# ABSTRACT

## THE INTERRELATIONSHIPS OF HONEY BEE ACTIVITY, FORAGING BEHAVIOR, CLIMATIC CONDITIONS, AND FLOWERING IN THE POLLINATION OF PICKLING CUCUMBERS, *CUCUMIS SATIVUS* L.

By

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Prior to successful pollination of pickling cucumbers, anthesis, anther dehiscence, nectar secretion, and initiation of foraging by the honey bee, *Apis mellifera* L., must occur, and all were primarily dependent on temperature. Anthesis began at 15° C; nectaries became moist and anthers dehisced at 16° C; and foraging activity was first observed at 16.5° C under normal conditions. Completion of anther dehiscence occurred at 19° C and maximum foraging between 21.5 and 30.0° C. Cucumber pollen was viable and stigmas receptive at the time of anther dehiscence. Pollination must take place on the day of anthesis, since pollen viability, stigmatic receptivity, and attractiveness to the bee last only one day.

Daily foraging activity and nectar secretion fluctuated in relation to environmental conditions. Multiple regression analysis indicated that bee flight was a function of temperature, solar radiation, relative humidity, and wind speed. Nectar volume and sugar production in pistillate flowers were functions of temperature, solar radiation of the three previous days, relative humidity, and the

total precipitation of the four previous days. In staminate flowers nectar secretion was positively affected by wind speed and negatively by precipitation. The sugar concentration of nectar was dependent on relative humidity, wind speed, and temperature.

The pattern of bee visits throughout the day produced a normal distribution centered at 11 - 12 a.m. EST. From 9 a.m. to 2 p.m. 82.3% of all visits occurred. From 7 - 9 a.m. pistillate flowers were more attractive than staminate. After 9 a.m. staminate flowers were preferred and preference increased throughout the day. Bees spent almost twice as long per visit on pistillate flowers as on staminate. Except for early morning and late afternoon, the average time bees spent on the flowers decreased throughout the day. Honey bees averaged 11.4 sec per flower visit for an overall foraging rate of 5.3 flowers per min. Sugar concentration was 40% higher in bee-excluded than bee visited flowers or nectar removed from the honey stomachs of bees.

Cucumber pollen was found primarily on mouthparts, ventral surface of the thorax, prolegs, mesolegs, and metalegs. The bees first visit to a flower placed significantly more pollen on the stigma than succeeding visits. Honey bees are capable of distributing cucumber pollen 60 - 70 feet from the pollen source, although the efficiency of the movement decreased after 10 feet. Flowers should receive 15 - 20 visits on the day of anthesis for maximum fruit set. Multiple bee visits increased fruit set and the average number of seeds per fruit but the number of perfectly shaped fruit did not increase accordingly.

Availability of pollen along with decreased light intensity and increased plant vigor seemed to trigger parthenocarpic fruit production. Fruit inhibition limited fruit production and excessive production of staminate flowers limited fruit uniformity for mechanical harvesting.

The transition from monoecious to gynoecious cultivars and high plant densities have changed the energetics of the flower-visitor relationship in the field. There was an inverse relationship between potential fruit production and total caloric reward available to the bee. Under optimum conditions, cucumbers produced an estimated 2.82 l of nectar/acre of 198,313 plants/day which would yield 2.13 pounds of honey. As the number of bee visits increased, the average area of individual visits increased.

Perfectly shaped fruit contained from 0 - 546 seeds. No significant correlations were obtained between production of perfectly shaped fruit and daily staminate:pistillate flower ratio, average seed count, or total bee visits per flower.

Maximum yield for machine harvest was achieved in less than a week when pickles had otimum pollen, uniform flowering, plenty of bees six days after the start of flowering, and good flying weather (temperatures above 21° C, relative humidity below 70%, winds less than 15 mph, plants dry, and bright sunshine). A technique is presented for the grower or researcher to assess pollinator activity in pickle fields in relation to needs for optimum pollination. A simulated mathematical model was developed to interpret the complex interrelationships between bees, flowers, and pollination of the crop.

It applied to daily ratio of staminate and pistillate flowers, nectar yield, number of foraging trips to collect available nectar, and potential fruit yield for various plant populations, cultivars, and seed blends.

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# INTRODUCTION

Flowers provide two types of attractants for the honey bee, *Apis mellifera* L.; primary which satisfy demands for food (nectar and pollen), and secondary that serve as labels which start a direct or indirect reaction of the sensory system in the visitor and would include texture, form, color, and odor. Primary attractants serve as a reward for the visitor; however, they would be useless by themselves, unless accompanied by the secondary labels, Faegri and van der Pijl (1966). The efficiency of pollination of any bee-pollinated crop must depend upon its profitability as a source of food for the visitor. Without this reward and sensory stimulation, the stimulus for the next response in the foraging sequence would be absent and the behavior pattern broken, Doull (1971).

Pollination of pickling cucumbers results from the establishment of a flower-visitor relationship. In plants where nectar appears to be more attractive than pollen, as in cucumbers, pollen presentation must be synchronized with nectar presentation to accomplish pollination, Faegri and van der Pijl (1966).

It is believed that long range attraction of the bee to the flower is based on vision, while close orientation depends on odor and surface texture. Surface texture is important in providing a foothold for the visitor and for light reflection. The original visual response depends on flower size, segmentation, depth, and color, Faegri and van der Pijl (1966). Brett and Sullivan (1972) found that the corollas of cucumber flowers provide the bee with marked contrast in color. Photographs through an ultraviolet filter showed that the central part of the corolla reflected only yellow light compared to a mixture of yellow and ultraviolet in the outer portion of the corolla. The nectar supply present may also provide the bees with a visual clue. Thorp, Briggs, Estes and Erickson (1975) found that nectar of cucumber fluoresced in the visible and absorbed in the ultraviolet spectrum. They suggested this may serve as a visual cue that foraging bees could use to determine the quantity of nectar available.

The honey bee exhibits a constancy for one flower species during foraging for long periods of time. Flower constancy is actually a preference, since the bee has identified the location, learned the secondary flower labels, discovered how to manipulate the blossom, and experienced the reward of acceptable nectar and pollen, Faegri and van der Pijl (1966). Heinrich and Raven (1972) pointed out that little attention has been paid to the caloric reward provided by the flowers of a particular plant species to the pollinator. They hypothesized that the amount of nectar per flower, in terms of calories of food energy needed to bring about maximum cross-pollination, would be related to the characteristic rate of energy expenditure of the pollinators. Other factors affecting the energetics of the interrelationship between plant and pollinator would be plant density, distance the bee has to travel between flowers, and ambient temperature.

The pollination mechanism of pickling cucumbers involves three phases; (1) release of pollen in the staminate flowers, (2) transfer of pollen from the staminate to the pistillate flower by a biotic agent, and (3) successful placement of pollen on the stigmatic surface followed by pollen grain germination. Honey bees have been recognized as necessary for economical cucumber production by Seaton, Hutson and Muncie (1936), Kremer (1943), Tuljyenkova (1955), Alex (1957), Glushkov (1958), Markov and Romanchuk (1959), Warren (1961), Shahin (1967), Williams and Kauffeld (1967), Connor (1969), Seyman et al. (1969), and Brett and Sullivan (1972). Current recommendations vary from one colony per four acres, Ward (1973), 0.6-1 colony per 2.5 acres, Glushkov (1958), 1 colony per acre, Rahmlow (1970), Sims and Zahara (1968), Brett and Sullivan (1972), Steinhauer (1970), one colony for every 50,000 plants in the field, Connor (1969), Cantliffe (1974), 1-2 colonies per acre, Stanger and Thorp (1972), Stephen (1970a), Seyman et al. (1969), 3 colonies per acre, Lawin (1974) and up to four hives per acre, Jaycox (1969).

Michigan has led the nation in pickle production every year but two since 1918, Michigan Science in Action (1974). However, pickle production in Michigan has undergone recent changes which have greatly increased the need for bees and for a better understanding of the complex interrelationships involved in the pollination of the crop. The ratio of staminate and pistillate flowers has been altered in the field through the development and use of gynoecious (predominantly pistillate) hybrids and mechanical harvesting. Over

90% of the 1973 crop in Michigan was harvested mechanically, Michigan Science in Action, (1974). Because uniform, small cucumbers bring top prices, adequate pollination within a restricted time span is essential for an optimum machine-harvest yield.

With the change to mechanical harvesting, plant populations in the field have increased rapidly from less than 20 thousand plants per acre to populations up to and exceeding 200,000 plants per acre. With more flowers per acre, the nectar and pollen productivity of the field is greatly increased and the honey bee has to expend less energy to get from flower to flower. This should make the crop more attractive to bees. On the other hand, the need for maximum pollination in as short a time as possible for an economical and uniform fruit set, may influence the grower to flood the field with bees, which would cause the energy budget to flow in the opposite direction because of increased competition.

In determining the number of honey bee colonies needed to pollinate a given area of a crop, various ecological factors must be considered. Any estimate of pollinator needs should take into account the attractiveness of the crop; weather conditions during the blooming period; density of flowering; the amount of nectar and pollen produced; the number of pollinating insects present; the behavior of bees on the crop; competitive plants in the area; and the morphological, physiological, and behavioral characteristics of the flowers.

The following study was undertaken to gain a better understanding of the complex interrelationships between the honey bee, flowers, and the weather, all of which are involved in crop pollination. This information should give apiculturists and pickle growers a better idea of the level of bee activity needed for maximum pollination and economic return. It is hoped that this work will provide a useable procedure for rapid and accurate assessment of the pollinating force required for cucumber production and that this knowledge may simplify development of similar formulae for other crops.

## LITERATURE

### Climatic Conditions Affecting Anthesis and Anther Dehiscence

Seaton, Hutson, and Muncie (1936) reported that both staminate and pistillate cucumber flowers usually open about two hours after sunrise, but the opening was markedly influenced by temperature and humidity. Seaton and Kremer (1938a) found that in Michigan the flowers reached anthesis at a temperature of 15 to 16° C. Peto (1951) observed that on average days, cucumber flowers were open at 6:45 a.m., Standard Time. In Russia, Nemirovich-Danchenko (1964) found the flowers to open between 7 and 11 a.m., 1.5-2 h later in colder weather. Seaton and Kremer (1938a) observed that the flowers borne above the leaves and exposed to the sun would open earlier than those in the shade under the leaves. However, they found the determining factor to be temperature, as all flowers opened at the same time when cloudy weather prevailed.

Banadyga (1949) reported that temperature was the most important climatological factor influencing dehiscence of the pollen sacs in cucurbits. Dehiscence may occur at any time of day with the proper temperature. Seaton and Kremer (1938a) and Cantliffe (1974) found that anther dehiscence did not occur until 17° C and was optimum at 18-21° C. Brett and Sullivan (1972) observed that optimum dehiscence occurred at 19° C. Seaton and Kremer (1938a) found that anthesis and dehiscence during August and September usually occurred between 6 and 9 a.m., with a mean time of 8 a.m. However, on warm days fully opened flowers with dehisced anthers were observed as early as 4 a.m. while on cool days (13° C or below) the flowers and the theceae of the anthers remained closed throughout the day. A highly significant positive correlation was found between the time of day and stage of anther dehiscence. However, they concluded that even though the time of day was a controlling factor for both anthesis and anther dehiscence, it undoubtedly was modified by temperature, since a highly significant positive correlation was found between temperature and anther dehiscence. Humidity apparently was not operative in influencing the time of anthesis or dehiscence. Seaton, Hutson, and Muncie (1936) reported that pollen was released soon after the petals were fully expanded.

### Duration of Pollen Viability and Stigmatic Receptivity

Barnes (1947), working under greenhouse conditions, found that anthers dehisced between 9 and 9:30 a.m., and pollen remained viable until 1 or 2 p.m. The optimum time for effective pollination was noon. Hayase (1955) found that the pollen actually became viable before the anthers dehisced, with maximum viability being at 20-25° C. Viability changed little when the staminate flowers were stored at 15-30° C for 21 h prior to anther dehiscence but with storage for 39 h, viability was prolonged by the lower temperatures and curtailed by the higher. Banadyga (1949) reported that the germination of pollen did not occur below 21° C, with the optimum being between

27-29° C. Therefore, he concluded in order to get pollination and fruit, the temperature must be above 21° C. Seaton and Kremer (1938b) found that little or no germination or pollen tube growth was observed at temperatures below 18° C. Knysh (1958) removed cucumber pollen from marked bees trapped at the hive entrance returning from plots 250, 500, 750, and 1000 m from the hive. This procedure was completed between 7-11 a.m. at temperatures of 19-20° C and a relative humidity of 60-70%. Pollen viability rapidly diminished with distance, with no germination at 750 m or more. It was believed that the loss of viability was because of the drying of grains, as the bees flew in a current of dry air. Banadyga (1949) also reported that laboratory tests have shown cucumber pollen to be quite sensitive to water absorption. This would help explain poor pollination during long periods of rainy weather. Rain may also wash pollen off the anthers before fertilization takes place. Choudhury and Phatak (1961) found that temperature influenced anther dehiscence and pollen fertility of cucumbers in India. However, under the high temperatures of Indian growing conditions, light intensity, and the time of day influenced anthesis far more than temperature. Under high temperature conditions, the period of receptivity of the cucumber stigma was short. Connor (1969) found no evidence that the stigma of the pistillate flower was receptive for only a short period of time in Michigan, as was observed in India. Successful pollinations were obtained at separate intervals throughout the day, implying that whenever bees were present in the field, fruit could be set. Cantliffe (1974) reported that pistillate flowers were receptive to pollen for 24 h or less depending on environmental conditions. High temperature, high humidity, wind, or drought shortened the time for pollination to fertilization. Seaton, Hutson, and Muncie (1936) reported that the stigma was receptive on the day the flower opened until the afternoon of the same day. They found the stigma most receptive early in the morning, but greatly influenced by climatic conditions.

## Climatic Conditions Affecting Foraging Activity in the Field

Kremer (1943) observed that bees did not appear in cucumber fields until after the pollen had begun to dehisce and nectar was being secreted. Banadyga (1949) reported that bees did not travel very far from the hive during cool, cloudy, or showery weather; thus, the proximity of hives to cucumber fields may decidedly influence the yield of fruit. Peto (1951) reported that weather conditions were the greatest cause of variability of visits to cucumber flowers.

On cool, windy, and foggy days, the foraging population was definitely less. Kauffeld and Williams (1972) found that favorable conditions for cucumber pollination by honey bees were: temperature above 21° C, relative humidity below 70%, winds less than 15 mph, plants dry, and bright sunshine. When weather conditions were otherwise, the number of bees working cucumbers decreased. Connor (1969) observed bees working under the canopy of leaves during light showers, without any major change in their behavior.

Lundie (1925) found that on heavily overcast days, with or without occasional precipitation, the low intensity of light seemed to be the major factor inducing bees to stay in the hive. He found that in June and July the temperature at which flight commenced was very inconsistent, varying between 13 and 27° C, being most active from 19 to 25° C. He concluded that at this time of year, temperature was not often a factor in retarding the beginning of flight. On one day, a wind velocity of 16-21 mph during the hours of 9-6 reduced the possible maximum flight by 28-53%. Bodenheimer and Ben-Nerya (1937) concluded that 16-32° C was the optimal range for flight activity, with reduced flight between 9-16° C and none below 8° C. Wratt (1968) found that wind speed was related to temperature and obtained a significant positive correlation between temperature and number of bees foraging. Nelson and Jay (1968) found that flight activity increased with environmental temperature and closely followed changes in it.

Park (1923) discovered that bees did not continue to work in a wind blowing 15 mph or more. Butler and Finney (1942) found within any one day, the number of bees leaving the hive increased by 15% for each increase in solar radiation rate of 0.1 cal/cm$^2$/min. Approximately 30% of the variability in bee activity was ascribed to irregularities in light intensity. Bodenheimer and Ben-Nerya (1937) observed that foraging activity rose with low, and fell with high humidity. They found that 66% of the total bee flights were recorded at humidities ranging between 10-40%, compared to 26% at humidities ranging between 40-70% and 8% for humidities between 70 and 100%. Von Frisch (1967) found that during flight, bees could detect relative humidity differences of 5-10%.

Brett and Sullivan (1972) reported that honey bees in cucumbers began foraging in the morning and reached peak activity about three to four h after cucumber flowers opened. After 4 p.m. the bees were almost inactive. Connor (1969) found that the average number of bee visits in cucumbers throughout the day produced a normal distribution pattern centered around 11 a.m. EST. Of all the bee visits, 78% occurred from 9 a.m. to 2 p.m. Only 7.5% occurred before 9 a.m. and 14.5% after 2 p.m. Seyman, Barnett, Thorp, Stanger, and Payne (1969) found that maximum bee pollination activity in cucumbers took place during mid-day. Bee counts taken at 8, 10, 12, 2, and 4 o'clock indicated that 91% of all bee activity occurred between 10 a.m. and 2 p.m. At 10 a.m. 26% of the bees were recorded, 46% at noon, and 19% at 2 p.m. However, Kauffeld and Williams (1972) found that the average daily activity of honey bees in cucumber fields had a bimodal effect; activity peaked near 11 a.m., decreased and a second, but lower, peak occurred between 2 and 3 p.m. Connor (1969) found that very warm mornings produced peak activity for the day between 8 and 9 a.m., while some cold days delayed the peak until 12 to 1 p.m., with no flight until 10 a.m.

## Climatic Conditions Affecting Nectar Secretion

Flowering is one of the later events in the life history of an annual plant and any factor to which the plant has been exposed at any time prior to flowering will, to some degree, influence flowering and with it nectar production, Shuel (1967a). External factors influencing secretion are those of weather and soil. Weather is a complex of interrelated factors, and it is often difficult to separate the individual components in field observations, Shuel (1975). In general, conditions which impose no appreciable limitations on growth and which promote a reasonable balance between vegetative and reproductive development seem to support good nectar production, Shuel (1967a).

Temperature has received more attention than any other factor and there is a difference of opinion regarding its importance. Records of daytime temperatures may reflect conditions of sunlight which in themselves cause wide variation in the nectar flow, Shuel (1967a). Temperature affects many plant processes which are proceeding at the same time. A certain threshold temperature is necessary if secretion is to occur. Within normal daily limits, temperature variation probably has little influence on the amount of sugar which the plant synthesizes, but it has a very marked affect on the rate at which the sugar is consumed in growth, respiration, and other processes. Flower development is accelerated at high temperatures and the duration of secretory activity is probably shortened, Shuel (1955a). Excessively high temperatures in combination with meager rainfall can lower nectar production by causing a moisture stress in the plant, Shuel (1975).

Throughout the growing season, water is an important factor in the regulation of plant growth. Either a shortage or an overabundance of water may stunt plant growth and lead to poor nectar yields. During the secretory period, a lack of water may reduce the amount of sugar synthesized, Shuel (1955a).

There can be little doubt of the primary importance to nectar secretion of sufficient sunlight to support a high level of photosynthesis. Most of the sugar in nectar probably comes from leaves fairly close to the flower. In herbaceous plants the nectar sugar is likely to be of recent origin, whereas in trees and shrubs, it may also be derived from stored carbohydrates, Shuel (1975). It is highly probable that any factor which alters the rate of buildup or breakdown of the carbohydrate supply will influence nectar secretion, Shuel (1955a).

Several authors have found that humidity has a pronounced inverse effect on nectar sugar concentration. It is likely that this effect is chiefly physical, operating in the following manner. As nectar is secreted, it begins to undergo a regulation of concentration until its vapor pressure comes to equilibrium with that of the atmosphere. Unless the humidity of the atmosphere is very high, the change will be a loss of water molecules to the air and an increase in sugar concentration. Rates of increase in nectar sugar concentration can be extremely rapid in flowers in which the nectar is exposed, Shuel (1975). A direct effect of atmospheric humidity on secretion has not been established. Evaporation is hastened by high temperature and rapid air movement across the nectaries. Also evaporation is more rapid from a thin film of nectar than from a large globule, Shuel (1955a). Individual projects involving climatic conditions and several crops have been extensively reviewed by Beutler (1953), Savos (1955a and b), Shuel (1954), Percival (1965), Shuel and Pedersen (1953), and Kenoyer (1916).

Banadyga (1949) and Kremer (1943) reported that nectar secretion commenced in cucumbers at temperatures of 17-18° C. Nemirovich-Danchenko (1964) found nectar secretion to be greatest in both staminate and pistillate flowers 3-4 h after opening. The daily average nectar yield was dependent on temperature.

Kenoyer (1916) found that cucumber nectar contained less sugar and was of less volume when plants were kept in the dark.

## Sugar Concentration of Cucumber Nectar Throughout the Day with Bee Visitation

Wilson, Moffett, and Harrington (1958) in analyzing the honey stomach contents of 18 bees, found cucumber nectar to average 42.2% sugar with a minimum of 37.8% and maximum of 49.2% in Colorado. Kauffeld and Williams (1972) made 10-20 hand refractometer readings of nectar from the honey stomachs of bees working cucumbers and found the range to be 36-41% sugar, depending on weather conditions in Wisconsin.

## Distribution of Cucumber Pollen on the Honey Bee's Body

Free (1970) observed that the bees body may be covered with pollen, whether it was packing pollen or not. He found that usually there was about twice as much pollen on a bee's thorax, than on its abdomen. Connor (1969) observed that when a honey bee visits a staminate cucumber flower, pollen comes in contact with both sides of the proboscis, mouthparts, and head. He also found that the pollen grains readily adhere to the body hairs. Stephen (1970) observed that the bees' access to the nectar of the staminate flower was gained through three narrow lateral passages between the stamens. When the bee inserted her proboscis into one of the passages, both sides of her head were dusted with pollen as well as the thoracic hairs.

## The Number of Bee Visits Needed for Adequate Pollination

Shemetkov (1957) found that a Russian hothouse cucumber flower needed to be visited 8-10 times on the first day of flowering, if it were to be satisfactorily pollinated. The weight of the fruit and the number of seeds it contained increased with the number of bee visits, up to 40-50. When individual flowers were visited 2-8 times, 9 fruit were produced per plant with an average weight of 221 grams and 60 seeds. When each flower was visited 50 times, the number of fruits produced was also 9, but the average weight was 500 grams and the number of seeds 140. Connor (1969) found that single bee visits produced fruit 53.1% of the time. He found little difference in the percentage of fruit set between single bee visits and multiple bee visits until nine or more visits, where fruit developed 79% of the time. A comparison of flowers receiving single visits and those receiving 9 or 10 visits were significantly different at the 5% probability level. Flowers receiving from 2 to 8 visits set fruit from 51.0% to 66.7% of the time, mean 57.8%. For 10-12 visits, fruit were set 80.0% of the time. In a greenhouse study, flowers received 2, 10, or 20 visits. Flowers receiving two visits developed 40.0% of the time, averaging 48.3 seeds per fruit; with 10 visits fruit developed 31% of the time, averaging 44.3 seeds per fruit. There was no significant difference. With 20 visits, fruit developed 55% of the time and produced an average of 64 seeds. The controls, which were flowers open to pollination the entire day, developed 93% of the time but did not contain any more seeds per fruit. Data indicated that at least 10 bee visits were needed to insure pollination under a variety of variable conditions.

## The Timing of Honey Bees as They Foraged on Cucumbers

Connor (1969) found that the length of a bee visit to a pistillate cucumber flower decreased as the number of visits increased. First visits to a cucumber flower in 1967 lasted an average of 36.2 sec, 39.2 sec in 1968, while the average length of subsequent visits dropped sharply. The average length of the fourth through twelfth visits to a flower was 10.6 sec in 1967 and 7.9 sec in 1968. Observations in the field indicated that bees settling on a flower worked around the stigma and style for 5 to 10 sec, even if unsuccessful in finding nectar, before moving on to another flower. The length of the first visit to a flower varied with the time of day of the visit. Early morning visits were shorter than those occurring after 11 a.m., indicating that a greater supply of nectar had accumulated. The average hourly visit length throughout the day ranged between 8.8 and 45.0 sec. Visits from 8-10 a.m. lasted 9-11 sec, 10 to 11 a.m. lasted 30 sec, and 11 a.m. to 6 p.m. lasted 38-45 sec.

## The Size of the Foraging Area

Levin (1966) found a close relationship between landmarks and the size of the working area of an individual bee. On the average, each bee worked an area of 210 $m^2$. In small plots with good landmarks, the bees confined their activities to a smaller area. Singh (1950) found that foraging areas were particularly restricted in size during calm, sunny weather when abundant nectar and pollen were present, but when forage was sparse, either because few flowers were present or the flowers were yielding little nectar or pollen, foraging areas were larger and the bees spent less time per flower and were more easily disturbed. He observed that individual bees returned to the same small area of the crop, trip after trip, day after day. This area varied from about 10 to 30-40 $ft^2$ in various flowers. Weaver (1957) found that competition from other foragers was important in determining the size of the foraging area. Competition operated by decreasing the amount of nectar available from the blossoms or by the reaction of a bee to the physical presence of competing foragers.

## The Movement of Cucumber Pollen by Honey Bees

The use of genetically marked cultivars of _Cucumis sativus_ and _Cucumis melo_ has provided several investigators with an indication of the distance that bees move pollen. Jenkins (1942) used such a genetic marker to separate two inbred lines of cucumbers. He found that in adjacent rows spaced six ft apart, the amount of natural crossing between rows was 32.9%. Knysh (1958) used two varieties of cucumbers and planted them at distances ranging from 250-2,000 m apart as well as adjacent to each other. Adjacent plots produced hybrids 23-25% of the time. Hybrids were also produced from seeds grown 250 m from the pollinating variety. Hybrids did not occur beyond 250 m nor in the control. Foster and Levin (1967) concluded that hybrid seed counts in muskmelon did not reveal individual bee movements, but the amount of cross pollination was dependent upon total bee activity. They found that the greater the distance from the pollen source, the less hybrid seed produced. Generally working bees traveled short distances, but their studies indicated that pollen was retransferred from flower to flower at least 35 ft beyond the point of initial transfer.

Connor (1969) used strips of gynoecious hybrids with a pollen source at one end to determine the distance honey bees moved cucumber pollen. In 1967 he found the weight of fruit per plant increased as the distance increased from 0 to 37.5 ft from the pollen source, while from 37.5 to 96 ft the weight of fruit per plant decreased. The percentage of perfectly shaped fruit increased from 23.8% at 0-7.5 ft, to 44.4% at 39-45 ft. Again, the values decreased beyond this point.

In 1968 the strips were divided into 25 ft sections. The highest yield based on dollar value per acre (60,000 plants) was found in the section adjacent to the pollen source at $281 per acre, then decreased to a low of $126 at 225-250 ft. Connor concluded that some of the fruit development at the greater distances was due to a few staminate flowers in the gynoecious strips rather than movement of pollen from the pollinator plot. There was a definite reduction in the number of fruit produced per plant and in seed counts as distance from the pollen source increased. No definite correlation was found between fruit shape and distance from pollinator. Yield of the gynoecious line decreased 35% twenty-five ft from the pollen source, although yields indicated some pollen movement took place up to 125 ft.

### The Relationship of Foraging Activity to Fruit Set

Kauffeld and Williams (1972) found that the use of five colonies per acre in Wisconsin produced a cash return only 10.9% higher and a total average weight of fruit only 16% higher than was obtained with one strong colony per acre. Connor (1969) in Michigan with a bee population estimated to be three colonies per acre found the average number of visits per flower for ten 30 min observation periods was 45.1 visits. Values were doubled to reflect 10 h of pollination. On this basis, the average flower received 90.2 visits from 7 a.m. to 5 p.m. On an average, each flower was visited once every 6.65 min at a rate of 9.02 visits per flower per hour (V/F/H). He found by taking counts at identical times in the plots of East Lansing, Michigan, and in a 20-acre field at Springport, Michigan, that the Springport field received 2.78 V/F/H, while the East Lansing plots received 8.28 V/F/H. Therefore, the Springport field, with one colony per acre, had one third the pollination activity of the East Lansing plots where three colonies per acre were present. When plants were harvested in both fields, the number of cucumbers produced per plant under these different bee populations did not differ statistically at the .05 probability level. East Lansing averaged 1.46 fruits per plant compared to 1.54 fruits per plant at Springport. At another time, similar counts were taken in a 16 acre field at Cedar Springs, Michigan, (1 colony per acre) and compared to East Lansing. At Cedar Springs 2.95 V/F/H were recorded compared to 8.68 V/F/H at East Lansing. Thus, the bee visit activity in the Cedar Springs field was 34.2% of that in East Lansing. Upon harvesting, the East Lansing plots averaged 1.47 fruit per plant and Cedar Springs 1.38, a non-significant difference. In two days time, the plants at Cedar Springs increased from 0.56 pistillate flowers per plant to 0.92 flowers per plant which represents an increase from 28,000 to 46,000 pistillate flowers per acre. No correlation between bee visits and yield should be inferred from these data, due to the variability in maturity of plants at the time counts were made.

## Fruit Inhibition

McCollum (1934) found that the growth of fertilized fruits had a strikingly depressive affect on plant development. Elongation of the central axis of the plant ceased when the developing fruit was about four inches in length. The growing region of the plant became a cluster of pistillate flower buds, which were yellow and abortive. The leaves lost their dark green color and showed a lack of vegetative vigor. Fruit from pollinated flowers remained on the plant in a dormant state, apparently without deterioration. The first sign of plant rejuvenation coincided with maturity or picking of the inhibiting fruit. At maturity fruit began to turn yellow and the seed coats harden. When fruits were produced on early nodes near the base of the plant, they did not have as great of an inhibiting effect on growth of the plant as did fruits produced further along the stem. By tagging fruits and recording the dates of pollination, fruit from the first pollinated flower developed 92% of the time and suppressed the growth of other fruits. In a number of cases, a second fruit started development, but only one fruit at a time continued to maturity. Foliage near the fertilized flower seemed to be essential for fruit development. Accumulation of accessible synthesized materials is apparently necessary for fruit development, but fruit development was not associated with an accumulation of carbohydrates in the plant. His explanation was that fertilized ovaries produced a growth-regulating substance. He found that fruit produced at the outermost node on the vine had a physiological advantage because of its physical nearness to photosynthetically active leaves.

Connor (1969) found that in competition for growth, fruit closest to the root developed 39.5% of the time; fruit in second position developed 29.1%, third position 18.5%, fourth position 15.8%, and fifth position 0.0% of the time. Never more than four fruits per plant developed at one time. The frequency of necks (fully formed only at the flower end) and nubs (fully formed only at the stem end) decreased very slightly as the number of other fruit increased, whereas the frequency of crooked fruit increased slightly. Fruit closest to the crown had the greatest probability of developing and the greatest probability of being well shaped. Perfect-shaped fruit decreased as the position increased, 29.4%, 17.5%, 16.5%, 10.5%, and 0.0% respectively. Young (1943) also found that developing fruits inhibited early growth of other fruits on the same vine. Stout, Ries, and Putnam (1963) reported that usually only one to three fruits developed to a marketable size at one time. Zobel and Davis (1949) found that the total yield of cucumber seed was not increased by regulating the number of fruits per plant. Maximum seed yields were obtained in treatments where all fruits were left on the vine to mature.

# MATERIALS AND METHODS

## Climatic Conditions Affecting Anthesis and Anther Dehiscence

In 1969 flowers were observed at 6 a.m. EST for 13 mornings at East Lansing, Michigan, to determine the factors that regulate flower anthesis and anther dehiscence. A centigrade thermometer was placed among the vines so that accurate prevailing temperature readings could be recorded. Ten pistillate flowers (MSU 35G) and ten staminate flowers (SMR 58) were picked daily each time the temperature increased one degree. Anther dehiscence was verified under a dissecting microscope.

## Duration of Pollen Viability and Stigmatic Receptivity

To check the viability of pollen and stigmatic receptivity at the actual time of anther dehiscence, hand pollinations were made in the field with a camel hair brush on three different days. The pollinated flowers were immediately closed with paper clips to prevent further pollination. The fruit were allowed to develop to maturity for seed counts. At the time the pollinations were made, bees were not flying in the field. The vines were not checked for previously developing fruit.

The duration of pollen viability and stigmatic receptivity was determined by the following studies. In order to determine if pollen from day-old staminate flowers still remained viable, 20 pistillate flowers (MSU 35G) were hand pollinated in cages on August 23, 1968, at 10 a.m. EST. Ten of the flowers were pollinated with pollen from day-old staminate flowers and ten with fresh pollen from the cultivar, Piccadilly. The flowers were evaluated on September 4. Similar studies were continued during 1969 in both the greenhouse and field. From June 24 to July 2, 33 pistillate flowers (7006) were pollinated with pollen from day-old flowers (Chipper) at 10 a.m. and clipped shut. The fruit were harvested before they were fully developed, since the vines were mature and ready to be destroyed. A second greenhouse study was conducted, starting on July 25 and ending on August 7. Forty-six pistillate flowers of the cultivar MSU 35G were pollinated with day-old pollen from Piccadilly flowers and clipped shut. Pollinations were done at 10:30 a.m. under very warm conditions. A similar group of controls were pollinated with pollen from fresh flowers.

In the field, pollinations were done at 10 a.m. and 4 p.m. In both cases SMR 58 served as the pollen source and the caged pistillate flowers were from MSU 35G. The afternoon pollinations were done from August 5 to August 19 and the morning from August 27 to September 2. Sixty-two flowers were hand pollinated in the afternoon and 51 in the morning.

To determine if the stigmas of one-day-old pistillate flowers were capable of setting fruit with fresh pollen, six day-old flowers (Piccadilly) were hand pollinated on August 23, 1968, with fresh pollen (Piccadilly) at 9 a.m. EST. The caged pistillate flowers were tagged during the previous day and evaluated on September 10. Similar work was continued in the field and greenhouse in 1969. From July 25 to August 7 in the greenhouse, 37 day-old pistillate flowers of the cultivar MSU 35G were pollinated with fresh pollen from Piccadilly. The flowers were pollinated at 10:30 a.m. under very warm conditions and were clipped shut. Fresh pistillate flowers of the same cultivar were pollinated with fresh pollen to serve as controls. In the field, pollinations were done at 10 a.m. and at 4 p.m. In both cases SMR 58 served as the pollen source and the caged day-old pistillate flowers were from MSU 35G. Afternoon pollinations were done from August 5 to August 19 and morning from August 27 to September 2. Thirty-three flowers were hand pollinated in the afternoon and 49 in the morning.

<u>Length of Time Flowers are Open in the Field</u>

Since previous studies had shown that day-old pistillate flowers were capable of setting fruit with fresh pollen, and pollen from day-old staminate flowers still has some viability, a survey was taken to see how long day-old staminate and pistillate flowers were open in the field in 1969. Counts of 100 flowers were taken with hand counters at different times of day from 9 a.m. to 3 p.m. The flower was considered closed if a honey bee could not work it and open if it could be worked. Counts of pistillate flowers were taken in the pollen movement strips (MSU 35G) and for staminate flowers in the monoecious plants (SMR 58) serving as the pollen source at the end of the strips.

## Climatic Conditions Affecting Foraging Activity in the Field

Honey bee flight activity in relation to the environment was recorded during 1974 in plots at East Lansing and in commercial fields at Eaton Rapids and Mulliken, Michigan. Each day 10 fresh flowers, five staminate and five pistillate within visual sighting range were tagged. Bees were counted on these flowers for alternating 10-min periods from 7 a.m. to 4 p.m. EST. This method was described by Levin, Kuehl and Carr (1968). After each 10-min sampling period of bee activity, the temperature was recorded within the plant canopy. Counts were made on 12 consecutive days during the period of August 13 to 24 at East Lansing, on seven days between July 25 through August 6 at Eaton Rapids, and on August 26, 29, and 30 at Mulliken.

Additional data on relative humidity, solar radiation, and precipitation for the East Lansing location were obtained from the department of agricultural engineering, MSU. Wind speed data were supplied by the Michigan Weather Service, Lansing, Michigan. Bees in East Lansing consisted of a private apiary of 13 colonies 0.4 miles from the cucumber plots.

All of the colonies included two deep hive bodies and a single shallow super. The university apiary was 1.2 miles away and contained 26 colonies of assorted sizes. On August 16 two colonies were moved from the university apiary to the plot perimeter at 6:15 a.m. The previous day the number of square inches of sealed brood in each of the colonies was measured to provide an index of colony strength. Colony #26 contained 484 sq inches of sealed brood and Colony #28, 430. Both of the colonies consisted of a deep hive body and a shallow super and were established on June 17, 1974, from two pound packages.

## Climatic Conditions Affecting Nectar Secretion

Analysis of nectar secretion within the staminate and pistillate flowers in relation to climatic conditions was carried out in 1968 and 1969. The nectar was removed with Drummond microcaps, measured, and analyzed with a Bausch and Lomb Abbe 3L refractometer as described by Collison (1973). Plants of the cultivar MSU 35G were planted on June 7, 1968. Each day from 7 a.m. to 4 p.m. a minimum of two pistillate flowers were picked each hour on the hour from July 26 to August 26. The flowers were either bagged prior to anthesis or caged. Staminate flowers of the cultivar SMR 58 were picked daily from August 14 to August 29, 1969. Each day from 7 a.m. to 4 p.m. six caged flowers were picked on the hour and nectar removed. Temperature and humidity data were recorded on campus and furnished by the agricultural engineering department. Solar radiation data was also recorded on campus and obtained from the Michigan Weather Service. Additional temperature data, wind speed, and precipitation were recorded at the NOAA station, Capital City Airport, Lansing, Michigan.

## Foraging Activity in Relation to Flower Age

Since it was shown that day-old pistillate flowers were capable of setting some fruit, the following studies were undertaken to determine if honey bees work day-old pistillate flowers in the field.

On August 19, 1968, 35 pistillate flowers (MSU 35G) one day prior to anthesis were bagged in 2.5 inch$^2$ organdy bags. The flowers remained bagged until 8:30 a.m. on August 21. At that time the bags were removed from the 35 one-day-old flowers, an additional 35 fresh pistillate flowers were tagged. All 70 flowers were exposed to foraging bees until 4:30 p.m., then clipped shut. All of the flowers were evaluated on September 10. The experiment was repeated on August 9, 1969. In addition, on August 27, 1969, one-day-old pistillate flowers were unbagged in the field for 10 min intervals during the afternoon to determine bee visitation.

### Sugar Concentration of Cucumber Nectar Throughout the Day with Bee Visitation

In order to see how nectar sugar concentration changes in the field throughout the day with bee visitation, honey bees were collected from cucumber flowers during the first two weeks of August, 1970. When a bee was observed working a cucumber flower, it was killed in a cyanide killing jar. Within five minutes after collection, the head of the bee was removed and its honey stomach contents squeezed onto the prism of the refractometer for analysis.

### Foraging Activity in Relation to Flower Sex

During 1969 in plots at East Lansing, in commercial fields at Mulliken in 1971, and at Eaton Rapids in 1974, foraging honey bees were followed as they visited staminate and pistillate flowers. The bees foraging pattern in relation to flower sex was recorded and compared to the staminate:pistillate flower ratio in the field.

Honey bee flight activity throughout the day in relation to flower sex was recorded in 1974 in plots at East Lansing and in commercial fields at Eaton Rapids and Mulliken. Each day 10 fresh flowers within visual sighting range were tagged, five staminate and five pistillate. Bees were counted on these flowers for alternating 10-min periods from 7 a.m. to 4 p.m. EST. Counts were made on 12 consecutive days during the period of August 13 to 24 at East Lansing, on seven days between July 25 through August 6 at Eaton Rapids, and on August 26, 29, and 30 at Mulliken.

## Distribution of Cucumber Pollen on the Honey Bee's Body

To determine the location of cucumber pollen on honey bees, pinned specimens from the summers of 1968 to 1970 were observed through a binocular microscope. The pollen was identified by making pollen slides and comparing them to reference slides previously made. A total of 236 honey bees were examined, 78 from the 1968 collection, 136 from the 1969 collection, and 22 from 1970. Eight body regions were checked for pollen grains: (1) face, (2) mouthparts, (3) neck, (4) thorax-underside, (5) prolegs, (6) mesolegs (7) metalegs, and (8) abdomen. If a large amount of pollen was found, it was noted. Since the 236 bees were collected from staminate flowers only, 100 bees were collected from staminate and pistillage flowers in 1971 to see if differences existed.

## The Number of Bee Visits Needed for Adequate Pollination

The number of honey bee visits to pistillate flowers were controlled to determine the effect of varying numbers of bee visits on fruit set, from July 28 through August 14, 1970, at the MSU research plots. Three plantings of the culitvar Piccadilly were made on May 23, June 6, and June 30 in rows three ft apart. Flower counts prior to the start of observations were taken daily to monitor the availability of pollen. No fruit set was allowed until flowering had reached at least the seventh node. Pistillate flowers were bagged one day prior to anthesis in 2.5 $inch^2$ organdy bags. The flowers were unbagged and one, five, ten, fifteen, or twenty separate bee visits were allowed on each flower between 10 a.m. and noon (EST). After the specific number of visits were completed, the flowers were clipped shut with paper clips, dated, and tagged. Fruit and flowers other than those observed were removed from the cucumber vines to prevent competition. On August 12, plants of the last planting were used and previous conditions were maintained.

## The Timing of Honey Bees as They Foraged on Staminate and Pistillate Cucumber Flowers

In 1968 honey bees working the cultivar Piccadilly were followed and timed with a stopwatch on staminate and pistillate flowers. Since this cultivar produced more staminate than pistillate flowers, more timings were taken from staminate than pistillate flowers.

The honey bees were timed at different periods during the day from July 22 to August 23, 1968. Time started when they began working the center of the flower for nectar and ended when they finished removing nectar from the flower. Often a honey bee will stop and groom itself after removing nectar from a flower before moving on to another. The time spent in grooming was not included in our timings. Also during 1974 as time allowed, bees were followed and timed with a stopwatch as they foraged on cucumbers to obtain a foraging rate. The number of staminate and pistillate flowers each bee visited was recorded as well as the total foraging time.

## The Size of the Foraging Area

To better understand the way bees moved cucumber pollen, individual honey bees were followed from flower to flower in 1969. The number of flower visits along with the length and width of the foraging area were recorded for each foraging trip. Observations started on July 31 and ended on August 19.

## The Movement of Cucumber Pollen by Honey Bees

To investigate the distance honey bees move cucumber pollen and the effect of different amounts of available pollen, six 240 ft long strips of gynoecious MSU 35G were planted on June 16, 1969. Each strip was 10 ft apart and contained two rows which were planted two ft apart. At the east end of each of these strips, a ten ft strip of monoecious SMR 58 was planted on June 12 to provide the pollen at various concentrations. The monoecious blocks were replicated twice in order of 0, 200, and 20 plants per block. The 240 ft long strips of MSU 35G were planted with a v-belt planter and the monoecious plants by hand. Because of poor germinating conditions, the plot layout was replanted on June 25 between the previous rows. The original plants were left for other experiments and destroyed as we finished with them (Figure 1). The first planting of monoecious plants was caged so as not to interfere with the pollen movement study. The first flowers appeared in the gynoecious strips on August 8 and the 12 strips were checked each morning for staminate flowers and any plants producing them were removed.

The cucumbers were harvested twice from the strips, when a majority of the cucumbers had started to yellow. Harvest dates were August 25 to 26 and September 15 to 18. The strips were divided into 10 ft sections and all cucumbers larger than two inches were harvested. Two adjacent colonies of honey bees provided pollination activity. For each 10 ft section, the number of plants and cucumbers were recorded. A minimum of 10 pickles of the first harvest and five the second were selected from each 10 ft section of each strip for seed counts. The seeds from 2,188 fruit were counted, 1025 from the first harvest and 1163 from the second. There was one monoecious plant for every 19.5 gynoecious plants.

To determine if the higher percentage of open, day-old pistillate flowers found at the end of the pollen movement strips farthest from the pollen source in 1969 was because of a lack of pollination, a total of 150 flowers were tagged on August 14, 15, and September 5.

Each day 25 red tags were numbered and placed on day-old pistillate flowers that were open and 25 white tags on day-old pistillate flowers that were closed. To further assess if pollinated flowers close up faster than nonpollinated, a total of 72 flowers were observed from July 16 to August 11, 1970. Each day one half of the caged flowers were hand pollinated and the other half were not. They were then compared throughout the day and again the next morning.

Because data from the 1969 pollen movement strips indicate (a) an inadequate pollen supply, and (b) the possibility that some staminate flowers in the gynoecious strips released pollen before they were found and removed; another approach was taken in 1972 to remove these sources of error. An area 24 ft x 250 ft was planted on June 10. The first 30 ft at the east end contained 20 rows of the monoecious cultivar SMR 15 to serve as the pollen source. Perpendicular to these rows were 16 rows of 713-5 x 71521 (100% gynoecious) each 220 ft long. The first staminate flowers appeared in the gynoecious block on July 24 and were destroyed as they appeared (Table 66). On August 15 all fruit and pistillate flowers were stripped from the vines and three colonies of bees were moved to the plots (Figure 2). Two of the colonies were placed adjacent to the gynoecious block between 111-130 ft from the pollen source.

The gynoecious block was divided into 10 ft sections and harvested on September 11 and 12. Seed counts were taken on 736 mature fruit, 32 from each section. There was one monoecious plant for every 9.7 gynoecious plants.

## The Movement of Fluorescent Powder

To further verify the results of 1969, the movement of fluorescent powder by the honey bee under various experimental designs was used in 1971. Fluorescein (Sodium Salt) was dusted on the petals of staminate flowers in the morning; later in the day flowers were sampled at 10 ft intervals from the dusted flowers. FLowers were then examined in a dark room with an ultraviolet light to check for traces of the bright yellow fluorescing powder. In the first set of trials, in a 25 x 50 ft plot at East Lansing, six SMR 58 flowers at the edge of the plot were dusted on three different days (August 9, 11, and 18). In the afternoon a total of 21 flowers were sampled at 10 ft intervals each day. Each 10 ft section contained three rows, therefore seven flowers were randomly picked from each row. Four strong nuclei of honey bees provided a high pollinator density.

In a second set of trials, two commercial pickle fields at Mulliken were used with both a circular and a rectangular sampling pattern. In each case flowers were sampled at 10 ft intervals from the dusted flowers. Depending upon the study, either 1, 6, 12, 18, or 50 flowers were dusted with the powder. On two days (August 21 and 24), multiple 30 x 70 ft strips, 200 yards apart were used, while on August 25 a 30 x 100 ft strip was used.

Circular designs were used on July 29 and August 5. The dusted flowers were observed for two hours on both days to see that they were being visited. Two native bees and five honey bees visited the dusted flowers on July 29 and 77 honey bees visited the six dusted flowers on August 5. Sample size was determined by size comparison of sampling areas. Commercially rented colonies of honey bees provided pollinator activity; eight colonies on July 29 and 40 the other days.

Additional studies in 1973 involved the movement of fluorescent powder by the bees at East Lansing. On June 19 a block of 12 rows, 30 inches apart and 110 ft long of the cultivar MSU 35G x 381G was planted. The dusting of flowers and sampling began on August 14.

## The Relationship of Foraging Activity to Fruit Set

The relationship of foraging activity to fruit set was monitored in an East Lansing plot during the summer of 1974, from the start of flowering until optimum mechanical harvesting conditions were reached (Figure 3). The plot consisted of seven rows, three ft apart and 72 ft long, of the culitvar Piccadilly (Med 1, Ferry Morse Co.) which were planted on June 27. Flowering began on August 6 and each days flowers were picked from the vines through August 12 to prevent fruit development. Daily observations of flowering, bee activity, and climatic conditions were recorded from August 13 to 24. The number of bees working five pistillate and five staminate flowers were counted as described previously. The five pistillate flowers being observed were tagged and the number of visits each received during the day recorded. All staminate and pistillate flowers in the plot were counted daily and the pistillate flowers tagged.

On August 27, three days after bee observations had ceased, yield counts were taken at destructive harvest time, but the fruit were left on the vines until maturity, for subsequent seed counts. The final destructive harvest was completed on September 22, 29 days after the bee observations had ceased. Adjacent to this plot was a similar sized block; cultivar MSU 9805 with 10% SMR 58. The two plots were separated by an 8 ft strip of bare soil. The second plot began flowering on August 8 and flowers were picked from the vines until August 13. The staminate and pistillate flowers were counted daily through August 24. The plot was destructively harvested on August 27 and the fruit were graded by size and shape.

## Changes in the Foraging Population with Additional Colonies in the Field

The effect of moving in colonies of bees on the activities of an existing foraging population was determined in the East Lansing plots during 1974. Four days after observations began on August 16, colonies #26 and #28 were moved from the university apiary to the plot perimeter at 6:15 a.m. The strength of the two colonies plus the size of the foraging population in the area were indicated earlier.

## Fruit Inhibition

A developing fruit on a cucumber vine inhibits the development of other fruit along the vine. In 1974 an attempt to assess the extent of inhibition and its implications in providing effective pollination was carried out. Fruit inhibition was assessed by determining the percentage of flowers that died and fruit that remained alive but stunted because of inhibition. Observations were made of the occurrence of individual flowers relative to other flowers on the same vine.

## RESULTS

### Climatic Conditions Affecting Anthesis and Anther Dehiscence

Observations showed that anthesis was not entirely dependent on time of day and temperature. On August 19 at 6 a.m., at 22° C in a field, with a heavy haze, flowers were closed and bees were trying to work them. When opened, 90% of the pistillate flowers contained many large beads of nectar and the staminate flower anthers had completely dehisced. By 6:30 the sun was beginning to break through the haze. At this time the flowers started to open slowly. On days when light conditions were normal, anthesis began at 15° C. Over the course of the sampling period, flowers were always tightly closed at temperatures from 9.5 - 15° C.

Microscopic examination of the anthers showed that 60% of staminate flowers started to dehisce at 16° C. At 17° C, 80% of the flowers were dehiscing, 92% at 18°, and 100% at 19°. Seventy flowers examined at temperatures between 12° and 15° C showed no signs of anther dehiscence. Periodic measurements of the expanding flower corollas as they opened on six mornings indicated that staminate flowers often opened at a faster rate than pistillate flowers (Figure 4). The faster opening rate was observed on August 5, 13, and 20 but not on August 12 (Table 1). Measurements excluding those of August 12 showed the average opening staminate flower to be 1.1 times larger than the pistillate flower. The staminate flower averaged

Figure 1.--Cucumber pollen movement strips, 1969.

Figure 2.--Cucumber pollen movement strip, 1972.

Figure 3.--Piccadilly plot in 1974 used to determine the relationship of foraging activity to fruit set in cucumbers.

Figure 4.--Staminate cucumber flowers opening at a faster rate than pistillate on August 5, 1969, at 7 a.m. EST, 18° C.

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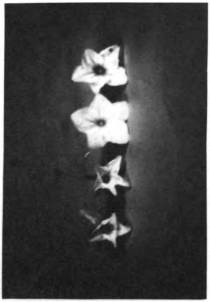

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TABLE 1.--The corolla expansion rate of staminate and pistillate cucumber flowers on the morning of anthesis, 1969.

| Date | Time | N | Average corolla size | | |
|---|---|---|---|---|---|
| | | | Staminate flowers | N | Pistillate flowers |
| July 30 | 7:00 | 30 | 27.7mm | 30 | 24.1mm |
| July 31 | 6:00 | 20 | 24.7mm | 20 | 23.1mm |
| August 12 | 6:00 | 20 | 14.9mm | 20 | 15.0mm |
| August 12 | 6:30 | 20 | 18.4mm | 20 | 20.4mm |
| August 14 | 6:00 | 20 | 27.9mm | 20 | 23.4mm |

26.8 mm compared to 23.5 for the pistillate. This difference does not seem great, but Collison (1973) found that pistillate flowers were 1.06 times larger when fully expanded. An attempt to correlate the factors inducing them to open faster on some mornings and not on others was made. These factors included the amount of sky cover, relative humidity, wind speed, temperature, low temperature during the night before anthesis, and percent of possible sunshine the previous day but no correlation could be ascertained.

## Duration of Pollen Viability and Stigmatic Receptivity

The early morning pollinations made at the time of anther dehiscence, prior to bee flight, showed that cucumber pollen was viable and stigmas receptive (Table 2). Mature fruit developed in 86.7% of the hand pollinations and the average seed count was 328 $\pm$ 36 seeds per fruit. All fruit were perfectly shaped and seed

TABLE 2.--Fruit development following hand pollinations made at the time of anther dehiscence in cucumbers.

| Date | Time | Temperature | Number pollinated | Cultivars | % fruit development |
|---|---|---|---|---|---|
| July 31, 1969 | 6:00 am | 17° C | 4 | SMR58 x Piccadilly | 100 |
| July 31, 1969 | 7:00 am | 19° C | 4 | SMR58 x Piccadilly | 100 |
| August 5, 1969 | 7:00 am | 16° C | 3 | SMR58 x Piccadilly | 100 |
| August 14, 1969 | 6:30 am | 19° C | 4 | SMR58 x MSU 35G | 50 |

counts ranged between 125 - 512 seeds. The seed counts indicated high pollen viability at the time of anther dehiscence.

The hand pollinations in 1968 showed that day-old pollen was not viable in the field. All 10 of the fresh pistillate flowers that were pollinated with day-old pollen failed to set fruit. In the controls that were pollinated with fresh pollen, 80.0% of the flowers developed into mature fruit and 20.0% of the ovaries were still alive after three days but were inhibited from growing by the presence of other developing fruit on the vine.

The first set of hand pollinations with day-old pollen, 30.3% set fruit in the greenhouse during 1969 (Chipper x 7006). However, most of the fruit were parthenocarpic and misshaped which indicated that in any assessment of effectiveness of pollination, fruit should be left on the vines to maturity and seed counts taken. In the second set of greenhouse pollinations (MSU 35G x Piccadilly) 10.9% of the pollinated flowers produced mature fruit with seeds from day-old pollen compared to 61.1% of the controls. The controls averaged 144 seeds per fruit and the experimental group 123. Seed counts ranged from 82-228 in fruit produced from day-old pollen. In the field, 2.0% of the morning pollinations with day-old pollen produced fruit compared to 85.7% for the controls. Only one fruit with 15 seeds developed in the day-old pollen group. The controls contained from 150 - 216 seeds with a mean of 183. In afternoon pollinations, 4.8% of the flowers pollinated with day-old pollen produced fruit. Seed counts ranged from 23 - 82 with a mean of 48 seeds per fruit. All were perfect in shape. The controls contained from 82 - 307 seeds with a mean of 151. Fruit developed on 73.3% of the controls and all were perfectly shaped.

Hand pollinations in 1968 showed that day-old pistillate flowers were capable of setting fruit with fresh pollen. Fruit developed on 83.3% of the pollinated flowers. Similar results were obtained in the greenhouse in 1969. Fruit developed on 43.2% of the day-old flowers pollinated with fresh pollen. Seed counts ranged from 26 - 237 seeds with a mean of 137. In the field 57.1% of the morning pollinations of day-old flowers produced fruit. Only two of the 28 fruit produced in the experimental group were misshapen. The fruit contained from 0 - 412 seeds with a mean of 141 seeds per fruit. Only one of the fruit contained no seeds. In the afternoon pollinations, 48.5% of the day-old pistillate flowers produced fruit containing 19 - 487 seeds with a mean of 190.

## Length of Time Flowers are Open in the Field

The counts of day-old flowers in the field indicated that fewer staminate flowers were open than pistillate (Table 3). From 30-76% (mean 47.8) of the pistillate flowers the day after anthesis were open compared to 2-26% (mean 13.3) of the staminate flowers. The east end of the pollen movement strips which were near the pollen source had a smaller percentage of flowers open than the west end, 38.3% compared to 56.6%. The number of open day-old flowers decreased slightly during the day. Day-old staminate flowers averaged 14.4% open in the morning and 11.6% in the afternoon. Pistillate flowers averaged 50.4% open in the morning and 44.5% in the afternoon.

TABLE 3.--Percentage of day-old staminate and pistillate cucumber flowers open in the pollen movement strips, 1969.

| Time | Date | % flowers open | | location | |
|---|---|---|---|---|---|
| | | Staminate | Pistillate | % east | % west |
| 9:00 am | 8/ 8 | 8 | 44 | | |
| | 8/13 | 26 | 52 | | |
| | 8/19 | 10 | -- | 33 | 54 |
| | 8/21 | 20 | -- | 60 | 76 |
| 10:00 am | 8/18 | 2 | -- | 30 | 51 |
| | 8/20 | 9 | -- | 40 | 62 |
| 10:30 am | 8/15 | 8 | 63 | | |
| 11:00 am | 8/10 | 23 | 51 | | |
| | 8/ 8 | -- | 40 | | |
| | 8/13 | 24 | 49 | | |
| Noon | 8/17 | 21 | 59 | | |
| 12:30 pm | 8/ 9 | 13 | 46 | | |
| 1:00 pm | 8/19 | 6 | -- | 33 | 52 |
| | 8/ 8 | -- | 37 | | |
| 3:00 pm | 8/15 | 8 | 57 | | |
| | 8/23 | 13 | -- | 33 | 49 |
| | 8/24 | 9 | -- | 39 | 52 |
| Overall | | | 48.3 | 38.3 | 56.6 |
| | | 13.3 | | 47.8 | |

N = 100

## Climatic Conditions Affecting Foraging Activity in the Field

The tagged flower technique of sampling bee populations within the field showed that in 1974 foraging began at 17.5° C; subsequent field observations supported this. A highly significant positive correlation was found between flight activity and temperature (Table 4). Of 6281 bees counted on tagged flowers, 85.6% of them were foraging at temperatures between 21.5 and 30° C. Only 3.8% of the bees were counted at temperatures below 21.50 C and 10.6% between 30.5 - 34.5° C. The average number of honey bee visits per sampling period was 1.9 at temperatures between 17 - 21° C, 10.0 at 21.5 - 25.5° C, 15.1 at 26 - 30° C and 8.9 for 30.5 - 34.5° C. Figure 5 indicates that foraging increased with temperature until 29° C, decreased between 29 - 32° C, and increased again from 32° - 34° C.

Conditions other than temperature must also have had some effect on the commencement of foraging, since observations varied from day to day and with location. Foraging was first observed on tagged flowers at 17.5° C in East Lansing (Table 5), at 19° C in Eaton Rapids (Table 6) and at 20.5° C in Mulliken (Table 7). Likewise, activity peaked at different temperatures, 29° C at East Lansing, 26° at Mulliken, and at 30.5° and 32.5° at Eaton Rapids.

On August 2, bee activity was first observed at 19.0° C (9:37° C, Eaton Rapids); August 1 (9:02, Eaton Rapdis), August 22 (8:07, East Lansing), and August 29 (10:00, Mulliken), at 19.5° C, August 21 (8:12, East Lansing), August 23 (8:22, East Lansing), and August 26 (8:59, Mulliken) at 20.5° C. At the other extreme on

TABLE 4.--Honey bee foraging activity in cucumbers as affected by temperature within the plant canopy, 1974.

| Temperature °C | Number of sampling periods | Total number of visits/ 10 flowers/ 10 min periods | Average number of visits per sampling period |
|---|---|---|---|
| 10.0 | 2 | 0 | 0.00 |
| 13.0 | 3 | 0 | 0.00 |
| 14.0 | 1 | 0 | 0.00 |
| 15.0 | 4 | 0 | 0.00 |
| 15.5 | 5 | 0 | 0.00 |
| 16.0 | 8 | 0 | 0.00 |
| 16.5 | 5 | 0 | 0.00 |
| 17.0 | 7 | 0 | 0.00 |
| 17.5 | 17 | 4 | 0.24 |
| 18.0 | 7 | 2 | 0.29 |
| 18.5 | 14 | 0 | 0.00 |
| 19.0 | 13 | 5 | 0.38 |
| 19.5 | 23 | 51 | 2.22 |
| 20.0 | 13 | 34 | 2.62 |
| 20.5 | 26 | 117 | 4.50 |
| 21.0 | 6 | 24 | 4.00 |
| 21.5 | 27 | 153 | 5.67 |
| 22.0 | 22 | 127 | 5.77 |
| 22.5 | 45 | 314 | 6.98 |
| 23.0 | 12 | 154 | 12.83 |
| 23.5 | 35 | 397 | 11.34 |
| 24.0 | 17 | 191 | 11.24 |
| 24.5 | 42 | 437 | 10.40 |
| 25.0 | 16 | 302 | 18.88 |
| 25.5 | 53 | 628 | 11.85 |
| 26.0 | 23 | 290 | 12.61 |
| 26.5 | 42 | 478 | 11.38 |
| 27.0 | 20 | 268 | 13.40 |
| 27.5 | 30 | 484 | 16.13 |
| 28.0 | 13 | 253 | 19.46 |
| 28.5 | 22 | 416 | 18.90 |
| 29.0 | 5 | 103 | 20.60 |
| 29.5 | 12 | 273 | 22.75 |
| 30.0 | 10 | 109 | 10.90 |
| 30.5 | 15 | 246 | 16.40 |
| 31.0 | 5 | 35 | 7.00 |
| 31.5 | 24 | 169 | 7.04 |
| 32.0 | 6 | 20 | 3.33 |
| 32.5 | 10 | 65 | 6.50 |
| 33.0 | 3 | 9 | 3.00 |
| 33.5 | 9 | 94 | 10.44 |
| 34.0 | 1 | 9 | 9.00 |
| 34.5 | 2 | 20 | 10.00 |
| TOTAL | 675 | 6281 | |
| r = 0.3847*** | t = 10.8 | df = 673 | |

*** = significant at the .001 probability level.

Figure 5.--Honey bee foraging activity in cucumbers in relation to temperature, 1974.

Foraging. Activity In Relation To Temperature

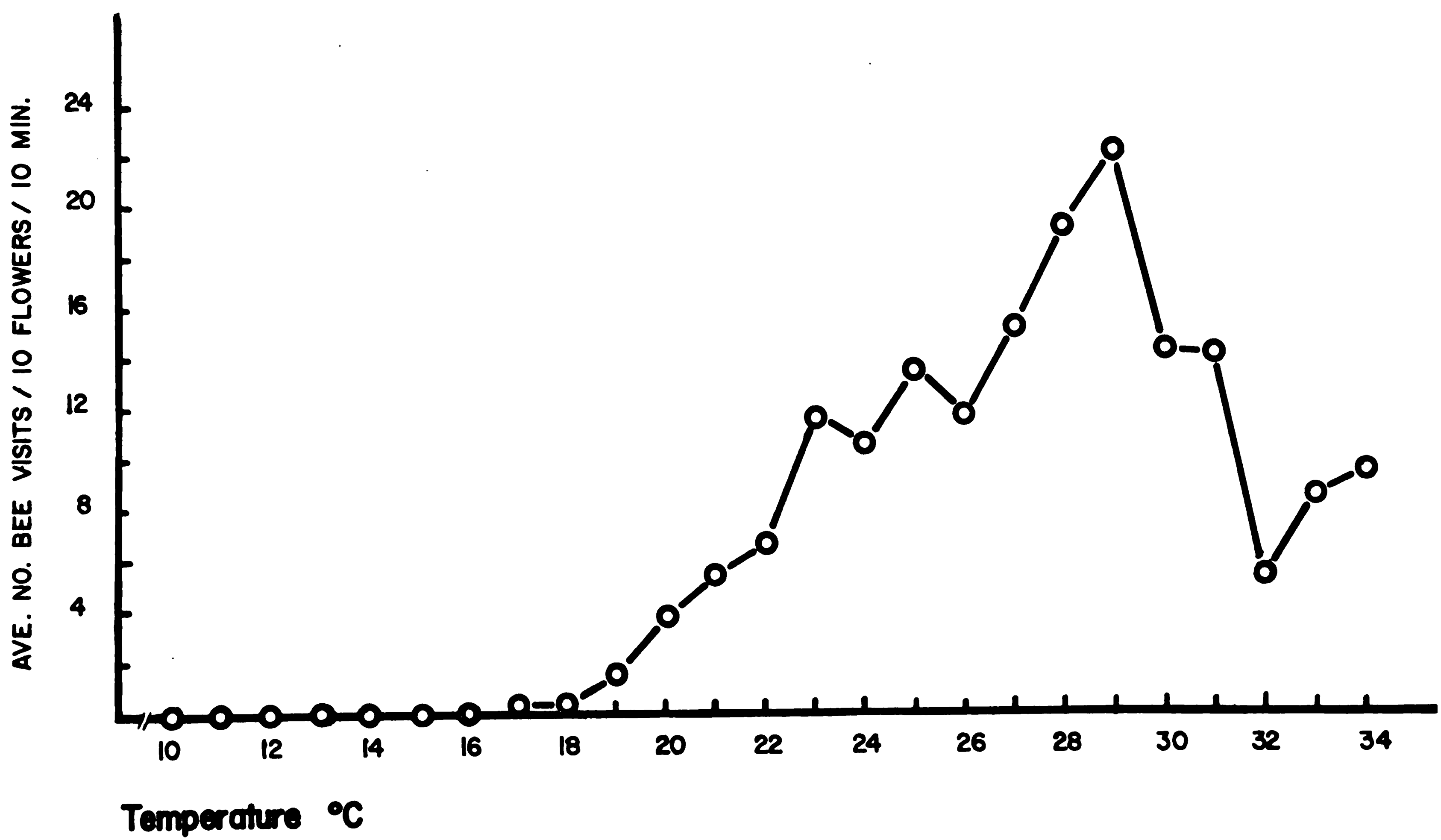


TABLE 5.--Honey bee foraging activity in cucumbers as affected by temperature within the plant canopy, East Lansing, 1974.

| Temperature °C | Number of sampling periods | Total number of visits/ 10 flowers/ 10 min periods | Average number of visits per sampling period |
|---|---|---|---|
| 15.5 | 3 | 0 | 0.00 |
| 16.0 | 3 | 0 | 0.00 |
| 16.5 | 2 | 0 | 0.00 |
| 17.0 | 3 | 0 | 0.00 |
| 17.5 | 7 | 4 | 0.57 |
| 18.0 | 5 | 2 | 0.40 |
| 18.5 | 5 | 0 | 0.00 |
| 19.0 | 4 | 1 | 0.25 |
| 19.5 | 12 | 41 | 3.42 |
| 20.0 | 6 | 25 | 4.17 |
| 20.5 | 15 | 108 | 7.20 |
| 21.0 | 2 | 9 | 4.50 |
| 21.5 | 15 | 98 | 6.53 |
| 22.0 | 7 | 61 | 8.71 |
| 22.5 | 23 | 210 | 9.13 |
| 23.0 | 6 | 89 | 14.83 |
| 23.5 | 18 | 218 | 12.11 |
| 24.0 | 10 | 138 | 13.80 |
| 24.5 | 12 | 177 | 14.75 |
| 25.0 | 9 | 199 | 22.11 |
| 25.5 | 23 | 328 | 14.26 |
| 26.0 | 8 | 155 | 19.38 |
| 26.5 | 23 | 282 | 12.26 |
| 27.0 | 6 | 96 | 16.00 |
| 27.5 | 19 | 324 | 17.05 |
| 28.0 | 8 | 191 | 23.88 |
| 28.5 | 13 | 304 | 23.38 |
| 29.0 | 3 | 99 | 33.00 |
| 29.5 | 9 | 192 | 21.33 |
| 30.0 | 4 | 72 | 18.00 |
| 30.5 | 10 | 211 | 21.10 |
| 31.0 | 1 | 13 | 13.00 |
| 31.5 | 18 | 142 | 7.89 |
| 32.0 | 4 | 19 | 4.75 |
| 32.5 | 5 | 34 | 6.80 |
| 33.0 | 1 | 8 | 8.00 |
| 33.5 | 1 | 6 | 6.00 |
| 34.0 | 1 | 9 | 9.00 |
| TOTAL | 324 | 3865 | |
| r = 0.4077*** | | t = 7.99 | df = 322 |

***Significant at the .001 probability level.

TABLE 6.--Honey bee foraging activity in cucumbers as affected by temperature within the plant canopy, Eaton Rapids, 1974.

| Temperature °C | Number of sampling periods | Total number of visits/ 10 flowers/ 10 min periods | Average number of visits per sampling period |
|---|---|---|---|
| 13.0 | 1 | 0 | 0.00 |
| 14.0 | 1 | 0 | 0.00 |
| 15.0 | 2 | 0 | 0.00 |
| 16.0 | 1 | 0 | 0.00 |
| 16.5 | 3 | 0 | 0.00 |
| 17.5 | 4 | 0 | 0.00 |
| 18.5 | 5 | 0 | 0.00 |
| 19.0 | 7 | 4 | 0.57 |
| 19.5 | 7 | 10 | 1.43 |
| 20.0 | 7 | 9 | 1.29 |
| 20.5 | 3 | 8 | 2.67 |
| 21.0 | 2 | 15 | 7.50 |
| 21.5 | 6 | 55 | 9.17 |
| 22.0 | 7 | 57 | 8.14 |
| 22.5 | 8 | 77 | 9.62 |
| 23.0 | 4 | 61 | 15.25 |
| 23.5 | 13 | 175 | 13.46 |
| 24.0 | 5 | 50 | 10.00 |
| 24.5 | 18 | 245 | 13.60 |
| 25.0 | 5 | 96 | 19.20 |
| 25.5 | 16 | 258 | 16.12 |
| 26.0 | 5 | 90 | 18.00 |
| 26.5 | 13 | 179 | 13.77 |
| 27.0 | 8 | 153 | 19.12 |
| 27.5 | 11 | 160 | 14.55 |
| 28.0 | 3 | 58 | 19.33 |
| 28.5 | 5 | 101 | 20.20 |
| 29.5 | 3 | 81 | 27.00 |
| 30.0 | 2 | 36 | 18.00 |
| 30.5 | 1 | 28 | 28.00 |
| 31.0 | 2 | 20 | 10.00 |
| 31.5 | 2 | 22 | 11.00 |
| 32.5 | 1 | 28 | 28.00 |
| 33.5 | 6 | 85 | 14.17 |
| 34.5 | 2 | 20 | 10.00 |
| TOTAL | 189 | 2181 | |

$r = 0.5232$*** $t = 8.44$ $df = 187$

***Significant at the .001 probability level.

TABLE 7.--Honey bee foraging activity in cucumbers as affected by temperature within the plant canopy, Mulliken, 1974.

| Temperature °C | Number of sampling periods | Total number of visits/ 10 flowers/ 10 min periods | Average number of visits per sampling period |
|---|---|---|---|
| 10.0 | 2 | 0 | 0.00 |
| 13.0 | 2 | 0 | 0.00 |
| 15.0 | 2 | 0 | 0.00 |
| 15.5 | 2 | 0 | 0.00 |
| 16.0 | 4 | 0 | 0.00 |
| 17.0 | 4 | 0 | 0.00 |
| 17.5 | 6 | 0 | 0.00 |
| 18.0 | 2 | 0 | 0.00 |
| 18.5 | 4 | 0 | 0.00 |
| 19.0 | 2 | 0 | 0.00 |
| 19.5 | 4 | 0 | 0.00 |
| 20.5 | 8 | 1 | 0.12 |
| 21.0 | 2 | 0 | 0.00 |
| 21.5 | 6 | 0 | 0.00 |
| 22.0 | 8 | 9 | 1.12 |
| 22.5 | 14 | 27 | 1.93 |
| 23.0 | 2 | 4 | 2.00 |
| 23.5 | 4 | 4 | 1.00 |
| 24.0 | 2 | 3 | 1.50 |
| 24.5 | 12 | 15 | 1.25 |
| 25.0 | 2 | 7 | 3.50 |
| 25.5 | 14 | 42 | 3.00 |
| 26.0 | 10 | 45 | 4.50 |
| 26.5 | 6 | 17 | 2.83 |
| 27.0 | 6 | 19 | 3.17 |
| 28.0 | 2 | 4 | 2.00 |
| 28.5 | 4 | 11 | 2.75 |
| 29.0 | 2 | 4 | 2.00 |
| 30.0 | 4 | 1 | 0.25 |
| 30.5 | 4 | 7 | 1.75 |
| 31.0 | 2 | 2 | 1.00 |
| 31.5 | 4 | 5 | 1.25 |
| 32.0 | 2 | 1 | 0.50 |
| 32.5 | 4 | 3 | 0.75 |
| 33.0 | 2 | 1 | 0.50 |
| 33.5 | 2 | 3 | 1.50 |
| TOTAL | 162 | 235 | |

$r = 0.2633^{***}$ $t = 3.46$ df = 160

*** = Significant at the .001 probability level.

August 6 at Eaton Rapids the first bee observed in the field was at 16.5° C at 8:35 a.m. On August 5, a few bees were observed flying in the field between 14° and 15° C. At this time the flowers for the day had not undergone anthesis, so the bees were working the flowers of the previous day. Possibly this unusual behavior could be explained by the fact that bad weather kept the bees in the hive the two previous days.

Highly significant positive correlations between temperature and foraging activity were found at all three locations sampled, East Lansing, Mulliken, and Eaton Rapids. Between 21.5 - 30.0° C, 83.7% of the flight activity occurred in East Lansing, 88.6% in Eaton Rapids, and 90.2% at Mulliken. In East Lansing 4.9% of the field population was foraging at 21° C and below, compared to 2.1% at Eaton Rapids, and 0.4% at Mulliken. At temperatures over 30° C, 11.4% of the field population was foraging at East Lansing, 9.3% at Eaton Rapids, and 9.4% at Mulliken. Overall, at the three locations, there was 14.8% association between foraging activity and temperature within the plant canopy as indicated by the correlation coefficient. Comparison of locations showed from 6.9% - 27.4% association between the two variables, Mulliken and Eaton Rapids respectively. East Lansing was close to the overall average at 16.6%. During the 12 day sampling period at East Lansing, hourly average temperatures ranged between 15.7 - 33.3° C, with a mean of 24.8° C. Bee visits/10 flowers/hour during the same time ranged from 0 - 115 with a mean of 35.8.

A highly significant positive correlation was also found between solar radiation and foraging activity in East Lansing (Table 8).

TABLE 8.--Honey bee foraging activity in cucumbers as affected by solar radiation, East Lansing, 1974.

| Solar radiation cal/cm$^2$/h | Number of sampling periods | Total number of visits/ 10 flowers/30 min | Average number of visits per sampling period |
|---|---|---|---|
| 0 - 5 | 2 | 0 | 0.00 |
| 6 - 10 | 5 | 8 | 1.60 |
| 11 - 15 | 4 | 44 | 11.00 |
| 16 - 20 | 6 | 96 | 16.00 |
| 21 - 25 | 6 | 93 | 15.50 |
| 26 - 30 | 5 | 108 | 21.60 |
| 31 - 35 | 7 | 203 | 29.00 |
| 36 - 40 | 10 | 259 | 25.90 |
| 41 - 45 | 16 | 721 | 45.06 |
| 46 - 50 | 9 | 308 | 34.22 |
| 51 - 55 | 10 | 523 | 52.30 |
| 56 - 60 | 9 | 424 | 47.11 |
| 61 - 65 | 10 | 577 | 57.70 |
| 66 - 70 | 8 | 448 | 56.00 |
| 71 - 75 | 1 | 53 | 53.00 |
| Overall | 108 | 3865 | 35.79 |
| r = 0.5425*** | t = 6.68 | df = 106 | |

*** = Significant at .001 probability level.

From 2.4 - 71.4 cal/cm$^2$/h were recorded with a mean of 42.1 cal/cm$^2$/h. Foraging activity was first observed in an hourly period when 10.8 cal/cm$^2$ were recorded. There were six hourly periods receiving from 2.4 - 9.6 cal/cm$^2$ in which no activity was observed. However, 10.8 cal/cm$^2$ cannot be considered a minimum threshold since no activity was recorded at values of 19.2, 20.4, 21.6, 33.6, and 36.0 cal/cm$^2$ on six different occasions. Overall, there was 29.4% association between solar radiation and foraging activity. Analysis indicated that there was a highly significant positive correlation between temperature and solar radiation, r = .6644 (significant at the .001 probability level) which indicates 44.1% association between the two variables.

A highly significant negative correlation was found between foraging activity and relative humidity in East Lansing (Table 9).

TABLE 9.--Honey bee foraging activity in cucumbers as affected by relative humidity, East Lansing, 1974.

| % Humidity | Number of sampling periods | Total number of visits/ 10 flowers/30 min | Average number of visits per sampling period |
|---|---|---|---|
| 90 - 100 | 7 | 48 | 6.86 |
| 80 - 89 | 10 | 205 | 20.50 |
| 70 - 79 | 12 | 324 | 27.00 |
| 60 - 69 | 16 | 603 | 37.69 |
| 50 - 59 | 20 | 960 | 48.00 |
| 40 - 49 | 29 | 1372 | 47.31 |
| 30 - 39 | 14 | 353 | 25.21 |
| Overall | 108 | 3865 | 35.79 |
| r = -.2630** | t = 2.82 | df = 106 | |

** = Significant at .01 probability level.

Relative humidity during the study ranged from 33 to 96%, with a mean of 58.4. Of 108 sampling periods, 12 had no foraging activity. During these periods the relative humidity ranged from 65 - 96%. Overall, there was 6.9% association between relative humidity and foraging activity. Highly significant negative correlations were also found between temperature and humidity, solar radiation and humidity;

r = -.7841 (significant at the .001 probability level), r = -.7400 (significant at the .001 probability level) respectively. Therefore, there was 61.5% association between temperature and humidity and 54.8% association between solar radiation and humidity.

Wind speed during observation periods varied from 0.0 to 14.9 mph in East Lansing with a mean of 8.1 mph. A significant positive correlation was found between foraging activity and wind speed (Table 10). No activity was observed at wind speeds ranging from 0 to 9.2 mph during some of the sampling periods. Overall, there was 4.2% association between foraging activity and wind speed. A highly significant positive correlation was found between temperature and wind speed, r = .4341 (significant at the .001 probability level), which indicated 18.8% association between the two variables. No correlation was found between solar radiation and wind speed, r = $.1050^{N.S.}$. A highly significant negative correlation was found between humidity and wind speed, r = -.3726 (significant at the .001 probability level) which indicated 13.9% association.

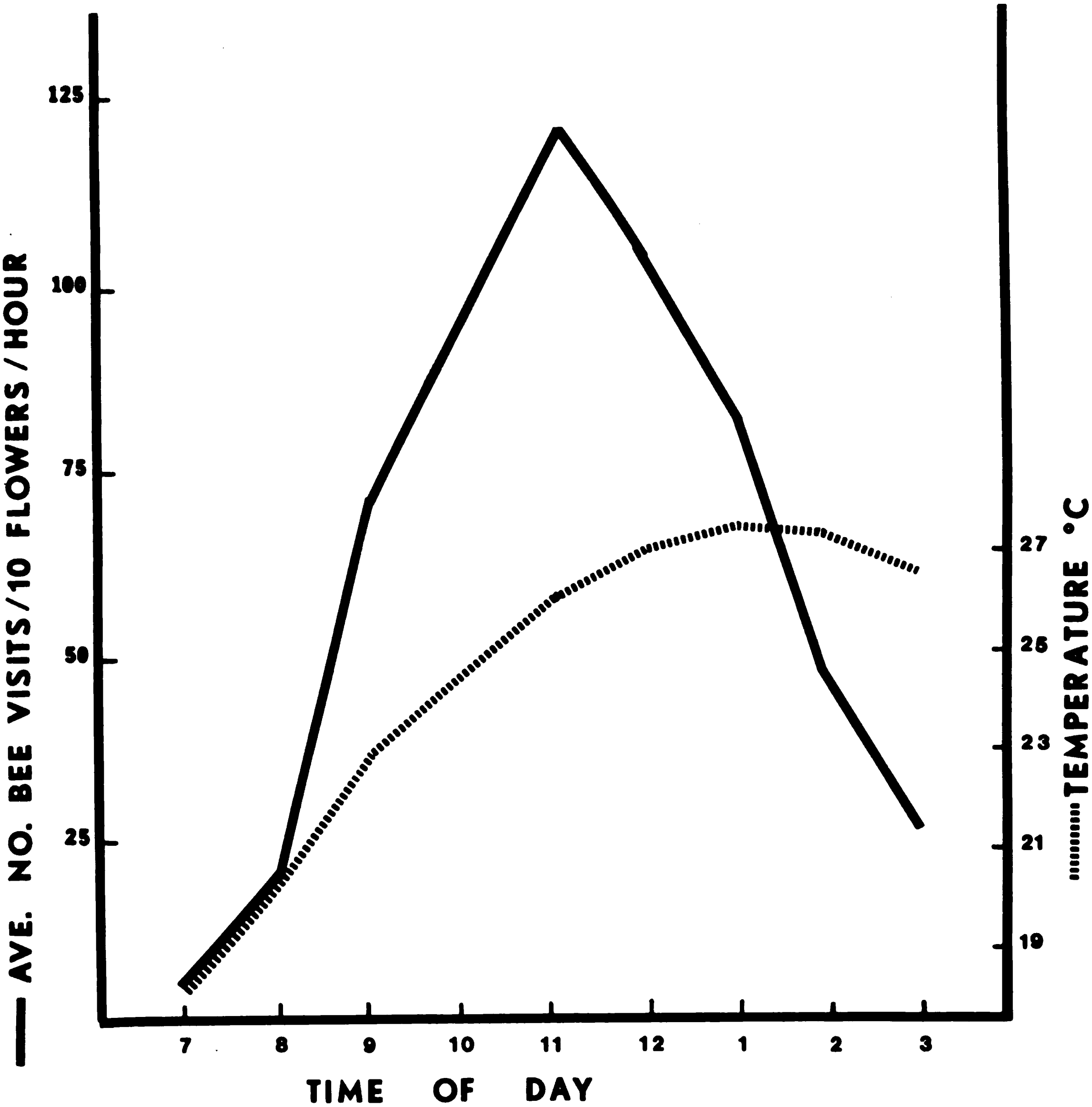
Overall, the pattern of bee visits throughout the day in 1974 produced a normal distribution pattern centered around 11 - 12 a.m. EST (Figure 6), with 82.3% of all bee visits occuring between 9 a.m. and 2 p.m. Only 4.3% of the visits occurred before 9 a.m. and 13.4% after 2 p.m. At East Lansing 82.4% of all bee visits occurred from 9 a.m. to 2 p.m., compared to 83.4% at Eaton Rapids and 73.6% at Mulliken for the same time period. Prior to 9 a.m., only 4.9% of the visits occurred at East Lansing, 3.4% at Eaton Rapids, and 0.0% at

TABLE 10.--Honey bee foraging activity in cucumbers as affected by wind speed, East Lansing, 1974.

| Wind speed mph | Number of sampling periods | Total number of visits/ 10 flowers/30 min | Average number of visits per sampling period |
|---|---|---|---|
| 0.0 | 5 | 31 | 6.20 |
| 3.5 | 2 | 50 | 25.00 |
| 4.6 | 14 | 359 | 25.64 |
| 5.8 | 9 | 298 | 33.11 |
| 6.9 | 12 | 484 | 41.33 |
| 8.1 | 14 | 508 | 36.29 |
| 9.2 | 18 | 794 | 44.11 |
| 10.4 | 12 | 609 | 50.75 |
| 11.5 | 17 | 644 | 37.88 |
| 12.7 | 2 | 24 | 12.00 |
| 13.8 | 2 | 37 | 18.50 |
| 14.9 | 1 | 27 | 27.00 |
| TOTAL | 108 | 3865 | |
| r = .2039* | t = 2.15 | df = 106 | |

* = Significant at the .05 probability level.

Figure 6.--Honey bee flight activity in cucumbers throughout the day and average hourly temperature, 1974.

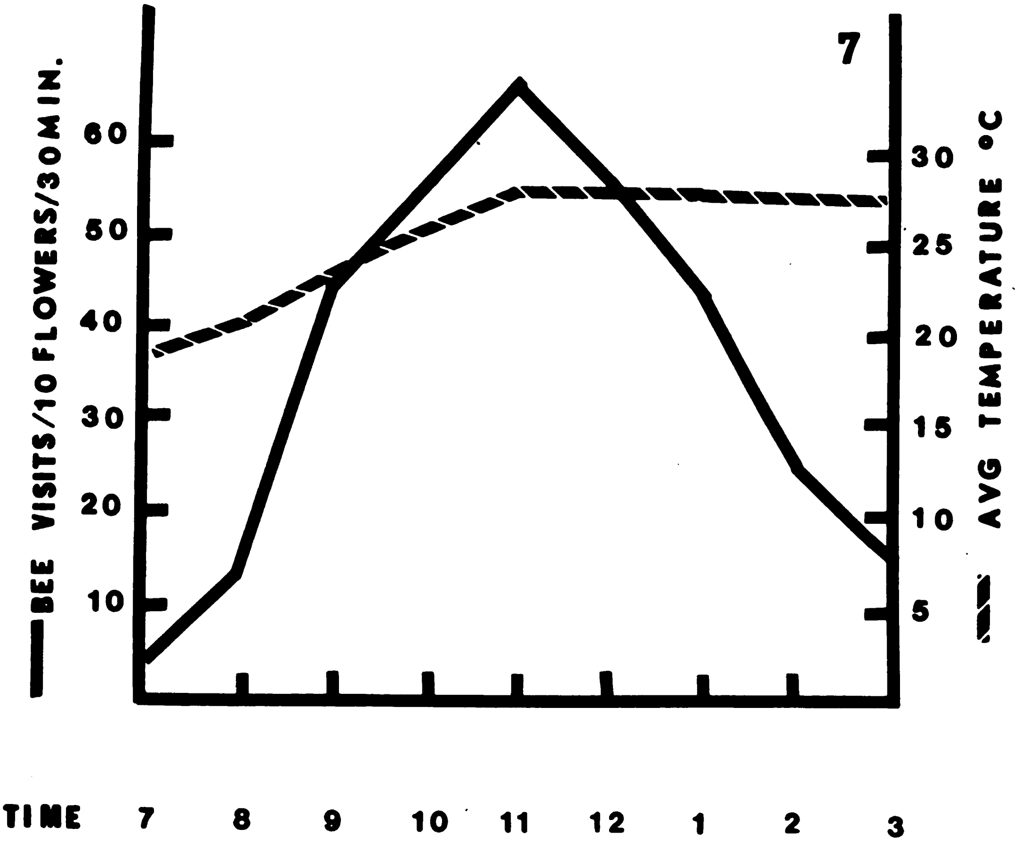

125
100
75
50
25
AVE. NO. BEE VISITS/10 FLOWERS/HOUR
27
25
23
21
19
TEMPERATURE °C
7
8
9
10
11
12
1
2
3
TIME OF DAY

Mulliken. After 2 p.m., 12.7% of the total visits occurred at East Lansing compared to 13.2% at Eaton Rapids, and 26.4% at Mulliken. Overall, as bee activity increased until noon, the average hourly temperature also increased until 2 p.m., rising from 18.0 - 27.5° C, then decreasing slightly to 27.4° and 26.6° C (Figure 6). At East Lansing the average foraging pattern throughout the day also produced a normal distribution pattern centered around 11 - 12 a.m. EST (Figure 7). During the day, the average temperature increased from 18.7 - 27.8° C by 2 p.m., then decreased to 27.7° C and finally to 27.1° (Figure 7). The average solar radiation increased throughout the day until 1 p.m., going from a low of 13.8 cal/cm$^2$ to a high of 55.7, then decreased during the rest of the afternoon down to 38.1 (Figure 8). The average relative humidity decreased during the day starting at a high of 85.1% and reaching a low of 43.0% at 3 p.m. (Figure 9). The average wind speed increased during the day until 5 p.m., going from 5.3 - 9.9 mph (Figure 10). Foraging activity and temperature changes throughout the day were similar at Eaton Rapids (Table 11) and at Mulliken (Table 12).

Average daily foraging activity at East Lansing fluctuated significantly in relation to environmental conditions. The flowers received from 10,739 to 94,478 bee visits per day (Table 13). However, values for August 13 - 16 should be considered separately since additional bees were moved in on August 16. Total visits between August 13 - 16 varied between 10,739 and 24,604. After the colonies were moved in, the visits ranged between 35,828 and 94,478. Comparison of flight activity on August 13 (Figure 11) and August 14

Figure 7.--Honey bee flight activity in cucumbers throughout the day and average hourly temperature in East Lansing.

Figure 8.--Honey bee flight activity in cucumbers throughout the day and average hourly solar radiation in East Lansing.


7
BEE VISITS/10 FLOWERS/30 MIN.
60
50
40
30
20
10
AVG TEMPERATURE °C
30
25
20
15
10
5
TIME 7 8 9 10 11 12 1 2 3

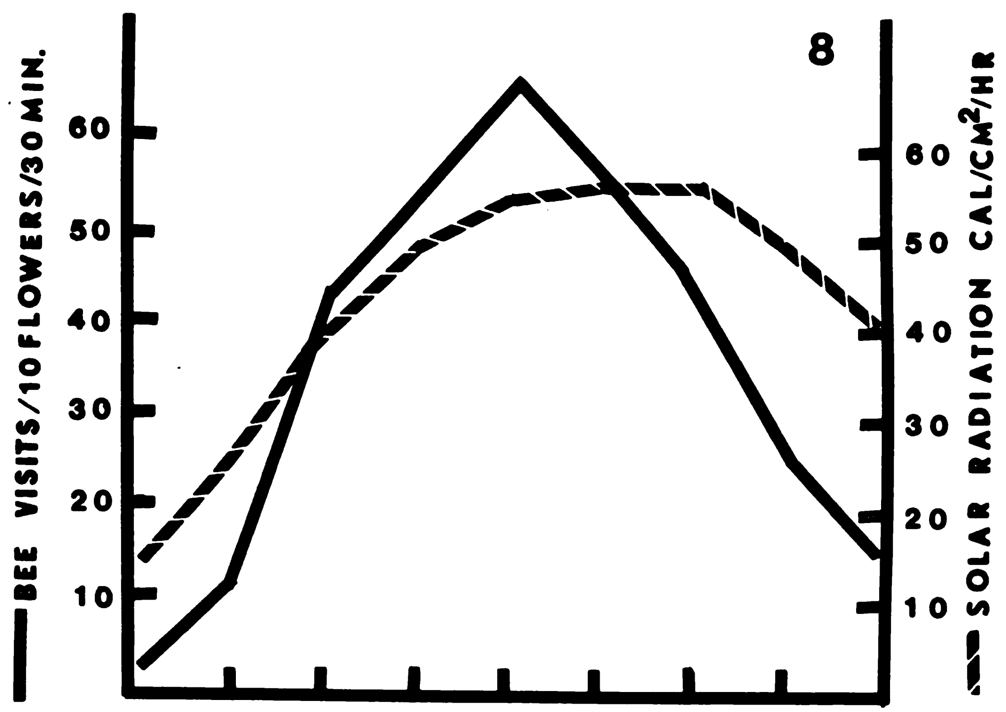
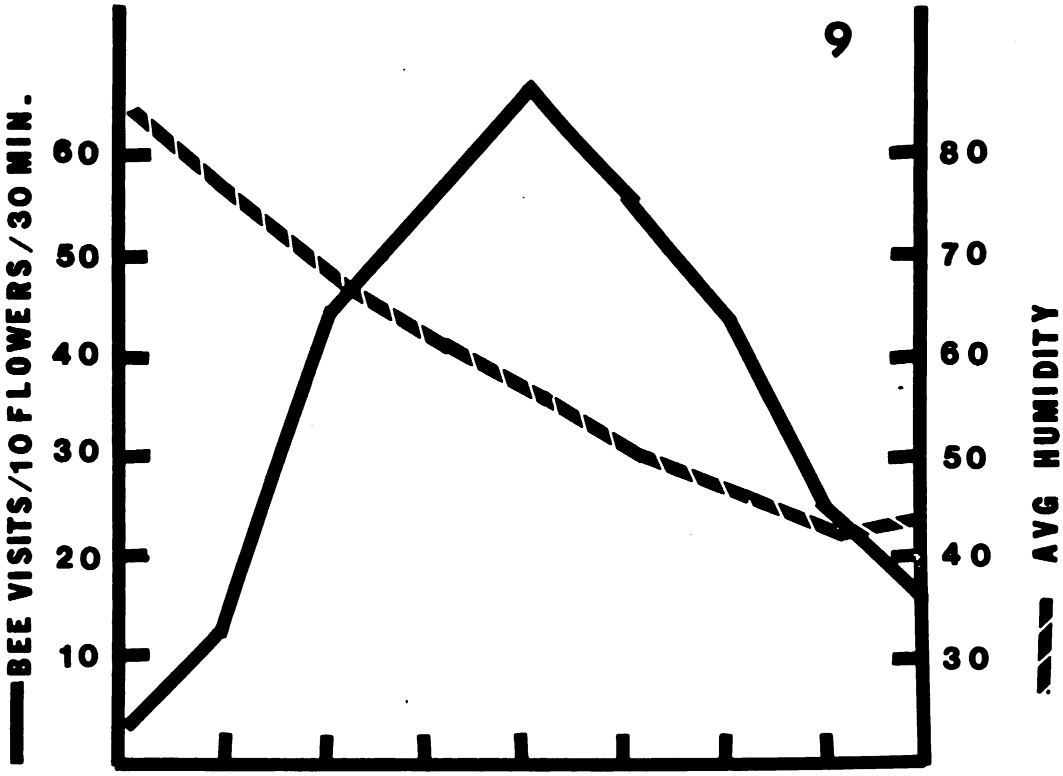

8
BEE VISITS/10 FLOWERS/30 MIN.
60
50
40
30
20
10
SOLAR RADIATION CAL/CM²/HR
60
50
40
30
20
10

Figure 9.--Honey bee flight activity in cucumbers throughout the day and average hourly relative humidity in East Lansing.

Figure 10.--Honey bee flight activity in cucumbers throughout the day and average hourly wind speed in East Lansing.




TIME 7 8 9 10 11 12 1 2 3

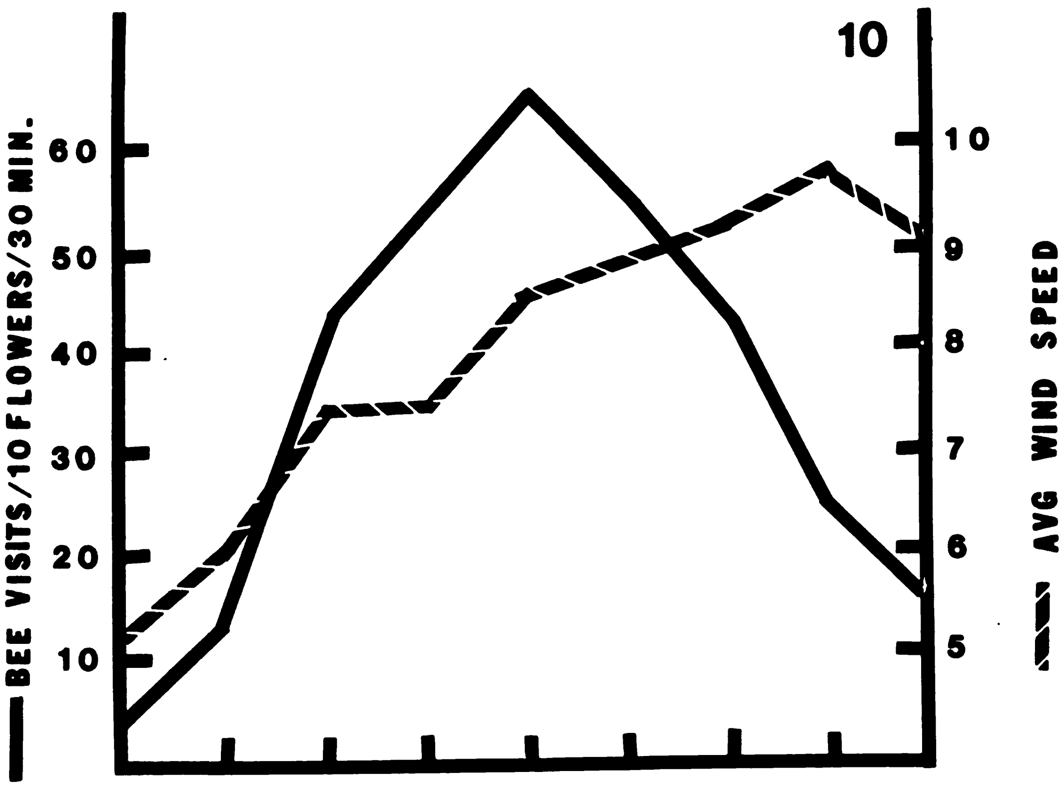


TABLE 11.--Honey bee foraging activity in cucumbers throughout the day, Eaton Rapids, 1974.

| Time | Avg. number of visits/ 10 flowers/day | Mean temperature | Range of temperature |
|---|---|---|---|
| 7:00 - 7:10 | 0.3 | 17.4 ± 1.1 | 13.0 - 21.5 |
| 7:20 - 7:30 | 1.0 | 17.8 ± .9 | 14.0 - 21.5 |
| 7:40 - 7:50 | 0.6 | 18.7 ± .8 | 15.0 - 22.0 |
| 8:00 - 8:10 | 2.0 | 19.7 ± .7 | 16.5 - 22.5 |
| 8:20 - 8:30 | 3.1 | 20.4 ± 1.0 | 17.5 - 24.5 |
| 8:40 - 8:50 | 3.7 | 21.1 ± 1.0 | 18.5 - 25.5 |
| 9:00 - 9:10 | 8.4 | 22.0 ± .9 | 19.5 - 26.5 |
| 9:20 - 9:30 | 9.6 | 22.6 ± 1.0 | 19.5 - 27.5 |
| 9:40 - 9:50 | 15.6 | 23.3 ± 1.1 | 19.5 - 28.5 |
| 10:00 - 10:10 | 18.1 | 23.9 ± 1.2 | 19.0 - 29.5 |
| 10:20 - 10:30 | 19.4 | 24.5 ± 1.3 | 19.0 - 29.5 |
| 10:40 - 10:50 | 17.6 | 24.9 ± 1.3 | 20.0 - 30.5 |
| 11:00 - 11:10 | 20.4 | 25.7 ± 1.5 | 20.5 - 32.5 |
| 11:20 - 11:30 | 18.9 | 27.2 ± 1.3 | 24.0 - 33.5 |
| 11:40 - 11:50 | 23.9 | 26.1 ± 0.8 | 23.5 - 29.5 |
| 12:00 - 12:10 | 17.1 | 26.7 ± 1.0 | 23.5 - 31.5 |
| 12:20 - 12:30 | 23.1 | 27.0 ± 0.7 | 24.5 - 30.0 |
| 12:40 - 12:50 | 21.1 | 27.1 ± 0.8 | 24.5 - 31.0 |
| 1:00 - 1:10 | 20.3 | 27.0 ± 1.2 | 23.5 - 33.5 |
| 1:20 - 1:30 | 15.6 | 26.6 ± 0.9 | 23.5 - 31.0 |
| 1:40 - 1:50 | 10.7 | 27.1 ± 1.3 | 23.5 - 34.5 |
| 2:00 - 2:10 | 10.1 | 27.1 ± 1.4 | 23.0 - 34.5 |
| 2:20 - 2:30 | 6.0 | 26.6 ± 1.3 | 22.5 - 33.5 |
| 2:40 - 2:50 | 9.3 | 25.9 ± 1.4 | 22.0 - 33.5 |
| 3:00 - 3:10 | 6.4 | 26.3 ± 1.4 | 22.0 - 33.5 |
| 3:20 - 3:30 | 4.4 | 25.8 ± 1.4 | 22.5 - 33.5 |
| 3:40 - 3:50 | 4.7 | 25.4 ± 1.1 | 22.5 - 31.5 |

2181 bee visits/10 flowers/7 days
July 25, 26, 29
Aug 1, 2, 5, 6

TABLE 12.--Honey bee foraging activity in cucumbers throughout the day, Mulliken, 1974.

| Time | Avg. number of visits/ 10 flowers/day | Mean temperature | Range of temperature |
|---|---|---|---|
| 7:00 - 7:10 | 0.0 | 14.2 ± 2.2 | 10.0 - 17.5 |
| 7:20 - 7:30 | 0.0 | 15.7 ± 1.4 | 13.0 - 18.0 |
| 7:40 - 7:50 | 0.0 | 17.0 ± 0.9 | 15.5 - 18.5 |
| 8:00 - 8:10 | 0.0 | 18.0 ± 1.3 | 16.0 - 20.5 |
| 8:20 - 8:30 | 0.0 | 18.7 ± 1.0 | 17.0 - 20.5 |
| 8:40 - 8:50 | 0.0 | 19.3 ± 1.2 | 17.5 - 21.5 |
| 9:00 - 9:10 | 0.3 | 21.2 ± 1.7 | 19.5 - 24.5 |
| 9:20 - 9:30 | 1.7 | 21.8 ± 1.3 | 20.5 - 24.5 |
| 9:40 - 9:50 | 0.0 | 22.8 ± 1.4 | 21.0 - 25.5 |
| 10:00 - 10:10 | 0.3 | 23.2 ± 1.4 | 21.5 - 26.0 |
| 10:20 - 10:30 | 0.7 | 23.5 ± 1.8 | 21.5 - 27.0 |
| 10:40 - 10:50 | 5.3 | 24.2 ± 1.9 | 22.0 - 28.0 |
| 11:00 - 11:10 | 4.3 | 24.5 ± 2.0 | 22.5 - 28.5 |
| 11:20 - 11:30 | 3.3 | 25.2 ± 1.8 | 22.5 - 28.5 |
| 11:40 - 11:50 | 9.7 | 26.2 ± 1.9 | 22.5 - 30.5 |
| 12:00 - 12:10 | 6.7 | 26.7 ± 2.0 | 23.5 - 30.5 |
| 12:20 - 12:30 | 5.3 | 26.2 ± 1.9 | 22.5 - 29.0 |
| 12:40 - 12:50 | 4.7 | 26.8 ± 2.4 | 22.5 - 31.0 |
| 1:00 - 1:10 | 6.7 | 26.8 ± 2.5 | 23.0 - 31.5 |
| 1:20 - 1:30 | 2.0 | 28.0 ± 2.0 | 25.5 - 32.0 |
| 1:40 - 1:50 | 6.7 | 28.3 ± 2.6 | 25.5 - 33.5 |
| 2:00 - 2:10 | 5.3 | 28.5 ± 2.0 | 26.5 - 32.5 |
| 2:20 - 2:30 | 6.0 | 28.2 ± 2.4 | 25.5 - 33.0 |
| 2:40 - 2:50 | 3.0 | 27.8 ± 2.3 | 25.5 - 32.5 |
| 3:00 - 3:10 | 2.3 | 26.7 ± 2.4 | 23.5 - 31.5 |
| 3:20 - 3:30 | 1.0 | 26.3 ± 1.8 | 24.5 - 30.0 |
| 3:40 - 3:50 | 3.0 | 26.2 ± 1.9 | 24.0 - 30.0 |

235 bee visits/10 flowers/3 days August 26, 29, and 30.

TABLE 13.--Foraging activity of honey bees in cucumbers in relation to climatic conditions, East Lansing, 1974.

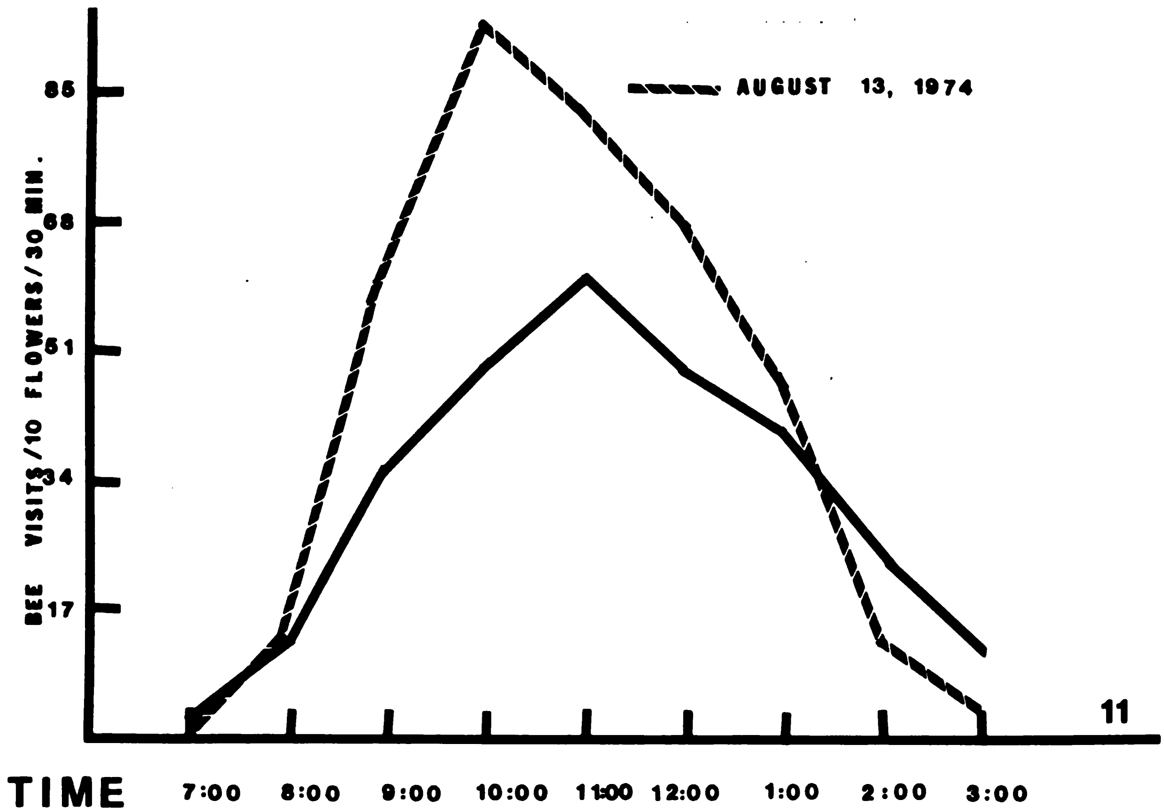
| Date | Total flower visits/day | Mean temperature | Temperature range | Mean solar radiation | Mean relative humidity | Mean wind speed |
|---|---|---|---|---|---|---|
| August 13 | 19,126 | 25.1 ± .4 | 19.0 - 28.0 | 45.2 ± 5.89 | 70.4 ± 5.47 | 7.79 ± 1.20 |
| August 14 | 10,739 | 22.9 ± .6 | 17.5 - 26.5 | 52.1 ± 6.57 | 55.7 ± 5.92 | 4.86 ± .82 |
| August 15 | 17,297 | 24.0 ± .6 | 17.0 - 27.5 | 50.9 ± 5.12 | 53.4 ± 5.09 | 5.88 ± 1.18 |
| August 16 | 24,604 | 24.3 ± .5 | 19.5 - 28.5 | 26.9 ± 5.02 | 64.7 ± 4.12 | 10.50 ± .97 |
| August 17 | 35,828 | 21.4 ± .3 | 18.0 - 25.5 | 25.3 ± 5.50 | 77.4 ± 5.78 | 9.97 ± .79 |
| August 18 | 80,376 | 24.3 ± .7 | 15.5 - 28.5 | 51.2 ± 5.36 | 51.2 ± 4.78 | 7.16 ± .81 |
| August 19 | 57,121 | 26.8 ± 1.0 | 16.0 - 32.5 | 46.2 ± 6.13 | 55.4 ± 6.59 | 8.82 ± .61 |
| August 20 | 47,444 | 28.8 ± .8 | 20.5 - 34.0 | 46.7 ± 4.79 | 53.7 ± 6.37 | 7.67 ± 1.19 |
| August 21 | 68,068 | 28.0 ± .7 | 20.5 - 32.5 | 46.7 ± 5.08 | 47.6 ± 5.34 | 9.46 ± .85 |
| August 22 | 94,478 | 27.2 ± .7 | 19.5 - 30.5 | 41.8 ± 4.64 | 54.0 ± 4.96 | 9.84 ± .55 |
| August 23 | 59,364 | 23.6 ± .4 | 20.0 - 27.5 | 33.9 ± 4.93 | 63.1 ± 6.14 | 7.16 ± 1.26 |
| August 24 | 50,220 | 20.6 ± .5 | 15.5 - 24.0 | 38.9 ± 6.27 | 54.0 ± 4.23 | 7.79 ± .50 |
| TOTAL | 564,665 | | | | | |

(Figure 12) indicate extremes not due to a difference in the number of bees available. Comparing these two dates, temperature seems to be the critical factor affecting bee visits, with temperatures averaging 25.1° C on August 13 compared to 22.9° C on August 14. Temperature increased slowly the morning of the 14th. During the first four hours on the 13th, average temperatures increased from 19.3 - 25.7° C compared to 17.7 - 22.8° C on the 14th. Solar radiation was also less on the 14th from 8 - 9 a.m., 22.8 cal/cm$^2$ compared to 34.8 on the 13th. Wind speed may also have affected visits, since a positive significant correlation was found between foraging activity and wind speed. On the 13th the wind averaged 7.8 mph compared to 4.9 on the 14th.

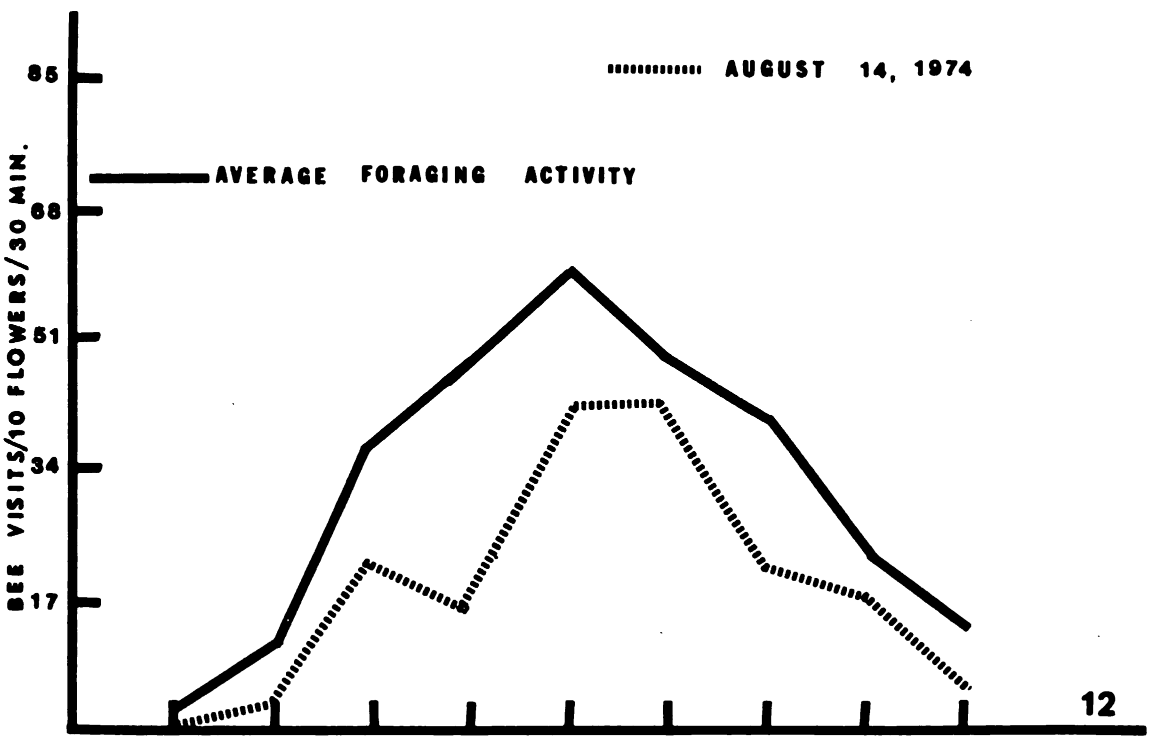
Even though significant positive correlations were found between foraging activity and temperature, solar radiation, and wind speed as well as a negative correlation between foraging activity and relative humidity, the cause of the large variations noted in Table 13 are not evident. Some variation probably resulted from day to day fluctuations in flowering, bee availability, and their combined influence on nectar secretion. Looking only at the climatic factors, paired comparisons of days in chronological order indicated that temperature and wind were responsible for the differences observed between August 13 and 14, and 15 and 16. None of the factors help to explain the differences between August 16 and 17. All of the increase may have been due to the two colonies that were moved to the plot and bees getting oriented to new forage. Comparison of August 19 and 20 and then 21 and 22 indicated that wind was primarily

Figure 11.--Above average foraging activity in cucumbers due to favorable climatic conditions, August 13, 1974.

Figure 12.--Below average foraging activity in cucumbers due to unfavorable climatic conditions, August 14, 1974.


AUGUST 13, 1974
85
68
51
34
17
BEE VISITS/10 FLOWERS/30 MIN.
TIME
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00

11


AUGUST 14, 1974
AVERAGE FORAGING ACTIVITY
85
68
51
34
17
BEE VISITS/10 FLOWERS/30 MIN.

12

responsible. Temperature was the major factor that appeared to be involved when comparing August 23 with 24. Triple combinations of temperature, wind, and humidity for August 14 and 15 and temperature, solar radiation, and humidity for August 17 and 18 seemed to be involved. Differences between August 18 and 19 were due to humidity and solar radiation compared to August 20 and 21, where wind speed and humidity were involved. All four factors were probably important when comparing August 22 and 23.

During the seven days of observation at Eaton Rapids, the total number of visits per flower fluctuated between 46.8 and 95.2 (Table 14). Average daily temperature ranged between 21.7 and

TABLE 14.--Average daily foraging activity in cucumbers in relation to temperature, Eaton Rapids, 1974.

| Date | Average number of visits per flower (9.0 h) | Temperature mean | Temperature range |
|---|---|---|---|
| July 25 | 53.4 | 24.7 $\pm$ .5 | 19.0 - 28.5 |
| July 26 | 81.4 | 29.5 $\pm$ .8 | 21.5 - 34.5 |
| July 29 | 95.2 | 24.0 $\pm$ .4 | 20.0 - 27.5 |
| August 1 | 52.0 | 21.7 $\pm$ .4 | 15.0 - 24.5 |
| August 2 | 46.8 | 22.2 $\pm$ .6 | 17.5 - 26.5 |
| August 5 | 51.6 | 23.0 $\pm$ .9 | 13.0 - 27.5 |
| August 6 | 55.8 | 24.5 $\pm$ .7 | 16.0 - 30.0 |

29.5° C. Positive correlations between temperature and foraging activity were found for all chronological pair comparisons except July 26 and 29 and August 1 and 2. Other climatological factors must have been involved but the data did not indicate what they were. A positive correlation between average daily temperature and total number of visits per flower at Mulliken was not found (Table 15). Total

TABLE 15.--Average daily foraging activity in cucumbers in relation to temperature, Mulliken, 1974.

| Date | Average number of visits per flower (9.0 h) | Temperature mean | Temperature range |
|---|---|---|---|
| August 26 | 4.9 | 27.3 ± 1.0 | 17.5 - 33.5 |
| August 29 | 8.3 | 21.4 ± .8 | 10.0 - 26.5 |
| August 30 | 10.3 | 22.6 ± .7 | 15.0 - 27.0 |

number of visits per flower ranged from 4.9 - 10.3 for the three days while temperature fluctuated between 27.3 and 21.4° C.

The effect of threatened storms and rain on foraging activity throughout the day was observed on August 2, 1974, at Eaton Rapids and on August 16 and 23 at East Lansing. On August 2 (Figure 13) at 7 a.m. flowers were open and the temperature was 17.5° C. It had rained during the night and was still sprinkling. From 7:35 to 8 a.m. there was no rain, then it rained again from 8 to 8:15. The sun came out at 8:15 and the first bee in the field was observed at 8:37. At 8:47 it started to rain, but two bees continued to work and rain stopped at 8:55. It rained again from 9:47 to 10:15. Again three bees were observed working during the rain. As a result, bee activity was delayed until 11 a.m. and peaked between 1 and 2. On August 16

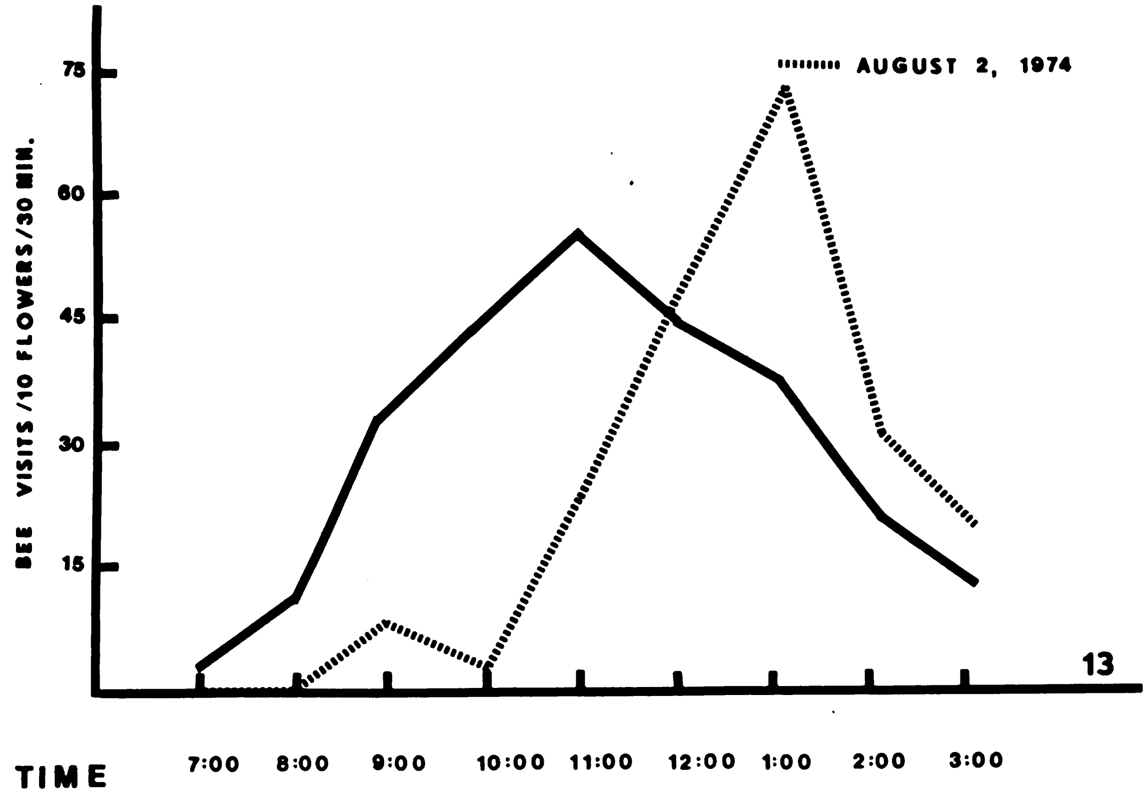
(Figure 14) at 7 a.m., temperature was 19.5° C, sunny with a slight haze, and flowers were completely open. At 10:30 it clouded up and a strong wind came up. As a result flight activity leveled off. At 12:35 it started to thunder, but the storm blew over and the sun came back out at 12:48. Bee activity peaked between 1 and 2 p.m. At 2:05 it clouded up and light rain started at 2:22. It became dark, started to thunder, and the wind came up. As a result bee activity decreased rapidly. By 5 p.m. 0.06" of rain had fallen. On August 23 (Figure 15) bee activity was interrupted in late morning and did not recover during the afternoon. At 7 a.m. temperature was 20° C and the flowers were fully open even though it was foggy. The sun broke through the haze at 7:15. With the temperature above average at 7 a.m., bee activity increased more rapidly than normal in the early morning. However, at 10:50 black clouds appeared and rain started at 11:08. A light rain continued until 11:45. As a result bee activity rapidly declined. At 12:47 the sun reappeared for the afternoon, but foraging activity remained depressed.

## Climatic Conditions Affecting Nectar Secretion

Because temperature and other weather factors vary daily, cucumber flowers begin to secrete nectar at different times of the day. The number of staminate and pistillate flowers producing nectar increased throughout the day at recorded hourly intervals until noon (Figure 16). The remainder of the afternoon values remained high and were not significantly different. On August 12, 1968, measurable amounts of nectar in the pistillate flowers did not appear until

Figure 13.--The effect of threatening storms and rain on foraging activity in cucumbers, August 2, 1974.

Figure 14.--The effect of threatening storms and rain on foraging activity in cucumbers, August 16, 1974.


AUGUST 2, 1974
BEE VISITS /10 FLOWERS/30 MIN.
75
60
45
30
15
13
TIME
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00

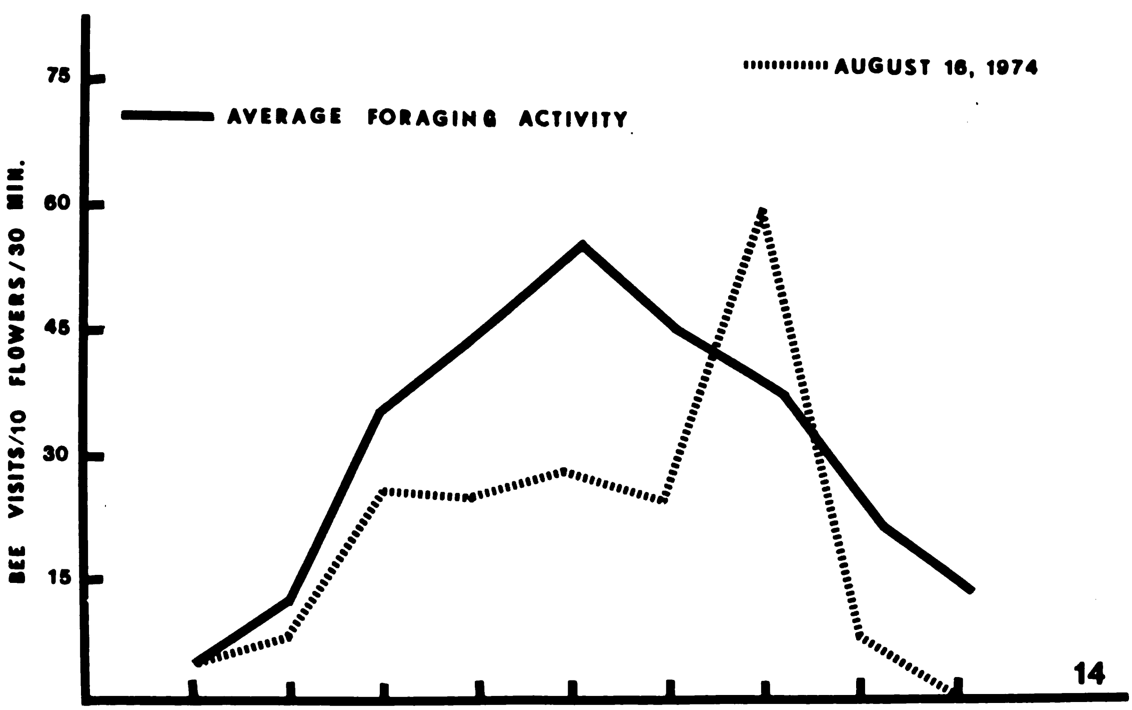

AUGUST 16, 1974
AVERAGE FORAGING ACTIVITY
BEE VISITS/10 FLOWERS/30 MIN.
75
60
45
30
15
14

Figure 15.--The effect of threatening storms and rain on foraging activity in cucumbers, August 23, 1974.

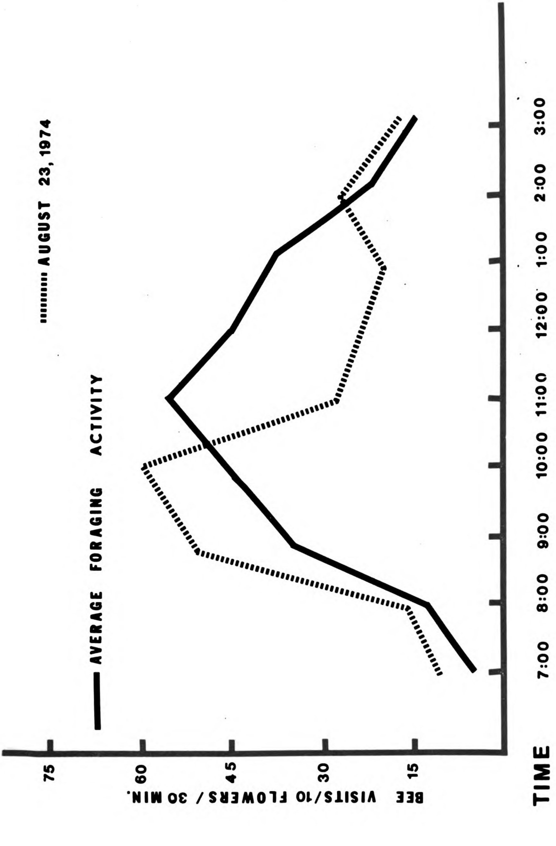
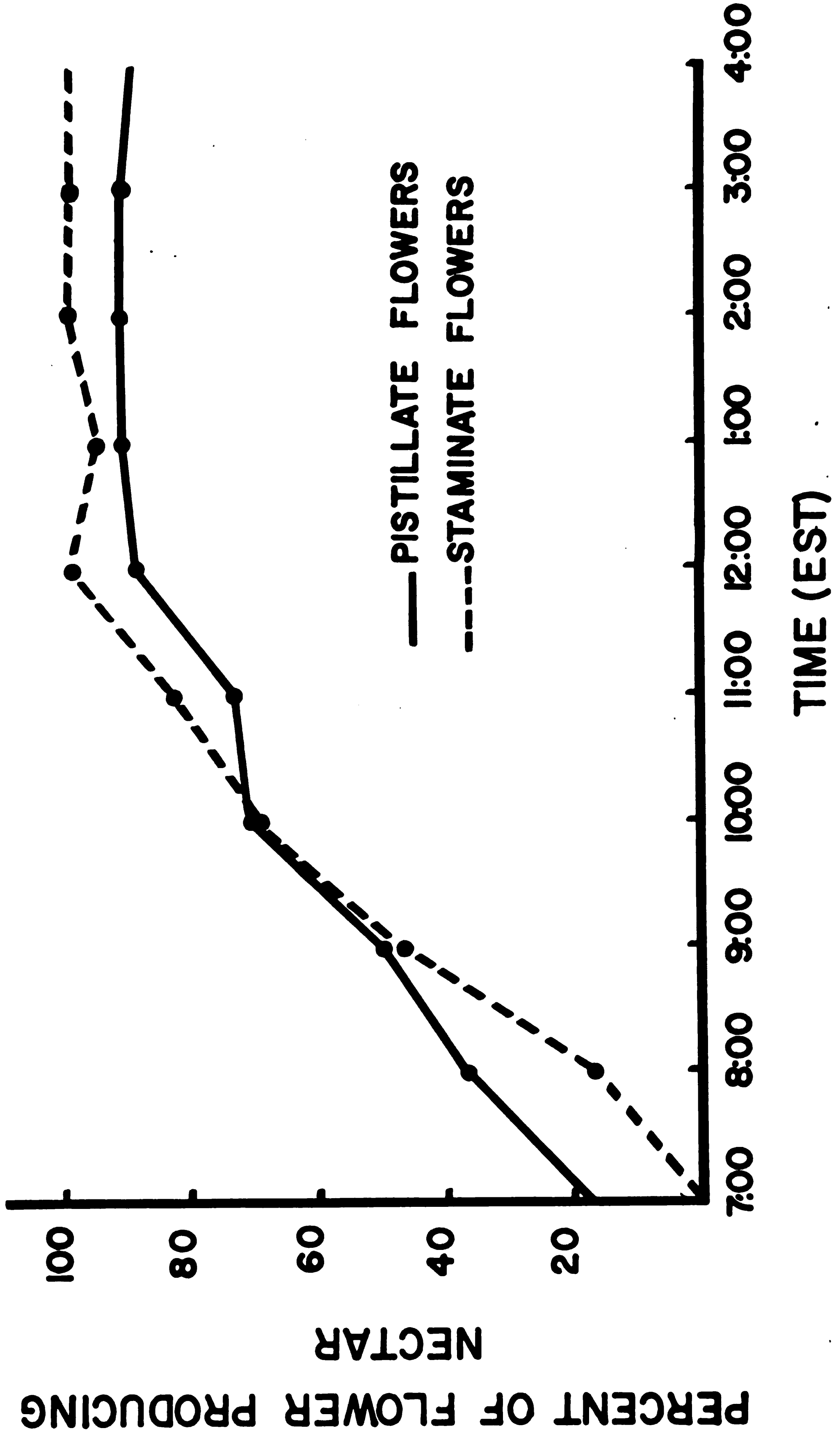

AVERAGE FORAGING ACTIVITY
AUGUST 23, 1974
BEE VISITS/10 FLOWERS / 30 MIN.
75
60
45
30
15
TIME
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00

Figure 16.--The percent of staminate and pistillate cucumber flowers producing nectar throughout the day.



PERCENT OF FLOWER PRODUCING NECTAR
100
80
60
40
20
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
TIME (EST)
PISTILLATE FLOWERS
STAMINATE FLOWERS

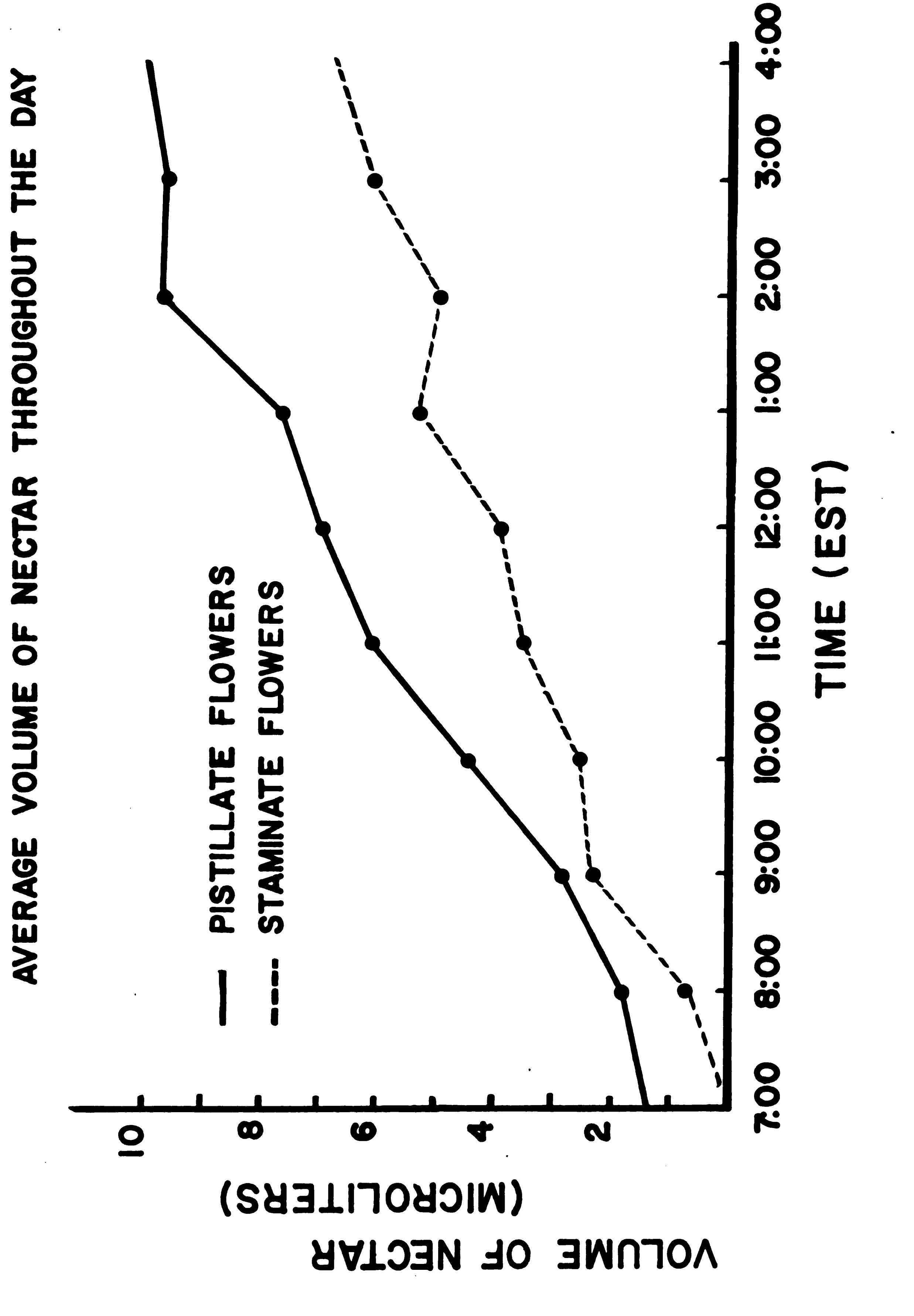
1 p.m. whereas on August 20, 21, and 22 temperatures were in the 70's by 6 a.m. and all flowers sampled were producing nectar at 7 a.m. During 1969, there were no days when the temperature was high enough for nectaries to produce measurable amounts of nectar by 7 a.m.

The average volume of nectar increased throughout the day in pistillate flowers, averaging from 1.40 ul in the morning to a high of 9.92 ul (Figure 17). The volume of nectar in pistillate flowers ranged from 0.0 to 34.15 ul of nectar with a mean of 6.05 ul/day. The average volume of nectar also increased throughout the day in staminate flowers averaging from .73 to 6.79 ul. Staminate flowers produced from 0.0 to 14.88 ul with a mean of 4.01 ul/day.

The average sugar concentration of pistillate flower nectar decreased throughout the day from 44.5% early in the day to 27.4% (Figure 18). The sugar concentration of the nectar ranged from 13.6 - 57.1% with a mean of 36.3%. In staminate flowers the average sugar concentration decreased through the morning from 46.1% to 43.7% and had a similar decline in the afternoon from 47.0 to 44.3%. The sugar concentration of the nectar ranged from 27.8 to 60.2% with a mean of 45.3%.

The actual weight of sugar in nectar from pistillate flowers increased during the day until 2 p.m., then began to decrease (Figure 19). The total weight of sugar in the nectar ranged from 0.06 to 12.33 mg with a mean of 2.29 mg/day. In staminate flowers the actual weight of sugar increased during the day from .42 to 3.63 mg. The total weight of sugar in the nectar ranged from .09 to 8.36 mg

Figure 17.--The average volume of nectar produced by staminate and pistillate cucumber flowers throughout the day.



AVERAGE VOLUME OF NECTAR THROUGHOUT THE DAY
PISTILLATE FLOWERS
STAMINATE FLOWERS
VOLUME OF NECTAR (MICROLITERS)
10
8
6
4
2
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
TIME (EST)

Figure 18.--The average sugar concentration of cucumber nectar produced by staminate and pistillate flowers and as it is collected by the honey bee throughout the day.

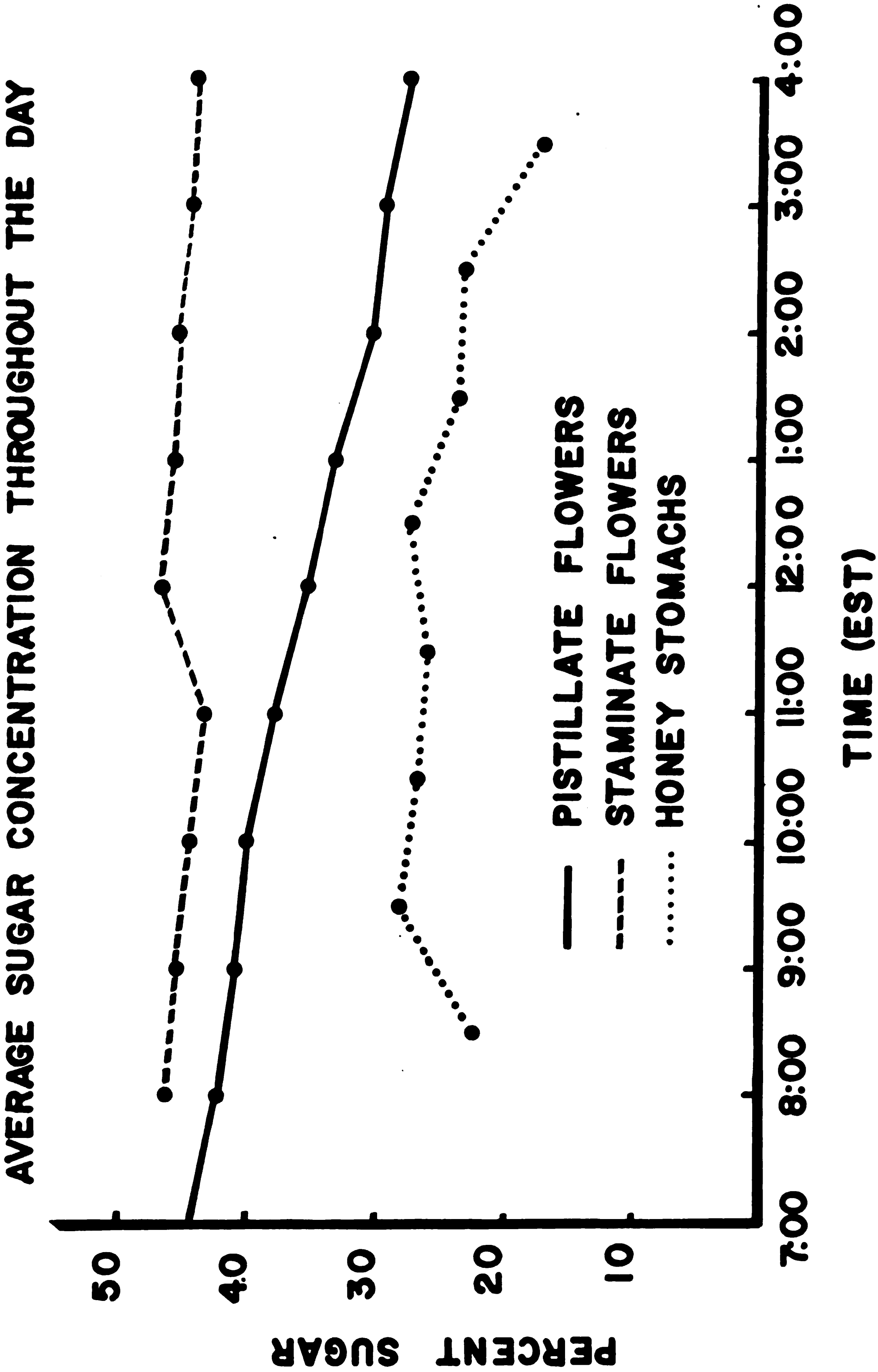
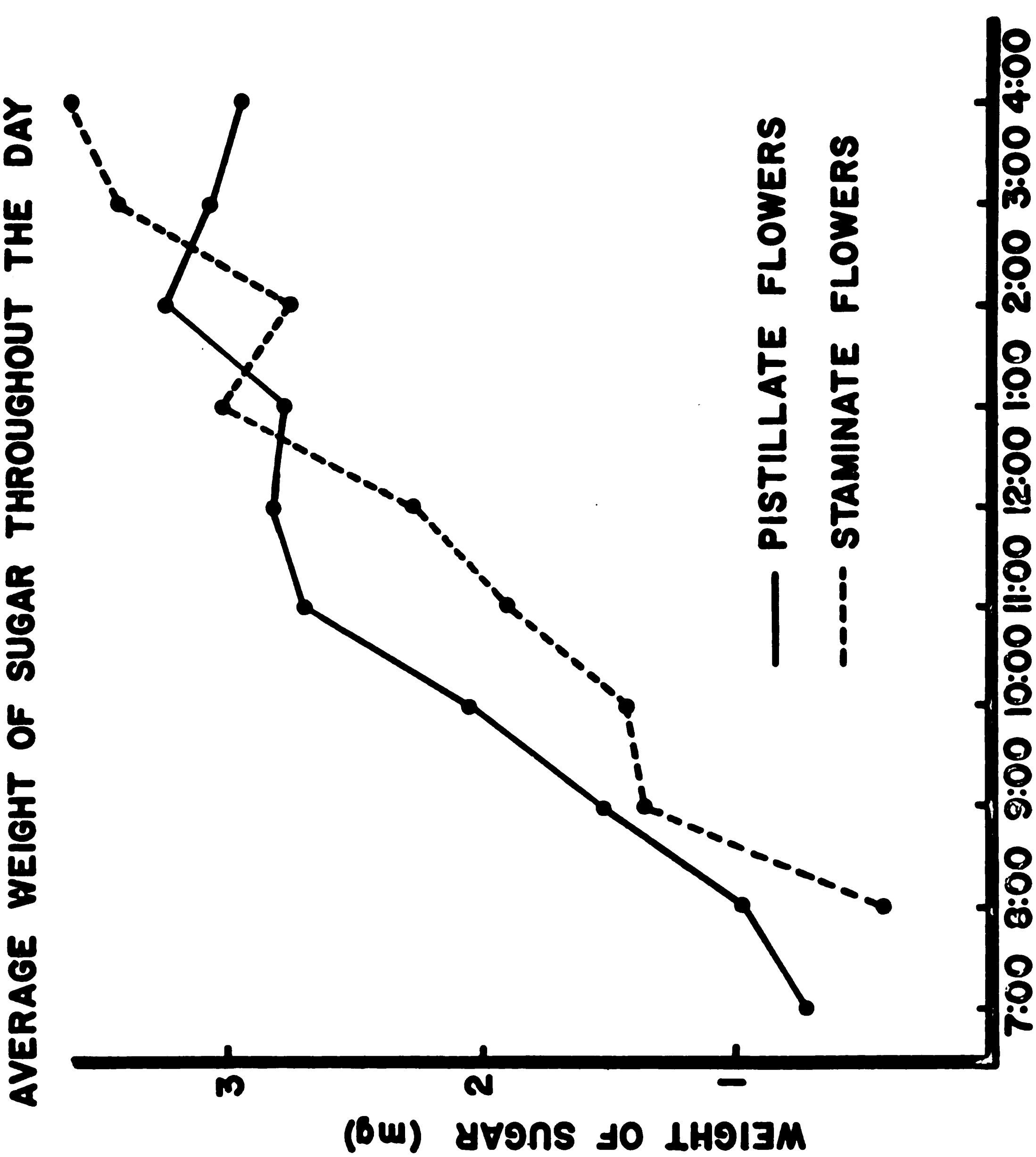

AVERAGE SUGAR CONCENTRATION THROUGHOUT THE DAY
PERCENT SUGAR
50
40
30
20
10
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
TIME (EST)
PISTILLATE FLOWERS
STAMINATE FLOWERS
HONEY STOMACHS

Figure 19.--The average weight of sugar in cucumber nectar produced by staminate and pistillate flowers throughout the day.


AVERAGE WEIGHT OF SUGAR THROUGHOUT THE DAY
WEIGHT OF SUGAR (mg)
1
2
3
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
TIME (EST)
PISTILLATE FLOWERS
STAMINATE FLOWERS

with a mean of 2.23 mg/day. All mean values were based only on those flowers which produced nectar.

Throughout the morning as the average volume of nectar and actual weight of sugar increased, along with the number of flowers producing nectar, the average temperature also increased. In 1968 the average temperature when flowers were producing nectar by 7 a.m. was 23.4° C increasing to a high of 28.2° C by 4 p.m. Similarly, in 1969 temperatures went from 19.4° C at 8 a.m. to a high of 28.0° C at 3 p.m. As the temperature increased, sugar concentration of nectar decreased. However, the two may not be related.

Daily nectar production fluctuated in response to changing climatic conditions. The average daily volume of nectar produced by pistillate flowers excluding flowers which produced no nectar ranged between 1.99 and 10.80 ul (Table 16). When all flowers were included, the range was 0.00-10.48 ul per day. In staminate flowers, daily nectar volumes excluding flowers which produced no nectar averaged 3.17 to 7.25 ul with a mean of 4.68 ul (Table 17). For all flowers, values ranged between 1.74 and 7.25 ul per day. Daily average sugar concentrations for the nectar of pistillate flowers fluctuated between 29.8% and 42.7% compared to 40.4% to 48.0% in the staminate flowers. Similar daily fluctuations were observed in the actual weight of sugar present in the nectar. When all flowrs were included, pistillate flowers averaged from 0.00 to 4.02 mg per day compared to 0.89 to 4.07 mg for staminate flowers. Basing the results only on flowers that were producing nectar gave a range of

TABLE 16.--The average volume of nectar, sugar concentration, and total weight of sugar secreted daily by pistillate cucumber flowers, 1968.

| Date | Sample size | Average volume (ul) | Average sugar concentration | Average weight of sugar (mg) | Sample size | Average volume (ul) | Average weight of sugar (mg) |
|---|---|---|---|---|---|---|---|
| | Based on flowers that produced nectar | | | | All flowers | | |
| 7-26 | 14 | 7.71 ± 1.27 | 32.8 ± 1.59 | 2.58 ± .33 | 24 | 4.50 ± 1.08 | 1.51 ± .33 |
| 7-29 | 13 | 4.27 ± .67 | 35.6 ± 2.08 | 1.73 ± .14 | 25 | 2.22 ± .56 | .83 ± .19 |
| 7-30 | 21 | 3.47 ± .58 | 29.8 ± 1.35 | 1.12 ± .17 | 35 | 2.08 ± .45 | .67 ± .15 |
| 7-31 | 11 | 3.26 ± .62 | 31.4 ± 1.59 | 1.07 ± .14 | 30 | 1.20 ± .37 | .39 ± .11 |
| 8- 1 | 17 | 3.07 ± .47 | 38.2 ± 1.25 | 1.31 ± .17 | 40 | 1.31 ± .32 | .56 ± .13 |
| 8- 2 | 18 | 5.81 ± .93 | 31.7 ± 1.20 | 1.91 ± .26 | 62 | 1.69 ± .43 | .56 ± .14 |
| 8- 5 | 18 | 5.29 ± .80 | 34.6 ± .77 | 2.06 ± .28 | 26 | 3.67 ± .74 | 1.43 ± .28 |
| 8- 6 | 29 | 7.13 ± .69 | 31.5 ± 1.45 | 2.34 ± .20 | 38 | 5.45 ± .73 | 1.79 ± .23 |
| 8- 7 | 16 | 9.14 ± 1.54 | 34.2 ± 1.13 | 3.39 ± .45 | 25 | 5.86 ± 1.33 | 2.17 ± .44 |
| 8- 8 | 30 | 9.87 ± 1.19 | 32.3 ± 1.36 | 3.20 ± .28 | 38 | 7.80 ± 1.16 | 2.53 ± .32 |
| 8- 9 | 27 | 6.72 ± .98 | 35.1 ± 1.36 | 2.34 ± .28 | 33 | 5.50 ± .93 | 1.92 ± .28 |
| 8-12 | 9 | 2.19 ± .50 | 33.0 ± 3.39 | 0.73 ± .10 | 46 | 0.43 ± .16 | .14 ± .05 |
| 8-13 | 42 | 1.99 ± .17 | 34.3 ± 1.01 | 0.78 ± .00 | 71 | 1.18 ± .16 | .45 ± .07 |
| 8-14 | 28 | 3.13 ± .46 | 42.7 ± 1.21 | 1.61 ± .20 | 40 | 2.20 ± .40 | 1.05 ± .19 |
| 8-15 | 14 | 5.03 ± .88 | 37.6 ± 2.71 | 2.22 ± .37 | 34 | 2.07 ± .56 | .85 ± .24 |
| 8-16 | 31 | 4.17 ± .85 | 36.6 ± 1.26 | 1.55 ± .26 | 34 | 3.81 ± .82 | 1.37 ± .26 |
| 8-19 | 47 | 6.22 ± .72 | 36.5 ± 1.09 | 2.45 ± .24 | 53 | 5.52 ± .70 | 1.99 ± .25 |
| 8-20 | 34 | 9.46 ± 1.41 | 37.3 ± 1.09 | 3.63 ± .50 | 36 | 8.94 ± 1.41 | 3.43 ± .50 |
| 8-21 | 27 | 10.48 ± 1.51 | 34.8 ± 1.67 | 3.67 ± .46 | 27 | 10.48 ± 1.52 | 3.67 ± .48 |
| 8-22 | 36 | 10.37 ± 1.34 | 36.9 ± 1.16 | 4.12 ± .45 | 36 | 10.37 ± 1.37 | 4.02 ± .47 |
| 8-23 | 38 | 10.80 ± 1.35 | 37.2 ± 1.02 | 4.18 ± .45 | 40 | 10.26 ± 1.36 | 3.97 ± .47 |
| 8-26 | 31 | 0.00 ± 0.00 | 0.00 ± .00 | 0.00 ± .00 | 31 | 0.0 | 0.00 |

TABLE 17.--The average volume of nectar, sugar concentration, and total weight of sugar secreted daily by staminate cucumber flowers, 1969.

| Date | Sample size | Average volume (ul) | Average sugar concentration | Average weight of sugar (mg) | Sample size | Average volume (ul) | Average weight of sugar (mg) |
|---|---|---|---|---|---|---|---|
| | Only flowers producing nectar | | | | All flowers | | |
| 8-14 | 42 | 5.61 ± .50 | 44.8 ± .54 | 3.09 ± .29 | 54 | 4.36 ± .51 | 2.29 ± .04 |
| 8-15 | 48 | 7.25 ± .53 | 46.9 ± .27 | 4.07 ± .28 | 48 | 7.25 ± .53 | 4.07 ± .07 |
| 8-18 | 46 | 4.95 ± .43 | 43.4 ± .57 | 2.62 ± .23 | 48 | 4.75 ± .44 | 2.51 ± .04 |
| 8-19 | 52 | 4.57 ± .42 | 47.4 ± .57 | 2.75 ± .26 | 60 | 3.96 ± .42 | 2.29 ± .04 |
| 8-20 | 33 | 3.17 ± .33 | 47.8 ± .93 | 1.98 ± .21 | 60 | 1.74 ± .28 | 1.02 ± .02 |
| 8-21 | 32 | 4.04 ± .41 | 40.4 ± .99 | 1.92 ± .20 | 60 | 2.16 ± .35 | 1.02 ± .02 |
| 8-25 | 40 | 3.90 ± .38 | 47.8 ± .61 | 2.40 ± .24 | 48 | 3.26 ± .39 | 1.90 ± .04 |
| 8-26 | 39 | 4.37 ± .34 | 48.0 ± .53 | 2.57 ± .21 | 54 | 3.16 ± .37 | 1.85 ± .04 |
| 8-27 | 28 | 3.81 ± .30 | 41.6 ± .98 | 1.90 ± .17 | 60 | 1.78 ± .29 | .89 ± .02 |
| 8-28 | 39 | 3.58 ± .30 | 42.9 ± .46 | 1.85 ± .17 | 58 | 2.41 ± .31 | 1.24 ± .02 |
| 8-29 | 49 | 3.96 ± .31 | 44.9 ± .44 | 2.17 ± .18 | 54 | 3.60 ± .33 | 1.97 ± .03 |

values from 0.73 to 4.18 mg per day for pistillate flowers and from 1.85 to 4.07 mg for staminate flowers. Comparison of the daily average volume of nectar with the daily average temperature gave significant positive correlations for both staminate and pistillate flowers. A correlation coefficient of .6270 (significant at the .05 probability level) was found in the staminate flowers and .8332 (significant at the .05 probability level) in the pistillate which indicated 39.3% and 69.4% association, respectively. Average temperatures ranged between 22.1 and 29.4° C for staminate flowers with a mean of 26.5, and between 20.7 and 27.8° C for pistillate flowers with a mean of 24.5. For both types of flowers, the lowest average temperature coincided with the lowest average volume of nectar and in pistillate flowers the highest average temperature coincided with the highest average volume of nectar.

Overall, a highly significant positive correlation was found between temperatures observed and the volume of nectar for both staminate and pistillate flowers (Table 20). Correlation coefficients of .6550 (significant at the .001 probability level) and .6575 (significant at the .001 probability level) were found for pistillate and staminate flowers respectively, when all flowers were included in the sample, compared to .6392 (significant at the .001 probability level) and .4881 (significant at the .001 probability level) when based only on the flowers that were producing nectar. From 40.9 - 42.9% association was found between temperature and nectar volume in pistillate flowers compared to 23.8 - 43.2% in staminate. The average volume ranged between 0.00 - 19.49 ul in pistillate flowers and 0.00 to 9.43 ul in staminate. The first measurable amounts of nectar were obtained at 18.3° C in the pistillate flowers and 18.9° C in staminate. The average volume peaked at 30.6° C in staminate flowers compared to 32.3° C in pistillate. Overall, pistillate flowers averaged 6.69 ul at a temperature of 26.2° C compared to 4.61 ul at 26.7° C in staminate flowers.

The data indicated that temperature affected only the sugar concentration of nectar in pistillate flowers (Table 21). A highly significant negative correlation was found with a correlation coefficient of -0.4150 which indicated 17.2% association. Mean sugar concentrations ranged between 44.0 and 22.9% at temperatures of 21.1 and 33.3° C, respectively. In the staminate flowers sugar concentrations ranged from 34.2 to 48.0%, occurring at 18.9° C and 26.1° C, respectively. A correlation coefficient of 0.0013 was obtained which was not significant. Overall, the pistillate flowers averaged 35.2% sugar compared to 45.1% in the staminate flowers at temperatures of 26.2 and 26.7° C, respectively.

Highly significant positive correlations were found between temperature and the actual weight of sugar found in the nectar of both staminate and pistillate flowers (Table 22). In pistillate flowers a correlation coefficient of 0.6050 was found for only the flowers producing nectar compared to 0.6607 for all flowers. These indicated an association of 36.6 - 43.7% between temperature and actual weight of sugar. In staminate flowers, correlation coefficients of 0.1731 and 0.5492 were found for the flowers producing nectar and for all flowers respectively, which indicated an associatin of 3.0 to 30.2%. Average sugar weights ranged from 0.00 to 6.59 mg for pistillate flowers and from 0.00 to 5.10 mg in staminate flowers. In staminate flowers, the peak average sugar weight occured at 30.6° C and in pistillate flowers at 32.3° C. Overall, pistillate flowers averaged 2.50 mg of sugar at a mean temperature of 26.2° C compared to 2.60 mg at 26.7° C for staminate flowers.

The data indicated that the amount of nectar and sugar available to bees depended upon the time of day that the threshold temperature for nectar secretion occurred (Figures 20, 22, 23, and 25). This was not so for the sugar concentration (Figures 21 and 24). In 1968 when pistillate flowers were sampled, if the threshold temperature was reached by 7 a.m. they secreted an average 8.77 ul of nectar compared to 5.09 ul by 8 a.m., 2.65 ul by 9 a.m. and 1.87 ul by 10 a.m. On July 30, the threshold temperature was not reached until 11 a.m. and the flowers averaged only 2.08 ul; on August 12 it was not reached until 1 p.m. and they averaged 0.43 ul (Tables 16 and 18). On August 26, the average temperature was 13.9° C, minimum 9.4° and the maximum 18.3° C. None of the 31 flowers sampled during the day contained measurable amounts of nectar. A similar trend was observed with the actual weights of sugar. If the threshold temperature was reached by 7 a.m., the flowers averaged 3.29 mg sugar compared to 1.74 mg if the threshold temperature was reached by 8 a.m., 0.85 mg by 9 a.m., and 0.75 mg by 10. On July 30 when the threshold temperature was reached by 11, the flowers averaged 0.67 mg sugar and on

Figure 20.--The daily average volume of nectar produced by pistillate cucumber flowers in relation to temperature.


TEMPERATURE °C
26.7
21.2
15.6
10.1
4.6
-1.0
-6.5
-12.0
AVG VOLUME OF NECTAR UL
12
10
8
6
4
2
T Max
T Avg
T Min
UL
JULY
AUGUST
26
29
30
31
1
2
5
6
7
8
9
12
13
14
15
16
19
20
21
22
23
26

Figure 21.--The daily average sugar concentration of nectar produced by pistillate cucumber flowers in relation to temperature.

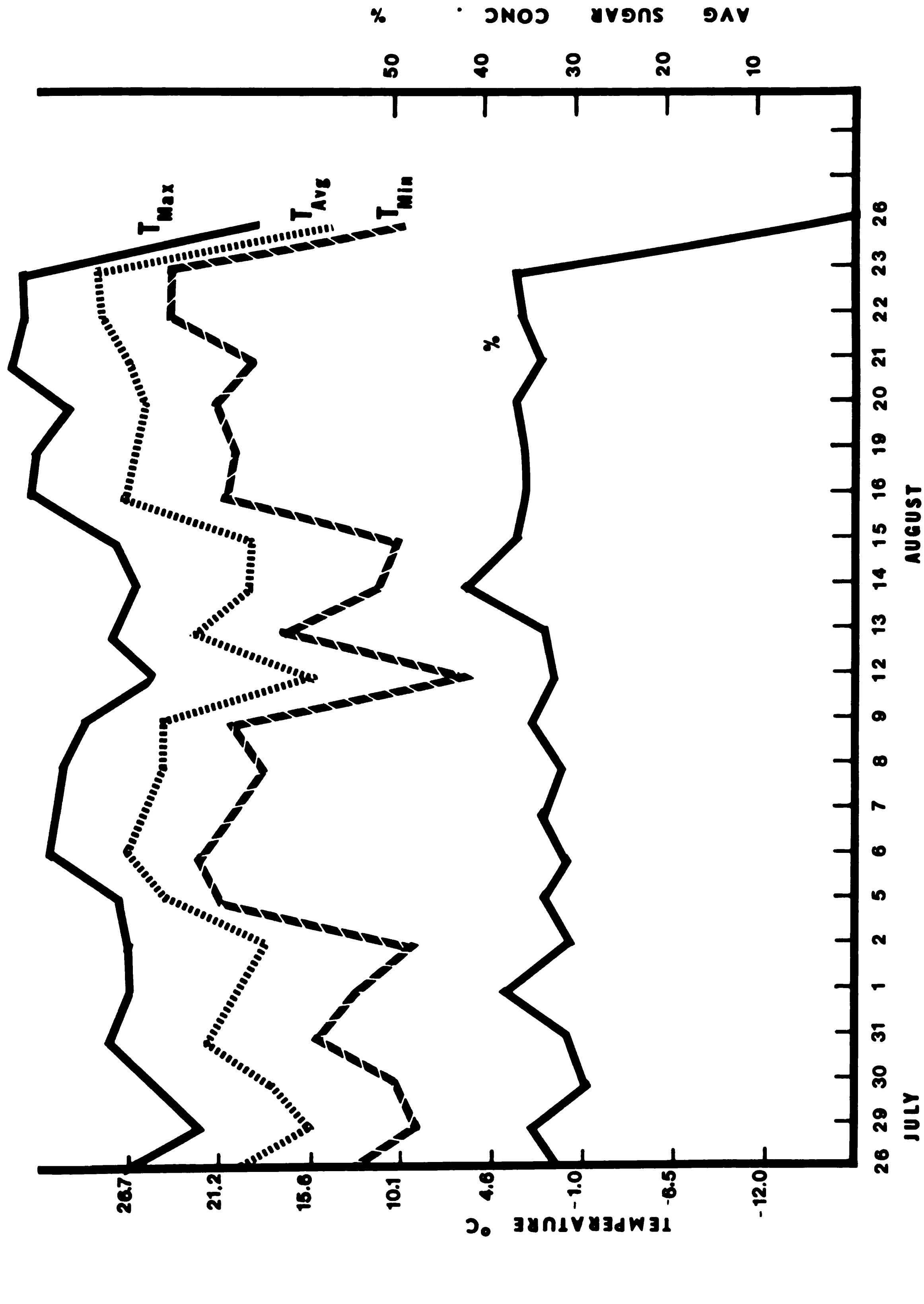
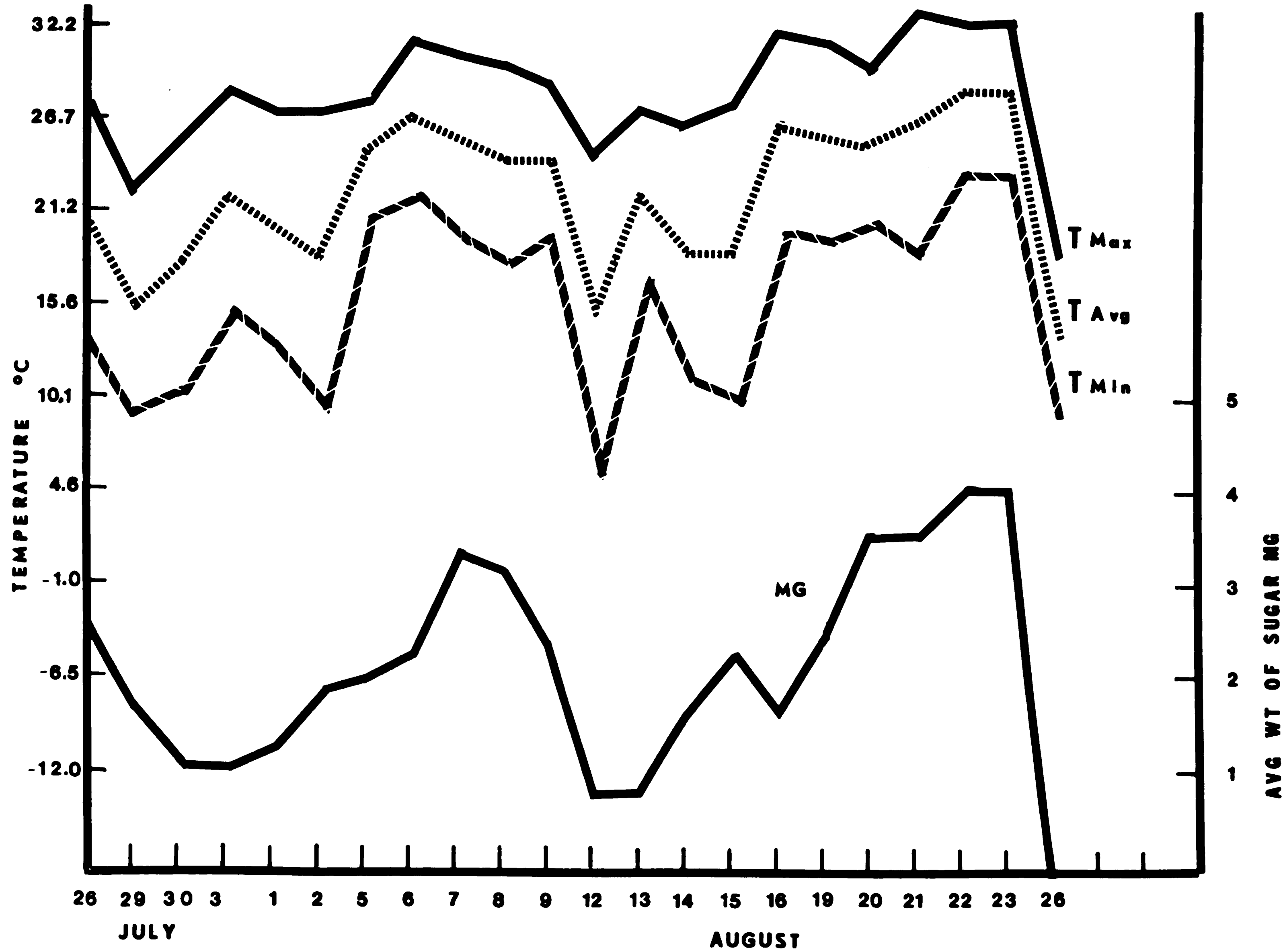

AVG SUGAR CONC. %
50
40
30
20
10
$T_{Max}$
$T_{Avg}$
$T_{Min}$
%
TEMPERATURE °C
26.7
21.2
15.6
10.1
4.6
-1.0
-6.5
-12.0
JULY
26 29 30 31
1 2 5 6 7 8 9 12 13 14 15 16 19 20 21 22 23 26
AUGUST

Figure 22.--The daily average weight of sugar in cucumber nectar produced by pistillate flowers in relation to temperature.



32.2
26.7
21.2
15.6
10,1
4.6
-1.0
-6.5
-12.0
TEMPERATURE °C
T Max
T Avg
T Min
MG
5
4
3
2
1
AVG WT OF SUGAR MG
26
29
30
3
1
2
5
6
7
8
9
12
13
14
15
16
19
20
21
22
23
26
JULY
AUGUST

Figure 23.--The daily average volume of nectar produced by staminate cucumber flowers in relation to temperature.

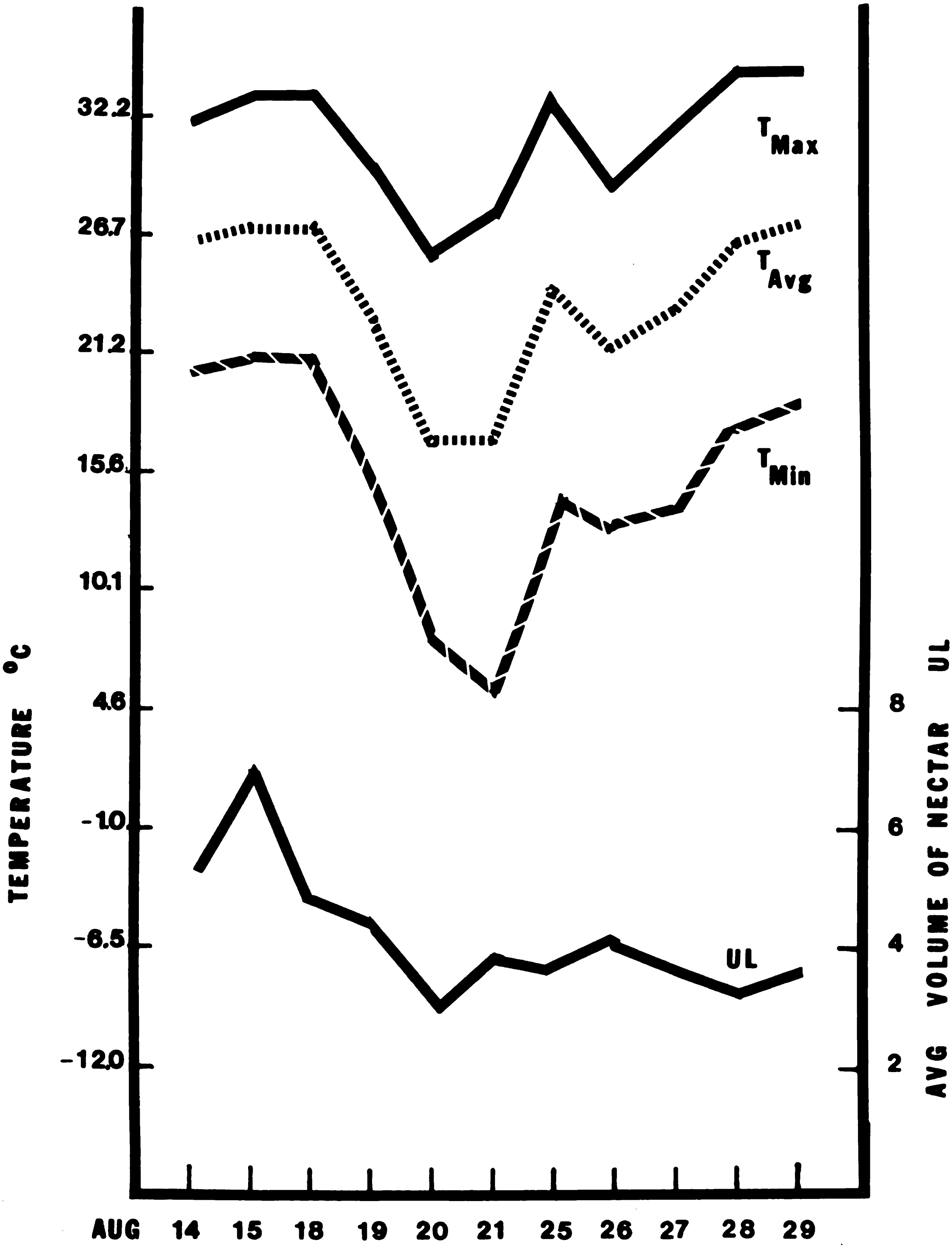
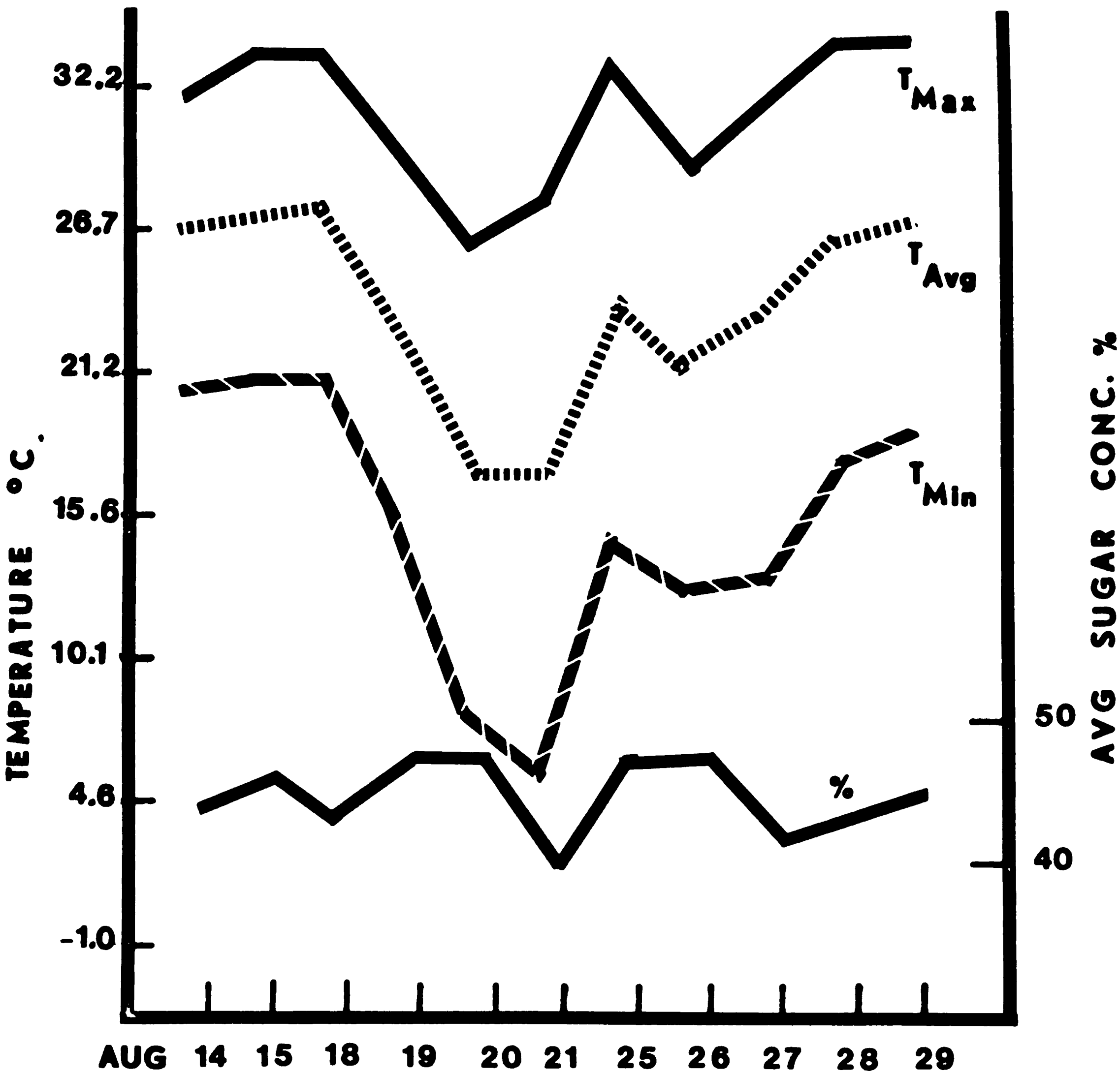
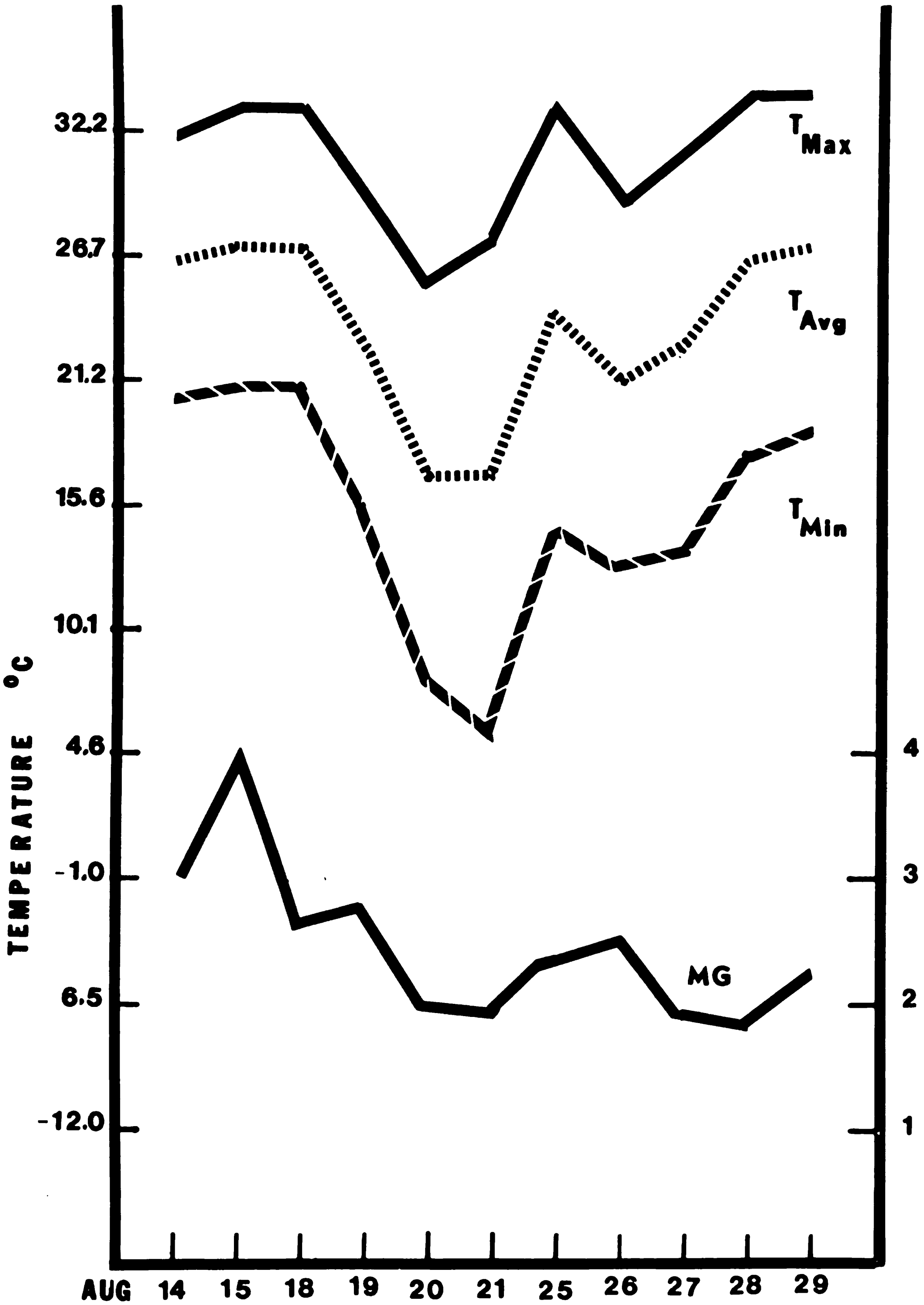

32.2
26.7
21.2
15.6
10.1
4.6
-1.0
-6.5
-12.0
TEMPERATURE °C
T Max
T Avg
T Min
UL
8
6
4
2
AVG VOLUME OF NECTAR UL
AUG 14 15 18 19 20 21 25 26 27 28 29

Figure 24.--The daily average sugar concentration of nectar produced by staminate cucumber flowers in relation to temperature.



32.2
26.7
21.2
15.6
10.1
4.6
-1.0
TEMPERATURE °C.
T Max
T Avg
T Min
%
50
40
AVG SUGAR CONC. %
AUG 14 15 18 19 20 21 25 26 27 28 29

Figure 25.--The daily average weight of sugar in cucumber nectar produced by staminate flowers in relation to temperature.


32.2
26.7
21.2
15.6
10.1
4.6
-1.0
6.5
-12.0
TEMPERATURE °C
$T_{Max}$
$T_{Avg}$
$T_{Min}$
MG
4
3
2
1
AVG WT OF SUGAR MG
AUG 14 15 18 19 20 21 25 26 27 28 29

August 12 when the threshold temperature was not reached until 1 p.m., only 0.14 mg. In 1969 the staminate flowers showed a similar trend (Tables 17 and 19). If the threshold temperature was reached by 8 a.m., the flowers averaged 4.24 ul compared to 2.84 ul if the temperature was reached by 9 a.m., 2.45 ul by 10 a.m., and 1.78 ul by 11 a.m. In the actual weight of sugar, values decreased from 2.34 mg for an 8 a.m. threshold to 1.57 mg for 9 a.m., 1.44 mg for 10 a.m., and 0.89 mg for 11 a.m.

The average volume of nectar and actual weight of sugar increased along with the number of flowers producing nectar until noon, while the average humidity decreased during the same time interval. At the same time the average sugar concentration of the nectar in both staminate and pistillate flowers was also decreasing. In 1968 the humidity decreased from a high of 97.4% at 7 a.m. to a low of 60.6% at 3 p.m. compared to 1969 when it went from 78.7% at 8 a.m. down to 46.7% at 4 p.m. Average daily humidity values fluctuated between 49.1% and 92.0% with a mean of 71.6% in 1968 (Table 18). During 1969 values were found between 44.6% and 64.7% humidity, with a mean of 54.3% (Table 19). Comparison of the daily humidity means with the average volume of nectar produced gave a correlation coefficient of $.4946^{N.S.}$ for the staminate flowers and $.2029^{N.S.}$ for the pistillate which indicated 24.5 and 4.1% association, respectively.

Overall, highly significant negative correlations were found between relative humidity and volume of nectar (Table 23). Correlation coefficients of -0.1763 and -0.2817 were found for the pistillate and staminate flowers which indicated 3.1% and 7.9% association, respectively. Analysis of the nectar volume data by various levels of relative humidity indicated that average volumes ranged between 1.61 and 10.44 ul in pistillate flowers and 0.00 - 5.38 ul in staminate. These volumes occurred at 95 - 100% and at 60 - 64% humidity in pistillate flowers and at 90 - 94% and 40 - 44% humidity in staminate respectively. Overall, pistillate flowers at a mean relative humidity of 72.6%, averaged 6.7 ul of nectar compared to 4.68 ul at a mean of 54.0% relative humidity in staminate flowers.

As was found with temperature, humidity only affected the sugar concentration of the nectar in the pistillate flowers (Table 24). A highly significant positive correlation was found with a correlation coefficient of 0.3350 which indicated 11.2% association. Mean sugar concentrations ranged between 40.8 and 30.9% at humidities of 95 - 100% and 55 - 59%, respectively. In staminate flowers sugar concentrations ranged between 48.8 and 40.9%, which occurred at 85 - 89% and 30 - 34% relative humidity, respectively. A correlation coefficient of 0.0119 was obtained which was not significant. Overall, pistillate flowers averaged 35.1% sugar at a mean relative humidity of 72.6% compared to 45.2% sugar at a mean relative humidity of 53.7% in staminate flowers.

Negative correlation coefficients found between relative humidity and actual weight of sugar in the nectar were highly significant in both staminate and pistillate flowers (Table 25). The average weight of sugar found in the nectar fluctuated between 0.66 and

3.59 mg in pistillate flowers and between 0.00 and 3.10 mg in staminate. The lowest values occurred at 95 - 100% and at 90 - 94% relative humidity compared to 60 - 64% and 40 - 44% for the highest values in pistillate and staminate flowers, respectively. A correlation coefficient of -0.1322 (significant at the .01 probability level), which indicated a 1.7% association, was found for pistillate flowers compared to -0.3532 (significant at the .001 probability level) and 12.5% association for staminate. Overall, pistillate flowers produced an average of 2.51 mg of sugar at an average relative humidity of 72.6% compared to 2.64 mg at 53.7% for the staminate.

Total solar radiation produced during the day of sampling fluctuated between 366 and 652 langleys (calories/$cm^2$/day) in 1969 (Tables 18 and 19). At the same time, the percent possible sunshine for the day ranged between 7 and 96% in 1968 and 22 and 100% in 1969. However, when the total solar radiation on the day of anthesis was compared to the volume of nectar, % sugar, and actual weight of sugar for both staminate and pistillate flowers, significant correlations were not found (Table 26). Therefore, to focus on the amount of solar radiation prior to anthesis needed to affect nectar secretion, correlations were run between the daily average nectar volume, sugar concentration, and actual weight of sugar with various combinations of solar radiation. In pistillate flowers, a significant negative correlation was first obtained between total solar radiation for the day of anthesis plus the two previous days and both volume of nectar and actual weight of sugar. Correlation

TABLE 18.--Climatic conditions affecting nectar production in pistillate cucumber flowers during 1968.

| Date | Time of 1st measurable nectar | % possible sunshine | Solar radiation (langleys) | Average humidity | Avg. wind speed | Precipitation |
|---|---|---|---|---|---|---|
| 7-26 | 9:00 | 96 | 710 | 49.1 | 4.9 | .00 |
| 7-29 | 10:00 | 88 | 612 | -- | 4.9 | .00 |
| 7-30 | 11:00 | 89 | 640 | 52.8 | 9.4 | .00 |
| 7-31 | 9:00 | 24 | 252 | 86.8 | 11.4 | .29 |
| 8- 1 | 10:00 | 70 | 565 | 71.5 | 5.6 | .00 |
| 8- 2 | 9:00 | 92 | 639 | 53.6 | 5.2 | .00 |
| 8- 5 | 9:00 | 7 | 175 | 92.0 | 6.3 | .91 |
| 8- 6 | 8:00 | 25 | 309 | 88.8 | 9.9 | .01 |
| 8- 7 | -- | 70 | 551 | 73.3 | 7.1 | .08 |
| 8- 8 | 8:00 | 53 | 337 | 83.3 | 3.9 | .30 |
| 8- 9 | 8:00 | 56 | 454 | 82.0 | 6.2 | .09 |
| 8-12 | 1:00 | 81 | 644 | -- | 3.6 | .00 |
| 8-13 | 8:00 | 76 | 543 | -- | 11.8 | .00 |
| 8-14 | 9:00 | 94 | -- | 54.6 | 6.0 | .00 |
| 8-15 | 10:00 | 79 | 575 | -- | 8.8 | .04 |
| 8-16 | 7:00* | 40 | -- | -- | 9.6 | .78 |
| 8-19 | 8:00 | 81 | 573 | -- | 10.9 | .75 |
| 8-20 | 7:00* | 66 | -- | -- | 12.5 | .00 |
| 8-21 | 7:00* | 65 | 376 | -- | 6.0 | .00 |
| 8-22 | 7:00* | 94 | -- | -- | 9.9 | .00 |
| 8-23 | 7:00* | 92 | 548 | -- | 9.1 | .00 |
| 8-26 | no secretion | 41 | 386 | -- | 7.9 | .00 |

*First sampling period, nectar was present.

TABLE 19.--Climatic conditions affecting nectar production in staminate cucumber flowers during 1969.

| Date | Time of 1st measurable nectar | % possible sunshine | Solar radiation (langleys) | Average humidity | Avg. wind speed | Precipitation |
|---|---|---|---|---|---|---|
| 8-14 | -- | 22 | 366 | 61.3 | 10.8 | T |
| 8-15 | 8:00 | 24 | 491 | 59.5 | 9.5 | 0 |
| 8-18 | -- | 84 | 544 | 59.3 | 10.8 | 0 |
| 8-19 | 8:00 | 96 | 628 | 50.7 | 7.5 | 0 |
| 8-20 | 10:00 | 100 | 652 | 47.5 | 6.6 | 0 |
| 8-21 | 8:00 | 100 | 642 | 44.6 | 3.0 | 0 |
| 8-25 | 9:00 | 92 | 570 | 54.3 | 9.5 | 0 |
| 8-26 | 10:00 | 100 | 604 | 51.0 | 6.8 | 0 |
| 8-27 | 11:00 | 89 | 551 | 47.0 | 7.5 | 0 |
| 8-28 | 9:00 | 82 | 482 | 57.9 | 7.9 | 0 |
| 8-29 | 8:00 | 45 | 383 | 64.7 | 7.2 | 0 |

TABLE 20.--The affect of temperature on the volume of nectar produced in cucumber flowers.

| Temperature | Pistillate Flowers 1968 | | | Staminate Flowers 1969 | | |
|---|---|---|---|---|---|---|
| | N | Mean volume | Range | N | Mean volume | Range |
| 10.0 | 0 | -- | | 6 | 0.0 | 0.0 |
| 11.7 | 9 | 0.0 | 0.0 | 6 | 0.0 | 0.0 |
| 12.2 | 16 | 0.0 | 0.0 | 0 | -- | -- |
| 12.8 | 3 | 0.0 | 0.0 | 12 | 0.0 | 0.0 |
| 13.3 | 23 | 0.0 | 0.0 | 0 | -- | -- |
| 13.8 | 3 | 0.0 | 0.0 | 0 | -- | -- |
| 14.4 | 7 | 0.0 | 0.0 | 0 | -- | -- |
| 15.0 | 23 | 0.0 | 0.0 | 6 | 0.00 | 0.00 |
| 15.6 | 11 | 0.0 | 0.0 | 6 | 0.00 | 0.00 |
| 16.1 | 17 | 0.0 | 0.0 | 12 | 0.00 | 0.00 |
| 16.7 | 14 | 0.0 | 0.0 | 0 | -- | -- |
| 17.2 | 3 | 0.0 | 0.0 | 6 | 0.00 | 0.00 |
| 17.8 | 11 | 0.0 | 0.0 | 16 | 0.00 | 0.00 |
| 18.3 | 9 | 0.27 | 0.00- 1.22 | 0 | -- | -- |
| 18.9 | 30 | 0.07 | 0.00- 1.25 | 12 | 0.02 | 0.00- 0.24 |
| 19.4 | 6 | 0.00 | 0.00 | 0 | -- | -- |
| 20.0 | 38 | 0.37 | 0.00- 3.28 | 23 | 0.06 | 0.00- 0.73 |
| 20.6 | 32 | 1.09 | 0.00- 5.31 | 12 | 0.00 | 0.00 |
| 21.1 | 21 | 1.48 | 0.00- 7.19 | 30 | 0.78 | 0.00- 4.15 |
| 21.7 | 15 | 2.57 | 0.00- 8.91 | 12 | 2.48 | 0.00- 6.10 |
| 22.2 | 43 | 1.41 | 0.00- 6.83 | 18 | 0.85 | 0.00- 4.88 |
| 22.8 | 25 | 1.97 | 0.00- 6.83 | 17 | 1.58 | 0.00- 4.39 |
| 23.3 | 23 | 2.64 | 0.00-10.00 | 43 | 2.89 | 0.00- 9.51 |
| 23.9 | 66 | 3.25 | 0.00-13.90 | 6 | 1.50 | 0.24- 3.41 |
| 24.4 | 49 | 3.83 | 0.00-12.44 | 42 | 2.93 | 0.00- 9.02 |
| 25.0 | 18 | 5.58 | 0.00-17.32 | 12 | 3.40 | 0.00- 7.56 |
| 25.6 | 53 | 2.74 | 0.00-15.63 | 24 | 3.42 | 0.00- 9.76 |
| 26.1 | 32 | 4.96 | 0.00-17.07 | 19 | 4.58 | 0.00- 9.27 |
| 26.7 | 32 | 6.27 | 0.00-17.32 | 36 | 3.48 | 0.73-10.98 |
| 27.2 | 13 | 7.75 | 0.24-14.23 | 18 | 5.99 | 1.95-11.71 |
| 27.8 | 24 | 8.18 | 0.00-18.29 | 30 | 4.07 | 0.00-10.24 |
| 28.3 | 19 | 9.78 | 1.22-31.95 | 42 | 4.73 | 0.00-12.69 |
| 28.9 | 13 | 9.98 | 0.00-31.71 | 48 | 5.68 | 0.00-13.18 |
| 29.4 | 26 | 9.81 | 0.00-23.90 | 36 | 5.44 | 1.71-12.44 |
| 30.0 | 33 | 10.73 | 0.00-23.66 | 36 | 6.74 | 1.71-13.66 |
| 30.6 | 13 | 6.44 | 0.49-13.66 | 12 | 9.43 | 2.68-14.88 |
| 31.1 | 14 | 11.81 | 3.17-33.66 | 6 | 7.85 | 3.90-10.00 |
| 31.7 | 15 | 13.45 | 0.00-30.49 | 0 | -- | -- -- |
| 32.2 | 19 | 19.49 | 8.05-34.15 | 0 | -- | -- -- |
| 32.8 | 0 | -- | -- -- | 0 | -- | -- -- |
| 33.3 | 6 | 13.94 | 2.20-25.12 | 0 | -- | -- -- |
| Overall | 827 | | | 604 | | |

with zero values $r = .6550$ $r = .6575$

$t = 24.81$*** $df = 825$ $t = 21.92$*** $df = 602$

without zero values $r = 0.6392$ $r = 0.4881$

$t = 19.31$*** $df = 496$ $t = 11.85$*** $df = 430$

***Significant at the .001 probability level.

TABLE 21.--The affect of temperature on the sugar concentration of nectar from cucumber flowers.

| Temperature °C | Pistillate flowers 1968 | | | Staminate flowers 1969 | | |
|---|---|---|---|---|---|---|
| | N | Mean | Range | N | Mean | Range |
| 18.3 | 3 | 35.8 | 28.3 - 47.8 | 0 | -- | -- -- |
| 18.9 | 2 | 42.2 | 38.6 - 45.7 | 1 | 34.2 | 34.2 |
| 19.4 | 0 | -- | -- -- | 0 | -- | -- -- |
| 20.0 | 5 | 40.9 | 36.1 - 47.3 | 3 | 36.1 | 33.4 - 40.4 |
| 20.6 | 14 | 41.5 | 37.1 - 54.5 | 0 | -- | -- -- |
| 21.1 | 8 | 44.0 | 40.7 - 57.1 | 12 | 47.9 | 38.2 - 60.2 |
| 21.7 | 7 | 36.1 | 27.2 - 43.6 | 8 | 44.0 | 29.0 - 51.0 |
| 22.2 | 21 | 40.4 | 30.8 - 49.2 | 9 | 44.9 | 32.8 - 55.3 |
| 22.8 | 21 | 37.6 | 26.4 - 48.8 | 9 | 46.0 | 42.2 - 49.0 |
| 23.3 | 16 | 38.3 | 23.6 - 47.7 | 33 | 45.9 | 34.7 - 55.2 |
| 23.9 | 56 | 35.5 | 19.4 - 55.0 | 5 | 41.5 | 37.7 - 46.5 |
| 24.4 | 38 | 35.6 | 24.3 - 47.9 | 32 | 43.8 | 29.0 - 54.7 |
| 25.0 | 17 | 37.8 | 29.1 - 47.8 | 11 | 46.0 | 31.6 - 52.3 |
| 25.6 | 45 | 38.2 | 21.9 - 48.7 | 23 | 45.9 | 34.9 - 51.8 |
| 26.1 | 30 | 37.1 | 21.6 - 49.5 | 18 | 48.0 | 38.8 - 50.9 |
| 26.7 | 27 | 33.4 | 22.2 - 42.0 | 36 | 44.4 | 27.8 - 53.1 |
| 27.2 | 12 | 34.2 | 13.6 - 46.5 | 18 | 47.7 | 45.4 - 55.9 |
| 27.8 | 21 | 35.3 | 28.4 - 43.6 | 29 | 45.1 | 31.0 - 54.4 |
| 28.3 | 16 | 32.6 | 21.7 - 41.2 | 39 | 45.0 | 30.1 - 50.0 |
| 28.9 | 12 | 28.6 | 20.3 - 40.8 | 46 | 44.8 | 37.2 - 51.2 |
| 29.4 | 22 | 31.1 | 21.1 - 45.8 | 36 | 43.4 | 31.0 - 50.4 |
| 30.0 | 32 | 30.7 | 21.3 - 46.8 | 36 | 46.5 | 39.7 - 54.8 |
| 30.6 | 13 | 34.8 | 27.7 - 46.7 | 12 | 43.2 | 35.0 - 45.5 |
| 31.1 | 14 | 35.8 | 30.1 - 49.2 | 6 | 45.9 | 44.0 - 47.4 |
| 31.7 | 14 | 29.0 | 24.2 - 34.3 | 0 | -- | -- -- |
| 32.2 | 19 | 29.6 | 25.8 - 35.2 | 0 | -- | -- -- |
| 32.8 | 0 | -- | -- -- | 0 | -- | -- -- |
| 33.3 | 6 | 22.9 | 20.0 - 25.4 | 0 | -- | -- -- |
| Overall | 491 | 35.2 | 13.6 - 57.1 | 422 | 45.1 | 27.8 - 60.2 |
| | | $r = -0.4150$ | | | $r = 0.0013$ | |
| | $t = 10.37^{***}$ | | $df = 489$ | $t = .026^{NS}$ | | $df = 420$ |

*** = Significant at the .001 probability level.

NS = Not significant.

TABLE 22.--The affect of temperature on the actual weight of sugar in the nectar of cucumber flowers.

| Temperature °C | Pistillate flowers 1968 | | | Staminate flowers 1969 | | |
|---|---|---|---|---|---|---|
| | N | Mean wt | Range | N | Mean wt | Range |
| 10.0 | 0 | -- | -- | 6 | 0.00 | 0.00 |
| 11.7 | 9 | 0.00 | 0.00 | 6 | 0.00 | 0.00 |
| 12.2 | 16 | 0.00 | 0.00 | 0 | -- | -- |
| 12.8 | 3 | 0.00 | 0.00 | 12 | 0.00 | 0.00 |
| 13.3 | 23 | 0.00 | 0.00 | 0 | -- | -- |
| 13.9 | 3 | 0.00 | 0.00 | 0 | -- | -- |
| 14.4 | 7 | 0.00 | 0.00 | 0 | -- | -- |
| 15.0 | 23 | 0.00 | 0.00 | 6 | 0.14 | 0.00 - 0.87 |
| 15.6 | 11 | 0.00 | 0.00 | 6 | 0.00 | 0.00 |
| 16.1 | 17 | 0.00 | 0.00 | 12 | 0.00 | 0.00 |
| 16.7 | 14 | 0.00 | 0.00 | 0 | -- | -- |
| 17.2 | 3 | 0.00 | 0.00 | 6 | 0.00 | 0.00 |
| 17.8 | 11 | 0.00 | 0.00 | 16 | 0.00 | 0.00 |
| 18.3 | 9 | 0.11 | 0.00 - .43 | 0 | -- | -- |
| 18.9 | 30 | 0.04 | 0.00 - .69 | 12 | 0.01 | 0.00 - 0.16 |
| 19.4 | 6 | 0.00 | 0.00 | 0 | -- | -- |
| 20.0 | 35 | 0.12 | 0.00 - 1.48 | 23 | 0.03 | 0.00 - 0.29 |
| 20.6 | 22 | 0.47 | 0.00 - 1.72 | 12 | 0.00 | 0.00 |
| 21.1 | 14 | 0.24 | 0.00 - 0.71 | 28 | 0.44 | 0.00 - 1.85 |
| 21.7 | 13 | 0.85 | 0.00 - 2.67 | 12 | 1.34 | 0.00 - 3.56 |
| 22.2 | 43 | 0.65 | 0.00 - 3.01 | 15 | 0.46 | 0.00 - 1.83 |
| 22.8 | 25 | 0.85 | 0.00 - 2.57 | 17 | 0.88 | 0.00 - 2.42 |
| 23.3 | 23 | 1.15 | 0.00 - 4.99 | 42 | 1.64 | 0.00 - 4.94 |
| 23.9 | 64 | 1.25 | 0.00 - 5.07 | 5 | 0.89 | 0.43 - 1.87 |
| 24.4 | 46 | 1.45 | 0.00 - 4.87 | 41 | 1.54 | 0.00 - 4.09 |
| 25.0 | 18 | 2.33 | 0.00 - 6.92 | 12 | 1.91 | 0.00 - 4.16 |
| 25.6 | 53 | 1.16 | 0.00 - 4.61 | 24 | 1.95 | 0.00 - 5.51 |
| 26.1 | 31 | 1.92 | 0.00 - 5.18 | 19 | 2.68 | 0.00 - 5.79 |
| 26.7 | 29 | 2.58 | 0.00 - 7.06 | 36 | 1.90 | 0.35 - 6.30 |
| 27.2 | 12 | 3.18 | 0.86 - 5.40 | 18 | 3.57 | 1.09 - 8.28 |
| 27.8 | 24 | 3.30 | 0.00 - 7.68 | 30 | 2.25 | 0.00 - 5.46 |
| 28.3 | 16 | 3.78 | 0.79 - 11.93 | 42 | 2.57 | 0.00 - 7.29 |
| 28.9 | 13 | 2.81 | 0.00 - 8.03 | 47 | 3.02 | 0.00 - 8.36 |
| 29.4 | 26 | 3.33 | 0.00 - 7.49 | 36 | 2.86 | 0.85 - 6.85 |
| 30.0 | 33 | 3.68 | 0.00 - 8.01 | 36 | 3.84 | 0.94 - 7.97 |
| 30.6 | 13 | 2.49 | 0.28 - 5.24 | 12 | 5.10 | 1.38 - 7.64 |
| 31.1 | 14 | 4.72 | 1.33 - 8.90 | 6 | 4.37 | 2.06 - 5.63 |
| 31.7 | 15 | 4.42 | 0.00 - 10.84 | 0 | -- | -- -- |
| 32.2 | 19 | 6.56 | 2.82 - 12.33 | 0 | -- | -- -- |
| 32.8 | 0 | -- | -- -- | 0 | -- | -- -- |
| 33.3 | 6 | 3.55 | 0.58 - 7.07 | 0 | -- | -- -- |
| Overall | 792 | | | 295 | | |

With zero values r = 0.6607 t = 25.03*** df = 790 | r = 0.5492 t = 16.59*** df = 593

Without zero values r = 0.6050 t = 17.49*** df = 489 | r = 0.1731 t = 3.61*** df = 416

*** = Significant at the .001 probability level.

TABLE 23.--The affect of humidity on the volume of nectar in cucumber flowers.

| Humidity | Pistillate flowers 1968 N | Pistillate flowers 1968 Mean volume | Pistillate flowers 1968 Range | Staminate flowers 1969 N | Staminate flowers 1969 Mean volume | Staminate flowers 1969 Range |
|---|---|---|---|---|---|---|
| 95 - 100 | 93 | 1.61 | 0.00 - 17.07 | 0 | -- | |
| 90 - 94 | 90 | 2.47 | 0.00 - 17.32 | 18 | 0.00 | 0.00 |
| 85 - 89 | 84 | 2.79 | 0.00 - 31.71 | 30 | 0.09 | 0.00 - 1.22 |
| 80 - 84 | 74 | 3.25 | 0.00 - 18.29 | 58 | 0.53 | 0.00 - 4.39 |
| 75 - 79 | 53 | 6.14 | 0.00 - 31.95 | 12 | 1.08 | 0.00 - 4.15 |
| 70 - 74 | 79 | 5.96 | 0.00 - 23.90 | 36 | 1.74 | 0.00 - 7.07 |
| 65 - 69 | 87 | 4.63 | 0.00 - 23.66 | 24 | 2.20 | 0.00 - 7.07 |
| 60 - 64 | 66 | 10.44 | 0.00 - 32.44 | 60 | 2.81 | 0.00 - 12.69 |
| 55 - 59 | 35 | 6.79 | 0.00 - 34.15 | 72 | 4.32 | 0.00 - 10.98 |
| 50 - 54 | 72 | 3.33 | 0.00 - 13.90 | 96 | 5.11 | 0.00 - 14.88 |
| 45 - 49 | 18 | 3.19 | 0.00 - 8.91 | 84 | 3.85 | 0.00 - 11.71 |
| 40 - 44 | 15 | 8.20 | 2.20 - 15.63 | 60 | 5.38 | 0.00 - 11.71 |
| 35 - 39 | 0 | -- | -- -- | 6 | 4.31 | 2.44 - 6.10 |
| 30 - 34 | 0 | -- | -- -- | 12 | 4.35 | 0.00 - 9.02 |
| | r = -0.1763 t = 4.05*** | | df = 503 | r = -0.2817 t = 5.88*** | | df = 395 |

*** = Significant at the .001 probability level.

TABLE 24.--The affect of humidity on the sugar concentration of nectar in cucumber flowers.

| Humidity | Pistillate flowers 1968 | | | Staminate flowers 1969 | | |
|---|---|---|---|---|---|---|
| | N | Mean sugar concentration | Range | N | Mean sugar concentration | Range |
| 95 - 100 | 51 | 40.8 | 21.6 - 55.0 | 0 | -- | -- -- |
| 90 - 94 | 47 | 39.2 | 30.3 - 48.7 | 18 | -- | -- -- |
| 85 - 89 | 43 | 36.6 | 21.3 - 47.8 | 3 | 48.8 | 44.6 - 57.0 |
| 80 - 84 | 34 | 34.9 | 15.6 - 45.6 | 13 | 45.5 | 41.1 - 55.3 |
| 75 - 79 | 36 | 32.7 | 21.1 - 47.3 | 5 | 44.7 | 38.2 - 49.8 |
| 70 - 74 | 60 | 35.8 | 24.6 - 49.2 | 25 | 46.1 | 39.3 - 50.9 |
| 65 - 69 | 66 | 33.6 | 21.7 - 57.1 | 18 | 42.8 | 27.8 - 47.2 |
| 60 - 64 | 60 | 31.5 | 21.9 - 48.8 | 40 | 46.1 | 40.5 - 50.6 |
| 55 - 59 | 18 | 30.9 | 20.0 - 42.0 | 54 | 45.1 | 37.0 - 54.2 |
| 50 - 54 | 56 | 33.3 | 19.4 - 52.5 | 78 | 44.3 | 29.0 - 60.2 |
| 45 - 49 | 12 | 34.2 | 21.7 - 48.1 | 76 | 45.5 | 27.8 - 54.8 |
| 40 - 44 | 15 | 32.0 | 22.5 - 47.8 | 59 | 47.2 | 34.7 - 55.9 |
| 35 - 39 | 0 | -- | -- -- | 6 | 42.3 | 31.1 - 46.5 |
| 30 - 34 | 0 | -- | -- -- | 11 | 40.9 | 30.5 - 46.3 |
| | | $r = 0.3350$ <br> $t = 8.13^{***}$ df = 496 | | | $r = 0.0119$ <br> $t = .2380^{NS}$ df = 404 | |

*** = Significant at the .001 probability level.

NS = Not significant.

TABLE 25.--The affect of humidity on the actual weight of sugar in the nectar of cucumber flowers.

| Humidity | Pistillate flowers 1968 | | | Staminate flowers 1969 | | |
|---|---|---|---|---|---|---|
| | N | Mean wt of sugar | Range | N | Mean wt of sugar | Range |
| 95 - 100 | 92 | 0.66 | 0.00 - 5.18 | 0 | | |
| 90 - 94 | 90 | 1.09 | 0.00 - 6.92 | 18 | 0.00 | 0.00 |
| 85 - 89 | 84 | 1.07 | 0.00 - 6.98 | 30 | 0.05 | 0.00 - 0.66 |
| 80 - 84 | 73 | 1.31 | 0.00 - 7.68 | 54 | 0.29 | 0.00 - 2.48 |
| 75 - 79 | 53 | 2.19 | 0.00 - 11.93 | 12 | 0.56 | 0.00 - 1.85 |
| 70 - 74 | 79 | 2.27 | 0.00 - 7.49 | 35 | 1.00 | 0.00 - 4.09 |
| 65 - 69 | 85 | 1.71 | 0.00 - 8.01 | 24 | 1.13 | 0.00 - 3.77 |
| 60 - 64 | 66 | 3.59 | 0.00 - 12.33 | 60 | 1.58 | 0.00 - 7.29 |
| 55 - 59 | 35 | 2.20 | 0.00 - 11.40 | 72 | 2.36 | 0.00 - 2.66 |
| 50 - 54 | 71 | 1.21 | 0.00 - 5.07 | 93 | 2.79 | 0.00 - 8.36 |
| 45 - 49 | 18 | 1.18 | 0.00 - 2.89 | 84 | 2.16 | 0.00 - 7.55 |
| 40 - 44 | 15 | 2.78 | 1.04 - 4.61 | 60 | 3.10 | 0.00 - 8.28 |
| 35 - 39 | 0 | -- | -- -- | 6 | 2.15 | 1.17 - 3.41 |
| 30 - 34 | 0 | -- | -- -- | 12 | 2.13 | 0.00 - 4.09 |
| | r = -0.1322<br>t = 3.04** | | df = 495 | r = -0.3532<br>t = 7.53*** | | df = 387 |

** = Significant at the .01 probability level.
*** = Significant at the .001 probability level.

TABLE 26.--The affect of solar radiation on nectar secretion of cucumber flowers as determined by correlation coefficients.

| Time of solar radiation | Volume | | % Sugar | | Actual wt of sugar | |
|---|---|---|---|---|---|---|
| | pistillate | staminate | pistillate | staminate | pistillate | staminate |
| Day of anthesis | -0.1858$^{NS}$ | -0.3686$^{NS}$ | 0.1384$^{NS}$ | 0.1384$^{NS}$ | -0.1475$^{NS}$ | -0.2925$^{NS}$ |
| Previous day | -0.3393$^{NS}$ | -0.7188* | -0.1403$^{NS}$ | -0.1651$^{NS}$ | -0.3518$^{NS}$ | -0.6942* |
| Both combined | -0.3409$^{NS}$ | -0.6334* | -0.1614$^{NS}$ | -0.0062$^{NS}$ | -0.3641$^{NS}$ | -0.5720$^{NS}$ |
| Day of anthesis + 2 previous | -0.6984* | -0.5020$^{NS}$ | -0.1296$^{NS}$ | 0.0166$^{NS}$ | -0.7388* | -0.4524$^{NS}$ |
| Two previous days | -0.7644** | -0.3956$^{NS}$ | 0.0716$^{NS}$ | -0.0497$^{NS}$ | -0.7980** | -0.3764$^{NS}$ |
| Day of anthesis + 3 previous | -0.7746** | -0.3101$^{NS}$ | 0.0049$^{NS}$ | -0.0892$^{NS}$ | -0.7512** | -0.3204$^{NS}$ |
| Three previous | -0.8593** | -0.1750$^{NS}$ | 0.2284$^{NS}$ | -0.1373$^{NS}$ | -0.8230** | -0.2122$^{NS}$ |
| Day of anthesis + 4 previous | -0.6235* | | -0.0658$^{NS}$ | | -0.6115* | |
| Four previous | -0.7069* | | -0.1140$^{NS}$ | | -0.6981* | |
| Day of anthesis + 5 previous | -0.5413$^{NS}$ | | -0.3120$^{NS}$ | | -0.5799$^{NS}$ | |
| Five previous | -0.6447* | | -0.4266$^{NS}$ | | -0.6984* | |
| Day of anthesis + 6 previous | -0.4999$^{NS}$ | | -0.1052$^{NS}$ | | -0.5094$^{NS}$ | |
| Six previous | -0.5710$^{NS}$ | | -0.1615$^{NS}$ | | -0.5876$^{NS}$ | |

NS = Not significant
* = Significant at the .05 probability level.
** = Significant at the .01 probability level.
*** = Significant at the .001 probability level.

coefficients continued to increase until they peaked at the total solar radiation for the three previous days, then they began to decrease. In all cases, a higher correlation coefficient was obtained for each combination of days when the day of anthesis was not included. A highly significant negative correlation of -.8593 was found between nectar volume and the solar radiation of the three previous days which indicated a 73.8% association. For the same time period, a highly significant negative correlation of -0.8230 was found for actual weight of sugar and solar radiation, which indicated a 67.7% association. After totaling the solar radiation for the five previous days, correlation coefficients for nectar volume and actual weight of sugar were no longer significant. At no time was there a significant correlation between solar radiation and nectar sugar concentration for either staminate or pistillate flowers. In staminate flowers, the only significant correlations obtained were between nectar volume and solar radiation for the previous day. There was also a significant correlation between solar radiation of the day before anthesis and actual weight of sugar.

When total solar radiation of the three days prior to anthesis was analyzed for correlation with the average daily nectar volume, a negative correlation coefficient of $-.2678^{N.S.}$ was obtained for staminate flowers and -.8563 (significant at the .01 probability level) for pistillate flowers. These coefficients indicated 7.2% and 73.3% association between the two variables, respectively. For the three day period prior to anthesis total solar radiation values ranged between 1035 and 1892 langleys, with a mean of 1464 in 1968 compared with 1074 to 1865 langleys and a mean of 1621 in 1969.

To further check on the data for pistillate flowers, nectar volume and actual weight of sugar for individual pistillate flowers was analyzed for correlations with solar radiation of the three days prior to anthesis. Highly significant negative correlations were again obtained, -0.4334 for volume and -0.4194 for actual weight of sugar. Sample sizes were 242 and 239, respectively. The flowers averaged 5.97 ul with a mean of 1445 langleys and 2.14 mg of sugar with a mean of 1441 langleys. These coefficients indicated 18.8% association between nectar volume and solar radiation and 17.6% between actual weight of sugar and solar radiation.

The affect of precipitation on nectar secretion in staminate flowers could not be determined, since it did not rain during the days of sampling, except for a trace on one day (Table 19). It rained on 9 of 22 days during the sampling of pistillate flowers in 1968 with precipitation varying from .01 to .91 inches. A total of 3.25 inches fell during the sampling period (Table 18). No significant correlation was evident between the average nectar volume, sugar concentration, and actual weight of sugar for pistillate flowers and precipitation on the day of anthesis (Table 27). A significant correlation was observed between the average volume of nectar and total precipitation for the day of anthesis plus the three previous days, and for the actual weight of sugar and the total precipitation of the three previous days. The first significant

TABLE 27.--The affect of precipitation on daily nectar secretion in cucumbers as determined by correlation coefficients.

| | Pistillate flowers | | | |
|---|---|---|---|---|
| | N | Avg. vol | Avg. % sugar | Avg. wt. |
| Day of anthesis | 21 | -0.1060$^{NS}$ | 0.0179$^{NS}$ | -0.1034$^{NS}$ |
| Previous day (2) | 21 | 0.1903$^{NS}$ | -0.0370$^{NS}$ | 0.1552$^{NS}$ |
| Day of anthesis & prev. (1&2) | 21 | 0.0509$^{NS}$ | -0.0121$^{NS}$ | 0.0275$^{NS}$ |
| Day of anthesis & 2 prev. (1-3) | 21 | 0.2937$^{NS}$ | -0.1072$^{NS}$ | 0.2451$^{NS}$ |
| Two previous (2&3) | 21 | 0.4100$^{NS}$ | -0.1316$^{NS}$ | 0.3550$^{NS}$ |
| Day of anthesis & 3 prev. (1-4) | 21 | 0.4499* | -0.2749$^{NS}$ | 0.3685$^{NS}$ |
| Three previous (2-4) | 21 | 0.5727** | -0.3175$^{NS}$ | 0.4807* |
| Day of anthesis & 4 prev. (1-5) | 21 | 0.5509** | -0.2399$^{NS}$ | 0.4730* |
| Four previous (2-5) | 21 | 0.6377** | -0.2599$^{NS}$ | 0.5553*** |
| Day of anthesis & 5 prev. (1-6) | 21 | 0.5218* | -0.1538$^{NS}$ | 0.4497* |
| Five previous (2-6) | 21 | 0.5909** | -0.1659$^{NS}$ | 0.5167* |
| (1-7) | 21 | 0.5033* | -0.1608$^{NS}$ | 0.4536* |
| (2-7) | 21 | 0.5114* | -0.1544$^{NS}$ | 0.4652* |
| (1-8) | 21 | 0.4065$^{NS}$ | -0.3599$^{NS}$ | 0.3527$^{NS}$ |
| (2-8) | 21 | 0.3924$^{NS}$ | -0.3057$^{NS}$ | 0.3457$^{NS}$ |
| (1-9) | 21 | 0.1683$^{NS}$ | -0.5216* | 0.0765$^{NS}$ |
| (2-9) | 21 | 0.1979$^{NS}$ | -0.4442* | 0.1200$^{NS}$ |

NS = Not significant
* = Significant at the .05 probability level.
** = Significant at the .01 probability level.
*** = Significant at the .001 probability level.

correlation between average sugar concentration and precipitation was with total precipitation for the day of anthesis plus the nine previous days. For both average volume and actual sugar weight, correlations were highest when compared to the precipitation of the four previous days. A highly significant positive correlation of .6377 was found for nectar volume and .5553 for sugar weight. These coefficients express 40.7 and 30.8% association between the two variables, respectively. Significance was no longer observed for either category after seven days prior to anthesis.

To further look at the affect of precipitation for four days prior to anthesis on nectar volume and actual weight of sugar, the data for individual flowers was analyzed. Highly significant positive correlations were found for both, 0.3088 (N = 519) for nectar volume and 0.3148 (N = 509) for actual weight of sugar. An average of 6.61 ul of nectar was produced when an average of 0.7 inches of rain fell during the four days prior to anthesis. An average of 2.47 mg of sugar was produced at the same time. There was 9.5% association between nectar volume and precipitation compared to 9.9% for actual weight of sugar.

Comparison of total precipitation for the four days prior to anthesis with the daily average volume of nectar produced, gave a significant positive correlation coefficient of .6594 for pistillate flowers and -0.0390 for staminate. This was not significant. Over the four day period in 1968, from 0.0 - 1.3 inches of rain fell with a mean of .7. In 1969 from 0.0 - 0.03 inches of rain fell with a mean of .01. An association of 43.5% was found between total precipitation and average daily volume of nectar in pistillate flowers.

The average daily wind speed fluctuated between 3.6 and 12.5 mph during the sampling of pistillate flowers in 1968. In 1969 when the staminate flowers were sampled, wind speed ranged between 3.0 and 10.8 mph. Comparison of the daily average wind speed with average daily volume of nectar, % sugar, and actual weight of sugar for both staminate and pistillate flowers did not produce significant correlations. The pistillate flowers averaged 5.89 ul of nectar (r - 0.0144) containing 33.4% sugar (r = 0.0096) with an actual weight of 2.18 mg (r = 0.0671). The mean wind speed during sampling was 7.8 mph. The staminate flowers averaged 4.47 ul of nectar (r = 0.5013) containing 45.1% sugar (r = 0.3033) with an actual average weight of 2.48 mg (r = 0.5565). The mean wind speed during sampling was 7.9 mph.

To further evaluate the effect of wind speed on nectar secretion, data from individual flowers were compared to the average wind speed at 7 a.m., 10 a.m., 1 p.m., and 4 p.m. In staminate flowers highly significant positive correlations were found between wind speed and both nectar volume and sugar concentration. A correlation coefficient of 0.1999 (N = 162) was found for nectar volume and 0.2050 (N = 160) for sugar concentration. These indicated 4.0 and 4.2% association, respectively. A significant positive correlation was also found for actual weight of sugar (r = 0.1661, N = 160) which indicated 2.8% association between the two variables. Staminate flowers averaged 5.08 ul of nectar containing 44.9% sugar with an actual weight of 2.84 mg while mean wind speed was 11.0 mph. In pistillate flowers, a significant negative correlation was found between wind speed and sugar concentration, (r = 0.1777, N = 196). Non-significant correlation coefficients of 0.0662 (N = 200) were found for nectar volume and 0.0613 (N = 196) for actual weight of sugar. Pistillate flowers averaged 6.6 ul of nectar containing 34.8% sugar with an actual weight of 2.38 mg when exposed to a mean wind speed of 10.6 mph.

## Foraging Activity in Relation to Flower Age

Comparison of fruit set between newly opened pistillate flowers and day-old flowers in the field during 1968 showed that bees generally do not work day-old flowers, even though they were not visited on the day of anthesis. Only 2.9% of the day-old pistillate flowers developed into fruit compared to 74.3% of the flowers exposed on the day of anthesis. The newly opened flowers and the day-old flowers were randomly mixed within the same group of plants. Fruit production indicated that honey bees were successfully pollinating fresh flowers, so they were carrying pollen to all flowers visited. The one fruit that did develop from a day-old flower may have resulted from parthenocarpic production. Seed counts were not taken. In 1969 40.0% of the fresh flowers set fruit compared to 7.0% for the day-old flowers. Examination of the two fruits that developed from day-old flowers showed that both had developed parthenocarpically. Day-old pistillate flowers in the field that were unbagged for 10 min intervals received no bee visits while the fresh flowers surrounding them were visited often.

## Sugar Concentration of Cucumber Nectar with Bee Visitation throughout the Day

The analysis of nectar from 495 honey bees foraging on cucumbers showed that the sugar concentration of the honey stomach contents did not significantly vary during the day. Average values ranged from 17.1% to 28.3% sugar (Table 28). The overall average was 24.5%. Morning values were highest, averaging 26.0% and the afternoons averaged 23.0%. Values peaked at 9-10 a.m. and 12-1 p.m.

TABLE 28.--Concentration of cucumber nectar in the honey stomachs of honey bees throughout the day.

| Time | Sample size | Avg. sugar concentration | Range of values |
|---|---|---|---|
| 8:00 - 9:00 | 58 | 22.7 ± 1.43 | 6.3 - 38.6 |
| 9:00 - 10:00 | 94 | 28.3 ± 0.98 | 6.9 - 46.5 |
| 10:00 - 11:00 | 70 | 27.0 ± 1.19 | 6.5 - 38.7 |
| 11:00 - 12:00 | 76 | 26.2 ± 1.30 | 6.8 - 40.0 |
| 12:00 - 1:00 | 97 | 27.5 ± 0.97 | 7.7 - 39.9 |
| 1:00 - 2:00 | 41 | 23.9 ± 1.77 | 7.1 - 38.3 |
| 2:00 - 3:00 | 27 | 23.3 ± 1.41 | 10.0 - 32.0 |
| 3:00 - 4:00 | 32 | 17.1 ± 1.55 | 2.6 - 33.7 |
| Overall | | 24.5 ± 1.28 | |

with a decrease throughout the rest of the afternoon. The range of values shows that the lowest sugar concentration of nectar carried by a bee was 2.6% and the highest 46.5%. Since some authors discard small samples with low sugar concentrations when analyzing honey stomach contents, the data used in Table 28 was reanalyzed, excluding any value less than 10% (Table 29). No new trends were found. Daily

TABLE 29.--Concentration of cucumber nectar in the honey stomachs of honey bees after removal of low values.

| Time | Sample size | Avg. sugar concentration |
|---|---|---|
| 8:00 - 9:00 | 45 | 26.9 ± 1.28 |
| 9:00 - 10:00 | 84 | 30.7 ± 0.74 |
| 10:00 - 11:00 | 64 | 28.8 ± 1.06 |
| 11:00 - 12:00 | 66 | 28.8 ± 1.18 |
| 12:00 - 1:00 | 88 | 29.4 ± 0.83 |
| 1:00 - 2:00 | 34 | 27.0 ± 1.67 |
| 2:00 - 3:00 | 27 | 23.3 ± 1.41 |
| 3:00 - 4:00 | 22 | 21.2 ± 1.60 |

variation in sugar concentration was not significantly different from the overall mean (Table 30). Daily averages varied between 22.9 and 27.8% sugar.

TABLE 30.--Daily variation in the concentration of cucumber nectar found in the honey stomachs of honey bees.

| Date | Sample size | Avg. sugar concentration |
|---|---|---|
| 8-5-70 | 10 | 24.9 ± 2.18 |
| 8-6-70 | 109 | 25.3 ± 0.91 |
| 8-7-70 | 15 | 27.5 ± 2.41 |
| 8-10-70 | 99 | 27.8 ± 1.04 |
| 8-11-70 | 128 | 27.1 ± 0.90 |
| 8-12-70 | 56 | 22.9 ± 1.51 |
| 8-13-70 | 62 | 24.1 ± 1.43 |

## Foraging Activity in Relation to Flower Sex

Following bees in the field as they foraged on staminate and pistillate flowers indicated that they had a slight preference for staminate flowers (Table 31). At the time the bees were followed, the staminate:pistillate flower ratio was determined and compared to the bee's foraging ratio. Overall, flowering in the fields gave a mean staminate:pistillate flower ratio of 1.46. A total of 290 bees were followed, as they visited 2441 flowers giving a mean staminate:pistillate flower foraging ratio of 3.03. Comparison of the two mean ratios indicated that the bees visited 2.08 times more staminate than pistillate flowers. During the 10 days of sampling, a floral preference for staminate flowers was exhibited on seven days. Preferences

TABLE 31.--Foraging behavior in relation to staminate and pistillate cucumber flowers in the field.

| Date | Staminate flowers | Pistillate flowers | Field s/p ratio | No. of bees followed | Flowers visited | Staminate flowers | Pistillate flowers | Foraging s/p ratio |
|---|---|---|---|---|---|---|---|---|
| 7-14-69 | 33 | 16 | 2.06 | 4 | 35 | 38 | 7 | 4.00 |
| 8-27-69 | 70 | 28 | 2.50 | 8 | 162 | 145 | 17 | 8.52 |
| 7-13-71 | 192 | 259 | 0.74 | 28 | 181 | 103 | 78 | 1.32 |
| 7-14-71 | 67 | 60 | 1.12 | 33 | 360 | 289 | 71 | 4.07 |
| 7-16-71 | 109 | 79 | 1.38 | 66 | 598 | 495 | 103 | 4.80 |
| 7-21-71 | 184 | 60 | 3.07 | 50 | 396 | 316 | 80 | 3.95 |
| 7-22-71 | 56 | 37 | 1.51 | 11 | 77 | 38 | 39 | 0.97 |
| 7-23-71 | 61 | 53 | 1.15 | 54 | 280 | 180 | 100 | 1.80 |
| 8-25-71 | 57 | 99 | 0.58 | 20 | 212 | 64 | 148 | 0.43 |
| 7-24-74 | 31 | 58 | 0.53 | 16 | 140 | 40 | 100 | 0.40 |
| Mean | | | 1.46 | | | | | 3.03 |

on those days for the staminate flower ranged from 1.29 - 3.63 times that of the staminate:pistillate flower ratio available in the field.

For days in which sampling occurred in both mornings and afternoons, the data were analyzed to see if honey bees preferred staminate flowers during the entire day (Table 32). In the morning, the mean staminate:pistillate flower foraging ratio was 2.30 compared to 3.06 for the afternoon. Five out of six days of sampling showed increased preference for staminate flowers in the afternoon. Using daily comparisons, increased preferences ranged from 1.09 to 1.59 times greater. During the morning, the maximum number of observed flower visits by one bee on one trip was 38 compared to 37 for the afternoon.

In 1974 the number of flowers of each sex was maintained at a 50:50 ratio so if bees indicated a floral preference, it could be monitored. Results indicated that bees exhibit floral preferences which change during the day (Table 33). Overall, results indicated that from 7 - 9 a.m., the pistillate flower was more attractive than the staminate with s/p ratios of .63 and .60. Evidence for this was observed at the East Lansing plots, but not at Eaton Rapids. No bee activity was noted at Mulliken while sampling in 1974. In addition to counting the number of visits to 10 marked flowers, other observations yielded similar results. On August 23, 1974, (8:45 a.m.) a honey bee was followed as it foraged at East Lansing. In 11 min and 46 sec 38 flowers were visited. She visited one out of every five staminate flowers that she approached. During the same morning

TABLE 32.--Comparison of morning and afternoon foraging behavior in relation to staminate and pistillate cucumber flowers in the field.

| Date | Field s/p ratio | Staminate flowers visited | Pistillate flowers visited | Morning visits, s/p ratio | Staminate flowers visited | Pistillate flowers visited | Afternoon visits s/p ratio |
|---|---|---|---|---|---|---|---|
| 7-14-71 | 1.12 | 111 | 34 | 3.26 | 178 | 37 | 4.81 |
| 7-16-71 | 1.38 | 252 | 64 | 3.93 | 243 | 39 | 6.23 |
| 7-21-71 | 3.07 | 249 | 65 | 3.83 | 67 | 15 | 4.47 |
| 7-23-71 | 1.15 | 49 | 29 | 1.69 | 131 | 71 | 1.85 |
| 8-24-71 | -- | 35 | 50 | 0.70 | 80 | 134 | 0.60 |
| 7-24-74 | 0.53 | 9 | 25 | 0.36 | 31 | 75 | 0.41 |
| Mean | | | | 2.30 | | | 3.06 |

TABLE 33.--Hourly foraging activity in relation to staminate and pistillate cucumber flowers.

| Location | Number of bee visits/10 flowers/hour | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 - 8 | 8 - 9 | 9 - 10 | 10 - 11 | 11 - 12 | 12 - 1 | 1 - 2 | 2 - 3 | 3 - 4 |
| Eaton Rapids | | | | | | | | | |
| Staminate visits | 18 | 64 | 232 | 410 | 488 | 488 | 360 | 206 | 130 |
| Pistillate visits | 8 | 60 | 238 | 362 | 396 | 372 | 292 | 150 | 88 |
| s/p ratio | 2.25 | 1.07 | .98 | 1.13 | 1.23 | 1.31 | 1.23 | 1.37 | 1.48 |
| East Lansing | | | | | | | | | |
| Staminate visits | 20 | 98 | 560 | 702 | 830 | 684 | 606 | 358 | 218 |
| Pistillate visits | 52 | 212 | 508 | 646 | 782 | 596 | 452 | 252 | 154 |
| s/p ratio | .38 | .46 | 1.10 | 1.09 | 1.06 | 1.15 | 1.34 | 1.42 | 1.42 |
| Mulliken | | | | | | | | | |
| Staminate visits | 0 | 0 | 8 | 32 | 88 | 68 | 62 | 54 | 26 |
| Pistillate visits | 0 | 0 | 4 | 6 | 16 | 32 | 30 | 32 | 12 |
| s/p ratio | 0.0 | 0.0 | 2.0 | 5.33 | 5.50 | 2.13 | 2.07 | 1.69 | 2.17 |
| Overall | | | | | | | | | |
| Staminate visits | 38 | 162 | 800 | 1144 | 1406 | 1240 | 1028 | 618 | 374 |
| Pistillate visits | 60 | 272 | 750 | 1014 | 1194 | 1000 | 774 | 434 | 254 |
| s/p ratio | .63 | .60 | 1.07 | 1.13 | 1.18 | 1.24 | 1.33 | 1.42 | 1.47 |

from 7 to 9 a.m., the five tagged pistillate flowers received 20 visits compared to 8 for the five tagged staminate flowers.

After 9 a.m. staminate flowers were preferred and preference increased throughout the day, going from a ratio of 1.07 to 1.47. Foraging patterns at Eaton Rapids, East Lansing, and Mulliken were not identical. Other than the first two hours at East Lansing and from 9 - 10 at Eaton Rapids, all other sampling times showed a preference for staminate flowers. At Eaton Rapids, foraging s/p ratios were between .98 and 2.25, compared to .38 - 1.42 at East Lansing and 1.69 to 5.50 at Mulliken. Values fluctuated within these ranges throughout the day. A total of 4362 visits were recorded at Eaton Rapids, 7730 at East Lansing, and 470 at Mulliken, with overall s/p foraging ratios of 1.22, 1.12, and 2.56 respectively. For the entire study, 12,562 visits were recorded with a foraging ratio of 1.18.

## Distribution of Cucumber Pollen on the Honey Bee's Body

Cucumber pollen was found primarily on the mouthparts, ventral surface of the thorax, and legs. Some was found on all eight of the regions mentioned in Table 34. Most was found on mouthparts and metalegs. An equal number of bees had pollen on the prolegs, mesolegs, and metalegs which would indicate they were attempting to discard pollen or move it back to the corbicula. Fewer bees had pollen in the neck region (36.0%), face (56.8%), and the ventral surface of the abdomen (61.0%). Occasionally, pollen grains from other plant species were found on the bees body. Bees taken from pistillate flowers had pollen more widely distributed on the eight

TABLE 34.--The location of cucumber pollen on the honey bee's body.

| Body region | Number of bees with cucumber pollen | % | Number with large amounts of cucumber pollen | % |
|---|---|---|---|---|
| Face | 134 | 56.8 | 0 | 0.0 |
| Mouthparts | 220 | 93.2 | 45 | 19.1 |
| Neck | 85 | 36.0 | 0 | 0.0 |
| Thorax - underside | 212 | 89.8 | 0 | 0.0 |
| Prolegs | 231 | 97.9 | 1 | 0.4 |
| Mesolegs | 231 | 97.9 | 5 | 2.1 |
| Metalegs | 230 | 97.5 | 50 | 21.2 |
| Abdomen - underside | 144 | 61.0 | 1 | 0.4 |

N = 236

areas than those from staminate flowers (Table 35). However, this wider distribution of pollen was found on areas of the body not involved with pollination; including the face, neck, and mesolegs. Of the bees from pistillate flowers, 30% had pollen located on the ventral surface of the thorax compared to 15% from staminate flowers. Nearly all bees had cucumber pollen on the mouthparts and prolegs.

## The Number of Bee Visits Needed for Adequate Pollination

. To determine the amount of effective pollen placed on the stigma with each flower visit and the relationship between number of flower visits and fruit set, a total of 2776 bee visits were observed on 339 pistillate flowers. Overall, 72.0% of the flowers visited set fruit (Table 36). From these fruit, a total of 48,576 seeds were counted. Based on seed count, each bee visit placed a minimum of 18 effective pollen grains on the stigma. However, the first visit placed significantly more pollen on the stigma, than succeeding visits; 129 pollen grains for first visits compared to 33 or less for succeeding visits (Table 37). Flowers receiving more than one visit averaged 16 pollen grains per visit. As the number of visits increased from five to twenty, the average number of effective pollen grains deposited on the stigma per visit decreased from 33 to 12.

A large portion of the stigma may be coated with pollen during the first visit and with each succeeding visit, there is significantly less receptive surface. This is partially substantiated by noting that flowers receiving one visit had the largest range of seeds, from 1-546, with 546 seeds in a fruit being the maximum number of seeds

TABLE 35.--Cucumber pollen distribution on the bodies of honey bees taken from staminate and pistillate cucumber flowers.

| Body region | Pistillate flowers | Staminate flowers |
|---|---|---|
| | % with cucumber pollen | % with cucumber pollen |
| Face | 57.0 | 39.0 |
| Mouthparts | 100.0 | 100.0 |
| Neck | 64.0 | 33.0 |
| Thorax - underside | 30.0 | 15.0 |
| Prolegs | 88.0 | 91.0 |
| Mesolegs | 21.0 | 4.0 |
| Metalegs | 2.0 | 1.0 |
| Abdomen - underside | 2.0 | 1.0 |
| Overall Means | 45.5 $\pm$ 17.2 | 35.5 $\pm$ 13.4 |

N = 100

TABLE 36.--Percentage fruit set, average seed counts, and fruit shape as affected by number of bee visits in cucumbers.

| Number of visits per flower | Sample size | Number of fruit set | Percentage fruit set | Fruit Shape | | | Seed Counts | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | % perfect | % nubs | % necks | Minimum | Maximum | Mean |
| One | 71 | 31 | 43.7 | 80.6 | 3.2 | 16.1 | 1 | 546 | $129 \pm 24^{ab}$ |
| Five | 71 | $48^{x}$ | 67.6 | 79.2 | 4.2 | 16.6 | 3 | 515 | $163 \pm 20^{bc}$ |
| Ten | 66 | 52 | 78.8 | 73.1 | 3.8 | 23.1 | 17 | 516 | $196 \pm 17^{acde}$ |
| Fifteen | 66 | 54 | 81.8 | 79.6 | 3.7 | 16.7 | 13 | 487 | $227 \pm 18^{ef}$ |
| Twenty | 65 | 59 | 90.8 | 91.5 | 0.0 | 8.5 | 42 | 495 | $246 \pm 16^{df}$ |
| Total | 339 | 244 | 72.0 | 81.1 | 2.9 | 16.0 | 1 | 546 | 200 |

Number of bee visits versus seed counts ($r = 0.2928$***, df = 241)
***Significant at the .001 probability level.
Mean seed counts in each column followed by the same small letter are not significantly different at the 5% probability level. (Student - Newman - Keuls multiple comparison test).

x-1 fruit developed, but rotted in field before seed counts were taken.

Developed fruis vs. non-developed - significant at the 0.005 probability level. $X^2 = 44.96$ with 4 degrees of freedom.

Developed fruit vs. total - not significant at the .05 probability level. $X^2 = 8.02$ with 4 degrees of freedom.

Perfect shaped fruit vs. imperfect - not significant at the .05 probability level. $X^2 = 6.58$ with 4 degrees of freedom.

Perfect shaped fruit vs. total - not significant at the .05 probability level. $X^2 = 0.67$ with 4 degrees of freedom.

TABLE 37.--Amounts of pollen placed on the stigma of a pistillage cucumber flower during varying numbers of bee visits as indicated by number of seeds produced.

| Number of visits per flower | Number of fruit set | Total number of seeds | Total number of visits | Avg number of effective pollen grains per visit |
|---|---|---|---|---|
| One | 31 | 3997 | 31 | 129 |
| Five | 47 | 7670 | 235 | 33 |
| Ten | 52 | 10178 | 520 | 20 |
| Fifteen | 54 | 12243 | 810 | 15 |
| Twenty | 59 | 14488 | 1180 | 12 |
| Total | 243 | 48576 | 2776 | 18 |

found during the study. Also 43.7% of the flowers receiving one visit, received enough pollen to set fruit (Table 36). The availability of pollen, however, would depend largely on the staminate: pistillate flower ratio in the field. Pollen levels at the beginning of the observations were certainly more than adequate (Table 38).

TABLE 38.--The flowering pattern of the cucumber cultivar Piccadilly prior to allowing a specified number of bee visits.

| Date | Number of pistillate flowers | Number of staminate flowers | s/p ratio |
|---|---|---|---|
| July 6, 1970 | 1 | 0 | -- |
| July 7, 1970 | 3 | 1 | .33 |
| July 8, 1970 | 2 | 21 | 10.50 |
| July 9, 1970 | 7 | 41 | 5.86 |
| July 10 & 11, 1970 | 44 | 114 | 2.59 |
| July 12 & 13, 1970 | 44 | 118 | 2.68 |
| July 14, 1970 | 88 | 210 | 2.39 |
| July 15, 1970 | 168 | 261 | 1.55 |
| July 16, 1970 | 109 | 324 | 2.97 |
| July 17, 1970 | 149 | 262 | 1.76 |
| July 18, 1970 | 109 | 126 | 1.16 |
| July 19, 1970 | 222 | 166 | 0.75 |
| July 20 & 21, 1970 | 283 | 278 | 0.98 |
| July 22, 1970 | 158 | 93 | 0.59 |
| July 23, 1970 | 165 | 63 | 0.38 |
| July 24, 1970 | 171 | 156 | 0.91 |
| July 25, 1970 | 223 | 192 | 0.86 |
| July 26, 1970 | 208 | 156 | 0.75 |
| July 27, 1970 | 350 | 308 | 0.88 |
| Overall | 2504 | 2890 | 1.15 |

Bee visits started on July 27.

From July 6, at the beginning of flowering, through July 27, the first day of observations, the overall staminate:pistillate flower ratio was 1.15, fluctuating between 0.33 and 10.50. In a second plot, pollen levels were even higher (Table 39). The overall

TABLE 39.--Flowering pattern of the June 30 planting of Piccadilly prior to the start of bee observations.

| Date | Number of pistillate flowers | Number of staminate flowers | s/p ratio |
|---|---|---|---|
| August 6, 1970 | 6 | 9 | 1.50 |
| August 7, 1970 | 8 | 16 | 2.00 |
| August 8, 1970 | 10 | 41 | 4.10 |
| August 9, 1970 | 14 | 63 | 4.50 |
| August 10, 1970 | 41 | 81 | 1.97 |
| August 11, 1970 | 32 | 92 | 2.87 |
| August 12, 1970 | 56 | 121 | 2.16 |
| August 13, 1970 | 58 | 91 | 1.56 |
| Overall | 225 | 514 | 2.28 |

Bee visits started on August 12.

average staminate:pistillate flower ratio was 2.28 ranging from 1.50 and 4.50.

Multiple visits increased fruit set and the average number of seeds per fruit (Table 36). With five visits, 67.7% of the flowers set fruit compared to 78.8% for ten visits, 81.8% for fifteen, and 90.8% for twenty. A highly significant postive correlation was found between number of bee visits and seed counts. A correlation coefficient of .2928 (significant at the .001 probability level) indicated 8.6% association between the two variables. Average seed counts ranged from 129 seeds per fruit for one flower visit to 246 seeds for 20 visits. The overall mean was 200 seeds per fruit. Flowers receiving five visits averaged 163 seeds, compared to 196 for ten visits, and 227 for fifteen. Flowers receiving from 1 - 15 visits produced perfectly shaped fruit 73.1 - 80.6% of the time. The number of perfectly shaped fruit did not increase with the number of bee visits. However, with twenty visits 90.8% of the fruit were perfectly shaped, compared to 81.1% overall. From 8.5 to 23.1% of the fruit were necks (constricted at the stem end) compared to a range of 0.0 - 4.2% for nubs (constricted at the flower end). Overall, 2.9% of the fruit were nubs and 16.0% necks. Perfectly shaped fruit contained from 1 - 546 seeds with a mean of 221 (Table 40). Even though nubs

TABLE 40.--Average number of seeds obtained from three shapes of cucumbers.

| Shape | Sample size | Seed Counts | | |
|---|---|---|---|---|
| | | Minimum | Maximum | Mean |
| Perfect - no constriction | 197 | 1 | 546 | $221 \pm 10^{b}$ |
| Neck - constricted at stem end | 39 | 17 | 386 | $108 \pm 12^{a}$ |
| Nub - constricted at flower end | 7 | 34 | 256 | $130 \pm 34^{ab}$ |

NOTE: This table does not imply that the number of seeds determines the shape of the fruit. Values followed by the same small letter are not significantly different at the 0.05 probability level.

contained only 34 - 256 seeds with a mean of 130, they did not contain significantly fewer seeds than perfectly shaped fruit.

Neck-shaped fruit contained from 17 - 386 seeds, with a mean of 108 seeds, significantly fewer than the perfectly shaped fruit, but not the nubs.

Flowers visited from 10 - 10:30 a.m. set fruit 87.5% of the time with 96.4% of the fruit being perfectly shaped which is higher than the three later consecutive 30 min periods (Table 41). Each visit distributed a minimum average of 26 effective pollen grains on the stigma which is also higher than the other three time periods. Flowers visited from 10:30 - 12 set fruit 65.5 - 76.5% of the time, which indicates that flowers receiving visits earlier in the day have a better chance of setting fruit. Over the two hour period, there was a decrease in perfectly shaped fruit from 96.4% at 10 - 10:30 a.m. to 73.0% at 11:30 - 12 a.m. A similar decrease in the amount of pollen being distributed was also observed, averaging 26.0 pollen grains from 10 - 10:30 a.m. to 15.4 from 11:30 - 12. The mean number of seeds ranged from 174 to 223 seeds per fruit. However, these values have little meaning since each flower did not receive an equal number of visits.

Daily variation in percent fruit set ranged from 47.6 - 96.4% (Table 42). The percentage of perfectly shaped fruit during the same time fluctuated between 40.0 and 100.0% while the amount of pollen being distributed with each visit ranged between 9.5 and 46.7 grains. Comparison of the daily percent fruit set with the amount of pollen being distributed with each visit gave a significant positive correlation ($r = 0.5216$, $df = 14$) which indicated 27.2% association

TABLE 41.--The effect of time of day of pollination on percent fruit set, fruit shape, and seed count in cucumbers.

| Time of day | N | % fruit set | Fruit Shape | | | Seed Counts | | | Avg pollen grains per visit |
|---|---|---|---|---|---|---|---|---|---|
| | | | % perfect | % nubs | % necks | Minimum | Maximum | Mean | |
| 10:00 - 10:30 | 32 | 87.5 | 96.4 | 3.6 | 0.0 | 72 | 515 | $210 \pm 24$ | 26.0 |
| 10:31 - 11:00 | 109 | 70.6 | 84.4 | 2.6 | 13.0 | 13 | 487 | $223 \pm 16$ | 19.3 |
| 11:01 - 11:30 | 85 | 76.5 | 80.0 | 1.5 | 18.5 | 5 | 546 | $198 \pm 17$ | 15.6 |
| 11:31 - 12:00 | 113 | 65.5 | 73.0 | 4.0 | 23.0 | 1 | 496 | $174 \pm 15$ | 15.4 |

TABLE 42.--Daily variation in fruit set, shape, and amount of pollen being distributed with each bee visit in cucumbers.

| Date | Sample size | % fruit set | Fruit Shape | | | Mean no of seeds | Avg pollen gains/ visit |
|---|---|---|---|---|---|---|---|
| | | | % Perfect | % Necks | % Nubs | | |
| July 27, 1970 | 10 | 80.0 | 87.5 | 12.5 | 0.0 | 168 | 15.6 |
| July 28, 1970 | 21 | 66.7 | 92.9 | 7.1 | 0.0 | 174 | 12.8 |
| July 29, 1970 | 21 | 95.2 | 95.0 | 5.0 | 0.0 | 309 | 36.3 |
| July 30, 1970 | 31 | 71.0 | 81.8 | 13.6 | 4.6 | 191 | 16.6 |
| July 31, 1970 | 34 | 64.7 | 86.4 | 9.1 | 4.5 | 117 | 9.5 |
| August 1, 1970 | 19 | 68.4 | 69.2 | 30.8 | 0.0 | 168 | 15.4 |
| August 3, 1970 | 26 | 84.6 | 95.5 | 4.5 | 0.0 | 117 | 10.7 |
| August 4, 1970 | 14 | 85.7 | 83.3 | 16.7 | 0.0 | 362 | 46.7 |
| August 5, 1970 | 28 | 96.4 | 74.1 | 22.2 | 3.7 | 251 | 23.3 |
| August 6, 1970 | 23 | 73.9 | 81.3 | 6.2 | 12.5 | 167 | 13.0 |
| August 7, 1970 | 20 | 65.0 | 76.9 | 15.4 | 7.7 | 179 | 14.4 |
| August 10, 1970 | 16 | 62.5 | 50.0 | 50.0 | 0.0 | 182 | 14.0 |
| August 11, 1970 | 29 | 51.7 | 40.0 | 60.0 | 0.0 | 109 | 9.7 |
| August 12, 1970 | 15 | 80.0 | 100.0 | 0.0 | 0.0 | 318 | 21.8 |
| August 13, 1970 | 11 | 63.6 | 85.7 | 0.0 | 14.3 | 220 | 14.7 |
| August 14, 1970 | 21 | 47.6 | 90.0 | 10.0 | 0.0 | 220 | 22.7 |

between the two variables. However, when the amount of pollen being distributed with each visit was compared to the daily production of perfectly shaped fruit, the correlation coefficient was not significant ($r = 0.2726$, df = 14). There was also no significant correlation between daily fruit set and percent perfectly shaped fruit ($r = 0.4167$, df = 14).

Analysis showed that the node position after the sixth node did not significantly affect daily percent fruit set or production of perfectly shaped fruit (Table 43). A correlation coefficient of .02673 (df = 17) was found between node position and percent fruit set, compared to -0.2845 (df = 17) for node position and production of perfectly shaped fruit. For nodes 7 - 25, the percent fruit set ranged from 56.2 to 94.4% with 44.4 to 100.0% being perfectly shaped fruit. Flowers received from 10.1 to 41.6 effective pollen grains per visit.

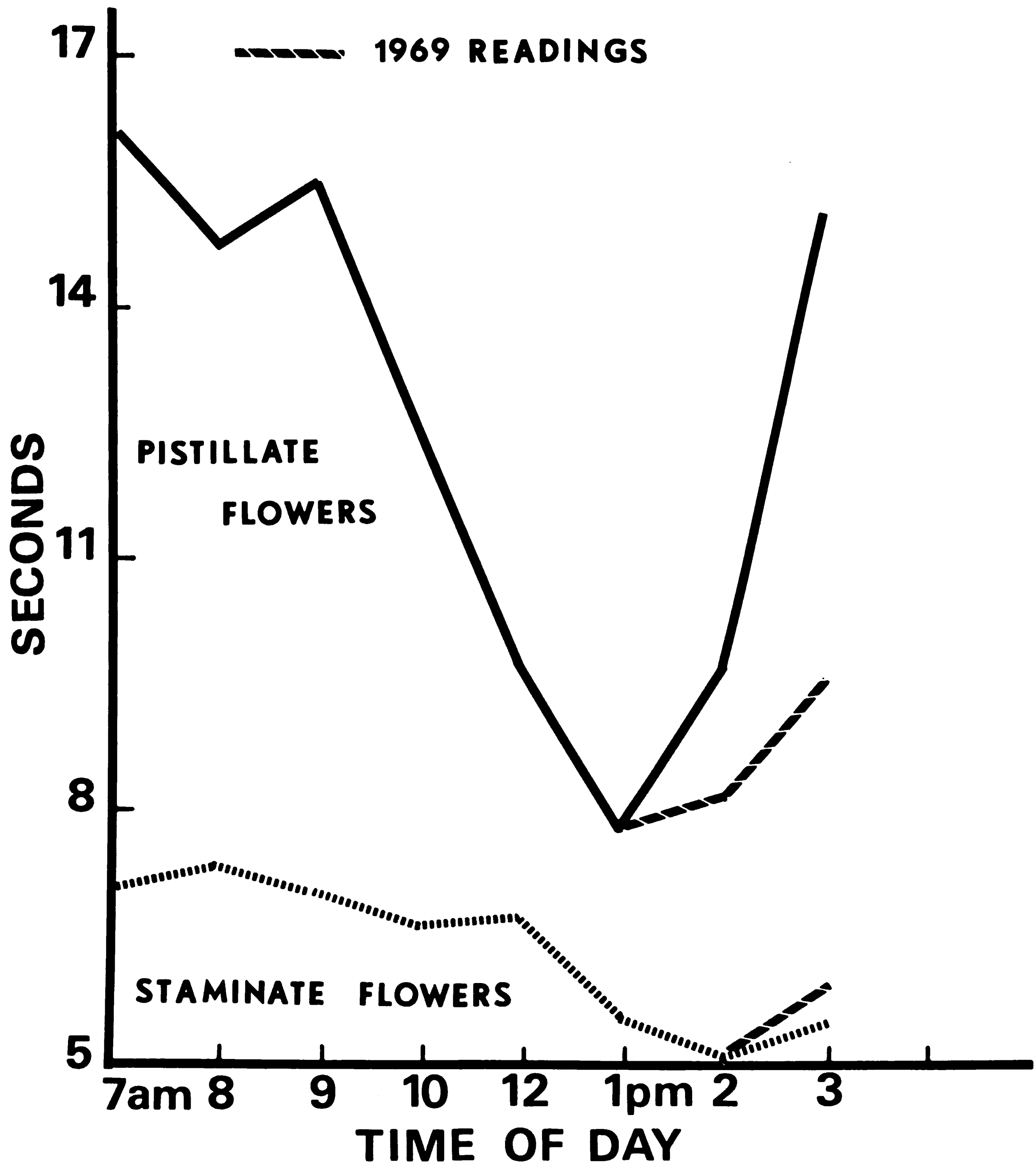
## The Timing of Honey Bees as They Foraged on Staminate and Pistillate Cucumber Flowers

Throughout the day honey bees spent twice as much time per visit on pistillate flowers as on staminate flowers (Figure 26). Honey bees averaged from 7.8 - 16.0 sec on pistillate flowers with an overall mean of 12.6 sec compared to 5.0 - 7.3 sec and a mean of 6.3 sec for staminate flowers. The average maximum time spent on pistillate flowers occurred between 7 - 8 a.m. and on staminate flowers from 8 - 9 a.m. Comparison of the morning and afternoon values shows that honey bees spent 1.86 - 2.25 times longer on

TABLE 43.--The effect of node position on fruit set and shape with competitive fruit removed in cucumbers.

| Node | N | % Fruit set | % Perfect shaped fruit | % Necks | % Nubs | Mean no. seeds | Total seeds | Pollen grains/ visit |
|---|---|---|---|---|---|---|---|---|
| 7 | 25 | 72.0 | 88.9 | 5.6 | 5.6 | 268 | 4825 | 22.1 |
| 8 | 8 | 62.5 | 100.0 | 0.0 | 0.0 | 258 | 1270 | 19.8 |
| 9 | 23 | 78.3 | 88.9 | 0.0 | 11.1 | 204 | 3678 | 18.0 |
| 10 | 14 | 57.1 | 100.0 | 0.0 | 0.0 | 200 | 1603 | 25.8 |
| 11 | 17 | 70.6 | 83.3 | 8.3 | 8.3 | 180 | 2156 | 22.4 |
| 12 | 15 | 60.0 | 88.9 | 11.1 | 0.0 | 177 | 1589 | 13.7 |
| 13 | 13 | 69.2 | 88.9 | 11.1 | 0.0 | 121 | 1085 | 10.1 |
| 14 | 15 | 73.3 | 72.7 | 27.3 | 0.0 | 209 | 2303 | 17.6 |
| 15 | 26 | 80.8 | 85.7 | 9.5 | 4.8 | 199 | 4171 | 16.6 |
| 16 | 25 | 80.0 | 65.0 | 35.0 | 0.0 | 126 | 2519 | 13.1 |
| 17 | 22 | 72.7 | 81.2 | 18.8 | 0.0 | 177 | 2825 | 16.9 |
| 18 | 18 | 94.4 | 88.2 | 11.8 | 0.0 | 252 | 4279 | 17.1 |
| 19 | 25 | 68.0 | 64.7 | 29.4 | 5.9 | 209 | 3337 | 19.6 |
| 20 | 21 | 76.2 | 75.0 | 25.0 | 0.0 | 210 | 3356 | 18.0 |
| 21 | 16 | 56.2 | 100.0 | 0.0 | 0.0 | 157 | 1409 | 16.0 |
| 22 | 12 | 75.0 | 44.4 | 55.6 | 0.0 | 205 | 1847 | 13.7 |
| 23 | 10 | 90.0 | 100.0 | 0.0 | 0.0 | 269 | 2422 | 33.6 |
| 24 | 11 | 81.8 | 66.7 | 33.3 | 0.0 | 197 | 1777 | 19.1 |
| 25 | 8 | 62.5 | 100.0 | 0.0 | 0.0 | 275 | 1373 | 41.6 |

Figure 26.--Comparison of the time spent on pistillate and staminate cucumber flowers by honey bees throughout the day.


1969 READINGS
17
14
11
8
5
SECONDS
PISTILLATE
FLOWERS
STAMINATE FLOWERS
7am 8 9 10 12 1pm 2 3
TIME OF DAY

pistillate than on staminate flowers in the morning compared to 1.42 - 2.73 times longer in the afternoon. Data from 2 - 4 p.m. for staminate flowers and 1 - 4 p.m. for pistillate flowers showed late day increases in the time spent on the flowers. Since sample sizes were small, additional data was taken in 1969. Once again late day increases were observed (Figure 26).

Analysis of the data on a daily basis, again indicated that honey bees spent more time per visit on pistillate than on staminate flowers (Figure 27). More variation was observed in the daily visits to pistillate than to staminate flowers due to smaller sample sizes. Daily average visit times throughout the day fluctuated between 3.4 and 12.8 sec for staminate flowers and between 6.1 and 19.7 sec for pistillate flowers. Except for early morning and late afternoon, the average time bees spent on the flowers decreased throughout the day.

During 1974, 150 bees were observed as they visited 2088 flowers, 541 pistillate and 1547 staminate (s/p ratio = 2.86). The bee visits totaled 23,726 sec or 11.4 sec per flower, which included both visiting time and flight time between flowers. Bees were successfully followed for 38 and 53 visits in the morning, 8:45 a.m. and 10:50 a.m. respectively. Higher counts were obtained in the afternoon, 60 visits at 1:43 p.m., 59 at 2:10 p.m., 55 at 3:10 p.m., and 63 at 3:59.

Throughout the day the hourly average number of seconds per flower visit fluctuated between 9.6 and 15.5 sec (Table 44). In the morning from 7 a.m. to 11 a.m. the bees averaged 15.2 sec per flower

Figure 27.--Average daily foraging time spent on staminate and pistillate cucumber flowers.

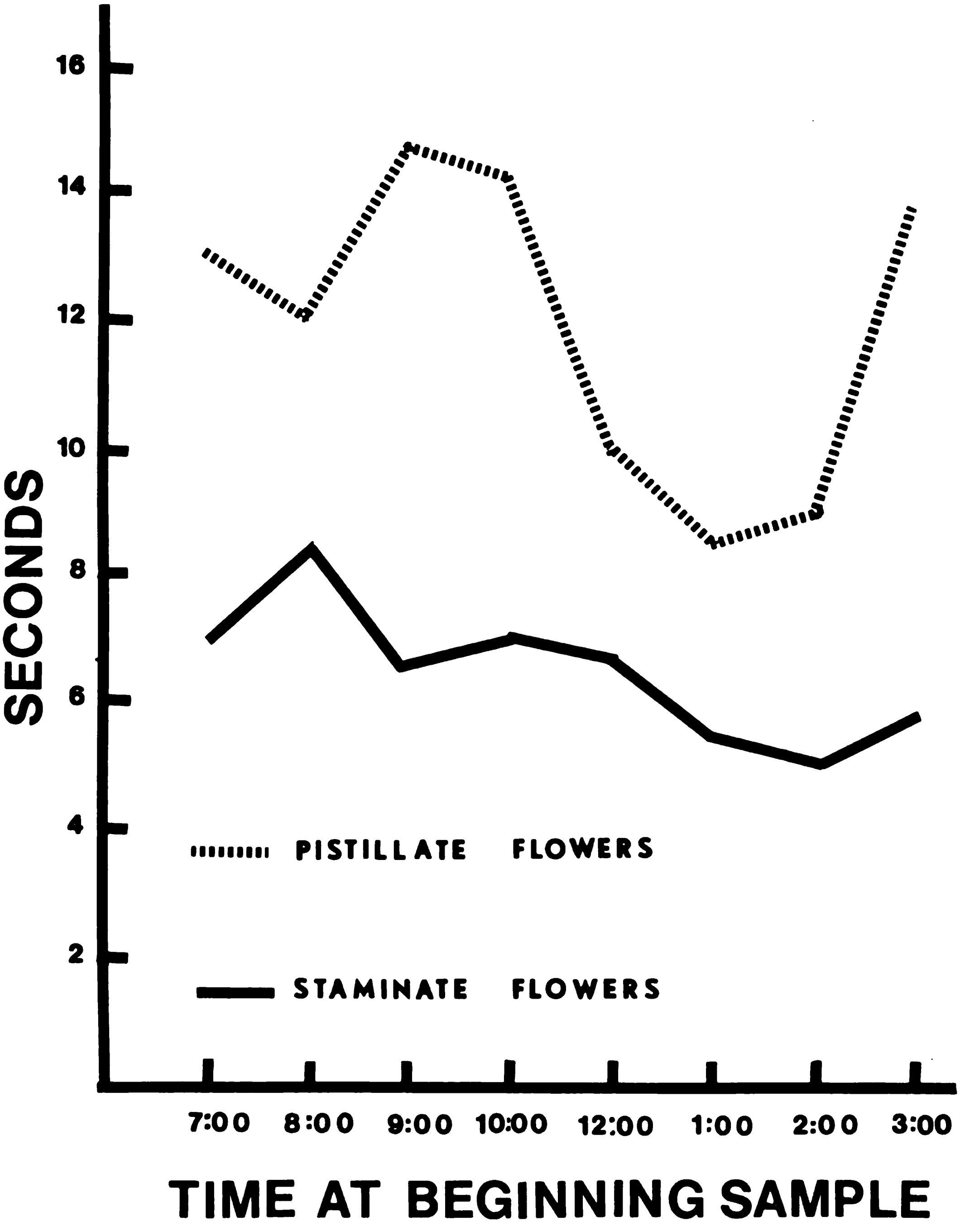

16
14
12
10
8
6
4
2
SECONDS
PISTILLATE FLOWERS
STAMINATE FLOWERS
7:00
8:00
9:00
10:00
12:00
1:00
2:00
3:00
TIME AT BEGINNING SAMPLE

TABLE 44.--The average visit time of a honey bee on cucumber flowers, throughout the day, including time in flight between flower visits.

| Time EST | No. of bees followed | No. of pistillate flowers visited | No. of staminate flowers visited | s/p ratio | Total flowers visited | Total sec | Number of sec/ flower | Mean sec/ flower/ bee |
|---|---|---|---|---|---|---|---|---|
| 7:00 - 8:00 | 4 | 37 | 40 | 1.08 | 77 | 1194 | 15.5 | 13.8 $\pm$ 1.8 |
| 8:00 - 9:00 | 17 | 39 | 108 | 2.77 | 147 | 2191 | 14.9 | 15.3 $\pm$ 2.0 |
| 9:00 - 10:00 | 11 | 31 | 106 | 3.42 | 137 | 2087 | 15.2 | 18.8 $\pm$ 4.6 |
| 10:00 - 11:00 | 8 | 28 | 75 | 2.68 | 103 | 1581 | 15.3 | 20.4 $\pm$ 4.3 |
| 11:00 - 12:00 | 12 | 66 | 118 | 1.79 | 184 | 1934 | 10.5 | 11.6 $\pm$ 1.7 |
| 12:00 - 1:00 | 30 | 92 | 339 | 3.68 | 431 | 4607 | 10.7 | 11.2 $\pm$ 0.7 |
| 1:00 - 2:00 | 32 | 98 | 348 | 3.55 | 446 | 4303 | 9.6 | 9.3 $\pm$ 0.4 |
| 2:00 - 3:00 | 28 | 120 | 339 | 2.82 | 459 | 4691 | 10.2 | 10.0 $\pm$ 0.6 |
| 3:00 - 4:00 | 8 | 30 | 74 | 2.47 | 104 | 1138 | 10.9 | 11.5 $\pm$ 0.7 |
| Overall | 150 | 541 | 1547 | 2.86 | 2088 | 23726 | 11.4 | 12.2 $\pm$ 0.6 |

visit compared to 10.3 sec for the rest of the day. Flower visits were shortest from 1 - 2 p.m., at 9.6 sec, then increased during the afternoon to 10.2 and 10.9 sec. The mean number of seconds/flower/bee increased each hour during the morning from 7 a.m. to 11 a.m. going from 13.8 to 20.4 sec. From 11 - 12 the average time was 11.6 sec decreasing to 9.3 sec at 1 - 2 p.m. Once again the mean number of seconds/flower/bee increased throughout the rest of the afternoon from 9.3 to 11.5 sec. The overall mean number of seconds/flower/bee was 12.2. The foraging staminate:pistillate flower ratio fluctuated throughout the day between 1.08 and 3.68. The mean s/p ratio from 7 - 11 a.m. was 2.48 compared to 2.86 in the afternoon. Comparison of the foraging staminate:pistillate flower ratio throughout the day with the number of seconds per flower gave a negative correlation coefficient of -0.2928 (df = 7) which was not significant. A similar comparison between the foraging s/p flower ratio and mean number of seconds/flower/bee also gave a non-significant negative correlation coefficient (r = -0.0278, df = 7).

Analysis of the data by plot location indicated that the foraging staminate:pistillate flower ratio affects the foraging rate (Table 45). However, the negative correlation between the foraging staminate:pistillate flower ratio and seconds per flower was not significant. Foraging s/p ratios ranged from 0.0 and 51.0 for the locations sampled. The bees took from 8.7 to 15.1 sec per flower visit which includes flight time between flowers. The mean number of seconds/flower/bee ranged between 10.0 and 15.5 sec.

TABLE 45.--The average time spent per flower visit throughout the day including flight time between flower visits at Eaton Rapids and East Lansing in cucumbers.

| Location | Number of bees followed | Pistillate flowers visited | Staminate flowers visited | s/p | Total flowers | Total sec | Sec/ flower | Mean sec/ flower/bee |
|---|---|---|---|---|---|---|---|---|
| Eaton Rapids | 28 | 109 | 143 | 1.31 | 252 | 3796 | 15.1 | 15.5 $\pm$ 1.6 |
| East Lansing Total | 122 | 432 | 1404 | 3.25 | 1836 | 19930 | 10.9 | 11.5 $\pm$ .6 |
| Art Well's Plots (E.L.) | 36 | 9 | 459 | 51.0 | 468 | 4078 | 8.7 | 10.0 $\pm$ 1.6 |
| Piccadilly and 9805 Plots (E.L.) | 86 | 423 | 945 | 2.23 | 1368 | 15852 | 11.6 | 12.1 $\pm$ .5 |
| Males visited only | 47 | 0 | 407 | 0.00 | 407 | 4053 | 10.0 | 11.0 $\pm$ 1.3 |

## The Size of the Foraging Area

A total of 413 bees were followed as they visited 5429 flowers. The maximum length covered by a single forager ranged from 32 to 60 ft, maximum width from 19 to 43 ft and the largest areas from 400 to 2280 sq ft (Table 46). Minimum length and width covered was one ft and the smallest area was one sq ft.

As the number of flower visits increased from 5 to 30, the average area covered by the forager also increased (Table 47). Foragers visiting from 5 - 10 flowers covered an average area of 59.9 sq ft, while those visiting 26 - 30 flowers covered an average area of 458.8 sq ft. A small number of bees visiting from 31 - 35 flowers averaged only 261 sq ft. With 35 - 40 visits, the average foraging area was 764.8 sq ft compared to 691.6 for over 40 visits. The mean average area covered for 5 - 25 visits was 180.1 sq ft compared to 544.1 sq ft for over 25 flower visits. The average area covered per flower visit ranged from 7.8 to 19.6 sq ft. The mean average area covered per flower visit for 5 - 25 visits was 11.3 sq ft compared to 14.2 sq ft for more than 26 flower visits.

Foraging areas were as large as 975 sq ft (mean 60 sq ft) for 5 - 10 visits on a single trip. Larger numbers of visits covered proportionately larger areas. With 36 - 40 visits a honey bee covered an area as large as 2064 sq ft (mean 765 sq ft). More than 40 flower visits by a single bee on a foraging trip were rarely observed.

The maximum average length covered on a foraging trip was 37.5 ft and maximum average width was 21 ft (Table 48). The average

TABLE 46.--Minimum and maximum distances and areas covered by the honey bee during foraging in cucumbers.

| Number of flower visits | Maximum length (ft) | Minimum length (ft) | Maximum width (ft) | Minimum width (ft) | Largest area (sq ft) | Smallest area |
|---|---|---|---|---|---|---|
| 5 - 10 | 39 | 1 | 25 | 1 | 975 | 1 |
| 11 - 15 | 38 | 4 | 23 | 1 | 494 | 8 |
| 16 - 20 | 44 | 6 | 27 | 3 | 1232 | 28 |
| 21 - 25 | 32 | 8 | 24 | 3 | 736 | 40 |
| 26 - 30 | 47 | 12 | 37 | 8 | 1739 | 96 |
| 31 - 35 | 50 | 12 | 19 | 5 | 400 | 100 |
| 36 - 40 | 60 | 22 | 43 | 3 | 2064 | 90 |
| Over 40 | 57 | 15 | 40 | 10 | 2280 | 195 |

TABLE 47.--Average area covered by a foraging honey bee in cucumbers.

| No. of flower visits | Sample size (No. bees) | Avg. area (sq ft) | Avg. sq ft/ flower visit |
|---|---|---|---|
| 5 - 10 | 223 | 59.9 ± 6.3 | 8.2 ± .8 |
| 11 - 15 | 73 | 147.8 ± 13.6 | 11.9 ± 1.1 |
| 16 - 20 | 56 | 253.0 ± 32.3 | 13.8 ± 1.7 |
| 21 - 25 | 22 | 259.8 ± 43.6 | 11.4 ± 1.9 |
| 26 - 30 | 16 | 458.8 ± 122.4 | 16.1 ± 4.2 |
| 31 - 35 | 7 | 261.0 ± 44.0 | 7.8 ± 1.3 |
| 36 - 40 | 6 | 764.8 ± 284.1 | 19.6 ± 7.0 |
| Over 40 | 10 | 691.6 ± 203.9 | 13.1 ± 3.6 |

TABLE 48.--Average length, width, and feet per flower visit covered by a foraging honey bee in cucumbers.

| No of visits | Sample size | Avg. length | ft/ visit | Avg. width | ft/ visit |
|---|---|---|---|---|---|
| 5 - 10 | 223 | 8.9 ± .4 | 1.19 | 5.2 ± .2 | 0.69 |
| 11 - 15 | 73 | 15.2 ± .7 | 1.17 | 8.9 ± .6 | 0.68 |
| 16 - 20 | 56 | 19.6 ± 1.2 | 1.09 | 11.4 ± .8 | 0.63 |
| 21 - 25 | 22 | 18.9 ± 1.4 | 0.82 | 12.3 ± 1.3 | 0.56 |
| 26 - 30 | 16 | 22.2 ± 2.7 | 0.79 | 17.3 ± 2.1 | 0.62 |
| 31 - 35 | 7 | 22.9 ± 4.7 | 0.69 | 13.6 ± 1.9 | 0.40 |
| 36 - 40 | 6 | 37.5 ± 6.0 | 0.99 | 19.0 ± 5.4 | 0.50 |
| Over 40 | 10 | 27.9 ± 3.9 | 0.54 | 21.2 ± 3.0 | 0.41 |

length and the average width increased with the number of flower visits. The average length fluctuated between 8.9 to 37.5 ft compared to 5.2 to 21.2 ft for the average width. Between 5 and 25 visits, the mean average length was 15.7 ft and the mean average width was 9.5 ft. For over 26 visits, the corresponding values were 27.6 and 17.8 ft respectively. During the same time interval the average distance covered between flower visits for both length and width decreased as the number of flower visits increased. For length, the average distance between flowers visited decreased from 1.19 to 0.54 ft. For width, the average distance between flowers visited decreased from 0.69 to 0.40 ft.

Regression analysis comparing the number of visits (5 - 24) to the average length, width, area, and square feet per flower visit gave highly significant positive correlations (Table 49). There was 84.2% association found between the number of bee visits and average length [r - .9176 (significant at the .001 probability level)], df = 18) compared to 80.0% between bee visits and average width (r = .8944, df = 18). A correlation coefficient of 0.8851 was found between number of flower visits and area compared to 0.6690 for the average square feet per visit indicating 78.3 and 44.8% association respectively.

Analysis of the hourly data indicated that the average length, width, area, and square feet per flower visit increased throughout the day (Table 50). The average length increased from 7.4 to 16.6 ft, average width from 5.1 to 10.9 ft, average area from 52.1 to

TABLE 49.--The average foraging area per bee with a specific number of visits to cucumber flowers.

| No. of visits | N | Avg. length | Avg. width | Avg. area sq ft | Avg. sq ft/visit |
|---|---|---|---|---|---|
| 5 | 56 | 6.2 ± .40 | 3.7 ± .30 | 25.9 ± 3.25 | 5.2 ± 0.64 |
| 6 | 46 | 10.2 ± 1.70 | 5.1 ± 0.42 | 56.1 ± 10.37 | 9.1 ± 1.71 |
| 7 | 37 | 10.1 ± 1.40 | 5.1 ± 0.66 | 62.5 ± 16.35 | 8.9 ± 2.33 |
| 8 | 34 | 8.7 ± 0.67 | 5.2 ± 0.37 | 49.1 ± 6.96 | 6.1 ± 0.86 |
| 9 | 33 | 12.1 ± 1.31 | 7.4 ± 0.91 | 118.9 ± 31.33 | 10.0 ± 1.90 |
| 10 | 17 | 12.3 ± 1.33 | 6.8 ± 0.63 | 83.5 ± 11.64 | 8.3 ± 1.16 |
| 11 | 25 | 14.4 ± 1.39 | 8.4 ± 1.04 | 142.8 ± 28.20 | 13.0 ± 2.56 |
| 12 | 14 | 16.1 ± 1.66 | 10.2 ± 1.55 | 152.6 ± 27.44 | 12.7 ± 2.29 |
| 13 | 11 | 15.4 ± 1.47 | 8.9 ± 1.61 | 155.6 ± 33.03 | 12.0 ± 2.54 |
| 14 | 12 | 16.0 ± 1.25 | 10.2 ± 1.38 | 163.8 ± 26.38 | 11.7 ± 1.88 |
| 15 | 11 | 15.0 ± 1.76 | 7.6 ± 1.25 | 127.4 ± 34.57 | 8.5 ± 2.30 |
| 16 | 13 | 16.3 ± 1.37 | 11.4 ± 1.31 | 197.7 ± 32.35 | 12.4 ± 2.02 |
| 17 | 6 | 19.7 ± 1.94 | 10.8 ± 1.82 | 223.5 ± 51.10 | 13.1 ± 3.01 |
| 18 | 11 | 18.7 ± 2.39 | 11.3 ± 1.87 | 242.7 ± 63.73 | 13.5 ± 3.54 |
| 19 | 12 | 21.8 ± 3.11 | 10.8 ± 2.09 | 279.3 ± 93.67 | 14.6 ± 4.94 |
| 20 | 14 | 21.4 ± 3.24 | 11.9 ± 1.62 | 296.0 ± 81.71 | 15.2 ± 4.18 |
| 21 | 3 | 18.0 ± 5.69 | 15.7 ± 4.63 | 333.7 ± 185.94 | 15.9 ± 8.86 |
| 22 | 7 | 17.1 ± 1.68 | 9.6 ± 1.36 | 165.6 ± 28.38 | 7.5 ± 1.29 |
| 23 | 4 | 20.0 ± 1.23 | 13.0 ± 0.91 | 257.8 ± 14.47 | 11.2 ± 0.63 |
| 24 | 5 | 25.0 ± 2.61 | 17.6 ± 2.77 | 464.2 ± 108.88 | 19.3 ± 4.54 |
| Greater than 24 | 42 | 25.1 ± 2.00 | 17.0 ± 1.45 | 497.1 ± 81.13 | 13.5 ± 2.11 |
| | | r = .9176 | r = .8944 | r = .8851 | r = .6690 |
| | | t = 9.79*** | t = 8.49*** | t = 8.07*** | t = 3.82** |

** = Significant at the .01 probability level.
*** = Significant at the .001 probability level.

TABLE 50.--Foraging profile of the honey bee in cucumbers throughout the day.

| Time of day EST | Sample size | Avg. no. visits | Avg. length | Avg. width | Avg. area | Avg. sq. ft/visit |
|---|---|---|---|---|---|---|
| 8:00 - 9:00 | 31 | 9.7 ± 1.26 | 7.4 ± .90 | 5.1 ± .70 | 52.1 ± 14.86 | 4.2 ± .60 |
| 9:00 - 10:00 | 71 | 12.5 ± .93 | 12.4 ± 1.07 | 7.0 ± .67 | 119.6 ± 26.34 | 7.7 ± 1.05 |
| 10:00 - 11:00 | 69 | 14.4 ± 1.36 | 13.2 ± .98 | 8.3 ± .82 | 155.6 ± 29.97 | 9.0 ± 1.17 |
| 11:00 - 12:00 | 68 | 14.9 ± 1.47 | 13.4 ± .92 | 8.7 ± .86 | 143.8 ± 21.89 | 9.3 ± 1.07 |
| 1:00 - 2:00 | 53 | 15.4 ± 1.34 | 16.6 ± 1.35 | 10.1 ± .88 | 207.4 ± 41.71 | 12.6 ± 1.33 |
| 2:00 - 3:00 | 56 | 10.9 ± 1.19 | 14.8 ± 1.50 | 7.4 ± .88 | 166.1 ± 45.87 | 11.6 ± 1.76 |
| 3:00 - 4:00 | 51 | 11.5 ± .94 | 15.0 ± 1.40 | 10.4 ± 1.01 | 213.6 ± 37.32 | 16.8 ± 2.78 |
| 4:00 - 5:00 | 10 | 12.9 ± 1.31 | 15.9 ± 1.72 | 10.9 ± 1.87 | 199.9 ± 49.41 | 15.4 ± 3.51 |
| Morning | 239 | 13.4 | 12.2 | 7.6 | 128.1 | 8.1 |
| Afternoon | 170 | 12.6 | 15.5 | 9.3 | 195.2 | 13.7 |
| Overall | 413* | 13.1 | 13.6 | 8.3 | 156.4 | 10.4 |

*Includes four observations made between 12 - 1.

213.6 sq ft, and the average square feet per flower visit from 4.2 to 16.8 sq ft. In the morning the honey bees that were followed averaged 13.4 flower visits totalling an average length of 12.2 ft, average width of 7.6 ft, an average area 128.1 sq ft and 8.1 sq ft per flower visit. During the afternoon honey bees moved greater distances to visit fewer flowers. An average of 12.6 flowers were visited, requiring an average length of travel of 15.5 ft, average width of 9.3 ft, average area of 195.2 sq ft and 13.7 sq ft per flower visited. The average length covered in the afternoon was 1.27 times greater than the morning, average width 1.22 times greater, average area 1.52 times greater and square feet per visit 1.69 times greater. Overall each honey bee averaged 13.1 flower visits covering an average field distance of 13.6 ft, an average width of travel of 8.3 ft, an average area of 156.4 sq ft and 10.4 sq ft per flower visit.

Daily foraging mobility varied greatly from day to day (Table 51). The average daily length covered by the bee fluctuated between 8.3 and 23.5 ft with a range of 4.6 - 16.0 ft for the average width. The daily average area covered showed even a greater fluctuation, going from 56.7 to 393.0 sq ft. From 5.2 to 27.2 sq ft were covered with each flower visit.

## The Movement of Cucumber Pollen by Honey Bees

A total of 8611 pickles were harvested from 4834 plants with two harvests in the 1969 pollen movement strips, which was an average of 1.78 pickles per plant. Plant populations for each of 24

TABLE 51.--Daily foraging profile of the honey bee in cucumbers.

| Date | N | Avg. visits | Avg. length | Avg. width | Avg. area | Avg. sq ft/visit |
|---|---|---|---|---|---|---|
| 7-31 | 8 | 10.8 ± 4.22 | 23.5 ± 5.00 | 11.6 ± 4.53 | 393.0 ± 241.67 | 27.2 ± 6.82 |
| 8- 1 | 3 | 26.0 ± 14.97 | 20.7 ± 8.17 | 11.7 ± 8.21 | 375.0 ± 330.71 | 9.1 ± 4.88 |
| 8- 4 | 20 | 14.0 ± 1.70 | 20.1 ± 2.20 | 11.6 ± 1.10 | 256.9 ± 51.41 | 19.8 ± 4.85 |
| 8- 5 | 13 | 14.0 ± 2.42 | 16.0 ± 2.38 | 10.3 ± 1.72 | 181.2 ± 44.43 | 14.8 ± 5.43 |
| 8- 6 | 22 | 15.5 ± 2.53 | 16.4 ± 2.47 | 8.8 ± 1.67 | 224.1 ± 100.43 | 9.8 ± 1.76 |
| 8- 7 | 29 | 18.7 ± 2.20 | 16.3 ± 1.71 | 9.6 ± 1.33 | 204.2 ± 48.05 | 10.1 ± 1.91 |
| 8- 8 | 52 | 15.9 ± 1.37 | 18.7 ± 1.69 | 10.6 ± 1.10 | 259.0 ± 49.47 | 13.6 ± 1.86 |
| 8- 9 | 6 | 22.7 ± 3.98 | 19.7 ± 1.42 | 10.8 ± 1.61 | 220.7 ± 42.69 | 9.7 ± 1.19 |
| 8-10 | 7 | 21.1 ± 4.37 | 17.1 ± 2.05 | 10.3 ± 1.20 | 186.4 ± 41.61 | 9.8 ± 2.04 |
| 8-11 | 21 | 11.0 ± 0.99 | 16.5 ± 1.61 | 10.3 ± 1.18 | 194.6 ± 33.50 | 17.5 ± 2.88 |
| 8-12 | 4 | 13.5 ± 2.87 | 19.0 ± 4.10 | 16.0 ± 3.74 | 348.5 ± 131.94 | 22.6 ± 5.33 |
| 8-13 | 53 | 15.0 ± 1.17 | 13.8 ± 1.05 | 9.7 ± .96 | 161.5 ± 27.82 | 10.6 ± 1.59 |
| 8-14 | 5 | 8.0 ± 1.76 | 10.6 ± 3.55 | 4.6 ± 1.46 | 60.2 ± 27.97 | 6.1 ± 2.05 |
| 8-15 | 35 | 9.0 ± 0.88 | 11.1 ± 1.24 | 6.8 ± 0.92 | 110.8 ± 29.14 | 10.2 ± 1.83 |
| 8-18 | 85 | 10.1 ± 1.04 | 8.5 ± 0.44 | 5.3 ± 0.38 | 56.7 ± 8.44 | 5.2 ± 0.46 |
| 8-19 | 50 | 10.2 ± 1.14 | 8.3 ± .70 | 5.6 ± 0.54 | 59.0 ± 9.43 | 5.3 ± 0.67 |

ten-foot sections ranged from 116 - 244 plants with a mean of 193 ± 6.1 plants. The total number of pickles produced within each 10-foot section ranged from 217 - 675 with a mean of 344 ± 24.1. Peak production of fruit occurred at 0 - 10 ft from the pollen source with an average of 4.14 fruit per plant. From that point on, fruit production decreased as the distance from the pollen source increased up to 90 ft; going from 3.33 to 0.96 fruit per plant. From 91 - 240 ft from the pollen source, fruit production increased starting at 1.00 fruit per plant and ending at 2.62 (Table 52). Fruit production in the first 30 ft averaged from 4.14 - 2.28 fruit per plant (mean 3.29) compared to a range of 2.05 - 0.96 from 31 - 90 ft (mean 1.37).

The data were analyzed as two sections for a regression analysis; 0 - 90 ft which showed a decrease in fruit production and 91 - 240 ft which showed an increase. From zero to 90 ft a highly significant slope was found [F = 73.5956 (significant at the .001 probability level), df = 1,52] however, the line was not linear ($F = 2.7616^{N.S.}$, df = 7,45). A highly significant slope was also found for 91 - 240 ft [F = 32.1210 (significant at the .001 probability level), df = 13,73].

Comparison of the first and second harvests showed some definite differences. A total of 3890 pickles (.80 pickles per plant) were picked during the first harvest and 4721 pickles (.97 pickles per plant) during the second harvest. Eighteen days elapsed from the appearance of the first flower in the strips to the first picking and 20 more days until the second picking. The first harvest,

TABLE 52.--Average number of pickles per plant, pollen movement strips, 1969.

| Distance | Q | R | S | T | U | V | Overall |
|---|---|---|---|---|---|---|---|
| Pollinator | 0.00 | 1.54 | 4.40 | 0.00 | 1.78 | 5.00 | 1.95 |
| 0 - 10 ft | 2.97 | 4.91 | 3.89 | 4.85 | 4.27 | 4.35 | 4.14 |
| 11 - 20 ft | 2.89 | 2.92 | 3.35 | 6.13 | 3.02 | 3.35 | 3.33 |
| 21 - 30 ft | 2.23 | 2.32 | 2.50 | 2.65 | 1.92 | 4.29 | 2.48 |
| 31 - 40 ft | 3.07 | 1.04 | 1.75 | 2.75 | 2.04 | 2.59 | 2.05 |
| 41 - 50 ft | 1.82 | 0.59 | 1.68 | 1.45 | 0.36 | 1.18 | 1.18 |
| 51 - 60 ft | 1.36 | 0.89 | 1.56 | 2.25 | 0.17 | 2.17 | 1.40 |
| 61 - 70 ft | 1.68 | 2.04 | 2.03 | 2.25 | 0.88 | 1.05 | 1.56 |
| 71 - 80 ft | 1.90 | 1.52 | 1.31 | 1.90 | 0.35 | 0.50 | 1.14 |
| 81 - 90 ft | 1.46 | 1.14 | 0.97 | 0.82 | 0.75 | 0.57 | 0.96 |
| 91 - 100 ft | 1.23 | 1.31 | 0.74 | 0.82 | 0.92 | 0.88 | 1.00 |
| 101 - 110 ft | 1.58 | 1.08 | 1.04 | 1.10 | 0.67 | 0.66 | 1.01 |
| 111 - 120 ft | 1.98 | 0.83 | 0.78 | 1.63 | 0.73 | 0.39 | 1.09 |
| 121 - 130 ft | 1.78 | 1.20 | 0.87 | 1.67 | 1.19 | 0.67 | 1.24 |
| 131 - 140 ft | 2.53 | 1.95 | 1.48 | 0.83 | 0.88 | 0.88 | 1.38 |
| 141 - 150 ft | 2.11 | 1.27 | 1.89 | 1.32 | 0.88 | 2.06 | 1.53 |
| 151 - 160 ft | 2.50 | 1.64 | 1.41 | 1.18 | 1.74 | 1.29 | 1.62 |
| 161 - 170 ft | 1.80 | 1.24 | 0.79 | 1.87 | 1.90 | 2.71 | 1.67 |
| 171 - 180 ft | 4.18 | 1.97 | 1.10 | 0.89 | 0.87 | 1.66 | 1.41 |
| 181 - 190 ft | 2.06 | 2.50 | 1.78 | 3.46 | 1.03 | 3.93 | 2.26 |
| 191 - 200 ft | 1.58 | 2.79 | 2.61 | 1.40 | 2.53 | 1.76 | 2.07 |
| 201 - 210 ft | 1.57 | 0.25 | 1.45 | 2.59 | 3.34 | 2.86 | 2.04 |
| 211 - 220 ft | 1.42 | 0.14 | 4.07 | 1.95 | 4.92 | 2.05 | 2.35 |
| 221 - 230 ft | 2.00 | 0.00 | 3.21 | 2.83 | 9.00 | 1.61 | 2.73 |
| 231 - 240 ft | 2.19 | 0.00 | 2.72 | 3.14 | 2.80 | 2.67 | 2.62 |
| Overall | 1.97 | 1.56 | 1.93 | 1.90 | 1.62 | 1.78 | 1.78 |

which would be equivalent to the time of a destructive mechanical harvest had a production pattern similar to overall production. Peak production occurred in the first 10 ft of the strips, averaging 2.61 pickles per plant. Production then decreased from 1.79 fruit per plant at 11 to 20 ft to .25 fruit per plant at 90 ft (Table 53). From 91 to 240 ft fruit production increased from a low of .27 fruit per plant to a high of 1.25. Fruit production in the first 30 ft ranged from 2.61 - 1.29 fruit per plant (mean 1.87) compared to a range of .80 - .25 pickles per plant (mean 0.51) from 31 - 90 ft.

The second harvest, however, did not present such a clear production pattern. There was no difference in the number of fruit produced per plant in the first 20 ft. After 40 ft there was no obvious decrease in fruit production up to 90 ft, nor a gradual increase after 90 ft. Only small fluctuations existed between 41 - 180 ft, then an increase was again observed (Table 54). Fruit production in the first 30 ft averaged from 1.19 - 1.54 fruit per plant (mean 1.42) compared to a range of 1.26 - 2.68 pickles per plant (mean .85) from 31 - 90 ft.

Comparison of strip yields for the various levels of pollen present seemed to indicate an inverse relationship between the number of fruit per plant and amount of pollen present (Table 55). The two strips without a pollen source at the east end averaged 1.93 pickles per plant compared to 1.58 pickles per plant for the two strips with the largest pollen concentration. Even removing the number of pickles and plants of the monoecious blocks from fruit production

TABLE 53.--Average number of pickles per plant in the first harvest, pollen movement strips, 1969.

| Distance | Pollen movement strip | | | | | | |
|---|---|---|---|---|---|---|---|
| | Q | R | S | T | U | V | Overall |
| Pollinator | 0.00 | 0.77 | 2.13 | 0.00 | 1.08 | 3.44 | 1.09 |
| 0 - 10 ft | 1.58 | 3.41 | 2.36 | 3.35 | 2.70 | 2.53 | 2.61 |
| 11 - 20 ft | 1.50 | 1.60 | 1.65 | 3.33 | 1.71 | 1.78 | 1.79 |
| 21 - 30 ft | 1.13 | 1.32 | 1.45 | 0.82 | 1.05 | 2.12 | 1.29 |
| 31 - 40 ft | 1.48 | 0.40 | 0.53 | 1.21 | 1.15 | 0.41 | 0.80 |
| 41 - 50 ft | 0.94 | 0.17 | 0.47 | 0.14 | 0.13 | 0.32 | 0.44 |
| 51 - 60 ft | 0.51 | 0.54 | 0.56 | 0.75 | 0.04 | 0.39 | 0.48 |
| 61 - 70 ft | 0.64 | 1.08 | 1.19 | 0.50 | 0.58 | 0.40 | 0.71 |
| 71 - 80 ft | 0.73 | 0.52 | 0.64 | 0.80 | 0.13 | 0.19 | 0.47 |
| 81 - 90 ft | 0.46 | 0.39 | 0.16 | 0.33 | 0.12 | 0.00 | 0.25 |
| 91 - 100 ft | 0.20 | 0.62 | 0.13 | 0.33 | 0.16 | 0.12 | 0.27 |
| 101 - 110 ft | 0.26 | 0.60 | 0.08 | 0.67 | 0.14 | 0.02 | 0.33 |
| 111 - 120 ft | 0.39 | 0.17 | 0.00 | 0.93 | 0.08 | 0.02 | 0.29 |
| 121 - 130 ft | 0.64 | 0.56 | 0.04 | 0.74 | 0.62 | 0.03 | 0.48 |
| 131 - 140 ft | 0.47 | 1.33 | 0.22 | 0.17 | 0.50 | 0.24 | 0.50 |
| 141 - 150 ft | 0.85 | 0.80 | 1.06 | 0.41 | 0.23 | 0.61 | 0.68 |
| 151 - 160 ft | 0.97 | 1.03 | 0.55 | 0.30 | 0.68 | 0.25 | 0.65 |
| 161 - 170 ft | 1.00 | 0.64 | 0.48 | 1.23 | 0.86 | 1.39 | 0.91 |
| 171 - 180 ft | 2.00 | 0.93 | 0.52 | 0.56 | 0.22 | 0.48 | 0.60 |
| 181 - 190 ft | 0.81 | 1.21 | 0.97 | 2.15 | 0.29 | 1.67 | 1.10 |
| 191 - 200 ft | 0.68 | 1.71 | 1.76 | 1.02 | 1.59 | 0.83 | 1.25 |
| 201 - 210 ft | 0.60 | 0.00 | 0.65 | 1.29 | 2.09 | 1.36 | 1.02 |
| 211 - 220 ft | 0.27 | 0.00 | 2.04 | 0.79 | 2.46 | 1.00 | 1.02 |
| 221 - 230 ft | 0.35 | 0.00 | 1.58 | 1.29 | 5.00 | 0.36 | 1.11 |
| 231 - 240 ft | 0.97 | 0.00 | 0.67 | 0.50 | 0.80 | 1.15 | 0.87 |
| Overall | 0.75 | 0.82 | 0.88 | 0.89 | 0.82 | 0.68 | 0.80 |

TABLE 54.--Average number of pickles per plant in the second harvest, pollen movement strips, 1969.

| Distance | Pollen movement strip | | | | | | |
|---|---|---|---|---|---|---|---|
| | Q | R | S | T | U | V | Overall |
| Pollinator | 0.00 | 0.77 | 2.27 | 0.00 | 0.70 | 1.56 | 0.87 |
| 0 - 10 ft | 1.38 | 1.50 | 1.53 | 1.50 | 1.58 | 1.82 | 1.53 |
| 11 - 20 ft | 1.39 | 1.32 | 1.69 | 2.80 | 1.31 | 1.57 | 1.54 |
| 21 - 30 ft | 1.10 | 1.00 | 1.05 | 0.82 | 0.87 | 2.18 | 1.19 |
| 31 - 40 ft | 1.59 | 0.65 | 1.22 | 1.54 | 0.88 | 2.19 | 1.26 |
| 41 - 50 ft | 0.88 | 0.41 | 1.21 | 1.32 | 0.23 | 0.86 | 0.74 |
| 51 - 60 ft | 0.85 | 0.36 | 1.00 | 1.50 | 0.13 | 1.78 | 0.92 |
| 61 - 70 ft | 1.04 | 0.96 | 0.84 | 1.75 | 0.30 | 0.65 | 0.86 |
| 71 - 80 ft | 1.17 | 1.00 | 0.67 | 1.10 | 0.22 | 0.31 | 0.68 |
| 81 - 90 ft | 1.00 | 0.75 | 0.81 | 0.48 | 0.63 | 0.57 | 0.71 |
| 91 - 100 ft | 1.02 | 0.69 | 0.62 | 0.48 | 0.76 | 0.76 | 0.73 |
| 101 - 110 ft | 1.32 | 0.48 | 0.96 | 0.43 | 0.52 | 0.63 | 0.68 |
| 111 - 120 ft | 1.59 | 0.67 | 0.78 | 0.71 | 0.65 | 0.37 | 0.81 |
| 121 - 130 ft | 1.14 | 0.64 | 0.83 | 0.93 | 0.57 | 0.59 | 0.76 |
| 131 - 140 ft | 2.06 | 0.62 | 1.26 | 0.66 | 0.38 | 0.65 | 0.88 |
| 141 - 150 ft | 1.27 | 0.48 | 0.83 | 0.92 | 0.65 | 1.44 | 0.86 |
| 151 - 160 ft | 1.53 | 0.62 | 0.86 | 0.88 | 1.05 | 1.04 | 0.98 |
| 161 - 170 ft | 0.80 | 0.60 | 0.31 | 0.63 | 1.03 | 0.32 | 0.76 |
| 171 - 180 ft | 2.18 | 1.03 | 0.59 | 0.33 | 0.65 | 1.17 | 0.82 |
| 181 - 190 ft | 1.26 | 1.29 | 0.81 | 1.31 | 0.74 | 2.27 | 1.17 |
| 191 - 200 ft | 0.89 | 1.07 | 0.84 | 0.38 | 0.94 | 0.93 | 0.83 |
| 201 - 210 ft | 0.98 | 0.25 | 0.80 | 1.29 | 1.26 | 1.50 | 1.03 |
| 211 - 220 ft | 1.15 | 0.14 | 2.04 | 1.17 | 2.46 | 1.05 | 1.34 |
| 221 - 230 ft | 1.65 | 0.00 | 1.64 | 1.54 | 4.00 | 1.25 | 1.62 |
| 231 - 240 ft | 1.22 | 0.00 | 2.06 | 2.64 | 2.00 | 1.52 | 1.76 |
| Overall | 1.22 | 0.74 | 1.04 | 1.01 | 0.80 | 1.09 | 0.98 |

TABLE 55.--The affect of various levels of available cucumber pollen on fruit production and seed counts at different distances from the pollen source, 1969.

| Production statistics | No. of monoecious plants at the end of the strips | | |
|---|---|---|---|
| | 0 | 24 | 212 |
| Total plants | 1550 | 1520 | 1764 |
| Total pickles | 3000 | 2809 | 2802 |
| Avg. pickles/plant | 1.93 | 1.84 | 1.58 |
| Total seeds | 41250 | 47892 | 53577 |
| Total fruit | 745 | 755 | 688 |
| Avg. seeds/fruit | 55 | 63 | 78 |
| 1st Harvest pickles | 1261 | 1190 | 1439 |
| Avg. fruit per plant | 0.81 | 0.78 | 0.81 |
| 1st Harvest seeds | 27935 | 32776 | 36193 |
| Total fruit | 373 | 312 | 340 |
| Avg. seeds/fruit | 75 | 105 | 106 |
| 2nd Harvest pickles | 1739 | 1619 | 1363 |
| Avg. fruit per plant | 1.12 | 1.06 | 0.77 |
| 2nd Harvest seeds | 13315 | 15116 | 17384 |
| Total fruit | 372 | 443 | 348 |
| Avg. seeds/fruit | 36 | 34 | 50 |

Pollen movement strips were 10 ft apart

counts did not alter the overall results. Comparison of the data from the second harvest proved to be similar to the overall findings. Fruit production for the three levels of pollen were similar during the first harvest.

Seed counts were taken to ascertain the degree of pollination and the production of parthenocarpic fruit at different distances from the pollen source. Fruit taken from the monoecious blocks averaged 358 seeds per fruit (Table 56). From zero to 60 ft the seed counts decreased sharply from 193 seeds per fruit to 39. For this distance, a regression test showed that there was a significant slope [$F = 23.6$ (significant at the .01 probability level), $df = 1,139$], however, not linear ($F = 6.10$, $df = 22, 117$). The average number of seeds from 61 - 240 ft fluctuated with a slight increase at the far end of the strips. Over this distance, the average number of seeds per fruit ranged from 20 - 68. A regression test showed that there was not a significant slope ($F = 0.0412$, $df = 1, 103$), each average value did not differ ($F = 0.9119$, $df = 17, 87$), and the regression was linear ($F = 0.9657$, $df = 16, 87$). Apparently a minimum level of pollen was moved to the 61 - 240 ft span. The overall mean for this distance was 40 seeds per fruit compared to 65 for the entire project.

Once again comparison of the first and second harvests showed some basic differences. Fruit from the first harvest averaged 95 seeds per fruit compared to 39 for the second harvest. However, average seed counts of the monoecious plants were higher in the second harvest, 376 compared to 351. From zero to 60 ft in the first

TABLE 56.--Average number of seeds per fruit in pollen movement strips, 1969.

| Distance | Pollen movement strip | | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | Q | R | S | T | U | V | |
| Pollinator | --- | 357 | 369 | --- | 376 | 352 | 358 |
| 0 - 10 ft | 160 | 188 | 214 | 199 | 181 | 218 | 193 |
| 11 - 20 ft | 63 | 87 | 92 | 114 | 119 | 91 | 93 |
| 21 - 30 ft | 60 | 23 | 131 | 44 | 104 | 67 | 71 |
| 31 - 40 ft | 64 | 33 | 64 | 95 | 126 | 27 | 69 |
| 41 - 50 ft | 129 | 24 | 32 | 5 | 35 | 16 | 39 |
| 51 - 60 ft | 32 | 48 | 52 | 41 | 6 | 26 | 39 |
| 61 - 70 ft | 59 | 55 | 104 | 18 | 69 | 20 | 51 |
| 71 - 80 ft | 56 | 27 | 61 | 77 | 22 | 35 | 48 |
| 81 - 90 ft | 88 | 31 | 17 | 8 | 35 | 16 | 34 |
| 91 - 100 ft | 42 | 73 | 18 | 27 | 39 | 25 | 37 |
| 101 - 110 ft | 8 | 71 | 14 | 60 | 29 | 5 | 31 |
| 111 - 120 ft | 15 | 40 | 4 | 105 | 46 | 11 | 39 |
| 121 - 130 ft | 40 | 54 | 10 | 50 | 95 | 8 | 43 |
| 131 - 140 ft | 34 | 72 | 11 | 12 | 40 | 103 | 45 |
| 141 - 150 ft | 12 | 78 | 103 | 6 | 63 | 6 | 47 |
| 151 - 160 ft | 2 | 69 | 19 | 15 | 10 | 8 | 22 |
| 161 - 170 ft | 18 | 20 | 16 | 56 | 47 | 68 | 39 |
| 171 - 180 ft | 16 | 18 | 30 | 16 | 34 | 6 | 20 |
| 181 - 190 ft | 45 | 73 | 27 | 112 | 32 | 3 | 54 |
| 191 - 200 ft | 8 | 84 | 101 | 61 | 31 | 71 | 59 |
| 201 - 210 ft | 14 | 3 | 44 | 44 | 72 | 62 | 49 |
| 211 - 220 ft | 30 | --- | 56 | 90 | 95 | 60 | 68 |
| 221 - 230 ft | 21 | --- | 45 | 98 | 17 | 18 | 41 |
| 231 - 240 ft | 76 | --- | 18 | 17 | 23 | 18 | 30 |

harvest, average seed counts peaked at 177 seeds in the first 10 ft and again at 31 - 40 ft with 107 seeds (Table 57). An overall mean of 118 seeds per fruit was found for the first 60 ft. In the second harvest over the same distance, average seed counts peaked in the first 10 ft at 247 seeds and rapidly decreased to 19 at 60 ft with an overall mean of 67 seeds per fruit (Table 58). From 61 - 240 ft values fluctuated from 27 - 102 seeds, with a mean of 65 in the first harvest. During the second harvest, average values for the same distance fluctuated between 10 and 60 seeds with a mean of 24.

Comparison of seed counts for the various levels of pollen present, indicated that the amount of pollen available at the end of the gradient strips affected pollen movement by the bees (Table 55). Strips lacking pollen in direct line with the strip averaged 55 seeds per fruit, those with a total of 24 monoecious plants in line with the strip 63 seeds per fruit and strips with a total of 212 monoecious plants 78 seeds per fruit. However, when the fruit from the monoecious blocks were eliminated, such an increase was not observed, averaging 55, 50, and 63 seeds per fruit, respectively. In the first harvest, fruit from the strips having intermediate and highest levels of pollen did not have a significantly different mean number of seeds, 105 and 106. Exclusion of fruit from the monoecious plants made the two higher levels closer to the lowest one. In the second harvest, the highest concentration of pollen gave fruit with the highest average number of seeds but the rows without a pollen source in direct line with the strip had slightly more seeds than rows with the intermediate concentration of pollen.

TABLE 57.--Average number of seeds per fruit, first harvest, pollen movement strips, 1969.

| Distance | Pollen movement strip | | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | Q | R | S | T | U | V | |
| Pollinator | -- -- | 318 ± 42 | 340 ± 41 | -- -- | 395 ± 18 | 341 ± 23 | 351 |
| 0 - 10 ft | 158 ± 22 | 168 ± 24 | 200 ± 24 | 182 ± 17 | 168 ± 23 | 189 ± 19 | 177 |
| 11 - 20 ft | 51 ± 5 | 89 ± 17 | 95 ± 25 | 91 ± 22 | 133 ± 21 | 103 ± 13 | 94 |
| 21 - 30 ft | 75 ± 12 | 33 ± 6 | 139 ± 14 | 60 ± 9 | 92 ± 20 | 79 ± 22 | 81 |
| 31 - 40 ft | 79 ± 20 | 70 ± 23 | 88 ± 21 | 106 ± 26 | 223 ± 37 | 98 ± 21 | 107 |
| 41 - 50 ft | 152 ± 38 | 0 ± 0 | 62 ± 21 | 6 ± -- | -- -- | 27 ± 5 | 96 |
| 51 - 60 ft | 35 ± 4 | 57 ± 20 | 94 ± 54 | 64 ± 23 | -- -- | 72 ± 24 | 62 |
| 61 - 70 ft | 44 ± 13 | 78 ± 41 | 102 ± 15 | 35 ± 12 | 101 ± 27 | 28 ± 11 | 66 |
| 71 - 80 ft | 74 ± 10 | 47 ± 20 | 77 ± 18 | 149 ± 37 | 47 ± 16 | 94 ± 22 | 83 |
| 81 - 90 ft | 121 ± 26 | 30 ± 11 | 51 ± -- | 12 ± 7 | 75 ± 11 | -- -- | 69 |
| 91 - 100 ft | 85 ± 2 | 89 ± 30 | 47 ± 10 | 42 ± 36 | 84 ± 30 | 92 ± 48 | 77 |
| 101 - 110 ft | 17 ± 10 | 92 ± 16 | 28 ± -- | 91 ± 25 | 58 ± 26 | 76 ± -- | 74 |
| 111 - 120 ft | 36 ± 15 | 107 ± 21 | -- -- | 133 ± 65 | 223 ± -- | 142 ± -- | 101 |
| 121 - 130 ft | 35 ± 15 | 60 ± 13 | -- -- | 57 ± 34 | 137 ± 56 | -- -- | 64 |
| 131 - 140 ft | 39 ± 18 | 78 ± 20 | 14 ± 14 | 2 ± .5 | 70 ± 20 | 250 ± 87 | 93 |
| 141 - 150 ft | 23 ± 11 | 94 ± 20 | 137 ± 29 | 44 ± -- | 187 ± 52 | 35 ± 5 | 102 |
| 151 - 160 ft | 3 ± 2 | 79 ± 22 | 9 ± 6 | 43 ± 17 | 14 ± 7 | 30 ± 9 | 35 |
| 161 - 170 ft | 0 ± 0 | 29 ± 11 | 10 ± 8 | 78 ± 22 | 53 ± 39 | 93 ± 12 | 49 |
| 171 - 180 ft | 1 ± .3 | 26 ± 8 | 40 ± 12 | 23 ± 15 | 147 ± 146 | 17 ± 10 | 27 |
| 181 - 190 ft | 47 ± 18 | 83 ± 17 | 26 ± 8 | 119 ± 24 | 66 ± 15 | 1 ± .7 | 69 |
| 191 - 200 ft | 18 ± 14 | 39 ± 9 | 89 ± 17 | 81 ± 18 | 48 ± 18 | 83 ± 18 | 63 |
| 201 - 210 ft | 1 ± .4 | -- -- | 43 ± 25 | 67 ± 34 | 47 ± 16 | 69 ± 24 | 50 |
| 211 - 220 ft | 45 ± 21 | -- -- | 81 ± 23 | 79 ± 20 | 67 ± 23 | 78 ± 13 | 73 |
| 221 - 230 ft | 63 ± 31 | -- -- | 103 ± 29 | 90 ± 28 | 94 ± 44 | 19 ± 18 | 77 |
| 231 - 240 ft | 103 ± 30 | -- -- | 35 ± 14 | 34 ± 12 | 73 ± 3 | 2 ± 1 | 50 |

TABLE 58.--Average number of seeds per fruit, second harvest, pollen movement strips, 1969.

| Distance | Pollen movement strip | | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | Q | R | S | T | U | V | |
| Pollinator | -- | 375 ± 20 | 426 ± 30 | -- | 322 ± 36 | 382 ± 24 | 376 |
| 0 - 10 ft | 165 ± 41 | 259 ± 23 | 254 ± 68 | 270 ± 41 | 220 ± 39 | 312 ± 32 | 247 |
| 11 - 20 ft | 82 ± 12 | 82 ± 17 | 88 ± 19 | 126 ± 37 | 93 ± 22 | 54 ± 12 | 92 |
| 21 - 30 ft | 26 ± 16 | 2 ± 2 | 111 ± 24 | 36 ± 9 | 122 ± 48 | 54 ± 16 | 55 |
| 31 - 40 ft | 42 ± 12 | 19 ± 6 | 32 ± 14 | 86 ± 24 | 82 ± 15 | 9 ± 3 | 43 |
| 41 - 50 ft | 70 ± 11 | 26 ± 6 | 25 ± 10 | 5 ± 2 | 35 ± 14 | 12 ± 6 | 22 |
| 51 - 60 ft | 28 ± 11 | 41 ± 19 | 20 ± 7 | 18 ± 12 | 6 ± 4 | 3 ± 2 | 19 |
| 61 - 70 ft | 76 ± 41 | 41 ± 12 | 109 ± 102 | 9 ± 6 | 4 ± 4 | 7 ± 5 | 35 |
| 71 - 80 ft | 20 ± 7 | 9 ± 4 | 40 ± 26 | 6 ± 4 | 10 ± 5 | 17 ± 8 | 16 |
| 81 - 90 ft | 11 ± 6 | 32 ± 8 | 14 ± 6 | 6 ± 3 | 20 ± 7 | 16 ± 5 | 17 |
| 91 - 100 ft | 35 ± 12 | 48 ± 14 | 14 ± 6 | 22 ± 6 | 27 ± 11 | 7 ± 5 | 23 |
| 101 - 110 ft | 4 ± 2 | 28 ± 9 | 13 ± 6 | 0 ± 0 | 24 ± 9 | 0 ± 0 | 11 |
| 111 - 120 ft | 4 ± 4 | 6 ± 3 | 4 ± 2 | 94 ± 33 | 31 ± 12 | .3 ± .3 | 24 |
| 121 - 130 ft | 43 ± 19 | 42 ± 26 | 10 ± 6 | 45 ± 16 | 79 ± 28 | 8 ± 5 | 33 |
| 131 - 140 ft | 32 ± 12 | 61 ± 23 | 10 ± 7 | 14 ± 6 | 26 ± 15 | 4 ± 4 | 21 |
| 141 - 150 ft | 5 ± 3 | 32 ± 21 | 47 ± 20 | 3 ± 3 | 1 ± 1 | 2 ± 1 | 10 |
| 151 - 160 ft | 0 ± -- | 44 ± 23 | 25 ± 11 | 3 ± 3 | 8 ± 5 | 2 ± 2 | 11 |
| 161 - 170 ft | 39 ± 14 | 2 ± 1 | 19 ± 9 | 17 ± 13 | 45 ± 18 | 19 ± 12 | 28 |
| 171 - 180 ft | 51 ± 36 | .2 ± .2 | 1 ± .3 | 6 ± 3 | 17 ± 10 | 3 ± 3 | 12 |
| 181 - 190 ft | 42 ± 34 | 45 ± 15 | 29 ± 15 | 88 ± 36 | 7 ± 7 | 4 ± 4 | 30 |
| 191 - 200 ft | 3 ± 1 | 174 ± 64 | 133 ± 72 | 18 ± 11 | 2 ± 1 | 55 ± 38 | 52 |
| 201 - 210 ft | 31 ± 15 | 3 ± -- | 45 ± 28 | 1 ± 1 | 122 ± 58 | 47 ± 14 | 47 |
| 211 - 220 ft | 22 ± 9 | -- -- | .2 ± .2 | 105 ± 36 | 151 ± 91 | 21 ± 12 | 60 |
| 221 - 230 ft | 8 ± 5 | -- -- | 27 ± 7 | 114 ± 61 | 4 ± 3 | 18 ± 14 | 24 |
| 231 - 240 ft | 23 ± 11 | -- -- | 13 ± 4 | 4 ± 2 | 15 ± 7 | 41 ± 39 | 17 |

Overall, seed counts ranged between 0 - 524 in the first harvest and 0 - 532 in the second. The fruit that contained 524 seeds was found at 131 - 140 ft, and that which contained 532 seeds was found in the monoecious plants.

Of the 2,188 fruit from which seed counts were taken, 591 or 27.0% were produced parthenocarpically and had no seeds. Most of the parthenocarpic fruit came from the second harvest, 42.6% compared to 9.4% in the first harvest. Parthenocarpic fruit were first found at 50 ft during the first harvest and at 30 ft during the second harvest. Overall, the percentage of parthenocarpic fruit from 50 - 240 ft varied from 17.6% to 51.2%. There did not appear to be any definite pattern in its production.

A higher percentage of day-old pistillate flowers within the strips were open at the ends fartherest from the pollen source. Tagging open and closed day-old pistillate flowers in the strips and following their development seemed to indicate that pollination may cause the flower to close sooner. Fruit resulted from 9.7% of the day-old open flowers compared to 13.8% of the day-old closed flowers. Seed counts in fruit from the open flowers averaged 198 seeds per fruit compared to 90 seeds in fruit from the closed flowers. However, in 1970 comparison of hand pollinated flowers with those not pollinated showed that pollinated flowers do not close up faster or differ in appearance from those not pollinated. Of the hand pollinated flowers, 75% produced fruit which none did for the unpollinated flowers.

Fruit production in the pollen movement strips during August, 1972, fluctuated between 1.18 and 2.58 pickles per plant within the 10 ft sections compared to 2.21 pickles per plant for the monoecious pollen source (Table 59). The single 220 x 24 $ft^2$ block of the gynoecious cultivar 713-5 x 71521 plus a 24 x 30 $ft^2$ block of the monoecious cultivar SMR 15 contained 4,572 plants which produced 8027 fruit or 1.76 fruit per plant. Comparison of the average number of fruit per plant with distance gave a significant positive correlation coefficient of .4828 which indicated 23.3% association. The Student's T-Test indicated a significant slope at the .02 probability level. In the first 90 ft, fruit production ranged from 1.18 to 1.77 fruit per plant with a mean of 1.43. After 90 ft fruit production ranged from 1.55 to 2.58 fruit per plant with a mean of 1.89. In the first 30 ft, fruit production decreased from 1.48 to 1.18 fruit per plant, then began to increase. Within the first 90 ft a significant positive correlation coefficient of .7113 was found between distance and fruit production. This value indicated 50.6% association between the two values. Again a significant slope was obtained [t = 2.68, (significant at the .032 probability level)]. A similar analysis of fruit production for 91 - 220 ft did not yield a significant correlation coefficient (r = -.4046, df = 11) or a significant slope. Comparison of the two means for fruit production, 0 - 90 and 91 - 220 ft, the Student's T-Test indicated that they were significantly different [t = 3.89 (significant at the .001 probability level, df = 20).

Average seed counts in the harvested fruit decreased over the first 70 ft, from 259 to 73 seeds per fruit (Table 60). From

TABLE 59.--Cucumber fruit production at different distances from a source of pollen, 1972.

| Distance | Total number of plants | Total number of pickles | Number of pickles/plant |
|---|---|---|---|
| Pollinator | 428 | 945 | 2.21 |
| 0 - 10 ft | 133 | 197 | 1.48 |
| 11 - 20 ft | 209 | 264 | 1.26 |
| 21 - 30 ft | 268 | 317 | 1.18 |
| 31 - 40 ft | 162 | 237 | 1.46 |
| 41 - 50 ft | 177 | 261 | 1.47 |
| 51 - 60 ft | 226 | 319 | 1.41 |
| 61 - 70 ft | 158 | 234 | 1.48 |
| 71 - 80 ft | 146 | 229 | 1.57 |
| 81 - 90 ft | 193 | 341 | 1.77 |
| 91 - 100 ft | 174 | 320 | 1.84 |
| 101 - 110 ft | 224 | 413 | 1.84 |
| 111 - 120 ft | 179 | 356 | 1.99 |
| 121 - 130 ft | 183 | 340 | 1.86 |
| 131 - 140 ft | 159 | 410 | 2.58 |
| 141 - 150 ft | 155 | 362 | 2.34 |
| 151 - 160 ft | 157 | 386 | 2.46 |
| 161 - 170 ft | 195 | 353 | 1.81 |
| 171 - 180 ft | 200 | 323 | 1.62 |
| 181 - 190 ft | 188 | 379 | 2.02 |
| 191 - 200 ft | 185 | 286 | 1.55 |
| 201 - 210 ft | 187 | 297 | 1.59 |
| 211 - 220 ft | 286 | 458 | 1.60 |

TABLE 60.--Number of seeds in cucumbers at different distances from a source of pollen, 1972.

| Distance | Sample size | Avg. no. of seeds | Range of seed counts | % parthenocarpic fruit |
|---|---|---|---|---|
| Pollinator | 32 | 331 ± 13 | 135 - 469 | 0.0 |
| 0 - 10 ft | 32 | 259 ± 11 | 121 - 354 | 0.0 |
| 11 - 20 ft | 32 | 199 ± 15 | 11 - 381 | 0.0 |
| 21 - 30 ft | 32 | 150 ± 14 | 49 - 363 | 0.0 |
| 31 - 40 ft | 32 | 132 ± 11 | 45 - 283 | 0.0 |
| 41 - 50 ft | 32 | 106 ± 14 | 1 - 387 | 0.0 |
| 51 - 60 ft | 32 | 85 ± 9 | 20 - 223 | 0.0 |
| 61 - 70 ft | 32 | 73 ± 10 | 5 - 245 | 0.0 |
| 71 - 80 ft | 32 | 85 ± 12 | 3 - 266 | 0.0 |
| 81 - 90 ft | 32 | 62 ± 10 | 3 - 215 | 0.0 |
| 91 - 100 ft | 32 | 33 ± 5 | 0 - 122 | 6.2 |
| 101 - 110 ft | 32 | 35 ± 7 | 2 - 148 | 0.0 |
| 111 - 120 ft | 32 | 36 ± 7 | 0 - 185 | 9.4 |
| 121 - 130 ft | 32 | 49 ± 8 | 0 - 158 | 6.2 |
| 131 - 140 ft | 32 | 49 ± 12 | 0 - 183 | 6.2 |
| 141 - 150 ft | 32 | 29 ± 8 | 0 - 120 | 6.2 |
| 151 - 160 ft | 32 | 88 ± 22 | 1 - 339 | 0.0 |
| 161 - 170 ft | 32 | 30 ± 7 | 0 - 158 | 12.5 |
| 171 - 180 ft | 32 | 25 ± 5 | 0 - 108 | 18.8 |
| 181 - 190 ft | 32 | 41 ± 12 | 0 - 331 | 9.4 |
| 191 - 200 ft | 32 | 36 ± 11 | 0 - 328 | 9.4 |
| 201 - 210 ft | 32 | 20 ± 5 | 0 - 154 | 9.4 |
| 211 - 220 ft | 32 | 54 ± 10 | 3 - 289 | 0.0 |
| Overall | 736 | 89 | 0 - 469 | 4.1 |

71 - 220 ft, average values ranged between 20 and 88 seeds per fruit. The overall mean for the study was 89 seeds per fruit. Fruit taken from the monoecious block averaged 331 seeds per fruit, ranging between 135 - 469 seeds, whereas, fruit within the pollen movement block contained from 0 - 387 seeds. An overall regression analysis between distance and average number of seeds gave a highly significant negative correlation of -0.7755 which indicated 60.1% association between the two variables. The slope was also found to be significant [t = -5.49 (significant at the .00005 level)]. Within the first 90 ft a highly significant negative correlation was found between distance and seed counts [r = -0.9282 (significant at the .001 probability level), df = 7). This value indicated 86.2% association between the two variables. A significant slope (t = -6.60) was also found which is significant at the .0003 probability level. A similar analysis for seed counts of fruit taken from 91 - 220 ft did not give a significant correlation or slope (r = -0.0246, t = -.08, df = 11). Comparison of the two means for seed counts, 0 - 90 and 91 - 220 ft, the Student's T-Test indicated that they were significantly different [t = 4.64 (significant at the .001 probability level), df = 20).

Parthenocarpic fruit first appeared in the 91 - 100 ft section. Overall, 4.1% of the fruit sampled developed parthenocarpically. Between 91 and 220 ft, from 0.0 to 18.8% of the fruit developed parthenocarpically.

## The Movement of Fluorescent Powder

In fluorescent powder movement studies in 1971, no powder was detected beyond 70 ft from the dusted flowers (Table 61). From

TABLE 61.--Movement of bees in cucumbers as indicated by transport of fluorescent powder, 1971.

| Distance from source | Sample size | % Flowers with powder |
|---|---|---|
| 0 - 10 ft | 199 | 76.9 |
| 11 - 20 ft | 231 | 39.0 |
| 21 - 30 ft | 263 | 18.6 |
| 31 - 40 ft | 295 | 9.2 |
| 41 - 50 ft | 327 | 4.6 |
| 51 - 60 ft | 296 | 0.7 |
| 61 - 70 ft | 328 | 2.7 |
| 71 - 80 ft | 20 | 0.0 |
| 81 - 90 ft | 20 | 0.0 |
| 91 - 100 ft | 20 | 0.0 |

0 - 30 ft, the percentage of flowers containing powder decreased from 76.9% to 18.6% with a mean of 44.8%. From 31 - 70 ft an average of 4.3% of the flowers contained fluorescent powder. Besides the rapid decrease in the percentage of the flowers containing powder, beyond 30 ft only tiny specks of powder were observed occasionally.

The study indicated that the size of the bee population, weather conditions, and concentration of powder affected its distribution. Using a circular sampling pattern and dusting 6 times as many flowers, greatly increased powder distribution (Table 62). On July 29, only one flower was dusted and almost all detectable powder

TABLE 62.--Movement of fluorescent powder by honey bees in cucumbers using a circular sampling pattern.

| Distance | Sample size | 7-29 (1 flower dusted) % with pigment | 8-5 (6 flowers dusted % with pigment |
|---|---|---|---|
| 0 - 10 ft | 8 | 37.5 | 50.0 |
| 11 - 20 ft | 24 | 4.2 | 45.8 |
| 21 - 30 ft | 40 | 0.0 | 15.0 |
| 31 - 40 ft | 56 | 0.0 | 10.7 |
| 41 - 50 ft | 72 | 1.4 | 8.3 |
| 51 - 60 ft | 88 | 0.0 | 1.1 |
| 61 - 70 ft | 104 | 0.0 | 0.0 |

One way analysis of variance $F_{(1,12)} = 1.78^{N.S.}$
Treatments were not significantly different at the 5% probability level (Student - Newman - Keul multiple range test).

was distributed within the first 20 ft, compared to August 5 when powder was distributed over 60 ft from six flowers. On August 5, flowers from 0 - 20 ft had large spots of powder and beyond 20 ft, only a few specks. On July 29 this was also the case, but large spots of powder were found only in the first ten ft. Using a circular sampling pattern, powder distribution decreased with distance; from 43.8% at 0 - 10 ft to 0.0% at 60 - 70 ft. However, comparison of the two concentrations of powder and distribution with Student-Newman-Keuls multiple range test indicated that the results of the two days were not significantly different at the .05 probability level.

Powder distribution within an isolated plot, 25 x 50 ft$^2$ was more efficient than observed in large commercial fields (Table 63).

TABLE 63.--Movement of fluorescent powder among cucumber flowers by honey bees at East Lansing, 1971.

| Distance | Sample size | 8-9 % with pigment | 8-11 % with pigment | 8-18 % with pigment | Overall % with pigment |
|---|---|---|---|---|---|
| 0 - 10 ft | 21 | 100.0 | 85.7 | 95.2 | 93.6 |
| 11 - 20 ft | 21 | 66.7 | 57.1 | 61.9 | 61.9 |
| 21 - 30 ft | 21 | 57.1 | 14.3 | 42.9 | 38.1 |
| 31 - 40 ft | 21 | 4.8 | 4.8 | 23.8 | 11.1 |
| 41 - 50 ft | 21 | 4.8 | 4.8 | 9.5 | 6.4 |

One way analysis of variance $F(2,12) = .21^{NS}$

Treatments were not significantly different at the 5% probability level (Student-Newman-Keul multiple range test).

From 0 to 50 ft, powder movement to flowers decreased from 93.6% in the first 10 ft to 6.4% in the last 10 foot section. The increased movement was probably explained by a larger bee population and a population confined to a small area. On all three days large blotches of powder were observed on the flowers in the first 20 ft and only specks after that. Distribution during the three days was not significantly different at the .05 probability level as indicated by the Student-Newman-Keuls multiple range test.

The application of fluorescent powder to strips in commercial fields and dusting from 6 to 18 flowers showed greater distribution with higher powder concentrations (Table 64). However, the differences were not great enough to be significant at the .05 probability level as indicated by the Student-Newman-Keuls multiple range test. Overall, the strips showed powder movement for 70 ft. Of the flowers in the first 10 ft, 68% received powder, compared to 1.0% of the flowers from 51 - 60 ft. Overall, 17.6% of the flowers from 0 to 70 ft received powder.

Even by increasing the number of flowers dusted to 50 in a single strip in the commercial field, powder distribution was not detected beyond 70 ft (Table 65). In the first 40 ft a mean of 53.8% of the flowers received powder while in the last 30 ft, 11.7% contained powder.

Dusting powder on the flowers worked best when applied to the petals only. Powder on the stamens seemed to repel the bees before they landed. With powder only on the petals, bees landed on the flowers and contacted the powder.

TABLE 64.--Movement by honey bees of fluorescent powder in commercial cucumber fields.

| Distance | Sample size | % with pigment | | | | | Overall |
|---|---|---|---|---|---|---|---|
| | | 8-21 | | | 8-24 | | |
| | | A (6 flowers dusted) | B (12 flowers dusted) | C (18 flowers dusted) | D (18 flowers dusted) | E (6 flowers dusted) | |
| 0 - 10 ft | 20 | 55.0 | 75.0 | 75.0 | 80.0 | 55.0 | 68.0 |
| 11 - 20 ft | 20 | 10.0 | 35.0 | 15.0 | 60.0 | 30.0 | 30.0 |
| 21 - 30 ft | 20 | 5.0 | 0.0 | 5.0 | 35.0 | 15.0 | 12.0 |
| 31 - 40 ft | 20 | 0.0 | 5.0 | 5.0 | 15.0 | 5.0 | 6.0 |
| 41 - 50 ft | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 2.0 |
| 51 - 60 ft | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 1.0 |
| 61 - 70 ft | 20 | 0.0 | 5.0 | 0.0 | 10.0 | 5.0 | 4.0 |

TABLE 65.--Movement of fluorescent powder from flower to flower in cucumbers by honey bees using a locus of 50 dusted flowers.

| Distance from source | Sample size | % Flowers with powder |
|---|---|---|
| 0 - 10 ft | 20 | 95.0 |
| 11 - 20 ft | 20 | 45.0 |
| 21 - 30 ft | 20 | 35.0 |
| 31 - 40 ft | 20 | 40.0 |
| 41 - 50 ft | 20 | 10.0 |
| 51 - 60 ft | 20 | 0.0 |
| 61 - 70 ft | 20 | 25.0 |
| 71 - 80 ft | 20 | 0.0 |
| 81 - 90 ft | 20 | 0.0 |
| 91 - 100 ft | 20 | 0.0 |

The movement of fluorescent powder, within a plot 32 x 110 ft$^2$ in 1973 indicated that within an isolated area, bees could move pollen at least 110 ft (Table 67). A highly significant negative correlation was obtained when the distance was compared to the percent of the flowers receiving fluorescent powder ($r = -0.9904$, $df = 9$), which indicates 98.1% association. Over the 110 foot distance, the percentage of flowers containing powder decreased from 91.1% to 42.1%, mean of 70.0%. A one-way analysis of variance showed that there were highly significant differences when the data from the nine days were analyzed. Comparison of powder movement with two concentrations of powder in the field, showed that there were significant differences at the .05 probability level (Paired t-test, $t = -2.07$, $df = 86$). When 10 flowers were dusted, 50.9 to 89.1% of

TABLE 66.--The number of staminate flowers in the gynoecious strips and the monoecious pollen source, 1972.

| Date | Gynoecious block<br>Number of staminate flowers | Nodes where staminate flowers appeared | Monoecious block<br>Number of staminate flowers |
|---|---|---|---|
| 7-24 | 10 | 3,4 | 23 |
| 7-25 | 45 | 2,3,4,5,6 | 56 |
| 7-26 | 14 | 3,4,5 | 202 |
| 7-27 | 5 | 3,4,5 | 368 |
| 7-28 | 10 | 3,4,5,6,7 | 519 |
| 7-31 | 11 | 3,4,5,6,7 | 416 |
| 8-1 | 0 | --- | 302 |
| 8-2 | 0 | --- | 450 |
| 8-3 | 1 | 5 | 593 |
| 8-4 | 1 | 6 | 599 |
| 8-7 | | Rained all day | |
| 8-8 | 0 | --- | 699 |
| 8-9 | 1 | 6 | 742 |
| 8-10 | 0 | --- | 672 |
| 8-11 | 0 | --- | 617 |

TABLE 67.--Movement by honey bees of fluorescent powder in cucumbers at East Lansing, 1973.

| Distance from source | % of flowers with powder after 7 hours | | | | | | | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|
| | 8-14 | 8-16 | 8-27 | 8-28 | 8-29 | 8-30* | 8-31 | 9-5 | 9-6 | |
| 0 - 10 ft | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 20.0 | 91.1 |
| 11 - 20 ft | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 20.0 | 91.1 |
| 21 - 30 ft | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 60.0 | 80.0 | 85.7 | 60.0 | 87.3 |
| 31 - 40 ft | 100.0 | 80.0 | 100.0 | 90.0 | 100.0 | 50.0 | 80.0 | 85.7 | 20.0 | 78.4 |
| 41 - 50 ft | 100.0 | 80.0 | 100.0 | 100.0 | 60.0 | 40.0 | 70.0 | 71.4 | 60.0 | 75.7 |
| 51 - 60 ft | 100.0 | 90.0 | 100.0 | 90.0 | 70.0 | 40.0 | 70.0 | 57.1 | 0.0 | 68.6 |
| 61 - 70 ft | 100.0 | 80.0 | 100.0 | 90.0 | 70.0 | 40.0 | 50.0 | 57.1 | 0.0 | 65.2 |
| 71 - 80 ft | 90.0 | 70.0 | 100.0 | 90.0 | 50.0 | 30.0 | 50.0 | 57.1 | 40.0 | 64.1 |
| 81 - 90 ft | 80.0 | 60.0 | 100.0 | 70.0 | 40.0 | 30.0 | 50.0 | 28.6 | 40.0 | 55.4 |
| 91 - 100 ft | 80.0 | 50.0 | 80.0 | 70.0 | 50.0 | 30.0 | 40.0 | 14.3 | 40.0 | 50.5 |
| 101 - 110 ft | 40.0 | 20.0 | 90.0 | 80.0 | 30.0 | 40.0 | 30.0 | 28.6 | 20.0 | 42.1 |
| Number of flowers picked/ ten feet | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 7 | 5 | |
| Number of flowers dusted | 25 | 10 | 25 | 10 | 25 | 10 | 25 | 10 | 5 | |

*Light rain 1 - 2 p.m.

the flowers received some powder with a mean of 69.4% compared to 65.4 to 97.3%, and mean of 80.7% when 25 flowers were dusted (Table 68). Since all daily means of the two treatments were not significantly different from each other, differences were probably due to climatic conditions and differences in bee populations. Comparison of the overall means for the two treatments at the various distances indicated the first significant difference at 21 - 30 ft. Beyond 21 ft treatments of 25 dusted flowers showed greater distribtuion of the powder to flowers than treatments of 10 flowers.

## The Relationship of Foraging Activity to Fruit Set

The Piccadilly plot used to determine the relationship of foraging activity to fruit set in 1974 produced an excessive number of staminate flowers over the 12-day monitoring period (Table 69). The staminate:pistillate flower ratio fluctuated between 1.30 and 3.93 with a mean of 2.24. A total of 2638 pistillate flowers and 5899 staminate flowers were produced. The number of flowers per vine each day ranged from 0.38 to 1.68, with a mean of 1.02. In comparison the adjacent plot of MSU 9805 over the same time period had a staminate:pistillate flower ratio between .84 and 4.47, with a mean of 2.25 (Table 70). A total of 1696 pistillate flowers and 3823 staminate were produced in the 12 days while the number of flowers per plant ranged between .14 and 1.53, with a mean of .80.

Foraging activity in the plot based on number of flowers and bee visits varied from 10,739 to 94,478 visits per day, with a mean of 47,055 (Table 71). Individual flowers received from 34.2 to 102.0

TABLE 68.--Comparison of movement by honey bees of two concentrations of fluorescent powder in a field of cucumbers, 1973.

| Distance | Ten flowers dusted | | | | Overall | Twenty-five flowers dusted | | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|
| | 8-16 | 8-28 | 8-30 | 9-5 | | 8-14 | 8-27 | 8-29 | 8-31 | |
| 0 - 10 ft | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 11 - 20 ft | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 21 - 30 ft | 100.0 | 100.0 | 60.0 | 85.7 | 86.4 | 100.0 | 100.0 | 100.0 | 80.0 | 95.0 |
| 31 - 40 ft | 80.0 | 90.0 | 50.0 | 85.7 | 76.4 | 100.0 | 100.0 | 100.0 | 80.0 | 95.0 |
| 41 - 50 ft | 80.0 | 100.0 | 40.0 | 71.4 | 72.8 | 100.0 | 100.0 | 60.0 | 70.0 | 82.5 |
| 51 - 60 ft | 90.0 | 90.0 | 40.0 | 57.1 | 69.3 | 100.0 | 100.0 | 70.0 | 70.0 | 85.0 |
| 61 - 70 ft | 80.0 | 90.0 | 40.0 | 57.1 | 65.8 | 100.0 | 100.0 | 70.0 | 50.0 | 80.0 |
| 71 - 80 ft | 70.0 | 90.0 | 30.0 | 57.1 | 61.8 | 90.0 | 100.0 | 50.0 | 50.0 | 72.5 |
| 81 - 90 ft | 60.0 | 70.0 | 30.0 | 28.6 | 47.2 | 80.0 | 100.0 | 40.0 | 50.0 | 67.5 |
| 91 - 100 ft | 50.0 | 70.0 | 30.0 | 14.3 | 41.1 | 80.0 | 80.0 | 50.0 | 40.0 | 62.5 |
| 101 - 110 ft | 20.0 | 80.0 | 40.0 | 28.6 | 42.2 | 40.0 | 90.0 | 30.0 | 30.0 | 47.5 |
| Mean | $75.4^{abc}$ | $89.1^{bc}$ | $50.9^{a}$ | $62.3^{a}$ | | $90.0^{bc}$ | $97.3^{c}$ | $70.0^{ab}$ | $65.4^{ab}$ | |

One way analysis of variance $F_{(8,90)} = 10.44^{**}$

Means of each column followed by the same small letter are not significantly different at the 5% probability level. (Student-Newman-Keuls multiple range test).

TABLE 69.--Flowering pattern of cucumber cultivar Piccadilly, 1974.

| Date | No. of pistillate flowers | No. of staminate flowers | S/P ratio | Total flowers | Flowers/ plant |
|---|---|---|---|---|---|
| August 6 | 5 | 0 | 0 | 5 | .01 |
| 7 | 5 | 1 | .20 | 6 | .01 |
| 8 | 5 | 2 | .40 | 7 | .01 |
| 9 | 14 | 20 | 1.42 | 34 | .05 |
| 10,11 | 148 | 42 | .28 | 190 | .28 |
| 12 | 100 | 97 | .97 | 197 | .29 |
| 13 | 108 | 154 | 1.42 | 262 | .38 |
| 14 | 137 | 179 | 1.30 | 316 | .46 |
| 15 | 118 | 321 | 2.72 | 439 | .63 |
| 16 | 175 | 435 | 2.49 | 610 | .88 |
| 17 | 170 | 361 | 2.12 | 531 | .77 |
| 18 | 283 | 505 | 1.78 | 788 | 1.14 |
| 19 | 319 | 461 | 1.45 | 780 | 1.13 |
| 20 | 246 | 376 | 1.53 | 622 | .90 |
| 21 | 304 | 632 | 2.08 | 936 | 1.35 |
| 22 | 271 | 699 | 2.58 | 970 | 1.40 |
| 23 | 280 | 884 | 3.16 | 1164 | 1.68 |
| 24 | 227 | 892 | 3.93 | 1119 | 1.62 |

TABLE 70.--Flowering pattern of cucumber cultivar MSU 9805, 1974.

| Date | No. of pistillate flowers | No. of staminate flowers | S/P ratio | Total flowers | Flowers/ plant |
|---|---|---|---|---|---|
| August 8 | 0 | 2 | 0 | 2 | .00 |
| 9 | 2 | 1 | .5 | 3 | .01 |
| 10,11 | 33 | 13 | .39 | 46 | .08 |
| 12 | 51 | 21 | .41 | 72 | .12 |
| 13 | 45 | 38 | .84 | 83 | .14 |
| 14 | 63 | 55 | .87 | 118 | .21 |
| 15 | 79 | 157 | 1.99 | 236 | .41 |
| 16 | 133 | 257 | 1.93 | 390 | .68 |
| 17 | 109 | 212 | 1.95 | 321 | .56 |
| 18 | 205 | 282 | 1.38 | 487 | .84 |
| 19 | 206 | 301 | 1.46 | 507 | .90 |
| 20 | 181 | 293 | 1.62 | 474 | .82 |
| 21 | 176 | 430 | 2.44 | 606 | 1.05 |
| 22 | 176 | 473 | 2.69 | 649 | 1.13 |
| 23 | 183 | 699 | 3.82 | 882 | 1.53 |
| 24 | 140 | 626 | 4.47 | 766 | 1.33 |

TABLE 71.--Average daily foraging activity in cucumbers, East Lansing, 1974.

| Date | Total number of visits/10 flowers (4.5 h) | Total visits/ flower (9 h) | Total flowers Piccadilly | Total field visits/day | Total number visits/10 flowers | | |
|---|---|---|---|---|---|---|---|
| | | | | | Staminate | Pistillate | Foraging s/p |
| August 13 | 365 | 73.0 | 262 | 19,126 | 198 | 167 | 1.19 |
| August 14 | 171 | 34.2 | 314 | 10,739 | 85 | 86 | 0.99 |
| August 15 | 197 | 39.4 | 439 | 17,297 | 116 | 81 | 1.43 |
| August 16 | 202 | 40.4 | 609 | 24,604 | 120 | 82 | 1.46 |
| August 17 | 338 | 67.6 | 530 | 35,828 | 193 | 145 | 1.33 |
| August 18 | 510 | 102.0 | 788 | 80,376 | 281 | 229 | 1.23 |
| August 19 | 369 | 73.8 | 774 | 57,121 | 187 | 182 | 1.03 |
| August 20 | 382 | 76.4 | 621 | 47,444 | 176 | 206 | 0.85 |
| August 21 | 364 | 72.8 | 935 | 68,068 | 181 | 183 | 0.99 |
| August 22 | 487 | 97.4 | 970 | 94,478 | 220 | 267 | 0.82 |
| August 23 | 255 | 51.0 | 1164 | 59,364 | 155 | 100 | 1.55 |
| August 24 | 225 | 45.0 | 1116 | 50,220 | 126 | 99 | 1.27 |
| Total | 3865 | 773.0 | 8522 | 564,665 | 2038 | 1827 | 1.11 |

visits per day with a mean of 66.3. The daily foraging staminate: pistillate flower ratio ranged from 0.82 to 1.55, with a mean of 1.11 which again indicated that honey bees have a slight preference for staminate flowers. The percent fruit set decreased rather rapidly from a high of 90.7% on the first day to a low of 17.9% on the eleventh day (Table 72). Overall, 39.9% of the pistillate flowers set fruit each day. Of the 108 flowers pollinated on the first day, 90.7% developed into mature fruit. Within three days, fruit development had decreased to 71.7% (mean 81.2%). Fruit development dropped to 22.3% by the eighth day. The mean for the last four days was 20.4%. Even though bee activity increased, fruit set decreased due to fruit inhibition.

The rapid decrease in fruit set while first formed fruit matured was not due to a lack of pollen. Seed counts of the mature fruit indicated that there was no lack of pollination (Table 73). The daily average number of seeds per fruit ranged between 203 and 263, with a mean of 229 seeds per fruit. From 0 to 540 seeds were found in individual fruits. Analysis indicated that there was no significant correlation between the daily staminate:pistillate flower ratio and average number of seeds per fruit (r = 0.5153, df = 10).

Overall, 82.0% of the fruit produced were perfectly shaped, 11.9% nubs, and 6.1% necks (Table 74). The daily production of perfectly shaped fruit fluctuated between 63.8 and 92.5%. Comparison of daily production of perfectly shaped fruit with the staminate:pistillate flower ratio, average seed counts, and total visits per day, did

TABLE 72.--Fruit set in the Piccadilly cucumber plot, East Lansing, 1974.

| Date | Total pistillate flowers | % producing mature fruit | % producing underdeveloped fruit | % failing to develop fruit |
|---|---|---|---|---|
| August 13 | 108 | 90.7 | 0.0 | 9.3 |
| 14 | 135 | 86.7 | 1.5 | 11.8 |
| 15 | 117 | 80.3 | 6.0 | 13.7 |
| 16 | 173 | 71.7 | 4.0 | 24.3 |
| 17 | 169 | 56.2 | 7.7 | 36.1 |
| 18 | 280 | 46.4 | 7.5 | 46.1 |
| 19 | 310 | 32.9 | 12.6 | 54.5 |
| 20 | 242 | 22.3 | 6.6 | 71.1 |
| 21 | 291 | 20.6 | 4.8 | 74.6 |
| 22 | 271 | 20.7 | 5.5 | 73.8 |
| 23 | 257 | 17.9 | 7.0 | 75.1 |
| 24 | 211 | 22.7 | 8.1 | 69.2 |
| Totals | 2564 | 39.9 | 6.6 | 53.5 |

TABLE 73.--Average number of seeds per fruit, Piccadilly plot, East Lansing, 1974.

| Date | Sample size | Avg. number of seeds per fruit | Range |
|---|---|---|---|
| August 13 | 98 | 232 ± 8 | 21 - 426 |
| August 14 | 117 | 226 ± 8 | 17 - 475 |
| August 15 | 93 | 263 ± 11 | 5 - 540 |
| August 16 | 119 | 246 ± 11 | 0 - 465 |
| August 17 | 95 | 230 ± 11 | 23 - 460 |
| August 18 | 127 | 222 ± 10 | 0 - 420 |
| August 19 | 101 | 203 ± 10 | 4 - 417 |
| August 20 | 54 | 218 ± 14 | 2 - 411 |
| August 21 | 60 | 206 ± 15 | 0 - 417 |
| August 22 | 55 | 225 ± 14 | 0 - 403 |
| August 23 | 45 | 234 ± 18 | 7 - 459 |
| August 24 | 47 | 238 ± 19 | 15 - 492 |

TABLE 74.--Fruit shape analysis of the Piccadilly cucumber plot.

| Date | Total no. of fruit | No. of perfects | % | No. of nubs | % | No. of necks | % |
|---|---|---|---|---|---|---|---|
| August 13 | 98 | 87 | 88.8 | 6 | 6.1 | 5 | 5.1 |
| August 14 | 117 | 106 | 90.6 | 7 | 6.0 | 4 | 3.4 |
| August 15 | 93 | 86 | 92.5 | 4 | 4.3 | 3 | 3.2 |
| August 16 | 119 | 101 | 84.9 | 16 | 13.4 | 2 | 1.7 |
| August 17 | 95 | 75 | 78.9 | 15 | 15.8 | 5 | 5.3 |
| August 18 | 127 | 100 | 78.7 | 22 | 17.4 | 5 | 3.9 |
| August 19 | 101 | 66 | 65.3 | 24 | 23.8 | 11 | 10.9 |
| August 20 | 54 | 48 | 88.9 | 5 | 9.3 | 1 | 1.8 |
| August 21 | 60 | 47 | 78.3 | 6 | 10.0 | 7 | 11.7 |
| August 22 | 55 | 45 | 81.9 | 8 | 14.5 | 2 | 3.6 |
| August 23 | 45 | 38 | 84.4 | 3 | 6.7 | 4 | 8.9 |
| August 24 | 47 | 30 | 63.8 | 4 | 8.5 | 13 | 27.7 |
| Overall | 1011 | 829 | 82.0 | 120 | 11.9 | 62 | 6.1 |

not give significant correlation coefficients; r = -0.3195, r = 0.4274, and -0.4600 (df - 10), respectively.

Of 54 tagged pistillate flowers with known number of bee visits, 51.8% set fruit. The fruit contained from 4 to 411 seeds, with a mean of 233. The flowers that set fruit received from 18 to 184 bee visits with a mean of 58. The flowers that died received from 16 to 134 visits, with a mean of 64. There was 75% of the fruit perfectly shaped and 25% nubs. The perfectly shaped fruit averaged 264 seeds compared to 140 for the nubs. Comparison of the number of flower visits with the number of seeds in each fruit did not give a significant correlation coefficient (r = 0.1181, df = 26). Each bee visit placed a minimum average of 5.7 effective pollen grains on the flower's stigma. The Piccadilly plot produced a total of 849 fruit or 1.23 fruit per plant (Table 75). In the simulated harvest,

TABLE 75.--Results of the Piccadilly simulated cucumber harvest.

| | Grades | | | | | | Total fruit |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| Total fruit | 229 | 102 | 234 | 148 | 117 | 19 | 849 |
| % of harvest | 27.0 | 12.0 | 27.6 | 17.4 | 13.8 | 2.2 | |

27.0% of the fruit were grade 1, 12.0% grade 2, 27.6% grade 3, 17.4% grade 4, 13.8% grade 5, and 2.2% grade 6 (Appendix A).

With a similar overall flowering pattern and foraging population, the adjacent plot of MSU 9805 averaged 1.15 fruit per plant.

Fruit shape analysis indicated that 92.0% were perfectly shaped, 4.5% nubs, and 3.5% necks. In regard to the curvature of fruit, 82.5% were straight, 13.1% slightly curved, and 4.4% severely curved. At the time of the destructive harvest, the fruit graded from 1 - 6 respectively were 28.4%, 20.7%, 33.8%, 14.0% 3.0%, and 0.1% (Table 76). An estimate based on a plant population of 50,000 plants per

TABLE 76.--The dollar value per acre of the cucumber cultivar MSU 9805--estimate based upon 50,000 plants per acre.

| Grade | Total pickles | % of harvest | Weight of sample (lbs) | No. pickles/ acre | Wt./ acre | $/ acre |
|---|---|---|---|---|---|---|
| 1 | 188 | 28.4 | 3.25 | 16,330 | 282.3 | 16.94 |
| 2 | 137 | 20.7 | 11.00 | 11,902 | 955.6 | 28.94 |
| 3 | 224 | 33.8 | 46.50 | 19,435 | 4034.5 | 80.69 |
| 4 | 93 | 14.0 | 32.25 | 8,050 | 2791.5 | 27.92 |
| 5 | 20 | 3.0 | 9.5 | 1,725 | 819.4 | 4.10 |
| 6 | 1 | 0.1 | 0.75 | 57 | 42.8 | 0.11 |
| Total | | | | | | 158.43 |

Number of plants = 557 Total pickles = 663
Number of fruit per plant = 1.15 Number of fruit per acre = 57,500

acre, indicated that the dollar return per acre would be $158.43 (Appendix A).

## Changes in the Foraging Population with Additional Colonies in the Field

For four days prior to moving two colonies of honey bees into the plots at East Lansing, the flowers averaged 23.4 bee visits per 4.5 h. For eight days after the colonies were moved in, the flowers averaged 36.6 visits per 4.5 h. Therefore, the two colonies with a total of 914 sq inches of sealed brood increased the field population 1.57 times. Comparison of the two sample means with the Student's T-test indicated that they were significantly different [t = 3.99 (significant at the .001 probability level, df = 322].

## Fruit Inhibition

Fruit inhibition was rapidly expressed in the field of Piccadilly (Table 77). Flowers pollinated on the first day that pistillate flowers appeared on the vine developed into mature fruit 91.7% of the time. The second day's flowers developed into mature fruit 49.6% of the time and with each succeeding set of flowers, fruit production decreased rapidly from 19.9% for the third set to 0.0% for the seventh set. Only 39.9% of the pistillate flowers produced mature fruit. In addition, 6.6% of the flowers set fruit, but development ceased before reaching maturity. These growth-inhibited ovaries either withered and died or remained green and unchanging for several weeks. This would indicate that there is an inhibition threshold present that probably varies from plant to plant and possibly with cultivar. Such under-developed fruit appeared on the second day of flowering and peaked at 12.6% on the seventh day (Table 72). Fruit inhibition appeared from the time the first flower on a vine was fertilized. A mean of 9.1% (6.1 to 10.5) of flowers on nodes 2 to 5 produced growth-inhibited fruit and those on nodes 6 to 9 produced 3.2% (2.1 to 4.0) growth-inhibited fruit with the remaining flowers aborting.

TABLE 77.--The inhibition of fruit development as affected by previous fruit set on the cucumber vine.

| Flowering pattern of each plant | Total pistillate flowers | % Forming mature fruit | % Forming underdeveloped fruit | % Failing to develop fruit |
|---|---|---|---|---|
| 1st node pistillate flowers | 662 | 91.7 | 1.2 | 7.1 |
| 2nd node | 550 | 49.6 | 10.0 | 40.4 |
| 3rd node | 437 | 19.9 | 10.5 | 69.6 |
| 4th node | 345 | 10.1 | 9.6 | 80.3 |
| 5th node | 248 | 6.4 | 6.1 | 87.5 |
| 6th node | 142 | 4.2 | 2.1 | 93.7 |
| 7th node | 93 | 0.0 | 3.2 | 96.8 |
| 8th node | 58 | 0.0 | 3.4 | 96.6 |
| 9th node | 25 | 0.0 | 4.0 | 96.0 |
| 10th node | 3 | 0.0 | 0.0 | 100.0 |

The five pistillate flowers that were observed daily in the East Lansing Piccadilly plots during 1974 provided further opportunity to analyze fruit inhibition. Of the flowers that set fruit and developed to maturity, 51.9% were found on node one, 33.3% on node two, 11.1% on node three, and 3.7% on node four. Of the flowers that died, 7.7% were found on node one, 11.5% on node two, 15.4% on node three, 19.2% on node four, 23.1% on node five, and the remaining 23.1% were scattered on nodes 6 - 18.

In the cultivar MSU 9805 during 1974, 62.0% of the fruit were found in position one, 28.3% in position two, 7.3% in position three, 2.0% in position four, and 0.4% in position five (Table 78). The

TABLE 78.--Influence of position on the cucumber vine, on fruit set and shape, MSU 9805.

| Position | Sample size | % Perfect | % Nubs | % Necks | % of the fruit |
|---|---|---|---|---|---|
| 1 | 410 | 94.2 | 2.9 | 2.9 | 62.0 |
| 2 | 187 | 72.7 | 18.2 | 9.1 | 28.3 |
| 3 | 48 | 83.3 | 12.5 | 4.2 | 7.3 |
| 4 | 13 | 84.6 | 15.4 | 0.0 | 2.0 |
| 5 | 3 | 66.7 | 33.3 | 0.0 | 0.4 |

highest percent of perfectly shaped fruit was found in position one, 94.2% and the lowest in position five at 66.7%, with an overall mean of 80.3%. Nub-shaped fruits were found in position one (2.9%) and in position five (33.3%). Neck shaped fruits were found only in the first three positions, 2.9%, 9.1%, and 4.2% in order. Overall, 87.0% of the fruit were perfectly shaped, 8.3% nubs, and 4.7% necks.

## DISCUSSION

This study has indicated that a series of events, linked to climatic conditions having minimum thresholds, must occur before bee foraging will be initiated, successful pollinations occur, and fertilization takes place in pickling cucumbers. Under normal light conditions, the sequence of events was initiated at 15° C. However, under conditions of reduced light, the process may be delayed. As the corolla expanded and the temperature rose, anthers of staminate flowers began to dehisce and the nectaries of pistillate flowers gained a moist appearance under the microscope at 16° C, Collison (1973). At 16° C 60% of the anthers started to dehisce and 100% of the flowers were dehiscing at 19° C. Anthers observed at temperatures between 12° C and 15° C showed no signs of dehiscence and below 16° C, all pistillate flower nectaries were dry, Collison (1973). Connor (1969) found that honey bees began foraging flights in cucumbers at the same general time that the flowers reached anthesis (16° C). Therefore, it would appear that foraging commences in response to the initiation of anther dehiscence in the staminate flowers, and to nectar secretion, in the pistillate flowers rather than anthesis, since anthesis commenced at 15° C. Additional support comes from observations made on August 19, 1969, when the flowers were tightly closed at a temperature of 22° C, and bees were vigorously trying to work them. Both nectar and pollen were present, even though the flowers were closed. Connor (1969) found that the average time and temperture of the first bee visits to flowers were at 7:30 a.m. EST at 17° C, excluding those nights when the overnight temperature did not fall below 21° C. This study indicated that at 17° C, 80% of the staminate flowers in the field were undergoing anther dehiscence and small beads of nectar were forming on the inner surface of the pistillate flower's cup-shaped nectary, Collison (1973). Activity in the field was first observed visually, at 16.5° C while flowers were undergoing anthesis. However, when bee flight had been restricted, foraging began at lower temperatures to the previous day's flowers. Collison (1973) showed that almost 1/3 of the day-old flowers contained some nectar under normal weather conditions.

Connor (1969) observed that bee flight rarely became abundant until the temperature reached 21° C. Collison (1973) found that from 18 to 21° C, the percentage of nectaries containing beads of nectar increased as well as the number and size of the beads. He found that the first amounts of nectar measurable with microcaps were obtained at 21° C and the volume was equal to 0.24 ul. Connor (1969) observed that flight commenced earlier than 7:30 a.m. when the overnight temperature did not fall below 21° C. Seaton and Kremer (1938a) observed dehisced anthers as early as 4 a.m. When temperatures during the day remained below minimum thresholds, flowers remained closed, anthers intact, nectaries dry, and the bees in the hives.

At the time of anther dehiscence, pollen was viable, and stigmas receptive. These results concur with the observations of

Hayase (1955) who found that pollen was viable before the anthers dehisced. Connor (1969) made similar observations when he exposed flowers to bees as soon as they started morning flights and found that 55.0% of the flowers set fruit and averaged 108 seeds per fruit. However, as the day progressed pollen viability and stigmatic receptivity decreased. Pollen viability was greatly reduced in day-old staminate flowers. Hand pollinations in both the field and greenhouse indicated that lower humidities and wind exposure may cause pollen to lose its viability sooner. Hand pollinations also indicated that day-old pistillate flowers were capable of setting fruit with fresh pollen. However, honey bees generally did not work day-old staminate and pistillate flowers in the field. Connor (1969) found that hand pollination of second day flowers was occasionally successful. Day-old pistillate flowers bagged in the field and opened for 10 min intervals received no bee visits, while fresh flowers surrounding them were visited often. Cucumber flowers normally closed in the afternoon on the day of anthesis and by the following morning the petals were withered.

Pollination of fresh pistillate flowers with day-old pollen, indicated that stigmas remain receptive longer than pollen remains viable. Undoubtedly, the rate at which pollen viability and stigmatic receptivity are reduced depends upon environmental conditions. Barnes (1947) found that pollen remained viable in the greenhouse until 1 or 2 p.m. on the day of anthesis. Connor (1969) found by exposing flowers to honey bees at different times of the day that the percentage of fruit development decreased after 2:30 p.m. Fruit pollinated between 10:30 a.m. and 12:30 p.m. produced slightly more seeds, but the differences were not significant. Therefore, it appeared that the amount of pollen or the loss of viability were not limiting factors in late afternoon pollinations.

Significant positive correlations were found between foraging activity and temperature, solar radiation, and wind speed. A significant negative correlation was found between foraging activity and relative humidity. Therefore, it appears that the number of bee visits to the field are affected by temperature, solar radiation, wind speed, and relative humidity.

A series of step-wise multiple regression analyses were run on the data, with the number of bee visits as the dependent variable and the various climatic conditions as the independent variables. Stepwise regression is a method of finding the combination of independent variables that most effectively predict the variation in the dependent variable. Using this technique, the independent variables are added successively to a regression equation according to their improvement of goodness of fit. Such information is needed to develop a predictive foraging model for the crop and a better understanding of the affect of the complex of climatic factors on the number of bee visits occurring in the field. The data used for the analysis were collected from the East Lansing plots in 1974. During the 108 hourly sampling periods, from 0 - 115 bee visits were recorded on 10 flowers, with an overall mean of 35.8 visits/10 flowers/30 min, which would be equivalent to 7 visits/flower/hour (V/F/H). Temperatures during sampling ranged from 15.7 to 33.3° C and the amount of solar radiation between 2.4 and 71.4 cal/cm$^2$/h. The mean temperature was 24.8° C and the mean solar radiation was 42.1 cal/cm$^2$/h. Comparison of the individual correlation coefficients between foraging activity and the various climatic conditions indicated that solar radiation was most important followed by temperature, relative humidity, and wind speed. Considering both temperature and solar radiation the following predictive linear regression equation was obtained.

$$Y_{\text{visits}} = -19.17 + .95\ (\text{temperature}) + .75\ (\text{solar radiation})$$

An AOV for the above regression indicated that it was significant at the 0.0005 probability level (F = 22.97). The coefficient of multiple determination was equal to .3044 which indicated 30.4% association between the number of bee visits and the two climatic conditions. With the addition of relative humidity, the following linear regression equation was obtained.

$$Y_{\text{visits}} = -147.60 + 3.15\ (\text{temperature}) + 1.13\ (\text{solar radiation}) + .99\ (\text{relative humidity})$$

The relative humidity ranged between 33 and 96%, with an overall mean of 58.4%. The level of significance did not change when relative humidity was added (F = 24.09). The coefficient of multiple determination was equal to .4100 which indicated 41.0% association between the number of bee visits and the three climatic conditions. The average wind speed was 8.1 mph, ranging between 0.0 and 14.9 mph.

The final linear regression equation, with wind speed added also remained at the same level of significance ($F = 20.71$).

$$Y_{visits} = -161.01 + 2.41\,(\text{temperature}) + 1.30\,(\text{solar radiation}) + 1.12\,(\text{relative humidity}) + 2.11\,(\text{wind speed}).$$

However, the overall coefficient of multiple determination only equaled .4457, meaning 44.6% of the variation can be accounted for by the four independent climatic variables chosen. Probably the remainder of the variation was due to the level of nectar secretion and sugar concentration present in the flowers which was also dependent on the climatic conditions as well as flower density and size of the foraging population.

Optimum foraging occurred between temperatures of 21.5 and 30.0° C (85.6%). Only 3.8% of the bees were counted at temperatures below 21.5° C and 10.6% between 30.5 - 34.5° C. Foraging began at lower temperatures in areas having the largest bee populations. Foraging was first observed on tagged flowers at 17.5° C in East Lansing (Table 5), at 19° C in Eaton Rapids (Table 6), and at 20.5° C in Mulliken (Table 7). Also, in East Lansing, 4.9% of the population was foraging at 21° C and below, compared to 2.1% at Eaton Rapids, and 0.4% at Mulliken. East Lansing averaged 64.4 flower visits per day, Eaton Rapids 62.3, and Mulliken only 15.7.

Lundie (1925) found that the internal condition of the colony was important in determining the temperature at which flight began.

Stronger colonies commenced flight at somewhat lower temperatures. Woodrow (1932) also found that in general, at any given temperature, the flight of a colony was roughly proportional to its strength.

Even though solar radiation appeared to be the most important climatic variable affecting foraging activity, no minimum threshold could be established from the data. Peak activity was observed at 61 - 65 cal/cm$^2$/h, averaging 57.7 bee visits per sampling period. No activity was observed below 10.8 cal/cm$^2$/h. During the entire sampling period, a mean of 42.1 cal/cm$^2$/h of solar radiation was recorded and the flowers received an average of 35.8 bee visits/10 flowers/ 30 min.

Peak flight activity was observed at relative humidities between 50 and 59% averaging 48.0 visits per sampling period (Table 9). A highly significant negative correlation was found between foraging activity and relative humidity. Similar observations were made by Bodenheimer and Ben-Nerya (1937).

Foraging activity in relation to wind speed indicated a significant positive correlation. The wind speed fluctuated between 0.0 and 14.9 mph with a mean of 8.1 mph. Peak flight was recorded at a wind speed of 10.4 mph, and flight decreased at higher speeds. Park (1923) found that flight was reduced at wind speeds above 15 mph. Connor (1969) reported that high wind velocity was often associated with poor bee activity. However, he observed that bees were able to work cucumbers at relatively high wind speeds due to the dense protective cover provided by the plants.

Observations at all locations indicated that foraging activity fluctuated significantly in response to environmental conditions. Comparison of daily flight activity at times seemed to indicate that temperature, solar radiation, relative humidity, and wind speed collectively affected flights while at other times only one variable seemed to dominate. Temperature, solar radiation, and wind speed usually increased during the day while relative humidity decreased. Even though significant positive correlations were found between foraging activity and temperature, solar radiation, and wind speed, and a negative correlation between foraging activity and relative humidity, clear distinct explanations for the large variations in foraging activity as expressed in Table 13 are not evident. Multiple regression analysis indicated that climatic conditions were not entirely responsible. At times the affect of threatening storms and rain were observed to reduce foraging activity. However, a few bees continued to work while it was raining, under the canopy of the leaves. Collison and Martin (1973) found that overhead irrigation during the day reduced honey bee activity in the cucumber fields by 80%, and flights were never fully resumed during the same day.

Nectar secretion data indicated that pistillate and staminate flowers of pickling cucumbers differ in nectar secretion, though their secretory rhythms were similar. In both types of flowers, nectar secretion varied with prevailing climatic conditions. Some flowers did not secrete any nectar, and the percentage of both staminate and pistillate flowers secreting nectar increased until noon. No significant change was observed in the afternoon. Without bee visitation, the average volume of nectar and total weight of sugar increased until late afternoon for both types of flowers. The average sugar concentration for both staminate and pistillate flowers did not significantly change throughout the day. On the day of anthesis, comparison of mean values indicated that pistillate flowers produced approximately 1.5 times more nectar than staminate flowers. Maximum production in both showed an even greater difference, 34.15 ul for pistillate flowers compared to 14.88 ul for staminate. Staminate flower nectar had a higher average sugar concentration, but in total weight of sugar produced, the two types of flowers were similar.

As the average temperature increased during the day, the volume of nectar, actual weight of sugar, and number of flowers producing nectar increased, the average temperature also increased. At the times the flowers were producing measurable amounts of nectar, average temperatures ranged between 23.4 - 28.2° C in 1968 and from 19.4 - 28.0° C in 1969. As temperature increased sugar concentration decreased.

Daily nectar production fluctuated in response to changing climatic conditions. Significant positive correlations were obtained between daily average temperature and daily average volume and when temperature was compared to volume of nectar and actual weight of sugar for individual staminate and pistillate flowers. A significant negative correlation was found between temperature and sugar concentration for pistillate flowers only. The data strongly indicated that the amount of nectar and sugar potentially available to bees depended upon the time of day that the threshold temperature was reached.

Average daily relative humidity was not significantly correlated with the average volume of nectar produced each day by staminate or pistillate flowers. However, highly significant negative correlations were found between relative humidity and volume of nectar as it was sampled hourly throughout the day in both staminate and pistillate flowers. As was found with temperature, a significant positive correlation was found only in the pistillate flowers between relative humidity and sugar concentration. Significant negative correlations were found between relative humidity and actual weight of sugar in the nectar of both types of flowers.

Highly significant negative correlations were obtained between solar radiation of the three previous days and daily nectar volume and actual weight of sugar in pistillate flowers only. In staminate flowers significant correlations were obtained between daily nectar volume, actual weight of sugar and solar radiation of the previous day. When the volume of nectar and actual weight of sugar obtained at each hourly sampling throughout the day was compared with the solar radiation of the three previous days, highly significant negative correlations were obtained for pistillate flowers.

When comparing the average daily nectar volume, sugar concentration, and actual weight of sugar in pistillate flowers with precipitation on the day of anthesis, no significant correlations were found. Continued analysis showed however, that for both daily average volume and actual sugar weight, correlations were highest when compared to the precipitation of the four previous days. During the sampling of staminate flowers in 1969, no precipitation was observed. When the hourly volume of nectar and actual weight of sugar for individual pistillate flowers was compared to the total precipitation of the four previous days, highly significant positive correlations were obtained.

Daily average wind speed was not correlated with average daily volume of nectar, percent sugar, or actual weight of sugar in staminate or pistillate flowers. However, significant correlations were obtained between wind speed and hourly nectar volume, sugar concentration, and actual weight of sugar in individual staminate flowers. In pistillate flowers a significant negative correlation was found between wind speed and sugar concentration only.

From the individual correlations presented it would appear that the nectar volume in pistillate flowers was a function of temperature, solar radiation of the three previous days, relative humidity, and the total precipitation of the four previous days. In staminate flowers, wind speed would be added and total precipitation deleted, since no precipitation was recorded during sampling. Sugar concentration of nectar from pistillate flowers was dependent on relative humidity, wind speed, and temperature. The actual weight of sugar in the nectar of pistillate and staminate flowers was affected by the same variables.

Since many authors have found that the quantity of nectar present in flowers influences their attractiveness to foraging bees, a series of step-wise multiple regression analyses were run on the data with volume of nectar as the dependent variable and the various climatic conditions as the independent variables. For pistillate flowers, data was obtained for 11 days. The average daily volume of nectar ranged from 3.07 to 9.87 ul with a mean of 5.87 ul while the average temperature ranged from 20.7° C to 27.8° C with a mean of 24.5° C. The average humidity ranged from 49.1 to 92.0% with a mean of 71.6%. Total precipitation for the four days prior to anthesis averaged 0.66 inches, ranging between 0.00 and 1.31 inches, while total solar radiation during the three previous days averaged 1464 langleys, within a range of 1035 - 1892 langleys. When considering the four independent variables, the following predictive linear regression equation was obtained.

$$Y_{\text{volume}} = -9.93 + .30\,(\text{temperature}) - .01\,(\text{relative humidity}) + .18\,(\text{precipitation}) - .004\,(\text{solar radiation}).$$

An AOV for the above regression indicated that it was significant at the 0.009 probability level (F = 9.44). The coefficient of multiple determination was equal to .8628 which indicated 86.3% of the variation can be accounted for by the four independent climatic variables chosen. For the improvement of goodness of fit, the analysis indicated that precipitation and relative humidity should be deleted from the regression equation. If relative humidity was included, its significance would be .584 and precipitation .798. With the deletion of precipitation, the overall regression was significant at the .002 probability level and when relative humidity was deleted, the regression was significant at the 0.0005 probability level (F = 23.73).

The final predictive linear regression equation obtained for pistillate flowers was:

$$Y_{volume} = -8.51 + .28\ (temperature) - .005\ (solar\ radiation)$$

The coefficient of multiple determination was equal to .8558 which indicates 85.6% association between volume of nectar and the two climatic conditions.

A similar type of analysis was performed on the data for staminate flowers. During the 11 sampling days when a complete set of weather data was available, the flowers averaged from 3.17 to 7.25 ul of nectar, with a mean of 4.68 ul. The average temperature was 26.4° C, fluctuating between 22.0° C and 29.4° C and the average relative humidity was 54.3%, fluctuating between 44.6 and 64.7%. Total precipitation four days prior to anthesis averaged .008 inches, ranging between 0.00 and 0.03 inches while total solar radiation during the three previous days averaged 1621 langleys, within a range of 1074 - 1865. When considering the four independent variables, the following predictive linear regression equation was obtained.

$$\begin{aligned} Y_{volume} = -2.65 &+ .12\ (temperature) + .02\ (relative\ humidity) \\ &- 21.8\ (precipitation) - .002\ (solar\ radiation). \end{aligned}$$

An AOV for the above regression indicated that it was significant at the .432 probability level. The coefficient of multiple determination was equal to .4253 which indicated 42.5% of the variation can be accounted for by the four independent climatic variables chosen. For the improvement of goodness of fit, the analysis indicated that precipitation, relative humidity, and solar radiation should be deleted from the regression equation. For each variable not included in the final regression, its significance if it were added next would be solar radiation .633, precipitation .782, and relative humidity .847. With the deletion of relative humidity, the overall regression was significant at the .252 probability level. With precipitation also deleted, significance improved to the .120 probability level and the removal of solar radiation gave a final significance of .039 ($F = 5.83$). The final regression equation was obtained for the staminate flowers.

$$Y_{volume} = -8.58 + .17 \text{ (temperature)}$$

The coefficient of multiple determination was equal to .3931, therefore, 39.3% of the variation can be accounted for by temperature. Since the test flowers were not accessible to bees, the rest of the variation was probably due to the general physiology of the plant. Since a lack of precipitation was evident, most of the variation was probably due to water stress. A second possibility would be developing fruit on the vine. As Shuel (1955b) indicated, the carbohydrates that are synthesized during photosynthesis, are utilized in growth, respiration, and other vital processes. Since plots were adjacent soil was probably not a factor.

In general, nectar secretion in cucumbers responded to climatic conditions as described by the literature, except solar radiation. Some authors have found significant positive correlations between nectar yield and solar radiation in some plants, our data indicated a significant negative correlation between solar radiation and nectar production in cucumbers. The individual flowers sampled were excluded from bees, however, fruit development continued on the vines and stress of fruit formation would appear to be the primary reason why a negative correlation was obtained. As Shuel (1975) indicated in his discussion on sugar translocation, the growth of a fruit creates a sink (region of utilization) to which sugar moves, and this would influence its availability to nectaries. When a vine has formed a fruit, its development becomes the primary function of the plant and this requires priority for use of the carbohydrate supply. Dearborn (1936) reported that the fertilization of the ovules of the cucumber flower results in a stimulation of growth which extends beyond the reproductive organs. He found that the fruit had a dominating influence upon the growth and chemical composition of the plant. Banadyga (1949) reported that high temperatures with a maximum amount of sunshine produced a higher sugar content in the fruit than in cloudy weather.

Nectar taken directly from pistillate flowers averaged 36.3% and from staminate flowers 45.3% sugar during the day when bees were excluded from the blossoms. The overall mean of the two values was 40.8% while the overall average sugar concentration of nectar from bee's honey stomachs was 24.5%, a 40% decline (Table 28). Collison (1973) also showed that nectar secreted in a flower after its removal was of lower sugar concentration than the original nectar. He found that the concentration of nectar removed from flowers at hourly intervals dropped from 42.3% to 13.8%. This reduction in sugar concentration must be considered in determining the caloric reward that the honey bee receives as it visits the flowers. Cucumber flowers are typically visited several times an hour by honey bees. Therefore, each load of nectar is an accumulation of small quantities from many individual flowers, both staminate and pistillate. Throughout the day, the sugar concentration of the honey stomach contents did not vary a great deal, with average values being 17.1 to 28.3% sugar. The morning values were highest averaging 26.0% and the afternoons 23.0% which also indicated a reduction in sugar concentration with visitation. Both Wilson, Moffett, and Harrington (1958) in Colorado and Kauffeld and Williams (1972) in Wisconsin obtained much higher sugar concentration values using a similar technique. However, their sample sizes were small and if taken with a hand refractometer may be subject to inaccuracies. Connor (1969) found that maximum bee flights in the field extended from 9 to 2 p.m. Similar observations were made in 1974 during this study. During this time interval, the sugar concentration of the honey stomach contents peaked at 9 - 10 a.m. and 12 - 1 p.m. with a decrease throughout the rest of the afternoon, which indicated a correlation between nectar concentration and presence of bees on the crop.

In both plot and commercial field studies, bees were shown to exhibit a preference for staminate flowers as they foraged. While pistillate flowers produced approximately 1.5 - 2.3 times more nectar than staminate flowers, staminate flower nectar had a higher sugar concentration. It would appear that bees prefer staminate flowers because of the higher sugar concentration. However, both types of flowers were quite close in total weight of sugar (caloric reward), with pistillate flowers having a slight edge. The honey bee has to visit more staminate than pistillate flowers to get a load of nectar, and therefore expends more energy, but is about equally rewarded by the staminate flower, because of the higher concentration of sugar. Therefore, one might expect them to be visited equally.

Staminate flowers offer both nectar and pollen and this may make the flower more attractive to bees. However, very few bees have been observed collecting cucumber pollen, and pellets which were collected were quite small compared to other major pollen sources. Connor (1969), Olsen (1975), and Williams and Kauffeld (1967) made similar observations. It has also been shown that the collection of cucumber pollen decreases during the day which is probably due to the depletion of the field supply. Doull (1966) found that when bees were collecting less attractive pollens, they worked more slowly in collecting the load and generally collected smaller loads. Therefore, if the amount of pollen being collected is an indicator of its attractiveness, cucumber pollen would not rate as a reward attractant but it may possess volatile materials which may attract bees. When gynoecious hybrids are used, the number of staminate flowers and available pollen is further reduced. It is not known whether cucumber pollen contains attractants like those that have been isolated from other pollens, Hugel (1962), LePage and Boch (1968), Hopkins et al. (1969), Starratt and Boch (1971). If attractants are present, cucumber pollen should be attractive from 7 - 9 a.m. after anthesis has occurred. However, the effects of chemical attractants could be masked first thing in the morning since Seaton, Hutson, and Muncie (1936) reported that at the time cucumber pollen is released, it is covered with an oily film and remains in masses in the pollen sac. It is possible that exposure to the air dries the film releasing the volatile chemical attractants.

Since the largest amounts of cucumber pollen were found on the mouthparts and metalegs, with most bees having some pollen on the ventral surface of the thorax, prolegs, and mesolegs, the honey bee should be very efficient in distributing pollen uniformly over the stigmatic surface as it collects the nectar which is located directly below the stigma. While removing nectar from a pistillate flower, a honey bee usually inserts and withdraws her proboscis 2 - 3 times. She inserts her proboscis at the periphery of the stigma, between the lobes, to reach the cup-shaped nectary below, Collison (1973). Therefore, her pollen-laden mouthparts are in direct contact with the receptive stigma 2 - 3 times each visit. In order to reach the nectar of a staminate flower she has to insert her proboscis between the central mass of the five anther lobes and the corolla, which would replenish the pollen supply of the mouthparts, Collison (1973). In moving about the pistillate flower, no doubt the pollen on the prolegs and ventral surface of the thorax comes in direct contact with the stigma occasionally.

The dependability of pollen transfer with a specific number of bee visits would vary with the availability of pollen in the field, the staminate:pistillate flower ratio, and density as well as distribution of the two types of flowers in relation to each other. Therefore, the projected number of visits that each flower should receive during the day would vary from field to field and day to day. This study has indicated that under high pollen concentrations the first visit to a pistillate flower places significantly more pollen on the stigma, than subsequent visits. A similar situation probably exists under lower pollen concentrations, but the decrease in pollen transfer with additional visits would not be as rapid. Apparently a large portion of the stigma is coated with pollen during the first visit and with each succeeding visit there is significantly less receptive surface available. Connor (1969) presented data which supports this observation. He found that flowers in the field receiving one or two bee visits produced fruit with an average of 258 seeds, which indicated that a large amount of pollen was placed on the stigma with one to two visits. With additional visits, there was an increase in fruit set and average number of seeds per fruit. However, as the number of visits increased, the number of perfect-shaped fruit did not increase proportionately. However, with 20 visits 90.8% of the fruit were perfectly shaped compared to 79.6% for 15 visits. Average seed counts from fruit set on flowers receiving 15 and 20 visits, were not significantly different, 227 and 246 seeds respectively. In all cases only one fruit was allowed to develop per plant. During 1974 first node pistillate flowers in the plots set fruit 91.7% of the time and received an average of 34.2 to 102.0 visits, 66.3 mean visits per day (Table 77). Fruit produced each day averaged between 203 and 263 seeds, with an overall mean of

229 seeds per fruit (Table 73). Of the pistillate flowers in position one that were monitored daily in 1974, 88.9% set fruit. The 18 flowers involved received from 18 to 100 visits and the resulting fruit contained from 74 to 411 seeds. Overall means were 46.2 visits per flower and 272 seeds per fruit. As an indication, rather than a direct comparison Connor (1969) found by taking counts at identical times in the plots at East Lansing and in a 20-acre field at Springport, Michigan, the Springport field received 2.78 V/F/H compared to 8.28 in East Lansing which would represent 28 and 83 flower visits per day, respectively. When plants were harvested in both fields, the number of cucumbers produced per plant did not differ statistically at the .05 probability level. Similar counts taken at Cedar Springs (2.95 V/F/H) and East Lansing (8.68 V/F/H) at another time, also gave a nonsignificant difference when harvested. On the basis of these results, it appears that flowers receiving more than 20 visits will not significantly produce more fruit, even though they may contain a few more seeds. The number of seeds would actually be an indicator of pollination efficiency. Conversely, flowers receiving one visit set fruit only 43.7% of the time. Connor (1969) found that single bee visits were capable of producing fruit 53.1% of the time, but Stephen (1970) reported that only under rare circumstances does one visit result in fertilization. He indicated that four or fewer visits were not dependable, but eight or preferably twelve provided sufficient pollen for adequate seed set and well formed fruit. Shemetkov (1957) under greenhouse conditions found that 8 - 10 visits were required. Additional visits increased fruit weight and

number of seeds. Connor (1969) found little difference in the percentage of fruit set between single and multiple bee visits until 9 - 10 visits. In the greenhouse, he found that flowers receiving two or ten visits did not differ significantly in fruit set. He suggested that at least 10 bee visits were needed to insure pollination under a variety of variable conditions. In cantaloupes, McGregor et al. (1965) found that fruit set and marketability improved with additional bee visits up to 13 to 14 visits per flower. Connor (1969) found that fruit receiving 11 or 12 visits averaged 320 seeds per fruit, significantly less than the 393 seeds found in fruits exposed to a full day of pollination. These results indicated that a flower on the day of anthesis should receive from 15 to 20 visits for maximum fruit set.

Node position after the sixth node did not significantly affect daily percent fruit set or production of perfectly shaped fruit. Therefore, the large daily variation in fruit set and shape that was observed, was due to factors other than fruit inhibition and node position.

Honey bees spent more time per visit on pistillate than on staminate flowers, with overall means of 12.6 and 6.3 sec, respectively. Collison (1973) found that nectaries of pistillate flowers had secreting surfaces approximately twice as large as nectaries of staminate flowers and they produced 1.5 - 2.3 times more nectar than staminate flowers, which correlated with the length of the visit. Honey bees, if not disturbed, stayed on a flower until they removed all the nectar. The pattern of bee visits throughout the day produced a normal distribution centered around 11 - 12 a.m. EST with 82.3% of all visits occurring from 9 a.m. to 2 p.m. (Figure 6). Only 4.3% of the visits occurred before 9 a.m. and 13.4% after 2 p.m. Prior to 9 a.m. the average time spent on each flower was greater than for the rest of the day. Fewer bees were working the flowers and the flowers contained a larger supply of nectar.

As bee density increased after 9 a.m., the average time per visit decreased because flowers being visited had only partially replenished their nectar supply following removal by earlier bee visits. Connor (1969) found that the length of a bee visit to a pistillate flower decreased as the number of visits increased. First visits to a cucumber flower lasted an average of 36.2 sec in 1967 and 39.2 sec in 1968, while the average length of subsequent visits dropped sharply. Collison (1973) showed that successive removal and replacement of nectar reduced sugar concentration and actual weight of sugar. Late day increases in the time spent on flowers increased from 2 - 4 p.m. for staminate flowers and 1 - 4 p.m. for pistillate flowers. Decrease in flight activity after 2 p.m. allowed greater accumulation of nectar per flower resulting in longer bee visits.

Linsley and MacSwain (1947) observed a depression in the number of bees working alfalfa in the early afternoon, followed by an increase later. The depression corresponded with periods of highest temperature and lowest relative humidities; such a decrease was observed in cucumbers at 32°C. Bodenheimer and Ben-Nerya (1937) found a reduction at 33° C and a rapid increase between 34 and 39° C, which they concluded was probably due to water transport. Flight activity in cucumbers decreased during the entire afternoon (Figure 6). Bees were followed for 53 flower visits in the morning and 63 in the afternoon. The number of visits required to obtain a load of nectar depended on the bee and flower density in the field as well as the staminate:pistillate flower foraging ratio. From 7 - 11 a.m., bees averaged 15.2 sec per flower visit (3.95 flowers per minute) compared to 10.3 sec for the rest of the day (5.83 flowers per minute) and flight activity peaked from 11 - 12. Foster and Levin (1967) found that bees worked cantaloupes at a rate of 3 - 7 sec per flower with an average of seven bee visits per minute. Mann (1953) reported 5.39 - 7.27 flower visits per minute. Bees spent an average of 5.28 sec at each flower and 5.85 sec between flowers. McGregor et al. (1965) observed that the average visit time of a honey bee on a cantaloupe flower was 10 sec.

Foraging mobility varied greatly from day to day due to differences in flower density, staminate:pistillate flower ratio, size of the foraging population, nectar production, and climatic conditions. Several authors have shown that flowering and sex expression are dependent on climatic conditions. McGregor and Todd (1952) observed that bees working canteloupes visited plants along a row more frequently than shifting from row to row. With dense cucumber plant populations rows are no longer visible and foraging patterns become more random although oriented more strongly in one direction.

Following individual bees as they foraged indicated that bees are capable of distributing cucumber pollen a distance of 60 ft.

Pollen movement and fluorescent powder studies indicated that honey bees carry cucumber pollen a considerable distance from the pollen source, although the efficiency of the movement decreased in as little as 10 ft as indicated by seed counts. Peak production of fruit occurred at 0 to 10 ft from the pollen source. Fruit production decreased as the distance from the pollen source increased, up to 90 ft in 1969 and 30 ft in 1972, then began to increase. Seed counts indicated pollen movement up to 60 ft in 1969 and 70 ft in 1972. A highly significant negative correlation was found between distance and average number of seeds. Besides the direct movement of cucumber pollen from the pollen source, the possibility of re-transfer of pollen from stigma to stigma exists. Seed counts indicated that retransfer of pollen was not of great significance to pollination. Foster and Levin (1967) observed the re-transfer of pollen from stigma to stigma in watermelon pollination.

Connor (1969) found evidence for the movement of pollen for at least 50 ft. Beyond 25 ft from the pollen source, there was a reduction in the dollar value, the number of fruit per plant, and the number of seeds per fruit. Foster and Levin (1967) found evidence for movement of canteloupe pollen at least 35 ft and Knysh (1958) for movement of cucumber pollen a distance of 250 m.

Fluorescent powder movement rapidly decreased as the distance from the source increased. In 1971, no powder was detected beyond 70 ft from dusted flowers. Most of the powder was distributed in the first 20 ft from the source. The use of the fluorescent powders indicated that the size of the bee population, weather conditions, and concentration of powder affect its distribution.

Comparison of pollen movement strip pairs for the various levels of pollen present seemed to indicate an inverse relationship between the number of fruit per plant and amount of pollen present, but the opposite was true for seed counts. There was a direct relationship between the amount of pollen available and the distance it was moved by the bees. Evidence suggests that the level of pollen present and its distribution along with decreased light intensity in late summer, Tiedjens (1928), seem to trigger the mechanism for parthenocarpic fruit production. Plants located farthest from the pollen source were greener and healthier looking, had larger leaves, and more flowers. McCollum (1934) found that parthenocarpic fruit did not put as much stress on the plant as fruits containing seeds. Decreased light intensity in August and September, and less available pollen may partially explain the increase from 9.4% parthenocarpic fruit for the first harvest, to 42.6% for the second harvest. Because of increased plant vigor indicated by a greater "vegetative response" plants farthest from the pollen source set more fruit parthenocarpically than those close to pollen. Parthenocarpic fruit were first found at 50 ft from the pollen source in the first harvest and at 30 ft in the second harvest. In 1972 when pollen levels were higher, only 4.1% of the fruit developed parthenocarpically and was first observed at 90 ft during the same time of the year.

The monitoring of two field plots in 1974 indicated that fruit inhibition limits fruit production and excessive production of staminate flowers limits fruit uniformity for mechanical harvesting. Staminate flower production predominated throughout the flowering period, particularly as the plant matured and fruit formed. In the Piccadilly plot, the daily staminate:pistillate flower ratios fluctuated between 1.30 and 3.93 with a mean of 2.24. In comparison the adjacent plot of MSU 9805 over the same time period had a staminate: pistillate flower ratio between .84 and 4.47 with a mean of 2.25. Similar situations were observed several times in commercial fields and other plots.

Fruit inhibition was rapidly expressed in the field. The first pistillate flowers that appeared on the vine developed into mature fruit 91.7% of the time; 49.6% of the second group developed into mature fruit. With each succeeding set of flowers, fruit production decreased rapidly from 19.9% for the third set to none for the seventh set. In the adjacent MSU 9805 plot, 62.0% were in position one, 28.3% in position two, 7.3% in position three, 2.0% in position four, and 0.4% in position five. Flower counts and seed counts indicated that there was no shortage of pollen. Foraging activity was not a limiting factor with projections of 10,739 - 94,478 bee visits per day. Climatic conditions were favorable for flight activity and fruit set during the entire monitoring period. Even under optimum pollination conditions, the Piccadilly plot averaged only 1.23 fruit per plant and the MSU 9805 plot 1.15 fruit per plant. Each succeeding flower has a decreasing chance to set fruit. Even if fruit development begins, it often reaches the inhibition threshold before attaining a size of economic value. Such growth-inhibited ovaries either withered and died or remained green and unchanging for several weeks, depending on the stage of development. The data indicated this threshold peaked within flowers 2 - 4 on the vine. If more than one flower on a plant is produced and pollinated on the first day of bloom further fruit set may be completely inhibited. It is likely that each cultivar has a genetic limit to the number of fruit it can mature at one time. If fruit is hand-picked, growth inhibited fruit further along the vine will than develop. Ability to develop many fruit at one time is an important economic factor in a cultivar for machine harvest.

Sims and Gldehill (1969) reported that several commercial gynoecious hybrids produced up to 50% staminate flowers. The blending of monoecious seed with the gynoecious hybrids is done but unnecessary. When staminate flowers are present in excessive numbers, they may be produced on some vines for several days in succession, resulting in a fruit set that is not uniform for mechanical harvesting. Connor (1969) found that best yields for a single harvest could be expected from the use of a highly gynoecious hybrid seed blended with a pollinator to produce a 1:2 staminate:pistillate flower ratio. Monoecious varieties produce an S:P ratio of approximately 20:1.

The 1974 study indicated that if a pickle field has adequate but not excessive pollen, uniform flowering, plenty of bees brought in about six days after the start of flowering, and good flying weather (temperatures above 21° C, relative humidity below 70%, winds less than 15 mph, plants dry, and bright sunshine), maximum fruit set for machine harvest could be achieved in less than a week.

Connor and Martin (1970) found with delayed pollination, an exposure period of six days of active bee pollination was sufficient for optimum single harvest yields. Without considering fruit inhibition, any estimate of pollinator needs may be excessive. As the seeds begin to mature in the fruit, they slowed the development of new pistillate flowers and inhibited further fruit set, Cantliffe (1974).

Some correlation was observed between the number of seeds and fruit shape. However, the extent of pollination only appears to be one factor involved. Other factors are probably physiological, climatic, and genetic in nature. Perfect-shaped fruit were found to contain from 0 to 546 seeds. No significant correlation was found between production of perfectly shaped fruit and daily staminate: pistillate flower ratio, average seed counts, or total bee visits per day. Connor (1969) found perfectly shaped fruit containing from one to 520 seeds. Connor (1969) was unable to find a correlation between the percentage of perfectly shaped cucumbers and the number of bee visits to the flowers. He found that the perfectly-shaped fruit had approximately twice as many seeds as the necks and three times as many as the nubs. Tiedjens (1928) found no correlation between the number of seeds and shape of the cucumbers. Seaton (1937) found that the number of developing seeds determined the amount of fruit tissue that developed, implying that more seeds resulted in better fruit shape. Wong (1938) found that a constriction of the stem end or blossom end of the fuit was due to seedlessness of that particular portion. Kremer (1943) hypothesized that anything interfering with the germination and growth of the pollen tubes through the ovary may be responsible for the constrictions in the various regions of the fruit. Seaton, Hutson, and Muncie (1936) reported that fruit shape depended largely on the weather conditions prevailing at the time fruit set. Miller and Ries (1958) found that conditions leading to a faster rate of growth were more conducive to better shaped fruit. An attempt was made to determine the number of bees required for maximum pollination and crop yield. Most current pollinator recommendations call for a specific number of colonies per acre of crop. However, the colony is not a standard unit and in order to have real meaning, it needs to be defined. Strong colonies are usually recommended in pollination literature but attempts to define this term vary widely. Such terms as "thousands of bees," "frames of brood," "square inches of brood," "the number of frames the cluster covers," and combinations of these have commonly been used. However, to the grower such terms have little meaning, since they refer to bees in the colony rather than on the flowers. From a pollination standpoint, the usefulness of a colony of bees is indicated by the number of foraging trips to the crop per unit of time. Various types of counting techniques and devices for measuring bee flight from a colony have been developed by Lundie (1925), Farrar (1931), Woodrow (1932, 1934), Brittain (1933), Bodenheimer and Ben-Nerya (1937) and Gary (1967). However, in assessing cucumber pollination such techniques have limited value since there are usually several species of plants in the area of the pickle fields that are more attractive to honey bees than cucumbers, Collison and Martin (1970). The following sampling technique was developed for the grower or researcher to assess pollinator activity in pickle fields and to determine if sufficient activity is present or more bees are needed. The incorporation of weather data would make it too cumbersome for the grower to use. This research has indicated that flowers on the day of anthesis should receive from 15 - 20 visits for maximum fruit set. Between 9 a.m. and 2 p.m., 82.3% of all bee visits occurred. Therefore, on a sunny day when flower petals are dry, temperature above 24° C, between 10 a.m. and 1 p.m., wind less than 15 mph, at least six days after start of bloom, select 10 fresh flowers, five staminate and five pistillate. Count the number of bee visits for 10 min. Rest 10 min, then repeat at two more locations. This will take one hour. Compare the one hour bee activity to Table 79 to obtain an indication of the adequacy of pollinations. Researchers requiring greater accuracy should extend sampling to three hours.

The number of seeds per fruit provided the best indicator of the amount of pollination that has taken place. Fruit contained from 0 - 546 seeds under various field and plot conditions. In order to estimate the amount of pollen that a pistillate flower should receive, the average number of ovules per flower should be known. Seed counts of the fruit receiving a specified number of bee visits in 1970 indicated that honey bees placed a minimum of 18 effective pollen grains on the stigma with each visit. Prior to sampling, staminate:pistillate flower ratios averaged 1.15 in the first plot and 2.28 in the second. Connor (1969) found a positive correlation between the length of the ovary and the number of ovules per longitudinal section.

TABLE 79.--Projected number of bee visits for the day based on the number of bees visiting 10 cucumber flowers in ten minutes with three samples per hour.

| Time EST | % of total visits for the day | Estimated sample level based on total no. of bees/30 flowers/30 min | | | | | |
|---|---|---|---|---|---|---|---|
| 7:00 - 8:00 | .8 | 0 | 0 | 0 | 1 | 1 | 1 |
| 8:00 - 9:00 | 3.5 | 0 | 1 | 2 | 3 | 4 | 4 |
| 9:00 - 10:00 | 12.3 | 1 | 3 | 6 | 9 | 12 | 15 |
| 10:00 - 11:00 | 17.2 | 1 | 4 | 9 | 13 | 17 | 22 |
| 11:00 - 12:00 | 20.7 | 1 | 5 | 10 | 16 | 21 | 26 |
| 12:00 - 1:00 | 17.8 | 1 | 4 | 9 | 13 | 18 | 22 |
| 1:00 - 2:00 | 14.3 | 1 | 4 | 7 | 11 | 14 | 18 |
| 2:00 - 3:00 | 8.4 | 0 | 2 | 4 | 7 | 8 | 11 |
| 3:00 - 4:00 | 5.0 | 0 | 1 | 3 | 4 | 5 | 6 |
| Calculated number of bee visits/flower/day | | 1 | 5 | 10 | 15 | 20 | 25 |
| | | | | | Recommended level of bee activity | | |

A regression was run on his raw data and the following regression equation,

$$Y = -1.62 + 2.93x$$

was obtained to be used in predicting the average number of ovules per ovary. A highly significant positive correlation was found between the length of the ovary and the number of ovules per longitudinal section [$r = 0.8358$, $t = 12.45$ (significant at the .001 probability level), $df = 67$], which indicated 69.9% association between the two variables. An approximate idea of how many ovules are present in an ovary was obtained by multiplying the number of ovules along one carpel edge by six. Connor (1969) found the average ovary length of Piccadilly at anthesis was 21.5 mm which indicated an average of 368 ovules per ovary. Collison (1973) found the average ovary length of SMR 58 to be 20.4 mm and of Spartan Progress 18.7 mm which represents 349 and 319 ovules per fruit, respectively. In 1968, ovaries taken from Piccadilly plots averaged 18.3 and 20.2 mm in length. The largest ovary measured was 28 mm in length which indicates 483 ovules/fruit. These values, certainly fall within the range of actual seed counts that have been made. Seed counts from more than 4200 fruit showed that the average number of seeds per fruit ranged between 66 in the 1969 pollen movement studies where pollen levels were low, to a high of 328 seeds per fruit for the early morning hand pollinations made at the time of anther dehiscence. Assuming that a honey bee distributes approximately 18 effective pollen grains per bee visit, the average ovary would require from 18 - 20 visits for complete fertilization which supports the recommendation that 15 - 20 visits are needed for maximum fruit set in the field. At lower pollen concentrations, more visits would be required for complete fertilization.

Heinrich and Raven (1972) pointed out that little attention has been paid to the caloric reward provided by the flowers of a particular plant species to the pollinator. They hypothesized that the amount of nectar per flower, in terms of calories of food energy needed to bring about maximum cross-pollination, would be related to the characteristic rate of energy expenditure of the pollinators.

Collison (1973) found that a honey bee removes all of the nectar present in a flower in one visit if not disturbed. When bees were excluded, the average volume of nectar in pistillate flowers increased throughout the day averaging 6.05 ul per day. Connor (1969) timed the length of initial bee visits to pistillate flowers throughout the day and found the average time to be 36.2 seconds. The two sets of data indicated that the honey bee removed an average of 0.17 ul of nectar per second (Table 80). Collison (1973) found that honey bees averaged 60.1 seconds in their initial visit and removed a mean of 9.64 ul of nectar during the afternoon, which equals 0.16 ul/second. Since flowers are visited repeatedly throughout the day, the amount of nectar obtained on each visit can be extrapolated from the time spent on staminate and pistillate flowers throughout the day and the average amount of nectar removed per second. We assume that nectar removal from staminate and pistillate flowers per unit of time is similar (Table 81). Calculations indicated that the average

TABLE 80.--The amount of nectar the honey bee removes from the pistillate cucumber flower throughout the day.

| Time EST | Avg. volume of nectar (ul) | Avg. length of initial bee visit (Connor, 1969) | ul/sec |
|---|---|---|---|
| 7:00 - 8:00 | 1.40 | 10.5 sec | 0.13 |
| 8:00 - 9:00 | 1.83 | 8.8 sec | 0.20 |
| 9:00 - 10:00 | 2.89 | 30.3 sec | 0.09 |
| 10:00 - 11:00 | 4.44 | 38.3 sec | 0.11 |
| 11:00 - 12:00 | 6.08 | 38.5 sec | 0.15 |
| 12:00 - 1:00 | 6.98 | 39.9 sec | 0.17 |
| 1:00 - 2:00 | 7.61 | 37.3 sec | 0.20 |
| 2:00 - 3:00 | 9.77 | 37.9 sec | 0.25 |
| 3:00 - 4:00 | 9.59 | 37.2 sec | 0.25 |
| 4:00 - 5:00 | 9.92 | 45.0 sec | 0.22 |
| Overall | 6.05 | 36.2 sec | 0.17 |

TABLE 81.--The predicted amount of nectar removed from pistillate and staminate cucumber flowers throughout the day by the honey bee.

| Time EST | Avg. time on pistillate flowers | Projected volume removed | Avg. time on staminate flowers | Projected volume removed |
|---|---|---|---|---|
| 7:00 - 8:00 | 16.0 | 2.72 | 7.1 | 1.21 |
| 8:00 - 9:00 | 14.7 | 2.50 | 7.3 | 1.24 |
| 9:00 - 10:00 | 15.4 | 2.62 | 7.0 | 1.19 |
| 10:00 - 11:00 | 12.3 | 2.09 | 6.6 | 1.12 |
| 11:00 - 12:00 | 9.6 | 1.63 | 6.7 | 1.14 |
| 12:00 - 1:00 | 7.8 | 1.33 | 5.5 | 0.94 |
| 1:00 - 2:00 | 8.2 | 1.39 | 5.1 | 0.87 |
| 2:00 - 3:00 | 9.6 | 1.63 | 6.0 | 1.02 |
| Overall | 12.6 | 1.99 | 6.3 | 1.09 |

volume of nectar removed from pistillate flowers was 1.99 ul/visit and from staminate flowers 1.09 ul. The projected volumes would not appear to be unreasonable since Collison (1973) found that pistillate flowers produced 1.5 to 2.3 times more nectar than staminate flowers and over the entire day honey bees spent twice as long on pistillate as on staminate flowers.

Park (1922) found that the honey bees maximum carrying capacity was 70 mg but the average loads weighed about 40 mg. Cucumber nectar removed from the honey stomach of bees taken directly from the field showed that the concentration of sugar ranged from 17.1 to 28.3%, averaging 24.5% over the entire day. The specific gravity of a 24.5% sucrose solution at 20 degrees centigrade is 1.1033. Therefore, 1 microliter of nectar would weigh 1.1033 mg. Thus a maximum load of 70 mg of cucumber nectar would contain 63.4 ul and an average load 36.3 ul. Therefore, a honey bee would have to visit 32 pistillate flowers to obtain a maximum load of nectar and 18 flowers for an average load. On the other hand, if the honey bee was to visit only staminate flowers, a maximum load would require 58 visits and an average load 33 visits. Certainly the bee population density within the field would affect these values. Since honey bees visit both staminate and pistillate flowers on a foraging trip, assuming all conditions are equal to the mean calculations, the honey bee would have to visit between 18 and 58 flowers on a foraging trip.

To determine the actual number of flowers the bee would visit in relation to the fields staminate:pistillate flower ratio, the following equation was developed:

$$1.99x + 1.09y = 36.3 \qquad \begin{array}{l} x = \text{pistillate flowers} \\ y = \text{staminate flowers} \end{array}$$

In the Piccadilly plot during the 1974 study, the field staminate: pistillate flower ratio was 2.24 and the foraging staminate:pistillate flower ratio was 1.12, exactly half the field ratio.

$$Y = \frac{(36.3)\ (FSP)}{1.99 + 1.09\ (FSP)} \qquad \text{FSP = Foraging staminate:pistillate foraging ratio.}$$

The honey bee receives .29 mg of sugar with each staminate flower visit, and .54 mg with each pistillate flower visit when the overall sugar concentration of 24.5% sugar is used. An average load would contain 9.81 mg of sugar and a full load 17.14 mg.

In order to attain a better understanding of the complex interrelationships between bees and flowers involved in the pollination of pickling cucumbers, the following simulated foraging model of a field was developed (Figure 28 and Appendix B, Program Yield). Based upon data collected during this study, the model was used to project values for daily production of staminate and pistillate flowers, potential nectar yield, number of bee foraging trips required to collect the field's nectar supply (carrying capacity) and potential fruit production for various plant populations, cultivars, and seed blends. The effect of climatic conditions on nectar secretion and foraging activity have previously been equated.

Prior to mechanical harvesting, plant populations ranged from 4,000 and 20,000 plants per acre. Downes, Carpenter, and Reed (1972) found the optimum plant population to be 198,313 plants per acre for mechanical harvesting. For comparison, three cultivars, Spartan 27 (monoecious), Piccadilly (commercial hybrid, intermediate between gynoecious and monoecious), and Spartan Progress (gynoecious) with a 10% monoecious blend of SMR58 were used at plant densities of 20,000 and 198,313 plants per acre. Since Connor and Martin (1970) obtained higher yield and quality of fruit by delaying pollination for 5 to 11 days, flowering patterns of the various cultivars used in the predictive model started eight days after the first flower appeared in the 1968 test plots and were continued for 12 days (Table 82). Only flowers on the day of anthesis were included in the model.

Collison (1973) found that to accurately compare nectar secreting characteristics of different culitvars, data for staminate and pistillate flowers had to be considered separately. No significant differences in nectar secretion were found in the cultivars compared. On a field basis, cultivars that produced predominantly pistillate flowers secreted larger volumes of nectar with more total sugar than staminate lines which produced nectar with higher average sugar concentrations. Since there was no significant difference between cultivars, values for the model were obtained from the sampling of MSU 35G in 1968 and SMR 58 in 1969. In both studies, the flowers were excluded from bee visitation and sampled throughout the day. The average pistillate flower produced 6.05 ul/day compared to 4.01 ul/day for the staminate flower.

Each pistillate flower could potentially become a fruit of economic value, however, this study has indicated that fruit

TABLE 82.--Flowering patterns of various cucumber cultivars.

| Cultivar | Days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Spartan 27 | | | | | | | | | | | | |
| Flowers per plant | 2.85 | 4.05 | 4.60 | 5.50 | 4.45 | 4.65 | 7.20 | 6.10 | 10.95 | 9.10 | 6.55 | 8.45 |
| % pistillate | .18 | .14 | .14 | .10 | .08 | .10 | .15 | .12 | .09 | .06 | .09 | .09 |
| Spartan Dawn | | | | | | | | | | | | |
| Flowers per plant | 2.25 | 2.80 | 2.25 | 2.80 | 2.80 | 3.65 | 2.80 | 2.85 | 4.20 | 3.50 | 5.60 | 4.15 |
| % pistillate | .62 | .70 | .49 | .46 | .63 | .52 | .57 | .40 | .60 | .39 | .41 | .39 |
| Spartan Progress | | | | | | | | | | | | |
| Flowers per plant | 2.25 | 2.75 | 2.05 | 1.45 | 1.80 | 2.10 | 1.20 | 2.15 | 3.10 | 2.15 | 3.10 | 3.15 |
| % pistillate | .98 | .98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| MSU 35G | | | | | | | | | | | | |
| Flowers per plant | 2.10 | 1.55 | 1.20 | 1.60 | 2.55 | 1.20 | 1.45 | 1.80 | 1.95 | 2.95 | 2.50 | 1.35 |
| % pistillate | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SMR 58 | | | | | | | | | | | | |
| Flowers per plant | 1.55 | 3.25 | 3.90 | 5.15 | 3.05 | 3.90 | 5.40 | 4.20 | 6.15 | 6.00 | 3.55 | 6.25 |
| % pistillate | .16 | .09 | .09 | .17 | .13 | .10 | .18 | .17 | .22 | .13 | .10 | .07 |
| Piccadilly/pollinator | | | | | | | | | | | | |
| Flowers per plant | 2.10 | 2.45 | 1.75 | 2.25 | 3.15 | 2.65 | 2.30 | 2.70 | 3.10 | 4.10 | 2.90 | 2.85 |
| % pistillate | .69 | .49 | .31 | .44 | .48 | .32 | .39 | .46 | .35 | .44 | .36 | .26 |
| Piccadilly | | | | | | | | | | | | |
| Flowers per plant | 2.42 | 2.70 | 2.08 | 2.23 | 2.93 | 3.15 | 2.48 | 3.15 | 4.25 | 3.25 | 5.15 | 4.53 |
| % pistillate | .61 | .65 | .59 | .43 | .44 | .48 | .47 | .48 | .49 | .45 | .40 | .41 |

inhibition limits this. Even though individual plants do not have identical flowering patterns, by delaying the introduction of bees into the field for 8 days after the start of flowering, a high percentage of the plants should be producing pistillate flowers and be physiologically ready to set fruit. Therefore, it was felt that the quantitative data obtained in 1974 on fruit inhibition could be used in the model (Table 77). The program requires the following input:

A. Number of plants/acre
B. Total number of acres
C. Seed blend
   % cultivar A
   % cultivar B
D. Daily number of flowers/plant, cultivar A
E. Daily number of flowers/plant, cultivar B
F. Daily percent pistillate flowers, cultivar A
G. Daily percent pistillate flowers, cultivar B
H. Daily fruit inhibition levels.

The program has provided some very useful information relative to understanding the pollination requirements of cucumbers. The transition from monoecious to gynoecious cultivars and high plant densities has greatly changed the energetics of the flower-visitor relationship in the field. With more flowers per acre, the nectar and pollen productivity of the field should be greatly increased and the honey bee would have to expend less energy to go from flower to flower. Comparison of the three cultivars at similar population levels indicated significant differences in total flower production (Table 83). Spartan 27 produced 1,489,000 flowers per acre over the 12 day period compared to 766,396 flowers for Piccadilly, and 595,200 flowers for the Spartan Progress and SMR 58 seed blend at a plant density of 20,000 plants per acre. The monoecious cultivar produced

TABLE 83.--Projected production of staminate and pistillate cucumber flowers for different cultivars and seed mixtures (20,000 plants/acre, 10 acres).

| Day | Spartan 27 | | Piccadilly without pollinator | | Spartan Progress - 90% SMR 58 - 10% | |
|---|---|---|---|---|---|---|
| | Staminate | Pistillate | Staminate | Pistillate | Staminate | Pistillate |
| 8 | 467,400 | 102,600 | 188,760 | 295,240 | 34,140 | 401,860 |
| 9 | 696,600 | 113,400 | 189,000 | 351,000 | 69,050 | 490,950 |
| 10 | 791,200 | 128,800 | 170,560 | 245,400 | 70,980 | 376,020 |
| 11 | 990,000 | 110,000 | 254,220 | 191,780 | 85,490 | 278,510 |
| 12 | 818,800 | 71,200 | 328,160 | 257,840 | 53,070 | 331,930 |
| 13 | 837,000 | 93,000 | 327,600 | 302,400 | 70,200 | 385,800 |
| 14 | 1,224,000 | 216,000 | 262,880 | 233,120 | 88,560 | 235,440 |
| 15 | 1,073,600 | 146,400 | 327,600 | 302,400 | 69,720 | 401,280 |
| 16 | 1,992,900 | 197,100 | 433,500 | 416,500 | 95,940 | 585,060 |
| 17 | 1,710,800 | 109,200 | 357,500 | 292,500 | 104,400 | 402,600 |
| 18 | 1,192,100 | 117,900 | 618,000 | 412,000 | 63,900 | 565,100 |
| 19 | 1,537,900 | 152,100 | 534,540 | 371,460 | 116,250 | 576,750 |
| Total | 13,332,300 | 1,557,700 | 3,992,300 | 3,671,640 | 921,700 | 5,030,300 |
| Average | 1,111,025 | 129,808 | 332,693 | 305,970 | 76,808 | 419,192 |

1.94 times more flowers than the intermediate cultivar and 2.50 times more than the gynoecious blend. The staminate:pistillate flower ratio was 8.56 for Spartan 27, 1.09 for Piccadilly and 0.18 for the Spartan Progress blend. Over the 12 day period, the Spartan Progress blend produced 1.37 times more pistillate flowers than Piccadilly and 3.23 times more than Spartan 27. Projected yields, assuming a sufficient number of bees and an adequate pollen supply would be .98 pickles per plant for Spartan 27, 2.71 for Piccadilly, and 3.76 for Spartan Progress (Table 86). Adams and Peterson (1972) found the number of fruit per plant to be a useful index in estimating potential yields for once over harvest. Rapid changes in fruit weight and size occur near harvest time.

For all three cultivars, increasing the plant populations from 20,000 plants per acre to 198,313 plants per acre increased the potential nectar production of the field by 9.92 times (Table 84). Comparison of the three cultivars indicated that with an increase in the gynoecious flowering characteristic, because of a reduction in total flowering, there is potentially less nectar available to the bees, even though the pistillate flowers produce from 1.5 - 2.3 times more nectar than staminate flowers. The increase in nectar production, however, is not large enough to offset the large decrease in the total number of flowers produced. With similar plant densities, the monoecious cultivar produced 1.64 times more nectar than Piccadilly and 1.84 times more than the Spartan Progress blend. Therefore, there is an inverse relationship between potential fruit production

TABLE 84.--Projected potential nectar production in a 10 acre cucumber field of various cultivars and seed blends for 20,000 and 198,313 plants/acre.

| Day | Spartan 27 | | Piccadilly without pollinator | | Spartan Progress - 90% SMR 58 - 10% | |
|---|---|---|---|---|---|---|
| | 20,000 | 198,313 | 20,000 | 198,313 | 20,000 | 198,313 |
| 8 | 2.50 | 24.74 | 2.54 | 25.22 | 2.57 | 25.46 |
| 9 | 3.48 | 34.50 | 2.88 | 28.57 | 3.25 | 32.20 |
| 10 | 3.95 | 39.19 | 2.17 | 21.51 | 2.56 | 25.38 |
| 11 | 4.64 | 45.96 | 2.18 | 21.61 | 2.03 | 20.11 |
| 12 | 3.71 | 36.83 | 2.88 | 28.52 | 2.22 | 22.02 |
| 13 | 3.92 | 38.86 | 3.14 | 31.17 | 2.62 | 25.94 |
| 14 | 6.22 | 61.63 | 2.46 | 24.44 | 1.78 | 17.65 |
| 15 | 5.19 | 51.47 | 3.14 | 31.17 | 2.71 | 26.84 |
| 16 | 9.18 | 91.07 | 4.26 | 42.22 | 3.92 | 38.91 |
| 17 | 7.52 | 74.58 | 3.20 | 31.76 | 2.85 | 28.30 |
| 18 | 5.49 | 54.47 | 4.97 | 49.29 | 3.68 | 36.44 |
| 19 | 7.09 | 70.27 | 4.39 | 43.54 | 3.94 | 39.16 |
| Total | 62.89 | 623.57 | 38.21 | 379.02 | 34.13 | 8.41 |
| Avg. | 5.24 | 51.96 | 3.18 | 31.58 | 2.84 | 28.20 |

Volume expressed in liters.

and total caloric reward potentially available to the bees. Also, the higher proportion of staminate flowers with the monoecious cultivar would provide the bee with nectar of a higher sugar concentration. If honey bees were able to collect all of the nectar potentially available from the high plant density fields over the 12 day period they would obtain 62.4 l/acre from Spartan 27, 37.9 l/acre from Piccadilly and 33.8 l from Spartan Progress. To do so, with the bees obtaining average size loads, a total of 1,717,800, 1,044,090, and 932,271 foraging trips would be required respectively (Table 85).

The model indicates that under optimum conditions for maximum fruit production, the field potentially produces 2.82 liters of nectar/acre/day with an overall sugar concentration of 24.5% sugar. The field averaged 491,816 flowers/acre/day with an overall staminate:pistillate flower ratio of .18. With an average load of nectar equaling 36.3 ul, a total of 77,689 foraging trips/acre would be required to collect all of the nectar. With a staminate:pistillate flower ratio of .18 in the field, the "foraging" staminate:pistillate flower ratio would be 0.09. Substituting it into the equation;

$$Y = \frac{(36.3)\ (FSP)}{1.99 + 1.09\ (FSP)}$$

on each foraging trip, the honey bee would visit an average of 1.56 staminate flowers and 17.4 pistillate flowers. Therefore, during the 77,689 foraging trips, the honey bee would visit staminate flowers 121,195 times and pistillate flowers 1,351,789 times.

TABLE 85.--Projected number of foraging trips required to collect the nectar produced in a 10 acre cucumber field of various plant populations, cultivars, and seed blends.

| Day | Spartan 27 | | Piccadilly without pollinator | | Spartan Progress - 90% SMR 58 - 10% | |
|---|---|---|---|---|---|---|
| | 20,000 | 198,313 | 20,000 | 198,313 | 20,000 | 198,313 |
| 8 | 68,733 | 681,531 | 70,059 | 694,677 | 70,748 | 701,513 |
| 9 | 95,852 | 950,437 | 79,379 | 787,090 | 89,453 | 886,983 |
| 10 | 108,869 | 1,079,509 | 59,748 | 592,442 | 70,511 | 699,163 |
| 11 | 127,697 | 1,266,198 | 60,047 | 595,401 | 55,862 | 553,911 |
| 12 | 102,318 | 1,014,551 | 79,225 | 785,564 | 61,184 | 606,681 |
| 13 | 107,962 | 1,070,513 | 86,589 | 858,590 | 72,055 | 714,471 |
| 14 | 171,213 | 1,697,690 | 67,893 | 673,206 | 49,023 | 486,096 |
| 15 | 142,999 | 1,417,926 | 86,589 | 858,590 | 74,582 | 739,528 |
| 16 | 253,002 | 2,508,682 | 117,305 | 1,163,152 | 108,108 | 1,071,964 |
| 17 | 207,189 | 2,054,416 | 88,242 | 874,981 | 78,633 | 779,696 |
| 18 | 151,339 | 1,500,627 | 136,936 | 1,357,810 | 101,242 | 1,003,883 |
| 19 | 195,239 | 1,935,924 | 120,960 | 1,199,394 | 108,800 | 1,078,825 |
| Total | 1,732,412 | 17,178,004 | 1,052,972 | 10,440,897 | 940,201 | 9,322,714 |
| Mean | 144,368 | 1,431,500 | 87,748 | 870,075 | 78,350 | 776,893 |

TABLE 86.--Projected potential fruit production of 10 acre cucumber fields of various plant populations, cultivars, and seed blends for 20,000 and 198,313 plants/acre.

| Day | Spartan 27 | | Piccadilly without Pollinator | | Spartan Progress - 90% SMR 58 - 10% | |
|---|---|---|---|---|---|---|
| | 20,000 | 198,313 | 20,000 | 198,313 | 20,000 | 198,313 |
| 8 | 94,084 | 932,906 | 270,735 | 2,684,514 | 368,506 | 3,653,973 |
| 9 | 56,246 | 557,720 | 174,096 | 1,726,275 | 243,511 | 2,414,572 |
| 10 | 25,631 | 254,150 | 48,843 | 484,306 | 74,828 | 741,968 |
| 11 | 11,110 | 110,163 | 19,370 | 192,064 | 28,130 | 278,922 |
| 12 | 4,557 | 45,184 | 16,502 | 163,626 | 21,244 | 210,643 |
| 13 | 3,906 | 38,731 | 12,701 | 125,937 | 16,204 | 160,669 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 195,534 | 1,938,854 | 542,247 | 5,376,722 | 752,423 | 7,460,747 |
| Fruit/plant | .98 | .98 | 2.71 | 2.71 | 3.76 | 3.76 |

The potential production of 2.82 liters of nectar per acre would contain 762.27 grams of sugar. White, Riethof, Subers, and Kushnir (1962) found that cucumber honey contained 38.20% fructose, 32.59% glucose, 1.45% sucrose, 5.66% maltose, and .96% higher sugars. Therefore, cucumber honey is 78.86% sugar. If the honey bees were to collect and convert all of the nectar, 2.13 pounds of honey would be produced.

The literature varies somewhat in the caloric values of honey and the sugars that make up nectar. Kilander (1951) stated, that, weight for weight, all carbohydrates have equal caloric values. On the other hand DuBois (1936) found that glucose yields 3.74 cal/gm and sucrose 3.96 cal/gm. Sense (1941) stated that carbohydrates yield 4 cal/gm and Bronson (1930) quoted it as 4.1. Waínio (1949) found that D-glucose and D-fructose both supply about 3.73 cal/gm when completely burned.

Caloric Values of Honey

| | | | |
|---|---|---|---|
| Sherman and Lanford | 1940 | 1/4 cup | 326 cal. |
| Taylor, MaCleod, and Rose | 1956 | 28 gm, 1 oz. | 83 cal. |
| Hawley, Carden, and Munves | 1955 | 21 gm | 62 cal. |
| Phillips | 1930 | 1 pound | 1480 cal. |
| Root | 1950 | 1 pound | 1540 cal. |

The 2.13 pounds of honey produced per acre would yield 2829-3152 calories using the values of Taylor, MaCleod, and Rose (1956) and Phillips (1930). Collison (1973) analyzed cucumber nectar with gas liquid chromatography for sucrose, fructose, and glucose. Cucumber nectar averaged 51.8% sucrose, 21.9% glucose, and 26.3% fructose.

Therefore, the 762.27 gm of sugar would have been 394.86 gm of sucrose, 166.94 gm of glucose, and 200.48 gm of fructose. Using the values of DuBois (1936) and Wainio (1949), the 762.27 gm of sugar would produce 2935.8 calories. Considering the individual bee, the maximum size nectar load would contain .066 calories and the average load .038. From each staminate flower, the honey bee receives approximately .001 calories compared to .002 for the pistillate flower.

This work further supports the conclusions of Collison (1973) that cucumbers cannot be rated as an important honey plant, primarily due to the relatively small number of flowers per acre when compared to other major nectar sources.

Wigglesworth (1950) found that a honey bee is dependent for fuel on the store of sugar in its stomach. A bee weighing 100 mg uses this sugar at the rate of about 10 mg per hour and has flying time of only about 15 min with a flight range of about four miles. This could be equivalent to an average foraging trip. With a potential production of only 2.13 pounds of honey per acre, if all of the nectar were collected and with 25% of it being used by the bee during the foraging trip, little would be left for maintenance of the colony. In areas where large acreages of pickles predominate, beekeepers report that colonies produce little surplus honey. There are also unsubstantiated reports that such colonies winter poorly. These observations would be supported by the energetic relationships calculated above. Also few bees collect cucumber pollen. Pellets observed were small compared to the pellets from major pollen sources.

Therefore, poor wintering could be caused by a lack of pollen for late fall brood rearing. With significantly more data on flowering patterns, nectar production, and fruit inhibition levels for many different cultivars and further testing for predictive accuracy, such studies could provide the plant breeder and others with data that would be very helpful for evaluating cultivars for productivity and the incorporation of other factors such as the effects of climatic conditions, soil types, fertilizer levels, plant densities, weed control, plant development, and irrigation on nectar secretion and foraging activity would make the field model even more useful.

## SUMMARY AND CONCLUSIONS

1. Anthesis, anther dehiscence, the commencement of nectar secretion, and foraging activity in cucumbers were found to be primarily dependent on temperature.

2. Under normal light conditions, anthesis began at 15° C. Under a certain undetermined set of conditions, staminate flowers opened at a faster rate than pistillate.

3. As the corolla expanded, the anthers of the staminate flowers began to dehise and the nectaries of pistillate flowers gained a moist appearance under the microscope at 16° C. Optimum dehiscence occurred at 19° C.

4. Bee foraging activity in the field was first observed visually at 16.5° C when the flowers were undergoing anthesis at their normal rate. Bee flight rarely became abundant until the temperature reached 21° C. Optimum foraging occurred between temperatures of 21.5° and 30.0° C.

5. When the night temperature does not fall below the minimum temperature for the events listed in number one, or the thresholds are reached by daybreak, the sequence of events should occur as soon as adequate light is available. When temperatures during the day remain below minimum thresholds, flowers remain closed, anthers intact, nectaries dry, and bees in the hive.

6. At the time of anther dehiscence, pollen is viable, and the stigma receptive. As the day progresses pollen viability and stigmatic receptivity decrease. Fewer day-old staminate flowers than pistillate flowers were open which may be correlated with a faster loss of pollen viability than stigmatic receptivity. Honey bees seldom work day-old flowers.

7. Average foraging activity fluctuated throughout the day in relation to environmental conditions. Significant positive correlations were found with temperature, solar radiation, and wind speed, while a significant negative correlation was found with relative humidity. Threatening storms and rain significantly decreased activity.

8. Multiple regression analysis provided the following predictive equation between foraging activity and climatic conditions.

$$Y_{visits} = -161.01 + 2.41\,(\text{temperature}) + 1.30\,(\text{solar radiation}) + 1.12\,(\text{relative humidity}) + 2.11\,(\text{wind speed}).$$

9. Foraging activity commenced at lower temperatures when high populations of bees were available in the area.

10. The pattern of bee visits throughout the day produced a normal distribution centered at 11 - 12 a.m. EST. From 9 a.m. to 2 p.m., 82.3% of all bee visits occurred. Only 4.3% of the visits occurred before 9 a.m. and 13.4% after 2 p.m.

11. Nectar production fluctuated in response to changing climatic conditions. There was a positive correlation between

temperature and volume of nectar and actual weight of sugar and a negative correlation with relative humidity for both staminate and pistillate flowers. In pistillate flowers there was a negative correlation between nectar volume and actual weight of sugar to solar radiation of the three previous days and a positive correlation with precipitation of the four previous days. Significant correlations were obtained between wind speed and hourly nectar volume, sugar concentration, and actual weight of sugar in individual staminate flowers.

12. Multiple regression analysis indicated that the two following predictive equations best described the variation of nectar volume in relation to climatic conditions for both staminate and pistillate flowers.

Pistillate flowers $^{Y}$ volume = -8.51 + .28 (temperature) - .005 (solar radiation).

Staminate flowers $^{Y}$ volume = -8.58 + .17 (temperature).

13. The amount of nectar and sugar available to bees is related to the time of day that the threshold temperature is reached.

14. With bees excluded, the mean sugar concentration of nectar from both types of flowers was 40.8%. The mean sugar concentration of nectar removed from the honey stomachs of bees gathering from cucumbers in the same field was 24.5%, showing a 40% difference in sugar concentration.

15. Bees exhibit floral preferences which change during the day. From 7 - 9 a.m., pistillate flowers were more attractive than staminate. After 9 a.m. staminate flowers were preferred and preference increased throughout the day.

16. Cucumber pollen was found primarily on mouthparts, ventral surface of the thorax, prolegs, mesolegs, and metalegs of the honey bee. Largest amounts were found on mouthparts and metalegs. This placement makes the honey bee very efficient in distributing pollen uniformly over the stigmatic surface.

17. The bees first visit to a flower placed significantly more pollen on the stigma than succeeding ones; an average of 129 pollen grains for first visit compared to 33 or less for those that followed.

18. Multiple bee visits increased fruit set and the average number of seeds per fruit. However, the number of perfectly shaped fruit did not increase accordingly. No significant correlation was found between daily fruit set and perfectly shaped fruit.

19. Bee activity should provide from 15 to 20 flower visits on the day of anthesis for maximum fruit set in the field.

20. Node position after the sixth node did not significantly affect fruit set or production of perfectly shaped fruit when only one fruit was allowed to develop on the vine.

21. A significant positive correlation was obtained between daily percent fruit set and the amount of pollen being distributed with each visit which depends on the staminate:pistillate flower ratio.

22. Bees spent almost twice as long per visit on pistillate flowers as on staminate flowers. Except for early morning and late afternoon, the average time bees spent on the flowers decreased

throughout the day. Honey bees averaged 11.4 seconds per flower visit or an overall foraging rate of 5.3 flowers per minute at a staminate: pistillate flower ratio of 2.86.

23. For visually observed individual foraging bees, the maximum progress in one direction was 60 ft, maximum width 43 ft and maximum area 2,280 sq ft. Throughout the day and as the number of flower visits increased, the average length, width, and area of the forager increased.

24. Based on visual observations as well as pollen and fluorescent powder movement honey bees are capable of distributing cucumber pollen 60 - 70 ft from the pollen source, although the efficiency of the movement decreased after 10 ft. In addition, the possibility of further transfer of pollen, through the re-transfer of pollen from stigma to stigma exists for plants at greater distances. Apparently there is a direct relationship between the amount of pollen available and the distance it is moved by bees.

25. More parthenocarpic fruit were produced as light intensity and pollen levels decreased in late summer and this was also correlated with increased plant vigor in plants receiving no pollination.

26. Fruit inhibition limits fruit production and the excessive production of staminate flowers by commercial gynoecious hybrids limits fruit uniformity for mechanical harvesting.

27. Fruit inhibition was rapidly expressed in the field. The first pistillate flowers on the vine developed into mature fruit 91.7% of the time compared to 49.6% for the second group. With each

succeeding set of flowers, fruit production was further inhibited from 19.9% for the third set to 0.0% for the seventh set.

28. Even if fruit development begins, growth is inhibited before it reaches a size of economic value. Growth-inhibited ovaries either withered and died or remained green and unchanging for several weeks. If more than one flower on a plant is produced and pollinated on the first day of bloom, further fruit set may be completely inhibited.

29. If a cucumber field has adequate but not excessive pollen, uniform flowering, plenty of bees brought in about six days after the start of flowering, and good flying weather (temperatures above 21° C, relative humidity below 70%, winds less than 15 mph, plants dry, and bright sunshine), maximum fruit set for machine harvest could be achieved in less than a week.

30. Perfectly shaped fruit were found to contain from 0 to 546 seeds. No correlations were found between production of perfectly shaped fruit and daily staminate:pistillate flower ratios, average seed counts, or total bee visits.

31. A sampling technique was developed for the grower or researcher to assess pollinator activity in pickle fields in relation to a need for effective pollination.

32. Honey bees removed nectar from the flowers at a rate of 0.17 ul per second. Calculations indicated that the average volume of nectar removed from pistillate flowers was 1.99 ul/visit and 1.09 ul/visit from staminate. Therefore, honey bees visit from 18 to 58 flowers to get a load of nectar on a foraging trip. The honey bee

obtains .29 mg of sugar from each staminate flower and .54 mg from each pistillate flower. This represents about .001 calories per staminate and .002 calories per pistillate flower.

33. The transition from monoecious to gynoecious cultivars and high plant densities has greatly changed the energetics of the flower-visitor relationship in the field. With an increase in the gynoecious flowering characteristic, there is less nectar available to the bees with the large decrease in the total number of flowers produced per plant. Therefore, there is an inverse relationship between potential fruit production and total caloric reward potentially available to the bees.

34. Under optimum conditions for maximum fruit production (198,313 plants/acre) the field potentially produces, 2.82 l of nectar/acre/day. If honey bees were to collect all the nectar, it would become 2.13 pounds of honey.

35. Two colonies with a total of 914 square inches of sealed brood increased the foraging population in the field (.04 acres) 1.57 times.

# APPENDICES

# APPENDIX A

# CUCUMBER GRADING STANDARDS

## APPENDIX A

Method of determining the dollar value for cucumbers based upon the diameter of the fruit. Harvested cucumbers were dropped through a grading board consisting of a series of holes of the specific diameters.

| Grades | Inches in Diameter | Dollar Value |
|---|---|---|
| #1 | Up to 1-1/16" | $6 per Cwt. |
| #2 | 1-1/16 to 1-1/2" | $3 per Cwt. |
| #3 | 1-1/2 to 2" | $2 per Cwt. |
| #4 | 2" to 2-1/4" | $1 per Cwt. |
| #5 | 2-1/4 to 2-1/2" | 50 cents |
| #6 | Over 2-1/2" | 25 cents |

RATINGS: 1 to 6, 1 is best, 6 is poorest.

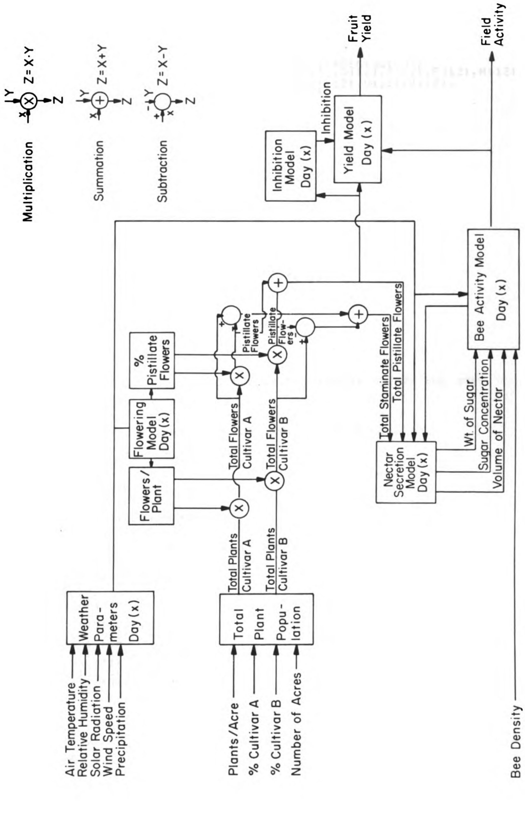
Developed by members of Pickling Cucumber Improvement Committee and approved as of 2/19/67.

# APPENDIX B

# ECOLOGICAL MODEL OF THE PICKLING CUCUMBER FIELD

# APPENDIX B

Figure 28.--A functional representation of the pollination ecology model used to interpret the complex interrelationships between honey bees, flowers, and pollination in the production of pickling cucumbers.



Multiplication
Z = X·Y
Summation
Z = X+Y
Subtraction
Z = X-Y
Air Temperature
Relative Humidity
Solar Radiation
Wind Speed
Precipitation
Weather Para-meters Day (x)
Plants/Acre
% Cultivar A
% Cultivar B
Number of Acres
Total Plant Popu-lation
Total Plants Cultivar A
Total Plants Cultivar B
Flowers/Plant
Flowering Model Day (x)
% Pistillate Flowers
Total Flowers Cultivar A
Total Flowers Cultivar B
Pistillate Flowers
Pistillate Flow-ers
Total Staminate Flowers
Total Pistillate Flowers
Nectar Secretion Model Day (x)
Wt. of Sugar
Sugar Concentration
Volume of Nectar
Bee Density
Bee Activity Model Day (x)
Inhibition Model Day (x)
Inhibition
Yield Model Day (x)
Fruit Yield
Field Activity

# Program Yield

```
      PROGRAM YIELD (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION MODE(12),IVAL(12),VAL(12),C(12),D(12),E(12),F(12),H(12),
     +G(12),Q(12),R(12),S(12),SP(12),SPP(12),T(12),U(12),P(12),
     +TVOLF(12),TVOLM(12),PS(12),IP(12),DV(12)
      EQUIVALENCE (IVAL,VAL)
      REAL MMV,MV,MFVT,IP,IPP
      M=0
      MM=0
      MMV=0.
      MV=0.
      IPP=0.
    1 FORMAT(*0TOTAL FLOWERS/DAY CULTIVAR A*)
    3 FORMAT(*0TOTAL FLOWERS/DAY CULTIVAR B*)
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 2)  GO TO 2000
      A=VAL(1)
      B=VAL(2)
      IF(MODE(1) .EQ. 2)  A=IVAL(1)
      IF(MODE(2) .EQ. 2)  B=IVAL(2)
      TPLANT=A*B
      WRITE (6,2) TPLANT
    2 FORMAT (*1TOTAL NUMBER OF PLANTS = *,F12.0)
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 2)  GO TO 2000
      CULA=VAL(1)
      CULB=VAL(2)
      IF(MODE(1) .EQ. 2) CULA=IVAL(1)
      IF(MODE(2) .EQ. 2) CULB=IVAL(2)
      CULATP=CULA*TPLANT
      CULBTP=CULB*TPLANT
      WRITE (6,4)CULATP,CULBTP
    4 FORMAT(1H0F12.0,*TOT PLANTS CUL A*,F12.0,*TOT PLANTS CUL B*)
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 12)  GO TO 2000
      DO 6 J=1,NUM
      IF(MODE(J) .NE. 4 .AND. MODE(J) .NE. 2)  GO TO 2000
      C(J)=VAL(J)
      IF(MODE(J) .EQ. 2) C(J)=IVAL(J)
      D(J)=C(J)*CULATP
    6 CONTINUE
      WRITE (6,1)
      WRITE (6,7)(D(K),K=1,12)
    7 FORMAT(1H 12F10.0)
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 12)  GO TO 2000
      DO 9 L=1,NUM
      IF(MODE(L) .NE. 4 .AND. MODE(L) .NE. 2)  GO TO 2000
      E(L)=VAL(L)
      IF (MODE(L) .EQ. 2) E(L)=IVAL(L)
      F(L)=E(L)*CULBTP
    9 CONTINUE
      WRITE (6,3)
      WRITE(6,7)(F(M),M=1,12)
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 12)  GO TO 2000
      DO 12 II=1,NUM
      IF(MODE(II) .NE. 4 .AND. MODE(II) .NE. 2)  GO TO 2000
      G(II)= VAL(II)
      IF(MODE(II) .EQ. 2) G(II)=IVAL(II)
      H(II)=G(II)*D(II)
      MM=MM+H(II)
      P(II)=D(II)-H(II)
      M=M+P(II)
      SP(II)=P(II)/H(II)
      WRITE (6,8) H(II),P(II),SP(II)
    8 FORMAT(1H0F12.0,*FEMALE FLOWERS*,F12.0,*MALE FLOWERS*,F8.2,*CULTIV
     +AR A*)
   12 CONTINUE
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 12)   GO TO 2000
      DO10 KK=1,NUM
      IF(MODE(KK) .NE. 4 .AND. MODE(KK) .NE. 2)  GO TO 2000
      Q(KK)=VAL(KK)
      IF(MODE(KK) .EQ. 2) Q(KK)=IVAL(KK)
      R(KK)=Q(KK)*F(KK)
```

```
      MM=MM+R(KK)
      S(KK)=F(KK)-R(KK)
      M=M+S(KK)
      SPP(KK)=S(KK)/R(KK)
      WRITE (6,11) R(KK),S(KK),SPP(KK)
   11 FORMAT(1H0F12.0,*FEMALE FLOWERS*,F12..,*MALE FLOWERS*,F8.2,*CULTIV
     +AR B*)
   10 CONTINUE
      WRITE(6,13) M,MM
   13 FORMAT(1H0I12,*TOTAL MALES*6X,I12,*TOTAL FEMALES*)
      DO 14 LL=1,12
      T(LL)=H(LL)+R(LL)
      U(LL)=P(LL)+S(LL)
      TVOLF(LL)=T(LL)*6.05
      TVOLM(LL)=U(LL)*4..1
      MMV=MMV+TVOLF(LL)
      MV=MV+TVOLM(LL)
      DV(LL)=TVOLF(LL)+TVOLM(LL)
      BEED=DV(LL)/36.3
      WRITE (6,15) T(LL),U(LL)
      WRITE(6,16) TVOLF(LL),TVOLM(LL)
   16 FORMAT(1H0F12.2,*NEC FEMALES*,6X,F12.2,*NEC MALES*)
      WRITE(6,17) DV(LL),BEED
   17 FORMAT(1H0F12.2,*DAILY NECTAR YIELD*,5X,F8.(,*BEE TRIPS NEEDED*)
   15 FORMAT (1H0F12.0,*FEMALE FLOWERS*,6X,F12.0,*MALE FLOWERS*)
   14 CONTINUE
      MFVT=MMV+MV
      NUM=12
      CALL EASYIN(IVAL,NUM,MODE,5)
      IF(NUM .NE. 12) GO TO 200
      DO 5 III=1,NUM
      IF(MODE(III) .NE. 4 .AND. MODE(III) .NE. 2) GO TO 2000
      IP(III)=VAL(III)
      IF(MODE(III) .EQ. 2) IP(III)=IVAL(III)
      PP(III)=IP(III)*T(III)
      WRITE(6,19) PP(III)
      IPP=IPP+PP(III)
   19 FORMAT(1H0F12.0)
    5 CONTINUE
      TPI=IPP/TPLANT
      BEE=MFVT/36.3
      WRITE(6,18)MMV,MV,MFVT
   18 FORMAT(*0FEMALES*,F20.2,*MALES*,F20.2,*TOT FIELD NEC*,F20.2)
      WRITE(6,20)TPI,IPP
   20 FORMAT(*0TOTAL FRUIT/PLANT*,F8.2,6X,*TOTAL FRUIT SET*F12.0)
      WRITE(6,21) BEE
   21 FORMAT(1H0F20.2,*TOTAL BEE TRIPS NEEDED*)
 2000 CONTINUE
      END
```

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