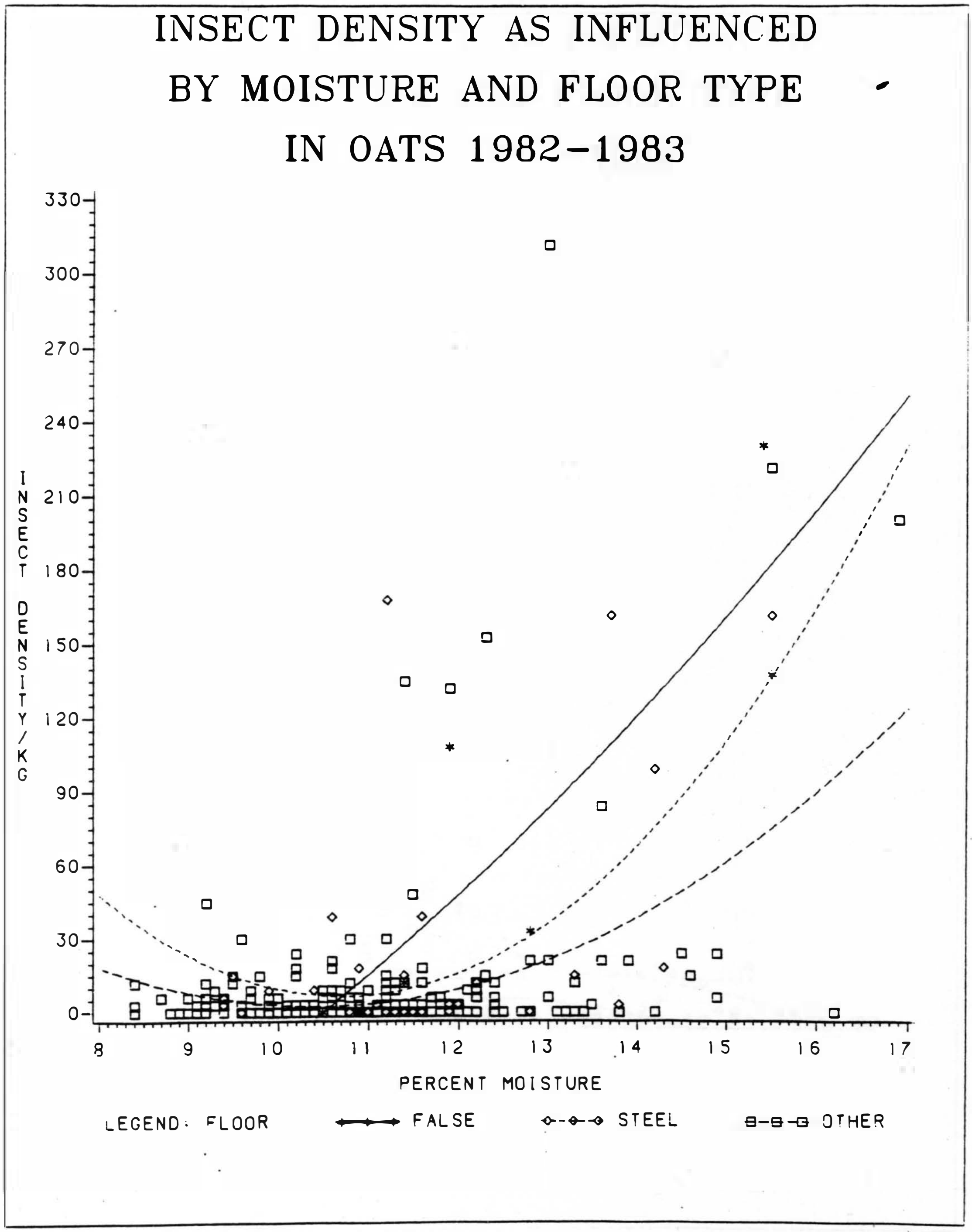

Figure 34. The lines represent the average insect density per kilogram. Each data point represents one sample. Other = cement and wood floors.

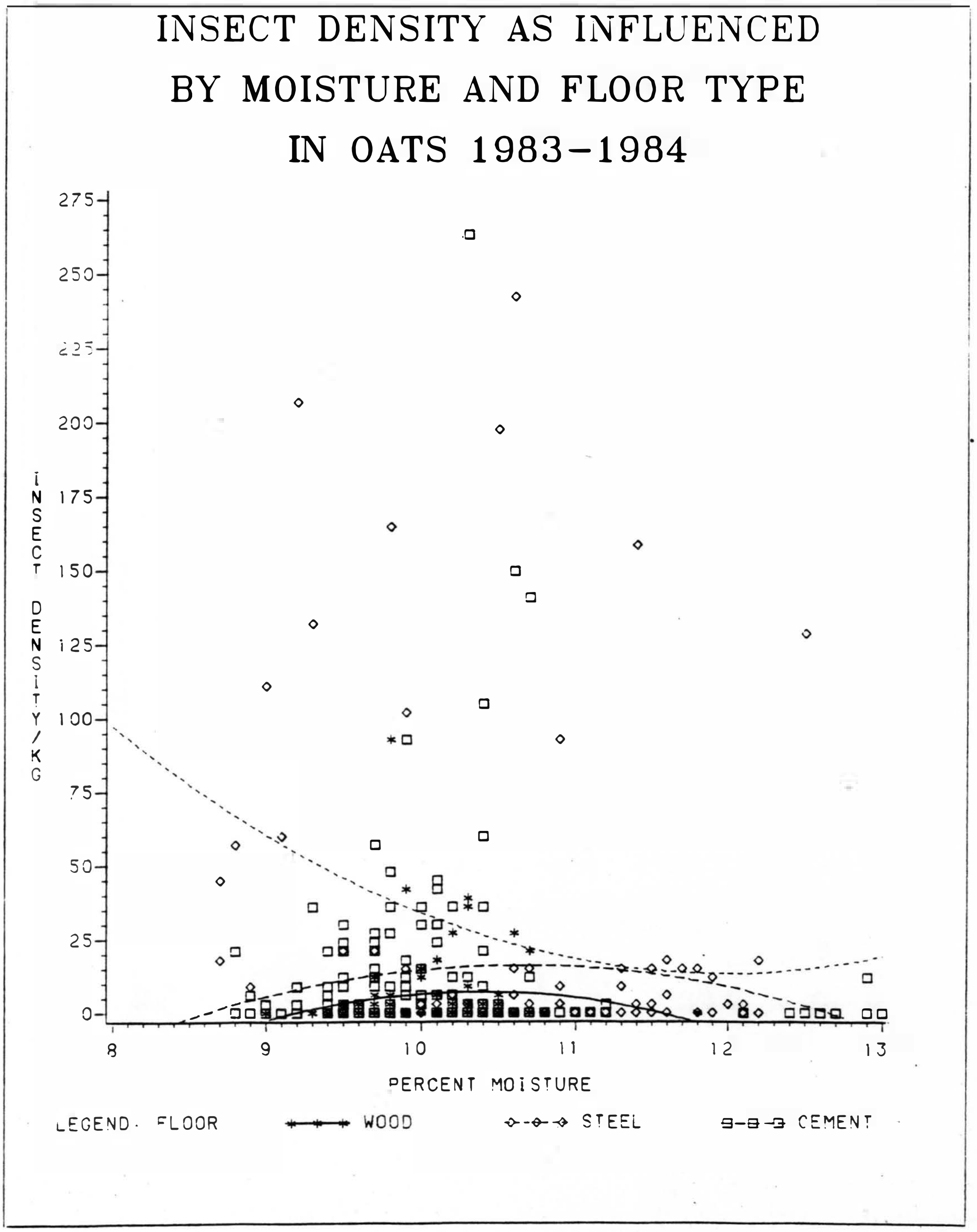

Figure 35. The lines represent the average insect density per kilogram. Each data point represents one sample.

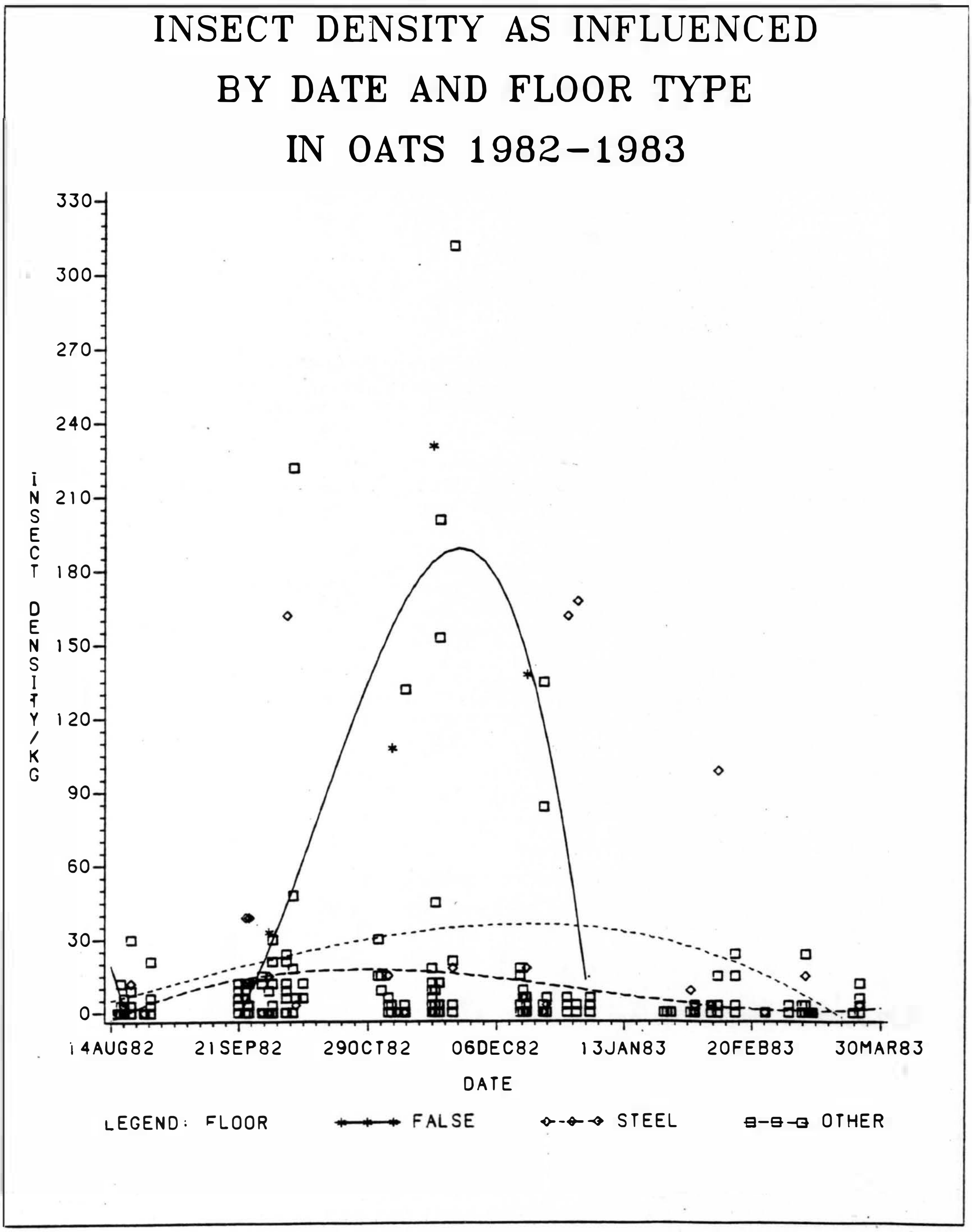

Figure 36. The lines represent the average insect density per kilogram. Each data point represents one sample. Other = cement and wood floors.

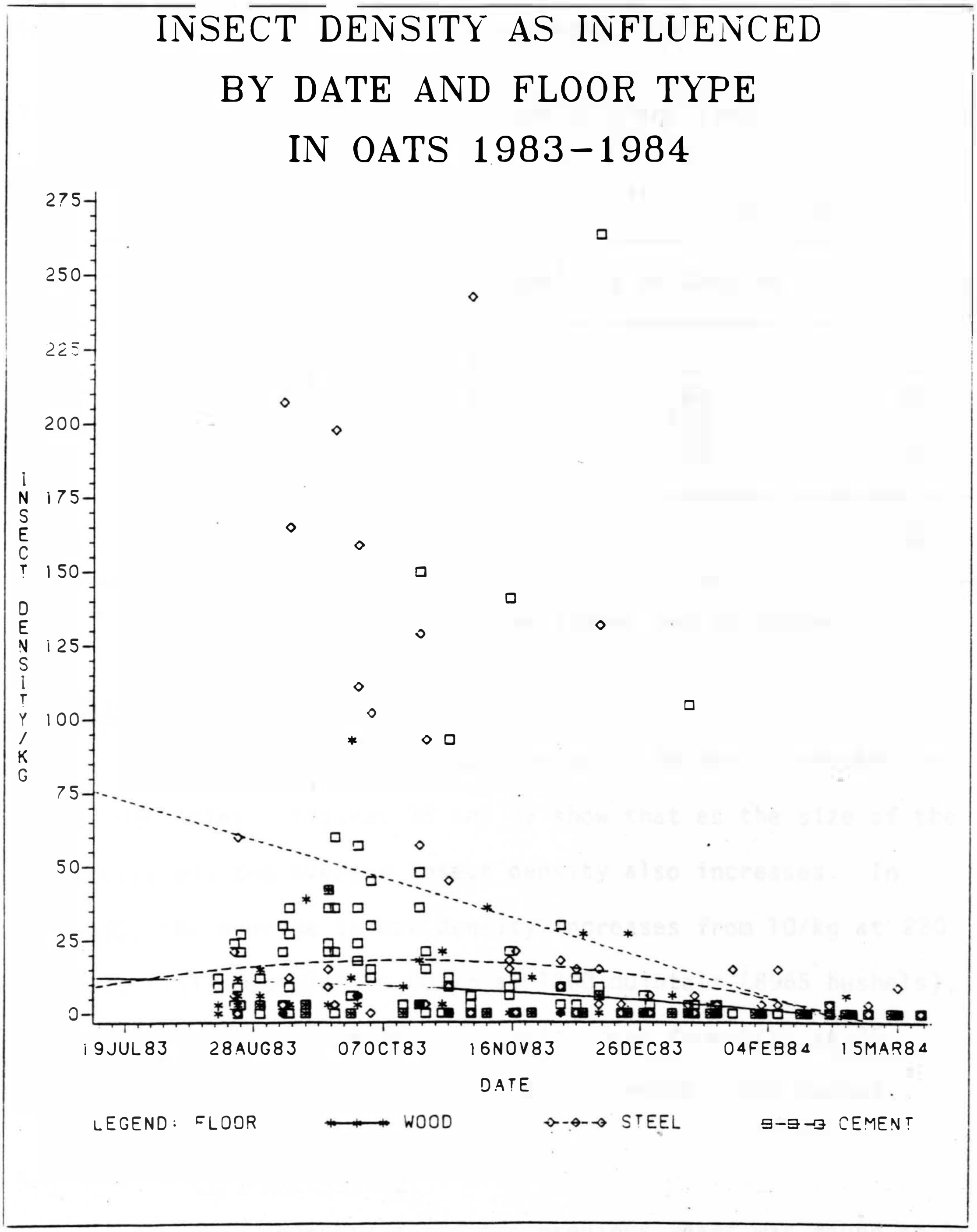

Figure 37. The lines represent the average insect density per kilogram. Each data point represents one sample.

incidences than bins with cement and wood floors.

Table 7. Insect incidence as related to floor type in all samples.

	1982-1983		1983-1984	
Floor Type	# of Samples	% Infested[A]	# of Samples	% Infested[A]
False	7	71	--	--
Steel	44	55	80	59
Cement	189	49	153	50
Wood	69	30	78	40
TOTAL	309	46	311	50

[A] - contained at least one live insect per kilogram

Bin Size

In 1983-1984 bin size was the major factor as related to insect densities. Figures 38 and 39 show that as the size of the bin increases, the average insect density also increases. In 1982-1983 the average insect density increases from 10/kg at 220 quintals (1517 bushels) to 50/kg at 1300 quintals (8965 bushels). In 1983-1984 the average insect density rose from 5/kg at 75 quintals (517 bushels) to 35/kg at 400 quintals (2759 bushels).

Resident Insect Populations

The peak infestation of the previous years was found to be significantly related to insect density. In 1983-1984 it was found that with increasing levels of previous year peak infestation levels, there is an increasing density the following year up to the previous

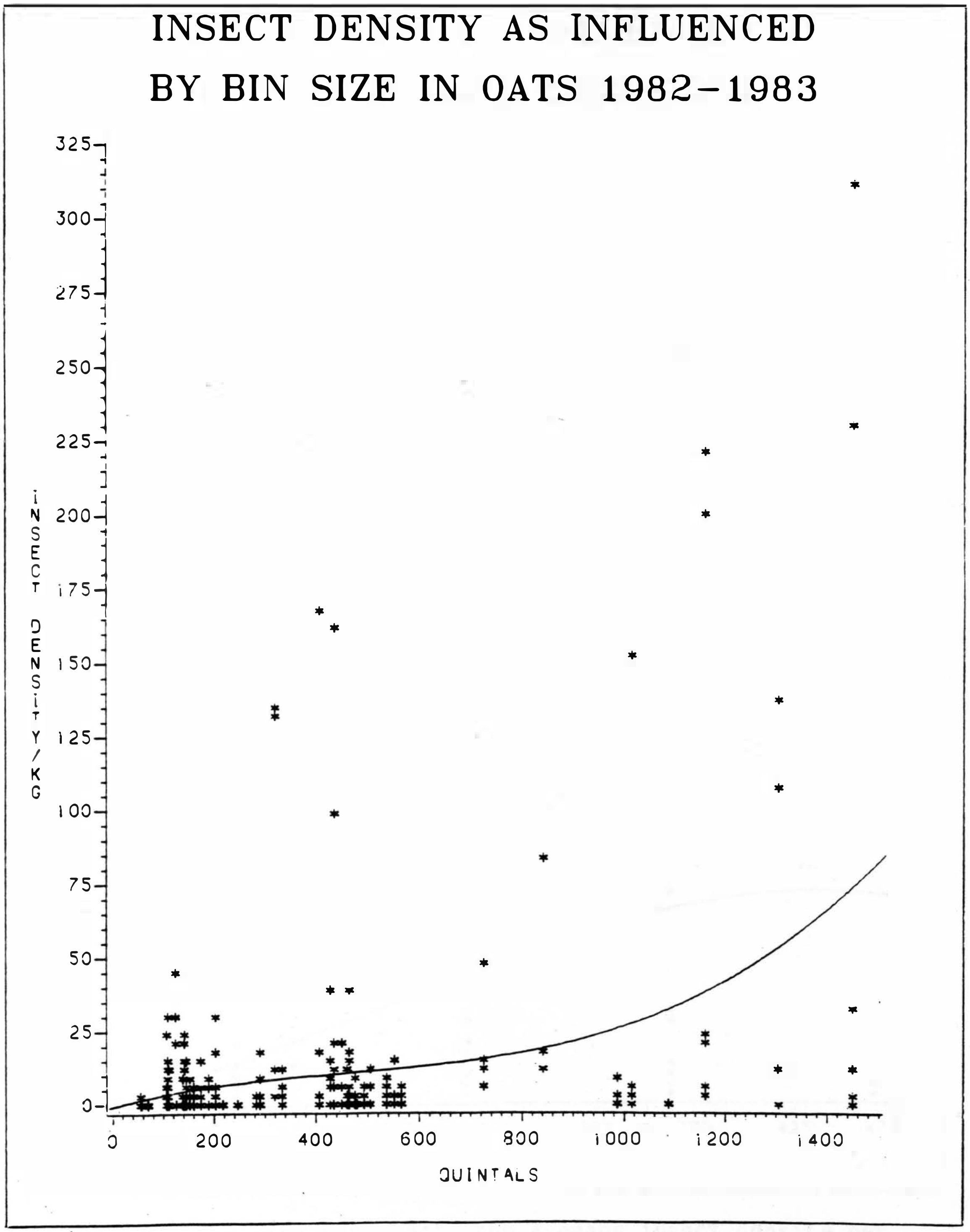

Figure 38. The line represents the average insect density per kilogram. Each data point represents one sample.

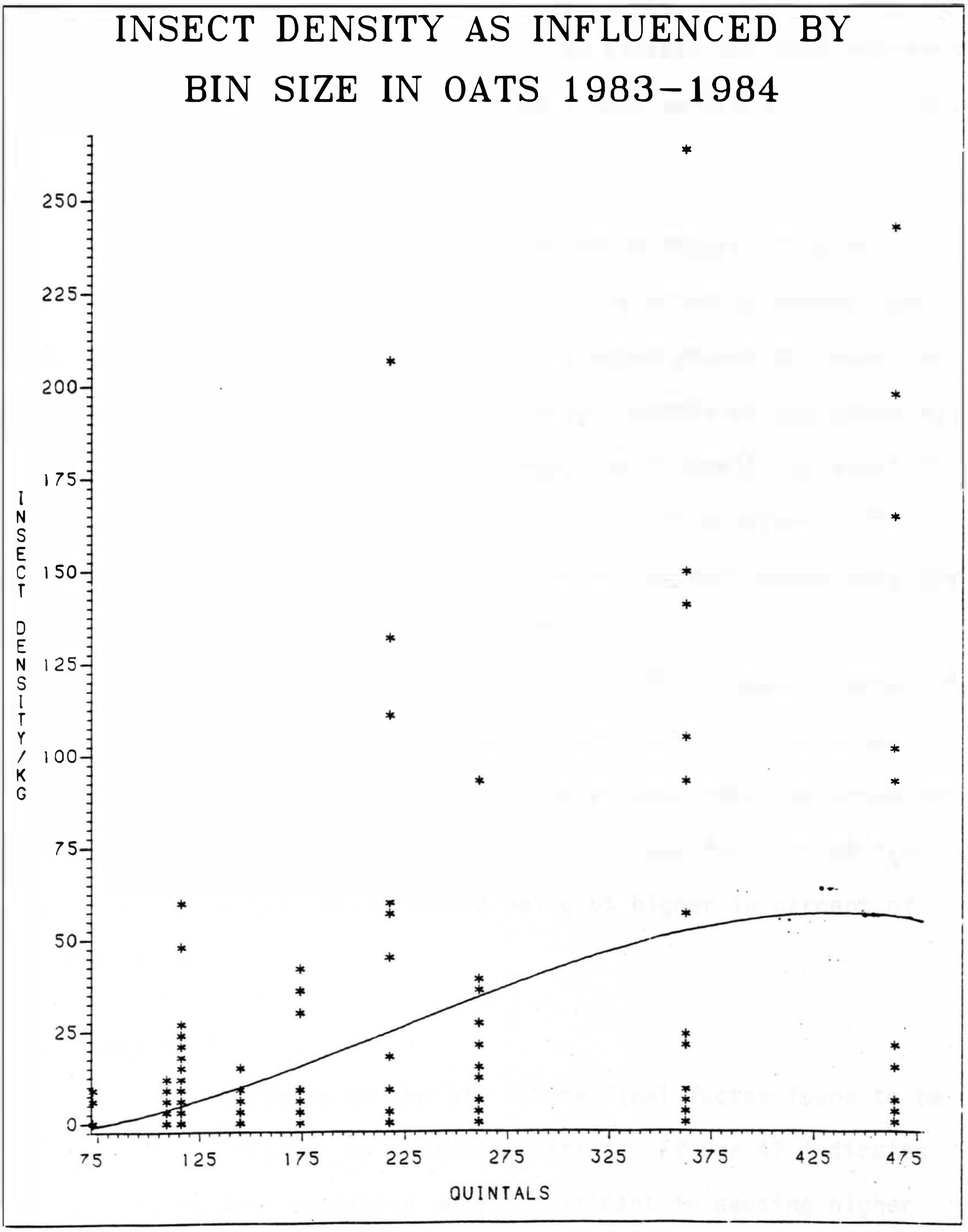

Figure 39. The line represents the average insect density per kilogram. Each data point represents one sample.

peak of 63 as shown in Figure 40. Beyond this peak the average density decreased. This decline may be because the oats representing the previous peak level of 85/kg had a test weight of only 21 pounds.

Cleaning Procedure

In 1983-1984 the cleaning procedure before the binning of the oats was found to be significant in relation to insect populations. The procedure of using just a scoop shovel to clean the bin was compared to the broom and vacuum methods of bin cleaning. In Figure 41 the scoop shovel average insect density is about 20/kg higher than the other methods from 8.5% to 10% moisture. This would be expected because the scoop shovel method leaves oats for resident populations to exist in the bin.

The incidence of insects in 1982-1983 in Table 8 shows the same type of trend as in 1983-1984 insect density. The scoop shovel method had a 15% higher incidence level than the broom and vacuum. In 1983-1984 the insect incidence was found to be reversed with the broom and vacuum method being 6% higher in percent of infestation.

Bin Condition

The condition of the bin is the final factor found to be significantly related to insect densities. Figure 42 indicates that bins in fair condition were significant in causing higher insect infestation levels than bins in good or poor condition. The reason is because a majority of the steel bins had steel floors.

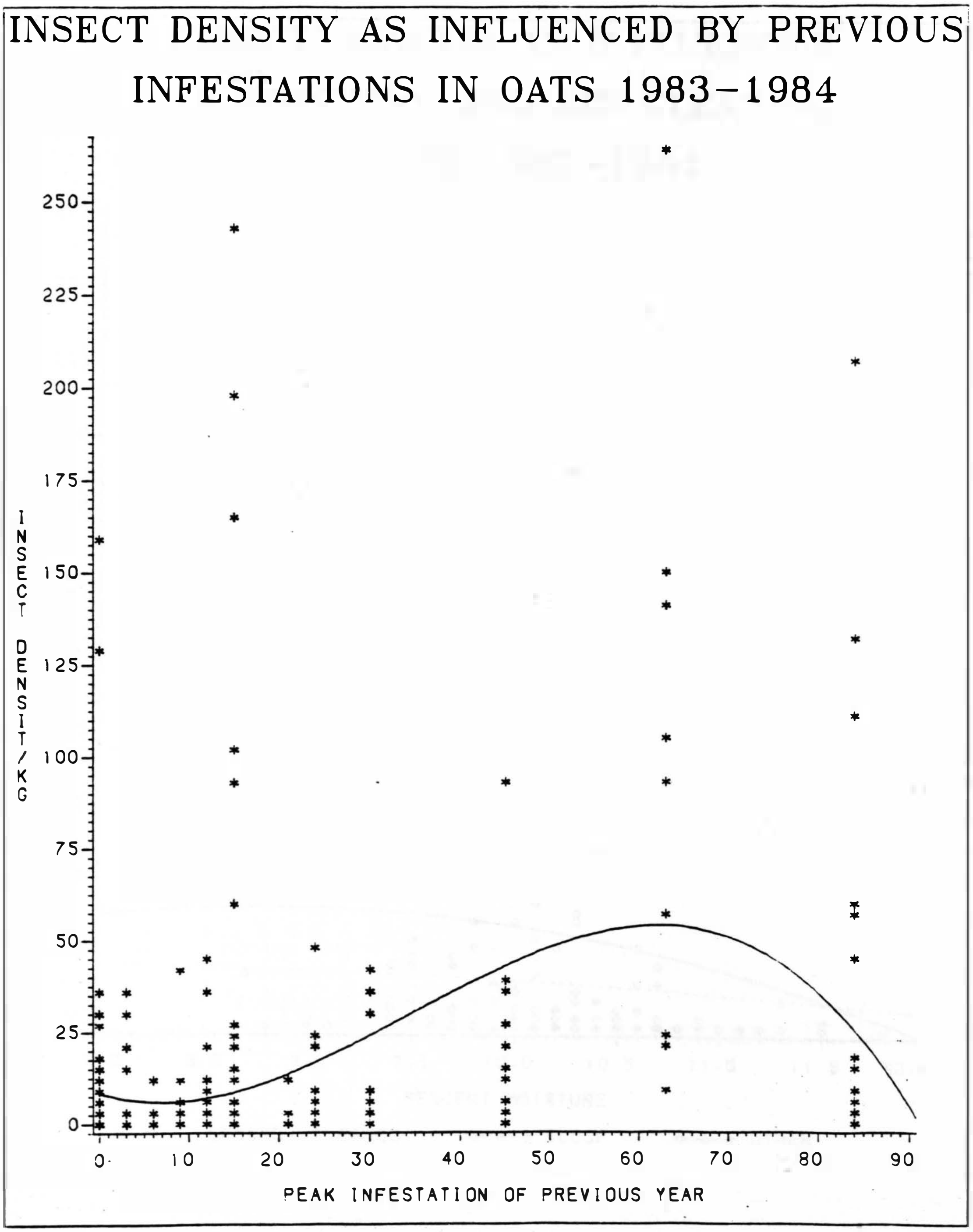

Figure 40. The line represents the average insect density per kilogram. Each data point represents one sample.

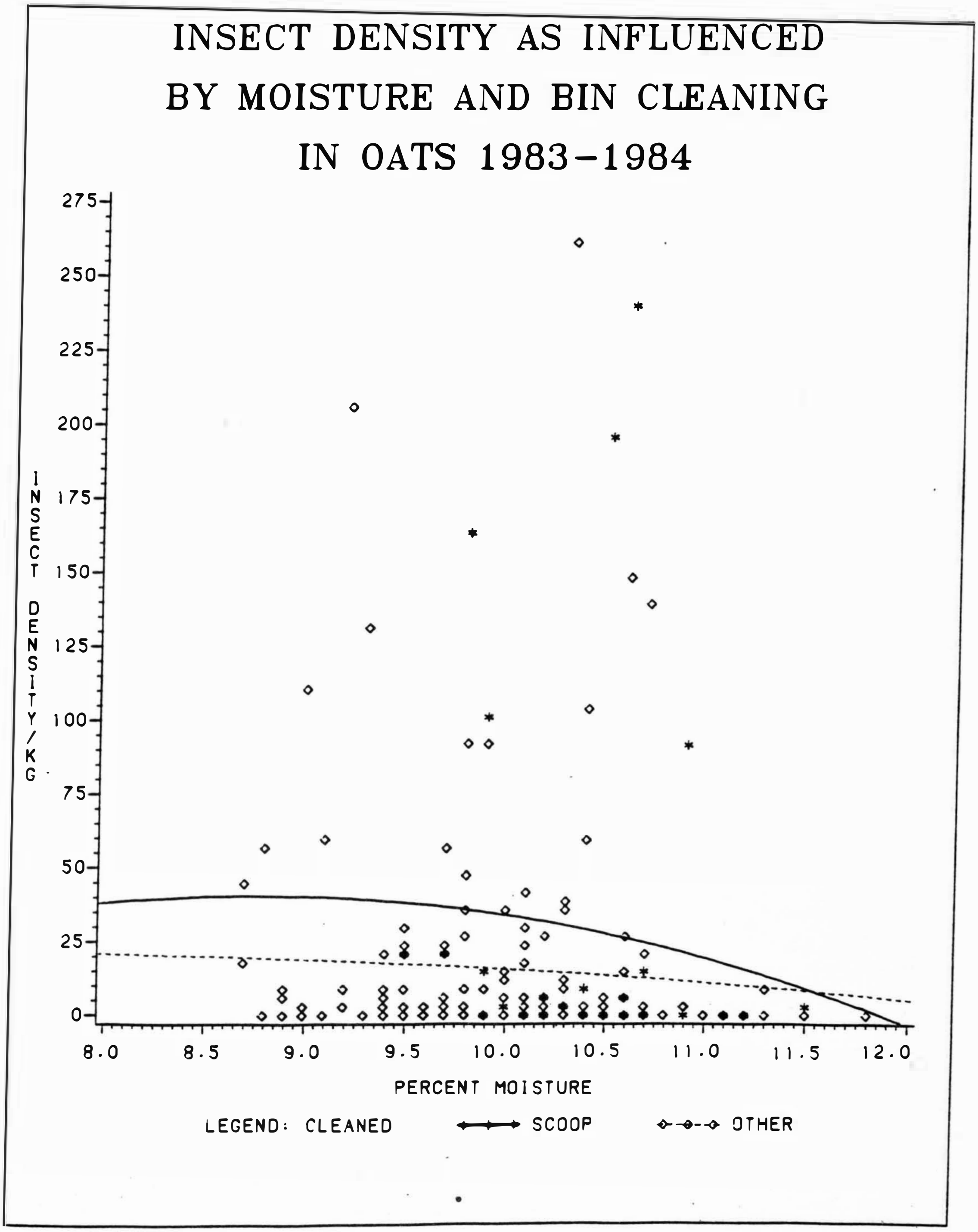

Figure 41. The lines represent the average insect density per kilogram. Each data point represents one sample. Other - broom and vacuum.

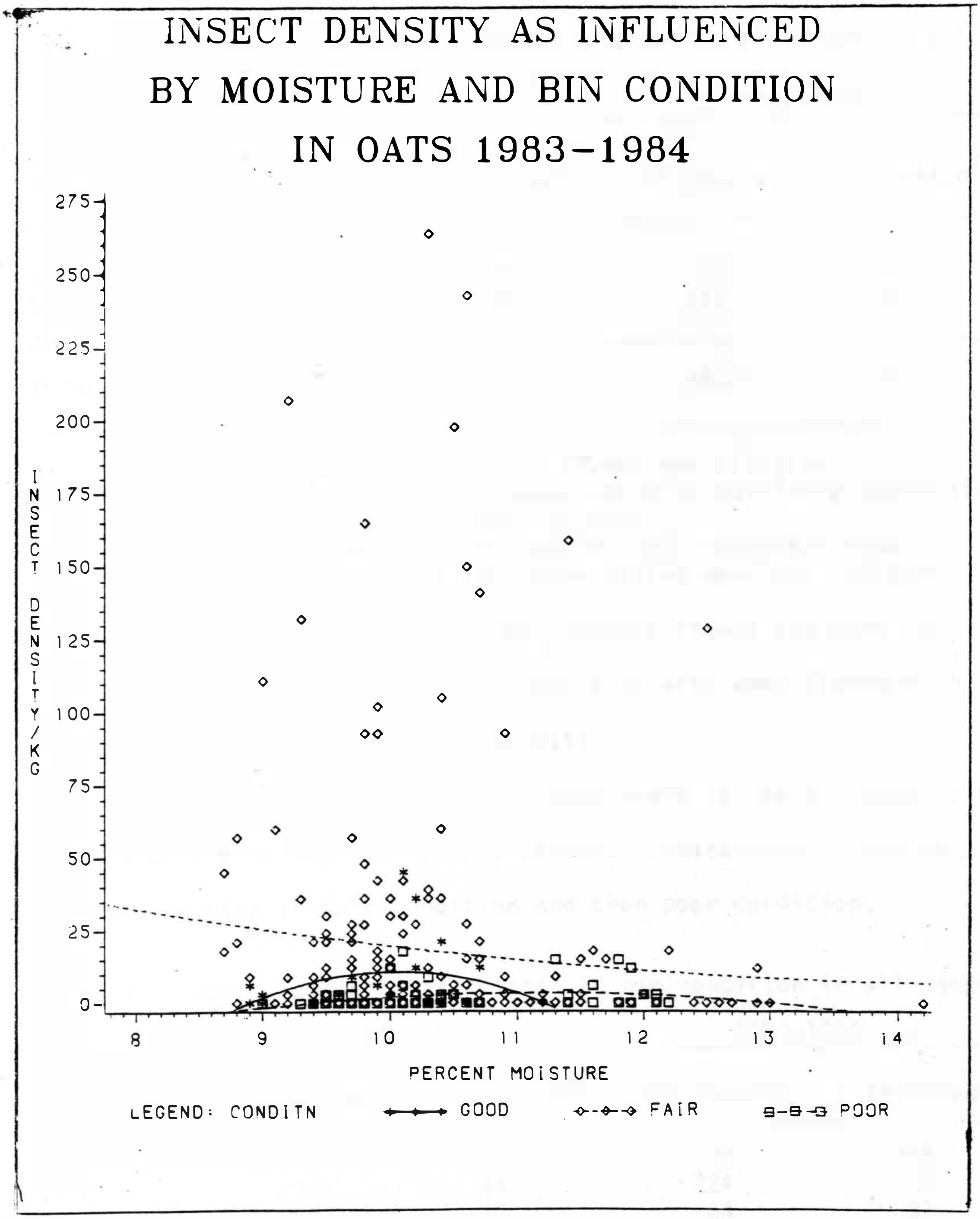

Figure 42. The lines represent the average insect density per kilogram. Each data point represents one sample.

Table 8. Insect incidence as related to cleaning procedure in all samples.

	1982-1983		1983-1984	
Cleaning Procedure	# of Samples	% Infested[A]	# of Samples	% Infested[A]
Scoop Shovel	35	60	32	50
Broom & Vacuum	242	45	151	56
TOTAL	277[B]	47	183[C]	55

[A] - contained at least one live insect per kilogram
[B] - thirty-two samples that represent bins partially containing oats when filled were not included
[C] - one hundred twenty-eight samples that represent bins partially containing oats when filled were not included

The bins in good condition had mostly cement floors and bins in poor condition were the old small wood bins with wood floors with excellent air movement through the oats.

The incidence of insects in both years in Table 9 shows bins in good condition had the highest percent infestations. This is followed by bins in fair condition and then poor condition.

Table 9. Insect incidence as related to bin condition in all samples.

	1982-1983		1983-1984	
Bin Condition	# of Samples	% Infested[A]	# of Samples	% Infested[A]
Good	118	55	23	65
Fair	138	44	224	53
Poor	53	32	64	31
TOTAL	309	46	311	50

[A] - contained at least on live insect per kilogram.

CONCLUSIONS

1. Moisture percent of the oats rose on an average of one percent from August through March.
2. The average insect density remained constant from 8% to 12% moisture. Above 12% the average insect density increased as moisture percent increased. Oats stored below 12% did not eliminate infestations because some species were adaptable to dry grain. However, below 12% moisture the average insect density was quite low.
3. Insect incidence was found to be the lowest in the 10% to 12% moisture range. From 8% to 10% it was slightly higher and above 13% moisture the insect incidence increased as moisture increased.
4. High densities of the sawtoothed grain beetle were found below 12% moisture, while high densities of *Cryptolestes* spp. were found above 13% moisture.
5. *Cryptolestes* spp. were found to be resistant to cold temperatures, while the sawtoothed grain beetle were found to be somewhat susceptible. The red flour beetle, the foreign grain beetle and the hairy fungus beetle were very susceptible to cold grain temperatures of January through March.
6. Insect densities were the highest in October, while insect incidences were the highest in September and October. Insect densities and incidences decreased after October because of cold temperatures.

7. Oats stored in quonsets or steel bins were found to have higher average insect densities and incidences than wood bins over various moisture levels and dates of sampling. The quonset and steel bins were larger than the wood bins. As bin size increased, the average insect density increased.
8. Bins equipped with false or steel floors were found to have higher average insect densities and incidences than bins with cement or wood floors.
9. Bins with high insect densities the first year had high average insect densities the second year.
10. Bins cleaned with a scoop shovel had higher average insect densities than bins cleaned with a broom or vacuum.
11. Bins in fair condition were found to have higher average insect densities than bins in good or poor condition over various moisture levels.

LITERATURE CITED

American Cyanamid Company. 1981. How to control insects in farm-stored grain. 23p.

Banks, H. J. 1979. Identification of stored product Cryptolestes spp. (Coleoptera: Cucujidae): A rapid technique for preparation of suitable mounts. J. Aust. Ent. Soc. 18:217-222.

Barak, A. V. and P. K. Harein. 1981. Insect infestation of farm stored shelled corn and wheat in Minnesota. J. Econ. Entomol. 74:197-202.

Bell, K. O. 1980. 1979-80 Kansas farm stored grain survey. (mineo). 6p.

Bell, K. O., G. Partida, and R. B. Mills. 1971. Kansas stored grain insects survey. (mimeo). 7p.

Berndt, W. L. May 24, 1982. Personal interview.

Cooperative Extension Service. 1980. Insect prevention in farm stored grain. South Dakota State University. EC-737. 3p.

Cotton, R. T. 1963. Insect pests of stored grain and grain products. Burgess Publishing Company. Minneapolis, Minnesota. 312p.

Foster, G. H. and B. A. McKenzie. 1979. Managing grain for year-round storage. Agricultural Engineering Department, Purdue University. Ae-90. 5p.

Furnival, G. M. and R. W. Wilson. 1974. Regression by leaps and bounds. Technometrics. 16:499-511.

Future trends in the management of stored product insects. 1982. Proceedings of an informal conference. F. V. Dunkel, Moderator, Toronto, Canada. 52p.

Grain Quality Newsletter. 1982. Marketing and delivery of quality cereals and oil seeds in domestic and foreign markets. S. A. Watson, Editor. 4:13-25.

Kantack, B. H. May 24, 1982. Personal interview.

Larrick, G. R. 1956. Clean grain program, Pest Control. 24(5);9-12.

Lingsley, E. G. and A. E. Michelbacher. 1943. A report on insect infestation of stored grain in California. J. Econ. Entomol. 36:829-831

Mills, R. B. and J. R. Pedersen. 1980. Sampling methods of a stored sorghum insect survey. (mimeo), 5p.

Peters, L. L. n.d. Insect prevention and control in farm stored grain. Cooperative Extension Service. University of Nebraska-Lincoln, EC 78-1534. 16p.

Pratt, H.D. and H. G. Scott. 1959. A key to some beetles commonly found in stored foods (Coleoptera). PHS, CDC Training Guide. Stored Food Insects.

Sinha, R. N. 1961. Insects and mites associated with hot spots in farm stored grain. The Canadian Entomologist, 43:609-621.

Storey, C. L., D. B. Sauer, and D. Walker. 1983. Insect populations in wheat, corn and oats stored on the farm. J. Econ. Entomol. 76:1323-1330.

Storey, C. L., D. B. Sauer, and D. W. Fulk. 1982. Insect infestations in wheat and corn exported from the United States. J. Econ. Entomol. 75:827-832.

Storey, C. L. June 8, 1982. Personal interview.

U. S. Department of Agriculture. 1980. Grain Inspection Handbook. Book II. Federal Grain Inspection Service. Chapter 7. p 14-16.

U. S. Department of Agriculture. 1979. Insect control in farm stored grain. U.S.D.A. Farmers Bulletin No. 2269. U.S. Government Printing Office. 18p.

U. S. Department of Agriculture. 1978. Stored grain insects. Ag Handbook No. 500. U.S. Government Printing Office. 57p.

Appendix 1. Best Statistical Model for 1982-1983.

R-square = .371

Intercept = 843.6

Predictor	Coefficient	F-Ratio
Moisture	111.200	1.12[A]
Date	-0.014	8.67**
Quonset Storage	27.710	15.32**
False Floor	44.210	14.53**
Steel Floor	12.070	5.56*
Moisture Squared	-11.710	1.79[A]
Moisture Cubed	0.408	2.93[A]

** - Significant at the 0.01 level
* - Significant at the 0.05 level
[A] - Overall moisture was significant at the 0.01 level

Appendix 2. Best Statistical Model for 1983-1984.

R-square = .299

Intercept = 1800.67

Predictor	Coefficient	F-Ratio
Previous Peak Infestation	0.294	18.05**
Bin Size	0.032	56.21**
Date	-0.022	20.41**
Moisture	-5.741	7.35**
Wood Bin	62.099	44.98**
Scoop Shovel Cleaning	11.145	3.06[B]
Poor Condition	23.306	8.92**
Steel Floor	52.288	27.92**
Cement Floor	24.624	13.49**

** - Significant at the 0.01 level
[B] - Significant at the 0.10 level