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NON-CHEMICAL METHODS OF MOSQUITO CONTROL FOR PLAYA LAKES IN WEST TEXAS [1]

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INTRODUCTION

The High Plains region of West Texas is an area of very gentle slopes with no well-defined watershed patterns. Small wet-weather lakes, known as playa or pluvial lakes, dot this extensive area of 35 thousand square miles at the remarkably uniform rate of 1 per square mile. Playa lakes show great variability in size and depth, ranging from a few yards to a mile in diameter, and from a few inches to 50 feet in depth. They are estimated to receive approximately 89 percent of the runoff water of the High Plains (Clyman and Lotspeich 1966) which, supplemented by excess irrigation "tail water," provides sufficient accumulations of water in the playas to produce more than 70 percent of the mosquito population in the area (Harmston, Schultz, Eads and Menzies 1956). Because of the nuisance and disease problems which arise from the several species of mosquitoes produced in the lakes, local mosquito control officials are forced to use some type of chemical control (Harmston, *et al.* 1956, Smith 1966, and Pigford 1957). Direct application of insecticides to these lakes in mosquito control efforts, coupled with the likely contamination of playa water through the accumulation of agricultural pesticides, has led to much concern about the use of recharge techniques in extending the life of the diminishing underground water supply in the Ogallala formation (Huddleston and Riggs 1965). This associated contamination problem, insecticide resistance possibilities, and the very real need for mosquito control due to the encephalitis problem has led to investigations into the potential use of non-chemical methods of mosquito control in playa lakes.

Various non-chemical methods of control have been proposed and a few have been investigated, including, especially, extensive modifications of the lake basins (Huddleston and Ward 1969). Further discussion of these and other modifications has been published by Hauser (1966). The use of cultural methods of mosquito control on these lakes had not been previously explored. Because of the well-known association of mosquito larvae

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with vegetation (Bates 1954, Anonymous 1947) and the detrimental effects turbidity can have on mosquito production (Herms 1958), this study was designed to explore cultural and other low-cost mosquito control methods for possible use on playa lakes. One of the major problems involved in evaluating any type of control measure in these lakes is the tremendous variation in population levels from lake-to-lake and from year-to-year in the same lake. Due to these obstacles, a method was developed for subdividing the lake into small, isolated, experimental units that would eliminate migration of larvae among the various treatments but would retain the characteristics of the natural playa. Five cultural control methods were evaluated with this small plot technique. In the second phase of this study, some of these same cultural methods were used on whole lakes; average mosquito production was compared with other lakes with various combinations of pit modifications and lake pump modifications and with others which were not modified.

METHODS AND MATERIALS

SMALL PLOT EVALUATIONS. Several methods and materials were evaluated as to their effectiveness in preventing larval migration among subdivisions of a playa lake. Metal, wooden, and earthen structures were found to be impractical because of the unpredictable water level fluctuations. Plastic pens were selected to make the subdivisions and they prevented larval migration while closely simulating conditions found in the unenclosed lake water. These pens were prefabricated in 40-foot lengths (allowing 10 feet for each of 4 sides) from 6 mil, visqueen plastic sheeting (DuPont) of the type often used in building construction. The sides of the pens were perpendicular to the lake bottom and the top edge floated slightly above the water surface while the bottom edge was anchored to the lake bed.

In making the sides of the pens, the top edge of a plastic sheet was folded and stapled to form a 2-inch seam. Four, 1 inch by 1 inch by 114 inches, buoyant styrofoam rods were inserted into the seams. A similar seam was fashioned along the bottom edge of the pen where 6-inch sections of ¼-inch diameter reinforcing steel bars were closely positioned and secured. The bars were chosen because of weight, compactness, and ease of handling; the length of the bars allowed the bottom edge of the pen to be flexible and to adapt to the contour of the lake bed. There was a distance of 24 inches from the top to the bottom of the pen which allowed for water level differences expected in the natural fluctuations of the lake. The styrofoam rod floated the top of the pens approximately 1 inch above the surface of the water.

When placed in the lake, the pens were manipulated to form a square, 10 feet on each side, enclosing 100 square feet of water surface. Wooden plaster laths, 3 feet in length, were placed in each corner of the pens to aid in retention of the desired shape. The laths were not attached in any way to the pens and did not interfere with the ability of the pen to move with water level fluctuations. The pens were used in evaluating all selected methods of non-chemical mosquito control in the small-plot studies.

Selection of the individual non-chemical measures was based on two primary factors; the equipment had to be readily available, and be economical for the landowner to operate. Keeping these guidelines in mind, five implements were chosen: a moldboard plow; a tandem disc plow; a one-way plow; a roto-tiller; and a propane gas weed burner.

Several playa lakes were evaluated for mosquito production during 1967. The most representative lake was located in northern Lubbock County, Texas and was found to produce large numbers of *Aedes* spp. and *Culex* spp. Locations of previous floodwater mosquito egg deposition zones were determined by flooding soil samples with water in the laboratory. The resulting larvae were identified as *Aedes vexans* (Meigen) and *Aedes nigromaculis* (Ludlow). Definite patterns of egg distribution were detected and provided the information needed for the correct placement of the pens.

The actual process of modification was begun by measuring plots and placing stakes as boundary markers. Each plot was 20 feet wide by approximately 215 feet long and except for the plots on the extremes, each plot was bordered on both sides by another plot. Standard soil tillage practices were used when possible.

The first extensive rain on the watershed of the lake occurred in mid-June 1968, and resulted in the inundation of the lake to a depth sufficient to cover a known egg zone. The 36 pens were positioned in the egg zone as soon after inundation as possible. The pens were placed in the center of each modified area which resulted in borders 10 feet wide between adjacent pens. Special care was taken not to step into the area encompassed by the pens. Sampling began on the following morning using a white enamel water dipper of approximately one-half pint capacity which was affixed to a handle 3 feet in length. Larval counts were made and recorded as to water depth at the dipping point, genera of mosquitoes present, and the number of each genus in each stage of development. Dips were made at 2.5 feet intervals counterclockwise around the pen. An additional dip was taken from the center of the pen, and followed by four other dips taken equidistant between each corner and the center of the pen. If, as a function of the treatment, there was a "dry" place at the point designated for a given dip and if there was water nearby, the dip was taken in the water. This method yielded 13 dips per plot or a total of 468 individual samples per day. After the pertinent information had been recorded, all samples were returned to their respective dipping points.

Sampling generally began at 8:30 a.m. and did not usually terminate until approximately 2:30 p.m. The plot in which sampling was begun was rotated daily in order to randomize any effects which time of day might have on the numbers of larvae sampled. On the 7th day after sampling began, the vast majority of the mosquitoes had emerged as adults and sampling was discontinued. By June 27, the lake did not hold free water; however, the lake bed was extremely muddy. The next heavy rain occurred on July 3, at which time 1.75 inches of rain was received on the watershed. Since the pens were already in position, the same sampling procedures were begun the day after the rainfall. This hatch of mosquitoes also emerged as adults on the 7th day and the second phase of sampling was ended.

Analysis of variance employing a split plot design was used to test certain pooled data. The analysis included six treatments (subplots) which were split upon the two dates of inundation (whole plots).

Whole Lake Evaluations. In the second phase of the project, a series of lakes was selected for weekly sampling to estimate mosquito population levels. During the 1967 season, the seven lakes studied included three natural or unmodified lakes, one with ditches which diverted water into pits where it was then pumped onto adjacent farmland, two that were tandem disc-plowed and also had a small pit and a pump, and another that was lister plowed. Sampling consisted of the usual dipper technique with various numbers of samples taken on a transect line.

During the second season a series of 24 lakes was sampled with the dipper technique utilizing a stratified sampling design. Whereas the data for the previous year were taken in water of varying depths, the samples in this case were taken at 30-foot intervals along a contour line of the lake so that all of the 24 samples on a given sampling date were taken in water that was approximately 4 inches deep. This deliberately biased sampling to the most productive area of a lake so that differences in control levels could be more easily determined (Huddleston and Ward 1969).

RESULTS AND DISCUSSION

Small Plot Evaluations. Each of the five surface modification methods employed in the first phase of this study differed in type and degree of modification of the soil surface and vegetative cover. The roto-tiller, which pulverized the soil to a depth of 4.5 inches, produced the most thorough surface modification and achieved a significant leveling effect which proved to be highly desirable. The propane gas weed burner, which heated the soil surface but did not change the structure, was used in such a way as to insure the destruction of the majority of the plant material and surface litter. A total scorching of the soil was not attempted since it is expensive, time-consuming, and is not the usual practice in weed burning. Each of the other three methods were intermediate between the two types already discussed. Depth of soil penetration varied from 9 inches for the moldboard to 4 inches for the tandem disc. Soil surface modification with the latter three methods also varied; the moldboard turned the soil in huge clods and left a very uneven surface, whereas the two types of disc plows produced a fairly level surface. The check, or unmodified plots, represented the natural state of the lake without modification where the vegetation was uniformly dense throughout the plot.

Aedes vexans and *A. nigromaculis* were found to occur throughout all plots in the experiment. Field differentiation between these two species was not feasible, and no distinction was made when recording field counts. All discussions of mosquito control refer to these two species. Two additional species, *Psorophora ciliata* (Fabricius) and *P. signipennis* (Coquillett), were found to occur, but only in three plots. These mosquitoes re-occurred in the same three plots throughout both sampling periods and because of their very limited and specific distribution, they were not included in analysis of the data. The 1968 mosquito breeding season was characterized by a marked reduction in numbers of *Culex* spp. and *Culiseta inornata* (Williston) throughout the High Plains and none were detected in the study lakes. There was, of course, no way to determine the effect of the control measures on these mosquitoes, and therefore interpretations were made only for *Aedes vexans* and *A. nigromaculis.*

The plastic pens were found to perform very satisfactorily in these evaluations. There were slight differences in wave action between the area enclosed by the pens and the remaining lake water, but differences would occur with any method of enclosure. The pens successfully prevented larval migration between the enclosed and unenclosed areas, and thus provided for more sensitive evaluation.

An examination of data from both inundation periods revealed that the 1st and 6th sampling dates were not representative of true mosquito populations. No mosquito samples were taken during the 1st day of the first inundation period, as this time was used for placement of the pens. Also, mosquitoes sampled on the 1st day of the second inundation were in the 1st instar and extremely difficult to see; this led to a low population estimate. Those mosquitoes sampled the 6th day during both inundation periods were primarily in the pupal stage and it appeared that many had already emerged as adults. For these reasons, days 1 and 6 were not included in analyses of the mosquito population data.

All five treatments were found to give significant control of mosquito larvae when compared with the check. However, the roto-tilled treatment was found to give significantly better control than the other four treatments except when the first inundation was considered alone (Table 1). The moldboard-plowed treatments did not differ significantly from those propane gas-burned in degree of control, but did give significantly better control than either those tandem-plowed or one-way plowed except when the two inundations are considered separately.

Table 1 illustrates the marked increases in mean numbers of mosquito larvae after the second inundation: these large differences resulted in significant differences between dates of inundation. The occurrence of such significant differences might possibly have been due to a "pre-condi-

TABLE 1.—Mean numbers of mosquito larvae per dip found after five cultural control methods were applied to small plots. Abernathy, Texas, 1968.

Control Method	Mean numbers of mosquito larvae per dip[1]		
	Inundation period		
	Combined	First	Second
Roto-tiller	0.16 (a)	0.06 (a)	0.27 (a)
Moldboard Plow	.40 (b)	0.41 (a)	0.39 (b)
Propane Gas Burner	1.88 (bc)	0.98 (a)	2.79 (b)
Tandem Disc Plow	2.27 (c)	1.15 (a)	3.39 (b)
One-Way Disc Plow	2.36 (c)	1.20 (a)	3.52 (b)
Check	8.47 (d)	3.55 (b)	13.38 (c)

[1] Numbers followed by the same letter are not significantly different at the 5% level of confidence by Duncan's new multiple range test.

tioning" inundation necessary to initiate hatching (Rosay 1955). It is also possible that the higher numbers were the result of eggs being deposited in the plots by the adults produced during the first inundation. If such egg deposition did occur, it is possible that the treated areas were less attractive to ovipositing mosquitoes since all treated plots were significantly lower in larval production than the check area (Table 1). The amount of vegetation within plots did not materially change between inundations, and it is believed that this factor played no critical role in differences in mosquito populations.

Since no eggs could have been laid between the time of soil treatment and the first sampling dates, it is assumed that only eggs deposited at some time prior to soil treatment were involved in producing larvae found in the samples. As for the effects of individual treatments, it would appear that some of the more obvious factors that resulted in control might be burial of eggs by plowing, crushing by the equipment as it passed through the plots, heating to the thermal death point by the burner (Shumkov 1969), or some other disturbance during the course of the treatments. The significant differences found in treatment effect on mosquito numbers indicate that some methods produced these effects more efficiently than others.

All plowing methods disturbed both vegetation and soil, and it is possible that the eggs were "turned under" by the action of the plows to a depth which prevented hatching. It might also be possible that the depth at which the eggs were buried would have allowed hatching, but caused the death of the young larvae by trapping them in the mud. All plowing treatments resulted in significant increases in turbidity of the water, but it appeared that turbidity in itself was not a primary control factor. The propane gas burner did not disturb the surface of the soil but did result in the destruction of much of the vegetation. Eggs deposited on plants, soil, or on or under surface litter might have been destroyed by the flames or may have reached a temperature which prevented their hatching.

Significant interaction was found between the inundation dates and plowing treatments. This was probably because roto-tilling was the only treatment which did not result in significant differences in mosquito numbers between the two inundations. All treatments gave some degree of mosquito control but roto-tilling was the most effective of all control methods tested and was accomplished much faster than moldboard plowing.

Certain expenses are involved in operating any tractor-drawn implement and propane gas burning also involves a considerable cost. However, if the high temperatures produced by the propane burner are not necessary to give the level of control found here, it would seem possible that a playa lake could be set on fire in the late winter (while the vegetation is dry) and significant reduction in mosquito numbers might result at little or no cost to the landowner.

WHOLE LAKE EVALUATIONS. The second phase of the project, the evaluation of various cultural and/or modification techniques by whole-lake-bed treatment, was made during two seasons. During 1967, the seven lakes studied revealed that most of the cultural or modification techniques would result in some reduction in the numbers of mosquitoes produced (Table 2).

unmodified, was very similar to the check lakes in amount of vegetative cover and turbidity.

Although the direct cause of the observed reduction in numbers of mosquitoes produced may be some related factor, it seems that reduction in emergent vegetation and/or high turbidity may be used as indicators of low production of *Culex* mosquitoes. Actual causes of reduction may be increased wave action and/or elimination or reduction of some food sources.

With these preliminary data showing a reduction in *Culex* numbers, an expanded study was initiated in 1968. From a survey of lakes in southwest Lubbock and southeast Hockley counties, 24 lakes were selected for inclusion in the study. Although all of the lakes were not inundated at that time, weekly sampling was initiated on June 25. The remaining lakes were sampled for the first time within 4 days of initial flooding.

TABLE 2.—Mean numbers of mosquito larvae per dip in natural and modified playa lakes. Lubbock and Hockley Counties, Texas, Summer, 1967.

Type of lake	Number of lakes in category	Mean numbers of mosquito larvae per dip [1]	Mean numbers of weeks water was present
Lister-plowed	1	0.00	4
Tandem-plowed and sump with pump	2	0.05	8.5
Ditches to pits [2] with pump	1	0.61	5
Unmodified check lakes	3	0.80	6

[1] Means of all weekly sampling dates when water was present.
[2] Lake basin unmodified except for the pit construction.

Most of the mosquitoes produced in the study lakes in 1967 were *Culex tarsalis* Coquillett and *C. quinquefasciatus* Say, as little water level fluctuation occurred after sampling was initiated in late July. Therefore, the effect of these modifications on control of mosquito production was evaluated for only these two species.

Of the factors considered, only amounts of vegetative cover and turbidity seemed to vary among the treatments. Check lakes had abundant emergent vegetative cover and the water was generally clear except for a short period after inundation or receiving recharge. Tandem- and lister-plowed lakes were generally void of emergent vegetation and remained highly turbid as long as they held water. The lake with ditches to divert water into deep pits from which the water could be pumped, but with the lake basin otherwise

The lakes included in the 1968 study were grouped into six major categories. Category 1 included 11 unmodified check lakes. These lakes were characterized by dense emergent vegetative cover, some had pot holes, most had deep cracks, and held water for long periods following heavy inundation. The lakes in category 2 were tandem-plowed by the farmer prior to the first inundation of the 1968 season. Three of the study lakes were of this type; each was characterized by little if any emergent vegetation and high turbidity. Four of the lakes were in category 3. These lakes were lister-plowed; this type of plowing is usually the final seedbed preparation prior to planting. The lakes were very turbid throughout the sampling period.

The 4th category consisted of two lakes that were modified with a pit which was furnished with a lake pump. These lakes were not modified in any other way, so that the natural vegetative patterns persisted in the areas not included in the pit. All samples used in comparison with other lake types were taken in the inundated area around the outside of the pit. Sampling from the pit area indicated very little mosquito production in these areas. Amounts of turbidity seemed to be intermediate between natural and plowed lakes. Only one lake included in category 5 was found. This lake was similar to those in category 4; it had a pit modification but no lake pump was used. Most farmers will utilize the water if they have invested in pit construction, so only very few lakes can be found that fit into this category.

The 6th and final category was represented by three lakes that were both tandem-plowed and had pits with pumps installed. The benefits from both types of modification were hoped to result in even lower mosquito production than when either was used alone. Tandem plowing resulted in the reduction of emergent vegetation and high turbidity, while the lake pump allowed for removal of water from the area around the pit. Once all water was inside the pit area, larval mosquito production was expected to be minimal.

The average numbers of mosquito larvae per dip for all sampling dates when water was present were pooled to calculate yearly average production figures for all lakes in each category. These data appear in graph form in Figure 1 and it is readily evident that all of the modification types drastically reduced mosquito production. It appears that plowing, whether in combination with pits with pumps or used alone, was best in reducing mosquito numbers.

It should be pointed out that, unlike the 1967 season, all of the 1968 production figures represent only floodwater mosquito production. The only species that were abundant during this season were *Aedes vexans* and *A. nigromaculis*. Some *Psorophora signipennis* were found but they were so rare that inclusion in the data would not aid in the interpretation of results, nor would the inclusion of *Culex tarsalis* larvae which were found on only one occasion in an unmodified lake.

Considering the data from both years, it appears that plowing of the lake bed prior to flooding will result in reduced production of both *Culex* and *Aedes* mosquitoes in playa lakes. Therefore, the incorporation of routine plowing of playa lakes in local mosquito control efforts should substantially reduce the amount of pesticides applied to these lakes. The increased turbidity levels complicate the use of this water to recharge the Ogallala formation; however, direct use of this water for irrigation should not be affected.

SUMMARY

The economy of the High Plains of Texas largely depends upon irrigated farming, however, the underground source of water is rapidly declining. Methods of recharging stored surface water are being perfected and playa lakes seem to offer potential sites for storage and recharge of such water. While having the potential for water conservation, playa lakes, in their natural state, are excellent breeding sites for mosquitoes which are of public health importance in the area. The chemical control of mosquitoes in playa lakes presents the possible problem of recharging contaminated water into the underground aquifer.

Research has indicated that large-scale modifications of playa lakes are highly successful in mosquito control, but each required a large investment by the landowner. This study was undertaken to seek economical and simple methods of preventing mosquito production in playa lakes, and to develop a technique for test-

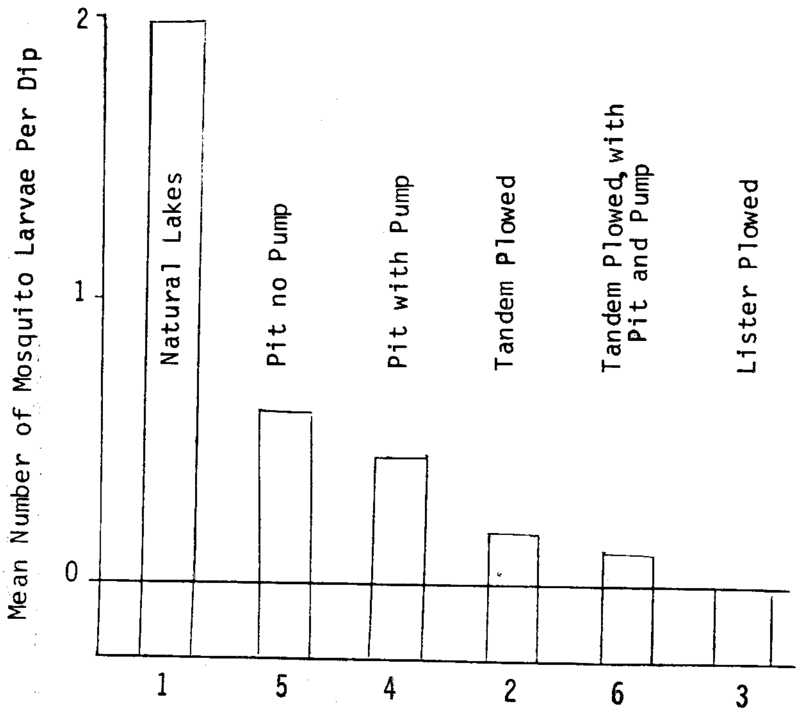

FIG. 1.—Mean number of mosquito larvae per dip for all sampling dates on lakes in each of 6 categories. Lubbock and Hockley Counties, Texas, 1968.

ing several methods of non-chemical mosquito control within a single playa lake.

Plastic pens which floated on the surface of the water while anchored to the lake bed were devised to prevent larval migration between treatments. The pens closely simulated the natural, unenclosed water in the lake, and were used in evaluation of five methods of non-chemical mosquito control.

Selection of the individual control methods was based upon economy of operation and availability to the landowner. The implements chosen were: a moldboard plow; a tandem disc plow; a oneway disc plow; a roto-tiller; and a propane gas weed burner. All treatments were made in the same playa lake which was chosen because it was known to have produced mosquitoes in the past. Sampling was achieved by the widely-used dipper sampling method and was conducted on the two inundations which the lake received during the 1968 mosquito breeding season. Since only *Aedes* mosquitoes were present in large numbers, this group alone was considered in determining the effectiveness of the control measures.

All types of non-chemical control methods evaluated were found to have given significant control of mosquito larvae when compared with the untreated check. Roto-tilling was determined to have afforded the best control when compared with all other treatments, but would involve some cost to the landowner. The most economical method of control appeared to be the burning of the lake bed.

The findings from the small plots were substantiated in the whole-lake-bed treatment studies. Additional results were obtained due to the presence of *Culex* mosquitoes during the 1967 season; however, *Aedes* mosquitoes predominated in these tests in 1968. These data indicated that plowing of the lake bed prior to initial flooding will result in reduced production of both *Culex* and *Aedes* mosquitoes in playa lakes. Therefore, the incorporation of routine plowing of these lakes in local mosquito control efforts should substantially reduce the amount of pesticides that must be applied to playa lakes. The increased turbidity levels observed in plowed lakes could further complicate the use of this water to recharge the aquifer; however, the direct use of this water for irrigation should not be severely affected.

Results suggest the need for future research involving cultural methods of mosquito control with particular emphasis on the evaluation of burning playa lake groundcover as an economical means of non-chemical mosquito control. It is also obvious that coordinated laboratory and field research needs to be conducted to determine the exact mechanisms of control by the various methods, and to yield information that may lead to other control measures.

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