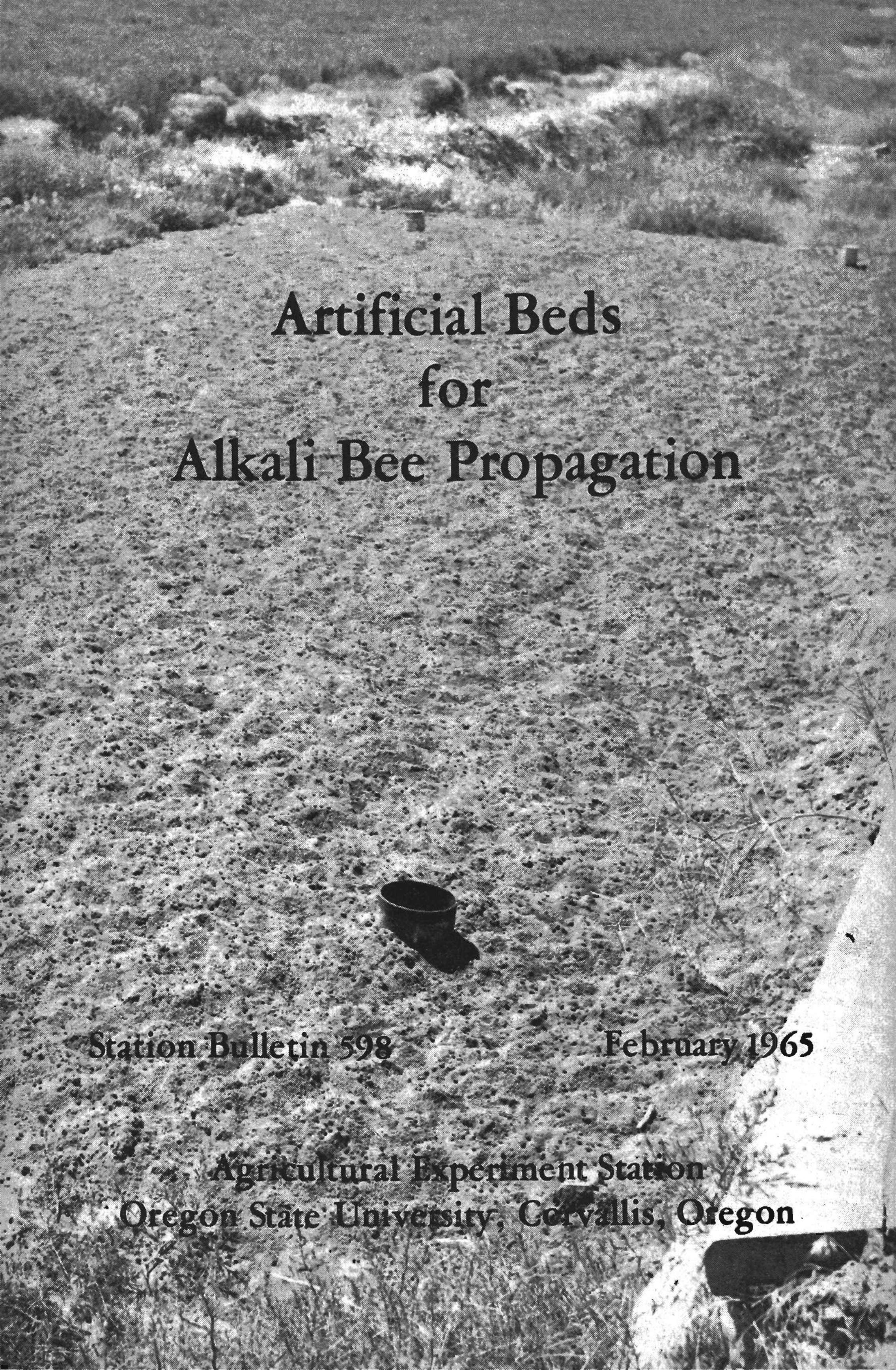

Artificial Beds for Alkali Bee Propagation

Station Bulletin 598 February 1965

Agricultural Experiment Station
Oregon State University, Corvallis, Oregon

CONTENTS

AUTHOR: W. P. Stephen is an associate professor of entomology at Oregon State University, Corvallis.

Artificial Beds for Alkali Bee Propagation

W. P. Stephen

INTRODUCTION

The increase in acreage of seed alfalfa in the Pacific Northwest has proceeded at a steady rate for the past ten years. In many areas, expansion of alkali bee populations has not kept pace with the acreage increase and pollination has suffered.

There are several factors that contribute to the restriction of alkali bee populations, i.e., extensive poisoning by insecticides; inclement weather during the flight season; and accidental flooding of the site while bees are active. Where forage is abundant, the principal limiting factor appears to be a shortage of optimal nesting areas.

In nature, bees occupy sites characterized by an adequate moisture level from the soil surface to the area of cell construction. The soil water supplying these sites, as well as any other permanently moist areas in the Great Basin, is maintained by an underground movement of salt-laden water over a hardpan and its subsequent rise in restricted areas by capillarity. Many apparently suitable sites are accepted by the bees in the early summer, only to be abandoned as the soil dries out during the season. Cutting of drainage ditches near existing beds or modified irrigation practices have resulted in changes in the quantity and/or direction of flow of the subsoil moisture responsible for their acceptability. In addition, any soil continually exposed to subirrigation by volumes of salty water gradually evolves to, and through, a condition deemed ideal for alkali bee utilization. The problem then becomes one of arresting the change in the soil structure-soil moisture-soluble salt complex at a point where it can be used by the alkali bee for prolonged periods. Because the water quantity and its salts cannot be controlled with sufficient preciseness, the condition of natural beds tends to fluctuate from year to year. Unless management practices are undertaken to regulate the water supply, control vegetation, and rework the soil surface, natural beds gradually become less populous and are often abandoned.

Artificial beds were developed as a means of exercising more complete control over the variables which lead to population fluctuation, and, more especially, to provide a means of propagating the alkali bee in areas where alfalfa seed may be grown but which lack suitable natural sites for bee establishment.

The types of artificial beds that have been used with success are outlined below and methods of construction and management are detailed.

ARTIFICIAL BEDS

Throughout much of the Great Basin, particularly in those areas characterized by soils that have been laid down as drainage-system flood plains, much of the soil is of suitable texture for artificial bee bed construction. In other alfalfa seed producing areas, soils of adequate texture are often very difficult to find. The importance of providing soils of optimal texture for the matrix of the bee bed cannot be overemphasized, for it is this, more than any other factor, which will determine the degree of acceptance by the alkali bee, as well as the ease of bed management in subsequent years.

It is recommended that artificial beds be constructed during the fall, or at the very latest during the early spring of the year preceding their anticipated use. Fall construction will permit the soils to settle so that the matrix is firm and compact at the time the bees are introduced. In addition, fall or winter rains assist in placing the surface salt into solution, providing a more uniformly dispersed soil surface.

Beds should be located immediately adjacent to alfalfa fields being retained for seed production. Where possible, they should be located downwind from the fields to be pollinated, so that bees will orient and forage upon them immediately after emergence.

Size. Bee beds have been built ranging in size from 4 feet by 4 feet to 200 feet by 400 feet. The size of the majority, however, has been determined by the size of available sheets of polyethylene used in bee bed construction. In larger bee beds, the polyethylene has been overlapped and the weight of the gravel and soil has provided an effective seal against water loss (Figure 1).

Depth. During the past six years, a series of experimental beds was constructed to depths ranging from 18 to 48 inches. While bees were successfully established in all, the shallower beds (18 to 24 inches) required frequent application of water in order to maintain an optimum surface moisture condition. The soil of the bed acts as a water reservoir, continually supplying moisture to the soil surface as evaporation occurs, and in the shallow beds this reservoir is meager. Frequent applications of water to these beds also resulted in excessive soil moisture conditions at the cell level which lay only a short distance above the gravel layer. Thus in the shallow beds, one is faced with a continually fluctuating condition between excessive moisture and moisture shortage. Beds with three feet of soil above the gravel layer maintained a remarkably stable moisture level throughout the flight season with the addition of water once a year.

While most beds have been excavated to a depth of 3 feet and the soil backfilled into them, several were dug 1½ feet deep and an additional foot and a half of soil added to the soil surface (Figure 2). In the latter, the nesting surface is well above the level of the surrounding soil, is protected from accidental flooding, and has a sufficiently convex surface to insure a rapid runoff of surface precipitation. Its main undesirable feature is that water added to the subsurface is inclined to percolate out around the periphery of the bed where the depth of soil above the gravel layer is the most shallow.

Upon completion of the excavation, the bottom should be transit-leveled. Holes or ridges on the bottom will result in a nonuniform distribution of

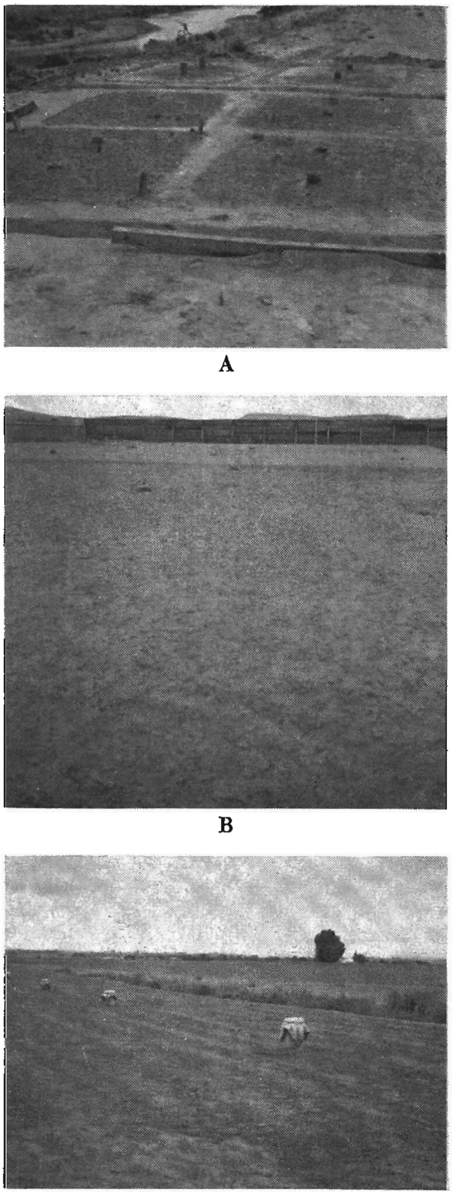

Figure 1. Examples of the size variation in artificial alkali bee beds. A. A series of four 4- by 8-feet beds. B. Several beds constructed to provide several thousand square feet of continuous nesting area. C. The most common form of bed, 30 to 50 feet wide by 50 to 200 feet long.

water, which in turn may be reflected in wet and dry spots on the surface of the bed.

Lining. The bottom is then covered with a sheet of 6 or 8 mil. polyethylene, sufficient in size to extend up the sides of the bed at least 18 inches. The manufacturers recommend that clear polyethylene be used in circumstances where it is not exposed to light. Caution should be exercised not to tear the polyethylene in the process of its placement or to puncture it while placing the gravel on its surface. In very large beds, it has been a practice to construct a 12-inch ridge of soil beneath the polyethylene every 25 feet along its length (Figure 3). This serves to isolate each of the segments of the bed into individual water reservoirs, and rupturing of the polyethylene in any one segment will result only in the loss of the damaged portion of the bed.

Gravel. More beds have been abandoned because of the use of dirty gravel than for any other reason. The purpose of the gravel is to act as a transporting medium for the water which will be subsequently added to the downspouts. Water is transported laterally through the gravel from which it can rise uniformly through the soil above it. Very fine gravel, or gravel with an admixture of sand and soil, impedes water flow to such an extent that it is virtually impossible to add the necessary quantity of water each season. Clean gravel, $\frac{3}{4}$ to 1 inch in size, is recommended. Crushed rock should not be substituted for gravel, as the sharp edges may puncture the polyethylene sheets. From 8 to 12 inches of gravel should be applied to the surface of the polyethylene. The greater the gravel depth, the larger the

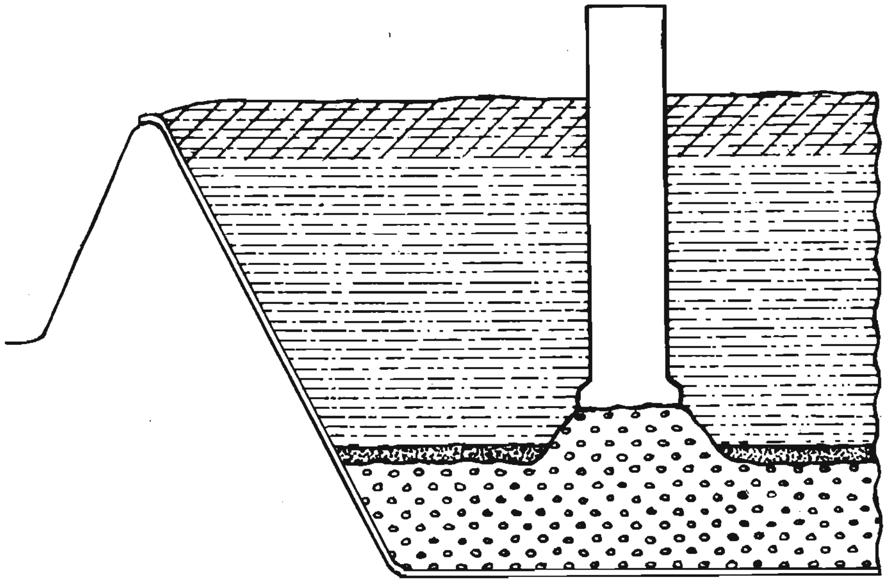

Figure 2. Diagrammatic representation of a bed with half of the soil matrix above the level of the adjacent soil surface. Banking reduces the percolation of water about the periphery of bed. (Legend as in Figure 3.)

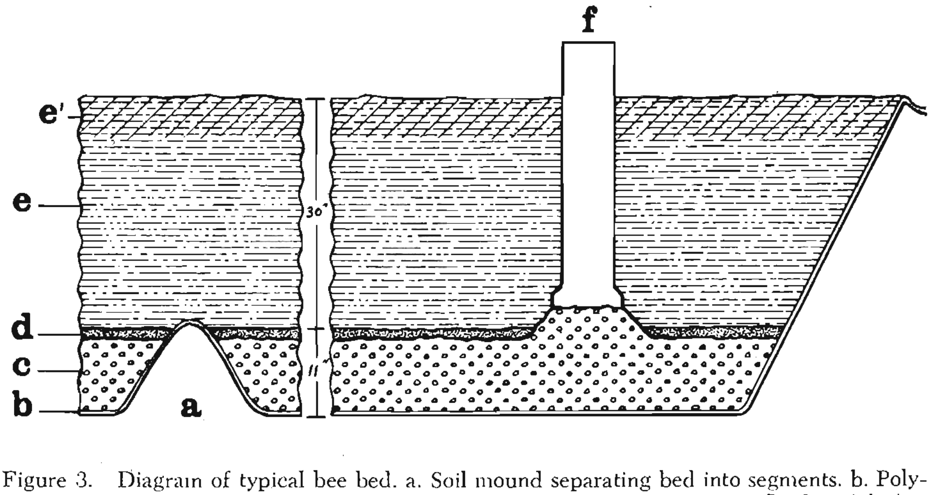

Figure 3. Diagram of typical bee bed. a. Soil mound separating bed into segments. b. Polyethylene lining. c. Ten-inch gravel layer. d. Coarse sand. e. Soil matrix; e'. Surface 8 inches with salt (NaCl) intermixed. f. Downspout situated on mound of gravel.

water reservoir of the bed and the more rapidly water can be added. In the larger beds where quantities of gravel are necessary, it has proven practical to unroll the polyethylene a short distance from one end so that gravel-transport trucks are able to back into the bed and deposit their load directly. The polyethylene is unfurled to the rear wheels of the truck and large sheets of cardboard are placed on the polyethylene where the load is to be dumped so as to protect it from rock damage. The cardboard may be left in place after the gravel is added, and the polyethylene can be rolled ahead enough to accommodate each subsequent load of gravel.

It is suggested that a layer of coarse sand, 1½ to 2 inches deep, be applied directly to the surface of the gravel, particularly if the soil to be backfilled is dry and powdery. The sand prevents the fine soil from filtering through the gravel and impeding the lateral water flow. This same effect may be accomplished by laying one or two layers of a very fine-meshed nylon upon the gravel surface, but the coarse sand provides better capillary continuity between the gravel and the soil layer above.

Downspouts. Each 400 to 600 square feet of bed should be provided with one large-sized downspout through which water may be added. It is preferable to locate each downspout in the middle of the area to which it will supply water; however, with a deep gravel layer there is usually no difficulty in effecting a uniform lateral water transport regardless of its position. It is suggested that the downspout be at least 10 inches in inside diameter, and that it be placed on a mound of gravel extending above the general level of the gravel layer (Figure 3). This assures a rapid transport of water away from the base of the downspout and permits the addition of large amounts of water in a short period of time. Downspouts may be placed *in situ* immediately after the gravel has been added (Figure 3), or they may be installed after the bed has been completed. The presence of protruding downspouts interferes with the activities of the bulldozer backfilling the bed with soil and prevents the operator of mechanical equipment from uniformly compacting the surface of the bed. To effect the introduction of downspouts after the bed has been completed, mounds of gravel should be prepared as indicated above, and each of these mounds should be covered with a burlap bag prior to backfilling with soil. The position of these mounds can be marked by stakes placed at the sides and ends of the bed; and upon completion of backfilling and packing, holes can be dug to the mounds, the burlap bags removed, and the downspouts put in place.

Soil matrix. It has been observed that alkali bees will nest in almost any soil that has a moist (not wet) soil surface, regardless of its texture. These observations, however, do not imply that the bee does equally well in each of the variable soil textures from which it has been taken. It is the purpose of the artificial bed to provide an optimal soil condition which will permit the bee to propagate itself in a most rapid and efficient manner. Soils high in sand (40 to 80%) have relatively poor capillary action and are difficult to seal at the soil surface. Evaporation from sandy beds is thus excessive, and a uniform moisture content at the position of the cells is difficult to maintain. Soils high in clay (over 12% clay-size particles) are not recommended because capillary action in such soils is extremely slow, and, during the summer, evaporation from the soil surface often proceeds at a greater rate than the moisture can be replenished from below. In addition, the moisture retaining capacity of high clay soils is much greater than that of silty soils. This is often responsible for high relative humidities within the cells and chambers of the alkali bee, which in turn promotes the germination and development of fungi and bacteria which can be fatal to overwintering bee prepupae. High-clay soils can and have been modified by adding divalent salts to them during the backfilling operation. The divalent salts, either calcium chloride or gypsum, bind the smaller clay-sized particles together. These flocculated clays then act much like silty soils in that the capillary rise of subsurface moisture is rapid and the surface of the bed can be maintained in good condition. It does not, however, overcome the problem of the high moisture-retention capacity of the soil and the high incidence of fungal and bacterial diseases which elevated relative humidities promote.

Soils that are planned to be used in the matrix of the bee bed should be analyzed well in advance of construction. For optimal results, use only those soils having less than 10% clay-sized-particle content and less than 40% sand-sized-particle content. Analyses should be made using the Bouyoucus method, preferably with the salts removed from the sample prior to the time the test is made. Most universities provide this service at a nominal cost. Approximately one pound of the test soil can be sent to the Department of Soils, Oregon State University, with a request for "Bee Bed Analysis" attached to the sample.

Soil of the desired texture qualities may be backfilled by a bulldozer, compacting it over the gravel as it proceeds. If the soil is dry and powdery, compaction is ineffective unless water is added to the gravel prior to backfilling or the fill-soil is moistened. A minimum of 30 to 36 inches of soil should cover the gravel for reasons already indicated, and the surface of the bed should be weakly rounded to promote the drainage of surface precipitation.

Salt. Salt (sodium chloride) should be added to the surface at the rate of 1 to 3 pounds per square foot. Finely ground hay or stock salt is preferable, as it dissolves most readily in the presence of minimal amounts of water. It should be emphasized that salt is not essential to the acceptance of the bed by bees, nor does it appear to exert any attractive influence upon them. Its presence at the surface merely disperses the soils, thus minimizing evaporation during the summer and providing an effective seal against the penetration of surface moisture during the winter and spring.

A series of four small adjacent beds was constructed in 1960 to determine the effect of surface salt on the moisture-retaining properties of each bed. Salt was added to the surface of three beds at the rate of ½, 1, and 2 pounds per square foot and thoroughly mixed to a depth of 6 inches with a hand rotovater. The fourth bed was treated in the same manner, except that no salt was included. Identical amounts of water were added to each, and the surfaces of all four were uniformly moist 24 hours later. The two beds with 1 pound and 2 pounds of salt per square foot required no further water during the flight season, while the bed with no salt needed additional water every second day in order to maintain its nesting population.

Certain soils have a tendency to concrete when sodium chloride alone is applied to the surface, so that by the end of the second year, bees have difficulty in penetrating them. The chemico-physical properties of the soil responsible for concretion in the presence of sodium chloride are not understood at present. However, the addition of a half pound of gypsum or a quarter pound of calcium chloride per square foot at the time of bee bed construction appears to rectify this condition and provides a surface which will remain homeostatic for some years.

The salts must be mixed thoroughly with a mechanical rotary tiller, preferably to a depth of 4 to 6 inches. Improper mixing invariably results in surface crusting or the presence of crystalline blocks of salt at or near the soil surface. Neither of these conditions will be accepted by the bee. If the bed is constructed in the fall, the surface should be lightly compacted so as to permit winter and spring precipitation to penetrate the bed and assist in dissolving the salts. The surface can then be repacked the following spring. If beds are constructed during the spring, a light surface-sprinkling prior to compaction will dissolve much of the salt and provide a better soil surface for the first year. It usually requires two years to effect complete solution of the salts and to bring them to the upper two inches of the bed.

Water. The amount of water to be added to a new bed depends upon the depth of soil, the size of bed, and the initial moisture content of the soil that is backfilled. This can be calculated roughly on the basis of the cubic-foot content of each bed. For example, a bed composed of soil having a sand-silt-clay-sized particle content approximating that recommended above (page 8), should have a moisture content at the bee cell level (6 to 8 inches) of from 14 to 18%. Thus a bed 30 by 50 by 3 feet deep contains 4,500 cubic feet. If 18% moisture is optimal, this would mean that 4,500 x .18, or 810 cubic feet of water is necessary. Since there are $7\frac{1}{2}$ gallons of water per cubic foot, the initial addition should be approximately 810 x 7.5, or 6,000 gallons of water. There is no means of calculating absolutely the amount of water necessary to achieve an optimal soil-moisture condition. Rather, it is necessary to add an initial amount and wait a couple of days before deciding whether further water is required. If the initial addition of water is sufficient, the soil surface should show good moisture within 36 hours. If by the end of two days the surface is not moist, more water must be added. It is desirable to retain records of the amount of water required to bring each new bed to an optimal condition, for each bed has unique soil qualities which make blanket recommendations impossible.

The surface of the bee bed should be compacted with a large hand roller immediately prior to the introduction of the bees. Packing, while the surface is moist, not wet, will promote capillarity directly to the soil surface and tend to reduce fluffy spots or soil incrustations which often appear.

In many areas of the Pacific Northwest, deep soils exist that have good moisture-capillary properties. These have the same clay-silt-sand-sized-particle ratios as recommended above, and if they are of uniform texture to a depth of 3 feet, they may be made acceptable for bee occupancy with a minimum of effort.

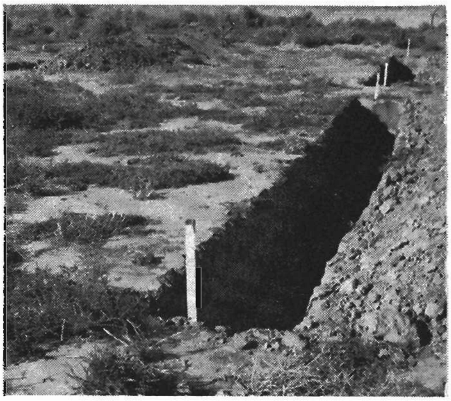

Figure 4. Independent trenches prior to placement of polyethylene and gravel. Adjacent trenches located 20 feet apart.

In these restricted areas, trenches 1 to 2 feet wide and 3 feet deep may be dug at 12- to 15-foot intervals across the area selected for the site of the bee bed (Figure 4). These trenches may be independent of each other or interconnected. The bottom of the trenches should be leveled and covered with polyethylene which extends up the side for at least a foot. The bed is completed as indicated above, except that the gravel layer in the trench should be from 18 to 24 inches deep. The trench bed resembles the artificial bed in all respects, except that it has a limited water reservoir. This reservoir, which will subirrigate both the soil directly above it and that of the area between adjacent trenches, must be replenished continuously throughout the season of bee flight.

The deep gravel layer provides the largest water reservoir possible in the confines of the trench without making the soil immediately above it too sloppy for bee inhabitation. It also permits a free and rapid lateral water transport through the hundreds of feet of continuous trench. The water from the trenches is transported by capillarity both vertically and laterally so that much of the area between the trenches can be made acceptable for the establishment of alkali bees.

Downspouts should be spaced at 50-foot intervals along the trenches so that water can be introduced at more than one point if the continuity of the trench is interrupted by soil collapsing into the gravel.

The surface of the soil between and above the trenches should be treated as outlined under artificial beds. Advantages of the trench bed are principally ease of construction, rapidity with which large areas may be made into a quasi-acceptable bee bed, and relative economy of construction.

Precise soil conditions must prevail before this type of bed is successful, and even then there are features which make the trench bed less desirable than the conventional artificial bed. Water must be supplied to the trench bed almost continuously throughout the summer; not in excessive amounts, but in sufficient amounts to replenish water that is removed from the small gravel reservoir. The soil immediately above the gravel layer often remains too wet for bee occupancy, while that at the point between the two trenches may not be moist enough. Population densities in the area covered by a trench bed rarely reach those achieved in the conventional artificial bed, and the bed must be kept under continuous scrutiny to avoid overwatering or dehydration.

BOX BEDS

Small artificial bee beds have been developed to propagate the alkali bee for the pollination of alfalfa in experimental plots. These beds are self contained units consisting of boxes constructed of 1-inch exterior plywood, 4 feet by 4 feet by 3 feet deep. The boxes may be located permanently in one position, or they may be attached to skids in order to make them semi-transportable (Figure 5).

Each box is tightly constructed and the interior lined completely with two layers of 8-mil. plastic in order to protect the plywood from the moist soil within and to minimize the possibility of plastic rupture and the loss of water from the gravel reservoir. Gravel settling about the periphery of the box has, through abrasion, caused leaks to appear in many of the boxes by the end of the second year. To avoid this leakage, it is suggested that a heavy water-proof canvas or other equally resilient material be placed on the bottom and up the sides of each box to protect the polyethylene at the gravel layer.

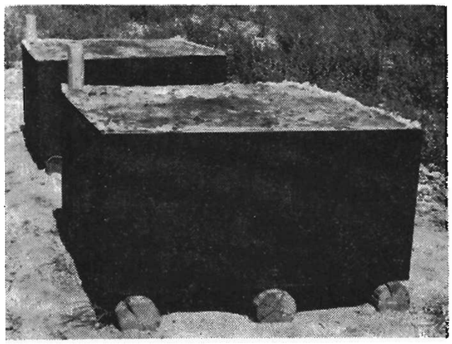

Figure 5. Semi-portable box beds employed for small-plot alfalfa pollination.

In all other respects, box beds are merely miniature artificial beds. Six to eight inches of gravel has proven sufficient to effect good lateral water transport and the insertion of a 3- to 4-inch downspout in one corner of the bed has been found to be satisfactory and convenient.

TRANSPLANTING BEES

The new beds can be stocked with overwintering bee prepupae at any time after the bed has settled and the moisture continum between the gravel and soil surface is complete. Transplants may be effected by transporting intact pieces of soil containing overwintering bee prepupae from established bee beds to the new bed, or by moving only the naked prepupae to the new site.

The soil "core" transplanting method is the most practical means of establishing populations, but where bees are to be moved to areas outside of their normal range, there is a possibility of introducing soil bacteria and fungi as well as bee parasites with the soil. Most of the microorganisms that appear to act as primary or secondary parasites of the alkali bee are common to native soils of western America and the principal parasites of the alkali bee (*Heterostylum robustum* and *Zodion obliquefasciatum*) are also found throughout this area. Thus, aside from the possibility of introducing a particularly virulent strain of a parasite in a new region of the West, there does not appear to be any other reason not to use soil cores. We have not as yet detected any exceptionally virulent strains of parasitic microorganisms in Oregon, nor have any been reported from the Pacific Northwest. Our lack of specific information may be due to the paucity of research on this phase of the program, but the consistent low incidence of mortality, attributable to causes not readily identifiable, would tend to indicate that bacterial and fungal parasites are rarely limiting.

The majority of bombyliid larvae, *H. robustum*, work their way up to within 1 to 2 inches of the soil surface shortly after they have matured. Most of them are at this level in the late fall, but those that mature late in the season do not begin their upward migration until soil temperatures rise the following spring. It is recommended that soil blocks or soil cores be moved just before bee emergence begins. At this time, the fly larvae are in the upper two inches of the soil, which can be shaved off of each core prior to loading. Since this species and the conopid fly, *Z. obliquefasciatum*, emerge ahead of, or concurrently with, the bee, and since both species emerge during the mornings and remain inactive for from 15 minutes to ½ hour while their wings expand and dry, the parasites in an introduced sample may be completely controlled by killing them as they appear.

Soil cores and soil blocks. The two most widely used means of *in situ* prepupal transplanting are the soil-core method, developed in this laboratory, and the soil-block method, recently developed by growers in order to simplify the process. Where the soil of the bee bed from which bees are to be taken is well compacted and the distance it is to be hauled is not too great, the soil-block method is suggested. It involves considerably less work and large numbers of blocks can be moved in a short time. Removal of square blocks reduces the waste of bees intrinsic to the soil-core method outlined below. The soil-core method is more laborious and slower, but if the soil of the bed has a high sand-size-particle percentage, is poorly compacted, or is friable because of high organic matter content, it is the only efficient method of transportation. Transportation of soil blocks over long distances subjects them to continuous vibration and subsequent fragmentation, destroying many of the prepupae. This situation is minimized by the tight-fitting liner around the soil cores, which also permits greater ease in handling.

The decision as to the method of moving should be arrived at only after an examination of the soil in the bed from which bees are to be taken and a consideration of the distance and time involved in their transport.

Soil blocks. This method consists of cutting the area of the bed to be moved into 10- or 12-inch square blocks. Cutting is accomplished with a modified garden rotary tiller; the cultivating bars have been replaced with two 24-inch saw blades. Teeth of the saw blades are usually tempered to retain their edge while moving through the highly abrasive soil. The direction of rotation of the drive gear of the blades is reversed so that the soil is thrown up in front of the tiller rather than behind. This eliminates the tendency of the blades to bind in the soil.

The blades are spaced so that 10- to 12-inch wide strips may be cut through the bed, and these are then cross-checked to yield rather uniform soil blocks. Each block can be broken free at its base by inserting a sturdy, tined fork beneath it and gently prying up (Figure 6). The blocks are carefully laid on the flat bed of a truck and removed to the new site. Close packing is necessary to avoid excessive crumbling of the blocks, and their fragile nature prohibits transporting more than a single layer at one time.

Figure 6. Natural bed with nesting area cut into square-foot blocks. The block on the right, broken loose by means of a heavy, tined fork, is ready for transport.

Soil cores. Equipment necessary for the extraction of soil cores consists of: a heavy gauge steel cylinder from 10 to 12 inches in diameter and 16 inches long, with a reinforced upper rim and a sharpened lower rim; a heavy steel cover which can be held in place on the top of the cylinder and which can sustain repeated pounding; a series of 28-gauge galvanized sheets, 3 feet long and 1 foot wide with the bottom ½ inch crimped and incised every ½ inch to a depth of ½ inch across the crimped edge (Figure 7A, B). The number of galvanized liners prepared is a function of the number of cores to be transported on each load, for they may be reused several times for this purpose.

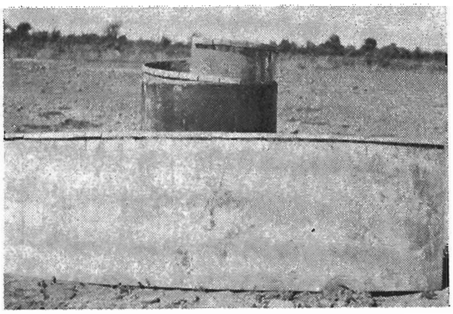

Figure 7A. Soil-core equipment, showing crimped and incised liner in the foreground and inverted steel cylinder behind, with a second liner partially inserted.

Figure 7B. Steel cylinder containing liner driven into the ground. The cover is held in place by loops welded to the cylinder. Several cores appear in the background with the liner held in place for transit by pieces of rubber tubing.

Incisions across the crimped edge of a galvanized liner permit it to be bent into a circle and inserted into the inverted steel cylinder so that the crimped edge overlaps its sharpened edge (Figure 7A). The cylinder is then righted, set on the soil from which the core is to be taken, the cover set in place, and the entire apparatus pressed or driven into the ground by a sledge, truck axle, or other heavy object. The pile-driving effect of an axle directly down upon the center of the cover does not jar and fragment the upper few inches of soil as much as the more glancing blows of a sledge. The cylinder is driven into the ground to the desired depth (8 to 12 inches), broken free by tilting, and lifted away from the bed. Lifting the cylinder by loops at its upper surface usually results in its sliding free of the enclosed galvanized liner and the soil core it contains. The cylinder is raised about 8 inches, and the liner is kept in place about the soil core with a single wrap of plastic or masking tape (Figure 7B). The process is repeated, using a new liner. Because of the protection offered by the liners, the cores may be stacked several layers deep for transport without damage (Figure 8).

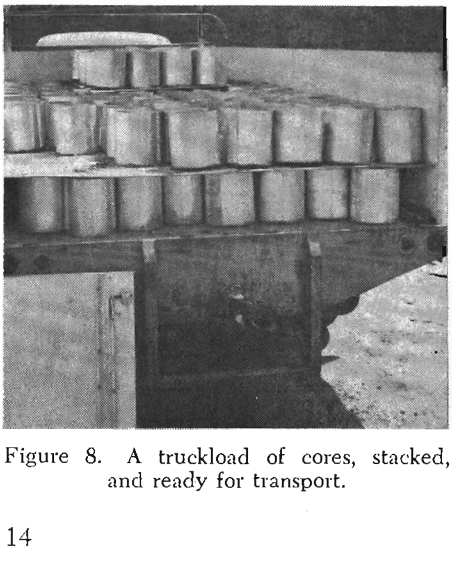

Figure 8. A truckload of cores, stacked, and ready for transport.

Prepupal transfers. When establishment of the alkali bee is contemplated in areas outside of western America, precautions are essential to prevent the dissemination of soil microorganisms and organisms other than the bee. This can be accomplished by the laborious method of digging and collecting individual prepupae from a natural bed and returning them to the laboratory. They should be kept for 2 to 3 weeks at temperatures within the developmental range of the bee (22° to 30° C.) to isolate those that have been damaged or infected with a latent bacterium or fungus. Prior to shipment, each prepupae should be dipped in 70% ethanol to remove or destroy any surface microorganisms and placed in a close-fitting compartmentalized container.

Containers may be of varied design, but among the simplest is the type consisting of a series of large-diameter straws (5 to 6 mm. i.d.) cut into 12 mm. lengths. The straws may be bound together in groups of 50 by a rubber band or by glue, with a bottom and top composed of a heavy sheet of beeswax foundation (Figure 9). The foundation should be warmed to soften it, and pressed into place so as to seal the upper and lower surfaces. The top (or bottom) sheet may be removed at the destination and the prepupae observed.

As an added quarantine precaution, the prepupae should be reared at their destination until the pupal stage is reached. Some of them harbor internal bacteria or fungi which do not immediately kill the prepupae. Once pupation has occurred, the chances of further loss by these causes are negligible.

Adults will emerge in 11 to 35 days after pupation occurs; the rate of development is dependent on the temperature. Thus, once pupation has oc-

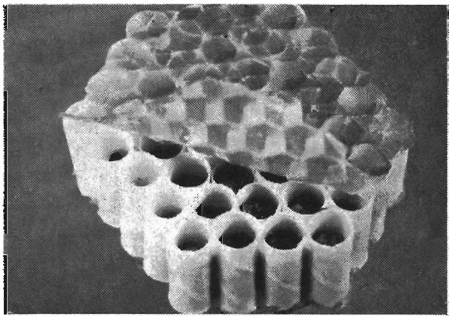

Figure 9. A prepupal transport packet consisting of short lengths of large-diameter soda straws glued together, with beeswax foundation serving as upper and lower surfaces. Prepupae can be seen in several of the straws.

curred, the foundation is replaced on the top of the shipping container and the entire "packet" set into the new site at a depth of 3 to 4 inches. Mature adults will chew through the wax and the superimposed soil.

The pupal transfer method is not recommended as a practical means of establishing alkali bees because of the labor involved in achieving desirable population levels. It is effective where restrictions prohibit the transportation and introduction of nonsterile soil.

Implanting soil blocks and cores. Implantation of blocks and cores is accomplished in the same manner. Trenches to accommodate one or more adjacent rows of cores or blocks are dug across the new bed, or a section of the bed is excavated in which all of the transplants can be placed contiguously (Figure 10). The depth of the trench at excavation is determined by the height of the blocks or cores to be introduced and by the position of the contained bee larvae in relation to the soil surface. Cores, from which the surface two inches were removed prior to transport, may have the larvae located within an inch or so of the new surface. If such cores are moved from an area where temperatures have been cool because of a retarded season into an area where unusually warm conditions prevail, the larvae may die because of the abrupt temperature change. Under these conditions, mortality may be minimized by implanting cores deep enough so that their surface may be covered and insulated by 2 to 3 inches of soil. On the other hand, cores moved just prior to bee

Figure 10A. Soil cores situated in a new bed, with liners removed. Spacing permits packing soil firmly against core sides.

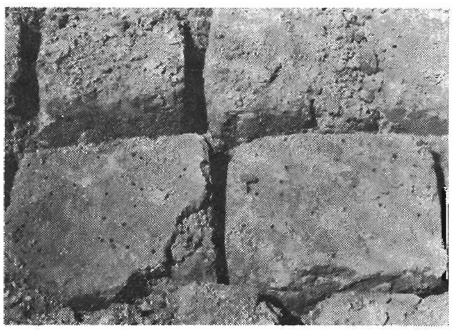

Figure 10B. Soil blocks partially implanted at a new site.

emergence into areas where unusually cool weather conditions prevail, or where the weather conditions in the two areas are comparable, should be implanted so that the core surface and that of the bed are on the same plane. The development of overwintering prepupae is temperature-influenced; thus the depth to which the prepupae are placed at the new site can determine the rapidity of their emergence.

The soil in the bottom of the trench should be loose and damp. Then, when the cores are set in place, the soil of the bed and the soil of the core form a continum for the upward movement of water by capillary action. Each core should be carefully placed and the soil tamped firmly about its sides (and top when the area is covered). Failure to achieve close contact between the core and the soil of the bed results in the desiccation of the transplant and the ultimate loss of the bees.

Where a section of the bed is excavated for the introduction of transplants, only a portion of the removed soil is used for backfilling, and as a consequence much of the surface salt is lost. Additional salt may be spread over the area into which the transplants were made and the surface lightly sprinkled with a garden or lawn sprinkler. Sprinkling will speed the salt into solution and also assist in the compaction of the soil about the cores. Caution should be exercised not to oversprinkle and to avoid any surface water runoff.

Size of transplant. A minimal number of blocks or cores are required to assure bee establishment, particularly in beds that are at a distance from large native populations. No less than twenty good cores should be introduced. Generally, the greater the number of cores introduced, the more rapid the population expansion in the bed. Many growers, anxious to obtain immediate benefit from their beds, have stocked each with from 200 to 800 cores, spacing them in trenches 1 to 2 feet apart. Since square-foot transplants from a good native bee bed should contain from 70 to 200 prepupae, the initial population in these beds is one of considerable size.

In exceptional instances, unstocked artificial beds constructed in areas having large native populations of the alkali bee and few suitable nesting sites have been completely occupied during the first year by inflights of nest-searching females.

Where beds are constructed within a mile of populous native or artificial sites, an attempt should be made to induce emergence from transplants in advance of that from competitive sites. The alkali bee tends to be highly gregarious, i.e., it prefers to nest in close proximity to others of its species. Hence, emergents from a small population, at a time when other populous beds are in full flight, often are attracted to an active site in which they will nest. Normally, emergents will begin renesting in the soil of the cores from which they emerged or in the soil immediately about them. If early emergence can be induced, even small nesting populations exert some attractive influence on the first nest-searching females from other beds and may draw considerable numbers of females to the new area. Once the nest tunnel construction has begun, the searching activities of the female are at an end, and, so long as the soil of the bed remains in good nesting condition, they will not leave.

Expansion of nesting areas. The population of nesting bees remains restricted to the confines of the artificial

Figure 11. A section of the surface of an artificial bed with over 200 nesting holes per square foot. The soil excavated in the process of tunnel construction imparts an undulating appearance to the surface.

site where soil conditions are optimal. Under natural conditions, 20 to 40 holes per square foot of bed surface has been considered an excellent population, but in artificial sites tunnel densities of up to 230 holes per square foot have been obtained (Figure 11). Reasons for this difference in population are readily explained. Under natural conditions, the nesting medium is not uniform in texture or compaction, and this results in a nonuniform rate of water transport to the surface. Also, natural sites are usually created by subsurface moisture flowing over an undulating hardpan ranging in depth from 3 inches to 3 feet from which it rises to the surface of soils with good capillary qualities. Bees will rarely burrow into soil that is excessively moist or into a dense impermeable hardpan. Thus, nests in the latter situations are often very shallow and tunnels are sparse. The cells are built in a single layer only at that level of the soil profile which has an optimal moisture content. In artificial beds, the soil texture is selected for uniformity, good capillarity, and good moisture-retentive properties. Bees are able to dig their tunnels 3 to 20 inches deep and find soils uniform in texture and moisture and suitable for cell construction. They are not limited to a single level of the soil profile, and they overcome increased population density by digging deeper, completely utilizing available soil for their brood nests. Figure 12 shows the cross-section of a core removed from the most populous bee bed yet noted. Approximately 1,800 prepupae per square foot were distributed continuously from 3 inches to 22 inches below the soil surface.

Populations should be permitted to become dense before new beds are built to accommodate the adults of the

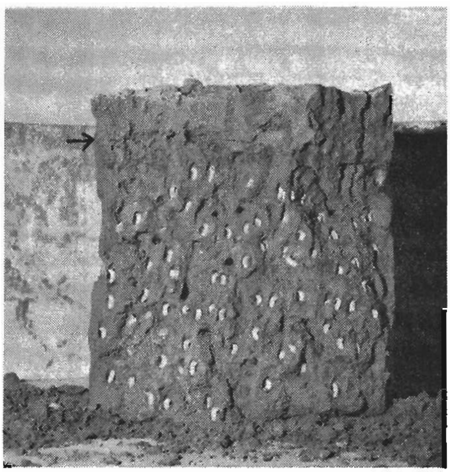

Figure 12. A section through a core from the artificial bed shown in Figure 11. Prepupae are located continuously from 3 to 22 inches deep. The arrow indicates the original soil surface. Soil above the arrow was excavated by females responsible for the prepupae illustrated.

succeeding generation. In the example cited above, populations reached an undesirable extreme because the bees had to dig to great depths to find space for each cell. Whereas each female may construct from 18 to 20 cells under optimal conditions, an average of only 7 cells were built as a result of the stresses of population density. When populations reach 75 to 100 tunnels per square foot, flight over the bed is usually heavy enough to drive away ovipositing adults of the bee-fly parasite, *H. robustum*. Beds having these populations, or higher ones, are virtually free of parasitism by this species.

MANAGEMENT

A new bed constructed immediately adjacent to one with a population of the density mentioned above will accommodate many of the progeny the following year. Additional beds may be added as required (Figure 13). Populations in bee beds appear to stabilize at from 70 to 100 tunnels per square foot when they are maintained in an optimal condition and when adequate forage is near-at-hand. The oldest artificial beds are now in their seventh year, and these beds do not appear to be any less acceptable to bees than adjacent, more recent additions.

Figure 13. Original bed in the foreground. Two beds (background) were added in subsequent years to accommodate the expanding population.

Number of beds. The number of bees, rather than the number of beds, is the critical factor in determining needs for optimal pollination and seed yield. Conservative estimates suggest that each female should be able to trip enough florets to yield at least one pound of alfalfa seed if flight and nesting conditions are good. Thus the occupants of a well-populated 30 by 50 foot bed should be responsible for 50,000 to 80,000 pounds of seed. However, the flight range of alkali bee females is extensive, and, as the season progresses, they may cover an area of several square miles about the nesting site. The seed-setting effect is thus diluted, although major benefits are most evident in fields nearest the bed.

As a rule of thumb, each well-populated 30- by 50-foot bed should supply enough bees to pollinate approximately 40 acres of seed alfalfa. This recommendation must be tempered by considerations of the total available forage in the area and the ability to maintain good bloom in nearby fields throughout the 6- to 8-week flight period of the bee. Perhaps one such bed per 30 acres should be an ultimate goal; growers rarely have indicated that they were content with existing bee populations.

Care of beds. If the beds have been constructed with care, their maintenance in succeeding years is minimal.

The principal recurring task is the addition of water, which should be done each spring just prior to emergence. The amount of water necessary to bring the surface of the bed to its condition of the previous year varies from bed to bed, even when they are of the same dimensions and have similar soils. Generally, beds lose from 50 to 70% of their water in a single season in the Pacific Northwest; thus a trial-and-error approach is necessary to establish the annual mean gallonage requirement of each bed. Once the water need has been determined for a given bed, it should be recorded as a reference standard for future seasons.

In the Northwest, beds built in the manner prescribed above require water only once each year. Areas with longer or hotter summers will have greater water needs, and the frequency of water supplementation should be based on the condition and appearance of the soil surface.

As indicated earlier, the extent of fungus loss in bee beds is associated directly with the moisture content of the soil. Peak moisture should be reached immediately prior to, or simultaneous with, bee emergence and the beds permitted to become progressively drier through late summer and winter.

The surface of the bed must be weed-free to keep water loss at a minimum and to permit the bees to utilize all of the available surface area without impediment. Usually, the high salt levels will prohibit weed growth, but where this fails, vegetation should be removed manually or with non-bee-toxic herbicides.

Soluble salts will gradually be transported to, and accumulated at, the surface of undisturbed soils having the properties of those comprising the matrix of a bee bed. This may result in an ultimate crustal formation or concretion at the surface, and may have to be remedied by periodic rotovation if the population of nesting bees is scant. Where dense bee populations exist, an annual natural "rotovation" results. Bees in the process of emergence pull down some of the topsoil to backfill the overwintering cells; but of greater significance is the salt-free soil they deposit on the surface in the process of nest construction. The soil core in Figure 12 reveals that 3 inches of subsoil has been added to the surface as a result of a single year's excavation, through which the salt ultimately will be carried. Thus, with good bee populations, the maintenance of an acceptable salt-surface condition is self perpetuating.

Occasionally, problems are encountered where the rate of capillary water-rise appears to decrease and the surface becomes hard and dry in spite of the addition of quantities of water. This condition is especially prevalent in beds where the matrix is composed of soils having a clay-size-particle content at or above the limit recommended above. The addition of calcium chloride to the water at the rate of one quarter of a pound per square foot of bed surface has been found to promote capillary water rise in such soils. Calcium chloride is readily soluble in water and should be added in solution.

Birds may inflict some population loss in certain years. Sparrows, black birds, magpies, and starlings are the most troublesome, descending on the bed each morning when emergence is under way and eating numbers of bees unable to take flight because of their unexpanded wings. Control attempts consisting of scarecrows, whirling plastic wheels, loose tin foil, etc., have some effect. At present, most farmers spend some time each morning during the emergence period shooting and scaring birds from the site.

Alkali bees establish a flight pattern between the nesting site and the field being foraged. They rarely fly more than 10 to 12 feet above ground level and often establish flight routes at 3 to 4 feet. Some mortality occurs when these flight routes cross heavily travelled roads or highways. Many growers have erected signs to alert motorists of this fact, particularly where major flight routes cross traffic arterials (Figure 14).

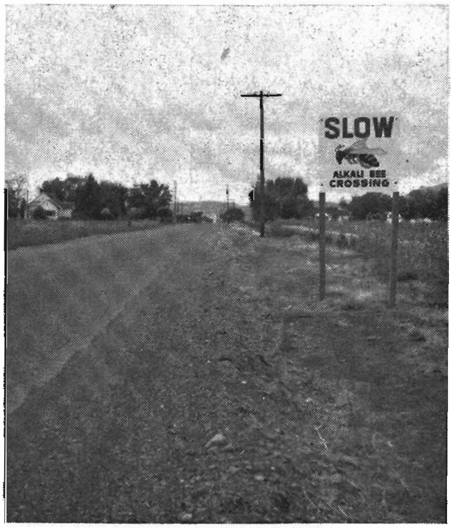

Figure 14. The ultimate in concern for bee safety. Growers have erected such signs where established flight routes cross main traffic arterials.