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Behavior of the Honey Bee (*Apis mellifera* L.) Mutant, Diminutive-Wing

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The recessive mutant, diminutive-wing (*di*), discovered in 1966 at the University of California, Davis, has fore wings averaging 7.5 mm in length (79.4 percent of normal), wing area (right side) 17.3 mm² (62.9 percent of normal), and a normal venation pattern. The queens have slightly convex wings and do not fly; thus they must be artificially inseminated. Some *di* workers and a few *di* queens uncouple their fore and hind wings.

In this study, the wing-beat frequency of *di* workers averaged 251.8 beats/sec (22.2 percent more than normal). Flight time to a feeder 1 km distant averaged 3.9 min (5.4 percent longer than normal), and return flights averaged 6.1 min (35.6 percent longer than normal).

Departing *di* foragers had an average of 1.9 μ liters of nectar (57.6 percent of normal), and returned with an average of 7.8 μ liters (30.8 percent of normal). Pollen loads averaged 16.4 mg (88.2 percent of normal). When given a 76-mg metal weight, 50 percent of the normal bees returned from 100 m, but none of the *di* bees were recovered. Syrup loads of both normal and *di* bees became larger when gathered at increasing distances from the hive.

The ratio of diminutive-wing to normal bees at feeding stations diminished with increasing distance. When *di* and normal foragers were from different colonies, *di* successfully dominated feeders to 300 m.

There were no significant quantitative or qualitative differences between normal and *di* bees with respect to communication of the distance to feeders. However, among nectar carriers, significantly more *di* than normal bees performed "round" dances, signifying food at close range.

Successful return of foragers released 1 km from the hive was 28.9 and 10.0 percent, respectively, for normal and *di* workers. Colonies of diminutive-wing bees appeared to have a natural foraging range that was less than that of normal bees, but the difference was not great.

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INTRODUCTION

HONEY BEES and insect-pollinated plants are interdependent. This relationship is not only an interesting biological phenomenon, it is of critical importance to man in that many of the foods of the human diet and many of the ornamental plants are in some way influenced by the pollinating activities of honey bees. It is appropriate, then, to enquire into the biology of honey bees, including foraging behavior and factors that influence it.

Mutations can be helpful in such studies, and a wing mutation—diminutive-wing—was utilized in this research. The objectives of this study were to describe the bees carrying this mutation and to measure experimentally some of the behavioral consequences

that result, particularly those involving flight, and the loads the bees carry.

The diminutive-wing mutation was discovered in 1966 by Laidlaw (unpublished) at the University of California at Davis, among the drone progeny of an otherwise normal queen. Subsequently, the mutant was shown by Laidlaw and Sylvester (unpublished) to be recessive and broadly linked with the mutant eye color garnet (*g*) and to have a crossover value of 14.5 percent, based on a count of some 1,500 drones. It was assigned the genetic symbol *di* after it was determined from tests for allelism that the gene is at a different locus from those for the wing mutations *short*, *truncate*, and *wrinkled*.

METHODS IN GENERAL

All bees used in this research were of the Italian race (*Apis mellifera ligustica* Spin.), which is the "yellow" race now prevalent in the United States.

I. To measure the wings, the right pair was removed and each member was mounted on a slide. Each slide (total, 202) was projected with a microslide projector at a ratio of 1:28.6. Measurements were then made of certain wing

characters, and later the values were divided by 28.6, the projection factor. To determine wing area, tracings of the projected wing outline were cut out and weighed.

II. To determine wing-beat frequency, we used a Strobotac¹ electronic stroboscope. When the flash frequency was adjusted to coincide with the wing movement, this illuminated the wings at

¹Stroboscope type 1531-AB, manufactured by General Radio Co., W. Concord, Mass. 01781. (U.S. Patent no. 2,966,257; flash-rate range: 110–25,000 flashes/min; accuracy: ± 1 percent of dial reading.)

precisely the same phase of the cycle of each beat, creating the optical illusion of motionlessness.

Worker bees (30 diminutive-wing and 30 normal) leaving the hive were captured individually while arriving at the hive entrance to ensure that all bees studied were in the same behavioral state. Only bees with intact wings were used, inasmuch as old foragers with frayed wings might have a higher wing-beat frequency than normal. Each bee was tested immediately after capture to minimize fatigue. The bees were restrained under a wire grid (2.4 mesh/cm) while a rigid wire was glued to the third abdominal tergite by using a small droplet of quick-drying Duco cement.² The other end of the tether wire was hand held such that the bee was forced to remain immobile in the air about 5 cm from the stroboscopic light, just long enough to take a reading. As precautions against fatigue, no anesthetic was used during the procedure, and the bees were tethered no longer than 3 min. Tethered bees, if necessary, were induced to fly either by directing a gentle stream of air at the head, or by stimulating the tarsi.

Audiospectrographic analyses of tape-recorded flight tones were done with *di* and normal workers fanning (without exposure of the Nassanov gland) and in free flight. Bees used in this experiment were fed sugar syrup (37.5 percent) *ad libitum* prior to testing. The microphone was positioned about 6 cm from the bee.

III-1. To obtain comparative data on the loads of normal and diminutive-wing workers, a colony was established in a four-frame, glass-walled observation hive³ in a laboratory room. A glass-covered runway (inside dimensions: length, 75 cm; width, 10 cm; depth, 2 cm) led to an opening in the wall to the exterior. The glass covering the runway

was cut into hinged strips (5.2×14.2 cm) to enable the investigator to remove bees at will. The queen of the colony had been reared in April, and was heterozygous at the *di* locus. She was mated to *di* drones by artificial insemination in order to produce progeny (workers and drones) in the phenotypic ratio of 1 diminutive-wing: 1 normal.

Observations on the loads of *di* and normal workers were made during the period July 3-7, 1972, from midmorning to midafternoon. Workers leaving the observation hive were sampled to determine their gross weight and honey stomach contents (volume and sugar concentration) until 30 bees with honey stomach loads of measurable quantity (≥ 1 μ liter) were captured. Each bee was anesthetized with CO₂ (ca. 10 sec), then held between thumb and forefinger while gentle pressure was applied to the abdomen. Honey stomach contents, expressed as a droplet on the proboscis, were then collected in a glass capillary tube (length, 100 mm; inside diam, 1 mm), and the liquid column length was measured on a calibrated scale. The sugar concentration (actually percent solids) was determined with a hand refractometer. Workers entering the hive were sampled similarly, and divided into two groups—those with and those without pollen. Pollen loads were removed from the corbiculae, weighed, then identified microscopically as to plant origin.

Honey stomach contents of entering and departing drones were analyzed for volume and sugar concentration in the afternoons of August 8-16, 1972. Inasmuch as drones present in the observation hive were too few for adequate sampling, drones from standard Langstroth hives were used.

III-2. To compare the maximum weight that di and normal workers can carry during sustained flight, bees were

² Manufactured by E. I. duPont de Nemours & Co., Inc., Wilmington, Del. 19898.

³ For details of observation hive construction, consult Gary (1963).

Fig. 1. Engorged bee carrying weights totaling 76 mg.

released at a point 100 m from the hive. To minimize the factor of nonreturn owing to disorientation, it was necessary to ensure that all the bees in the experiment were familiar with the area between release point and hive. Therefore, foragers in the observation-hive colony were trained during a three-day period to forage at a gravity-type feeder (Gary and Witherell, 1971) containing sugar syrup (37.5 percent*) to which green vegetable dye (3 drops/liter) had been added. Thus, when they returned to the hive, engorged bees were identified by their swollen abdomens, through which could be seen the green syrup. Detection of the syrup was facilitated by light transmission from a fluorescent tube beneath the glass runway connecting the observation hive to the exterior. Each returning syrup-engorged bee was captured and placed in an individual cylindrical screen cage

(length, 5 cm; diam, 2.2 cm; corked at ends). Then metal weights (26, 50, or 76 mg) were glued to the abdomen and mesonotum of each worker. Weights consisted of one to three ferrous metal discs with a plastic numbered tag glued on top⁴ (Fig. 1).

As engorged, weighted bees returned from the feeding station, the observer at the runway entrance captured and reweighed them. After 30 min of runway observation, the observer placed a magnetic trap (Gary, 1971) at the hive entrance for an additional 24 h in order to retrieve the numbered weights from bees that may have returned after the observation period was ended. Laden weights were determined for bees that returned within 30 min of release; other bees were simply tallied.

III-3. To study the volume of syrup intake by individual normal and dimin-

* The concentration of sucrose syrup used in all experiments was 37.5 percent unless otherwise specified.

⁴26 mg weight = metal disc + numbered plastic tag glued to disc; attached to scutum. 50 mg weight = two metal discs + numbered plastic tag glued together; attached to scutum. 76 mg weight = 26 mg weight (as above) attached to midregion of abdominal tergum + 50 mg weight (as above) attached to scutum.

Fig. 2. Bee in a wire cage being fed from a glass capillary tube.

utive-wing bees, as related to sugar concentration, two approaches were devised. In one, bees leaving the observation hive were captured and placed in individual screen cages in which food was presented in a glass capillary tube (Fig. 2). Different groups of bees were offered one of five concentrations of sucrose syrup. The volume of liquid removed from the tube in 15 min was recorded. In the other approach, a gravity-type feeder of sucrose syrup (one of three concentrations) was placed in the runway 60 cm from the hive entrance. Within 30 min, several hundred bees were collecting syrup and carrying it into the hive. A few dozens of these bees were identified by marking the thorax with white paint. Later, engorged, marked bees were captured while walking back to the hive. These bees were then anesthetized, and their honey stomach contents measured volumetrically.

III-4. To study the volume of sugar syrup intake by normal and diminutive-

wing bees, as related to feeder distance, the bees were trained to forage at a feeding station located at an increasingly greater distance from the hive. Training, by a method modified from Gary and Witherell (1971), originated at an observation hive that contained equal numbers of normal and *di* bees. A gravity-type feeder containing sucrose syrup scented with eucalyptus oil⁶ at 2 drops/liter, was placed in the runway. During a 1-h period, the feeder was moved gradually to the end of the runway, and then to the exterior of the building where several other feeders were placed in a row on a table juxtaposed to the runway entrance. When the nearest feeder became crowded with bees, some walked to the next feeder and began feeding there. Finally, after 6 h, many bees were flying to the end of the table to a feeder 2 m from the runway entrance. This feeder was placed on a stand (height, 60 cm; diam, 32 cm) and protected from ants by periodic application of a barrier of sticky substance

⁶ Floral scents are obtainable from Lorann Oils, 4518 Aurelius Rd., Lansing, Mich. 48910.

Fig. 3. Technique for tagging bees without the use of anesthesia.

(Tanglefoot®) to each leg of the stand. A piece of absorbent paper containing 2 drops of pure eucalyptus oil, replenished periodically, was placed on the stand to provide an olfactory stimulus to enhance the attraction of bees.

Each trained bee was given a distinctive numbered tag⁷ (Fig. 3) and, in addition, the green-dyed syrup technique was used (as in III-2) to identify the bees entering the hive that were returning from a foraging trip at the feeder. Their honey stomach loads were analyzed as in III-1. Load volume data were thus obtained for 100, 250, and 1000 m flight distances.

IV. To study the mating success and flying ability of normal and diminutive-wing queens, 20 queen cells of homo-

zygous di stock and 20 of normal stock, all within 24 h of emergence, were introduced singly into 40 miniature hives ("nuclei"), each of which had been stocked the previous day with ca. 100 g of bees, two combs, and a feeder containing moistened Drivert⁸ sugar. The nuclei were then placed in a cool, dark room for 60 h. At sunset, 2 days later, the nuclei were moved to the experimental site, where they were placed 0.5 m apart in an area that provided afternoon shade. To minimize drifting (straying of bees between hives), the entrances of adjacent nuclei were positioned in different directions. When the entrances were opened, some bees flew for a few minutes before nightfall. Two days later, each nucleus was inspected

⁶Tanglefoot is manufactured by the Tanglefoot Co., 314 Straight Ave., S.W., Grand Rapids, Mich. 49502. It contains castor oil (70 percent), natural gum resins (25 percent), and vegetable wax (5 percent).

⁷Opalithplättchen are manufactured by Chr. Graz K. G., Fabrik für neuzeitliche Imkereigeräte, 7057 Endersbach, Wurtemberg, Germany.

⁸Baker's Drivert (U.S. patent no. 2,824,808) is a pure cane fondant sugar containing ca. 8 percent invert, and manufactured primarily for the baking trade by C & H Sugar Co., San Francisco, California 94106.

for queen cell emergence, and was given a third comb. Subsequent inspections were made at weekly intervals, and the feeders refilled as needed, until the queens had mated and had begun to produce brood. Mating success of queens was determined by the presence of worker progeny, inasmuch as these must arise from fertilized eggs.

We also tested the flying ability of a second sample of virgin queens in a closed room and measured their live and dry weights 8 days after emergence.

V. *To determine the ratio of simultaneously trained normal and diminutive-wing bees at feeders of various distances*, two experiments were designed. In the first experiment (V-1), the *di* and normal bees originated from two different colonies; in the second experiment (V-2), they originated from the same colony.

In Experiment V-1, two colonies in two-story Langstroth hives, approximately equal in population (14 frames of bees), were used. One contained homozygous *di* stock, and the other contained bees with normal wings, and were homozygous for cordovan body color. The hives were moved to the experimental site on the morning of Oct. 3, 1972, and placed back to back.

The following day, the flight activity was determined at hourly intervals (11:15 a.m. through 4:15 p.m.) by the technique of Gary (1967). In this procedure, a screen funnel is placed against the entrance to each hive, and the number of bees departing during 30 sec is taken as the "flight activity index."

Beginning at 11:30 a.m., bees from both hives were trained to forage at a feeder containing spearmint-scented sucrose syrup which was gradually moved in a northerly direction as the bees discovered the syrup. All alien bees (those which were neither *di* nor cordovan) seen in the vicinity of the feeder were captured with forceps and killed. Entrainment was discontinued at a

distance of 300 m, reached at 4:00 p.m., when the feeder was removed.

The following day at 1:05 p.m., training of the *di* and cordovan colonies was renewed by the release of a few drops of pure spearmint scent at the hive entrances. Within minutes, bees were in the area where feeders had been stationed the previous day. Feeders were then placed at 50-m intervals in the direction in which the bees had been trained to fly to feed. The bees began feeding immediately, and were permitted to recruit other bees at their respective hives for 30 min. The feeders were then removed, and were replaced by scent traps (Fig. 4) designed to capture and kill all bees attracted to the odor to which they had been conditioned. After 1 h, the captured bees were counted and sorted according to genetic stock.

In Experiment V-2, an observation hive was used in which the queen was heterozygous for *di*, and was artificially inseminated with sperm from *di* drones. Hence, phenotypically, half of the worker progeny was *di* (homozygous), and the other half was normal (heterozygous).

The technique described in V-1 was used to train distinctively tagged *di* and normal bees (11 each, confirmed at the observation hive as well as at the feeder) to forage for eucalyptus-scented sucrose syrup at increasing distances from the hive. Distances at which the ratios of *di* to normal bees were determined were 0 (in the hive runway), 10, 100, 250, and 1000 m. During the training period, the feeder was often stationed at any of several intermediate points between the test distances listed above. At such times, the only bees permitted to forage were the 22 numbered bees; all recruits were killed. When the feeder first was positioned at the respective test distances, all bees were permitted to forage there for 15 min before the feeder was removed. The following

Fig. 4. Scent trap for honey bees. Bees enter through the entrance tube (E) in response to the attractive scent on the wick (B). Once inside, bees fall into the soapy water (D) where they are entrapped. Elastic band (A) holding cotton or gauze wick (B) saturated with scent (pure spearmint oil) to which bees have been conditioned to associate with food. C, glass jar (0.95 l). The tube E (length, 4.25 cm; diam 4 cm) is composed of transparent plastic, and is inserted into a screw-type cap with open center (F). G, transparent acetate sheet top (diam, 6.8 cm; central opening, 4 cm), fitting between rim of jar and screw top, to hold the entrance tube and prevent bees from escaping.

morning, training was resumed by releasing pure eucalyptus scent in the observation hive runway. Then the unnumbered bees (recruits) appearing at the feeder within the next 70 min were counted and killed, but the distinctively tagged (trained recruiters) were permitted to return to the hive. The ratio of *di* to normal bees recruited is of interest because both carried the same colony odor and thus were not competing with each other (unlike the case in V-1).

VI. To study the trip time of normal and diminutive-wing bees foraging 1 km from the hive, bees of both kinds, from the same observation hive, were trained over a 2-week period to forage at a feeding station located 1 km north of the hive, using methods discussed previously. Temperature (26–34 C) and

gentle, variable breezes from the south (0–5 km/h) were judged to be insignificant factors. Observations were conducted from 10 a.m. to 4:02 p.m. on Aug. 9th. One observer was positioned at the feeder site, and another was at the observation hive. Using synchronized watches and walkie-talkies, the two observers recorded the departure and arrival times (to the nearest sec) of three *di* and eight normal, individually numbered bees, which were active at the feeder on that day.

VII. To study the dance communication of distance by normal and diminutive-wing bees, an observation hive estimated to contain 34 percent *di* and 66 percent normal bees, was used. Feeder distances for which observations on dance behavior were made were 0 (in the hive runway), 10, 100, 250, and

1000 m. To identify at the hive the numbered bees which had just returned from the feeder, the green-dyed syrup technique (see V-2) was used. Every 30 min, unnumbered recruit bees at the feeder were killed in order to reduce congestion and stimulate dance behavior among the 22 numbered bees (11 *di* and 11 normal).

Bee dances in the hive were recorded for a total of 8.8 h over a 50-day period. Owing to natural mortality during the experiment, the same numbered bees were not observed at all five test distances; but some of the same bees survived long enough to be observed at two or three of the feeder locations. New recruits were numbered at a rate approximating the mortality rate, so that the total population of bees with numbered tags always remained about the same.

Each time a numbered bee returned to the hive with a load of syrup, the "dance tempo" and duration of each waggle-run were recorded. "Dance tempo" (von Frisch, 1967) may be defined as the number of waggle-runs per 15 sec. Both variables are known to be distance-correlated.

In the second phase of the experiment, the dances of bees foraging on natural flora were studied in the same observation hive for 7.4 h. Recorded were the genetic stock of each dancer, dance tempo, duration of waggle-runs, and the presence or absence of pollen. The purpose of these observations was to gather data that would enable us to estimate the foraging range of normal and *di* bees under natural conditions, as calibrated from distance communication data when bees were foraging at feeders at known distances.

VIII. To study the rate of return to the hive of flight-experienced normal and diminutive-wing honey bees released at various distances, two adjacent colonies in two-story Langstroth hives,

Fig. 5. Magnetic trap mounted on a hive between two "escape screens," 13 cm square, and about 1 cm from the hive wall. Returning foragers enter the hive by passing under the magnets. The purpose of the escape screens was to reduce the number of magnets required per hive. Bees leaving the hive may do so by passing under the magnets, or by using the escape screens ("up and out"). Returning bees, however, attracted to the darkness of the entrance and odors emanating therefrom, pass under the magnets, thus losing any ferrous metal tags they may be carrying.

one containing *di* and the other containing bees of normal stock, were used. The entrances to these hives were equipped with magnetic traps (Fig. 5) to facilitate the recovery of tags from released bees that returned (Gary, 1971).

Each morning, Sept. 5-9, 1971, ca. 100 returning workers were captured in a net at the entrance to each of the two hives during a period of several hours. Periods when many young bees were apparently taking "play" (orientation) flights were avoided. A ferrous metal disc (2.3 mm diam) weighing ca. 10 mg was applied to the middle region of the abdominal tergum of each bee. Discs were color-coded to identify the release distance and genetic stock of the bee. Any pollen pellets were removed from the corbiculae at this time. After being tagged, the bees were placed in small, cardboard cages with screened tops (3.1 mesh/cm). The cages were provisioned with a soft candy composed of a 1:1 mixture of granulated fondant sugar to which had been added

5 percent wheat⁹ and enough water to give the candy a dough-like consistency. Not more than 40 bees (20 normal and 20 *di*) were placed in any one cage. All bees were tagged and caged by mid-afternoon of each day. They were then brought to the field and released in a northwesterly direction from the apiary, at distances of 10 m, and 1, 2, 3, 4, and 5 km. A full cage of bees was released at each site, on each day, for 5 days. On each morning following release, the tags were retrieved from the magnetic traps at the hive entrances, and tallied according to distance and genetic stock. During the 5-day period, 449 *di* and 448 normal bees were released. The temperature range and wind speeds (predominantly crosswinds) during release were 26 to 30 C and 0 to 16.7 km/h, respectively, and were judged to be insignificant factors.

On the afternoon of Sept. 10th, returning drones were tagged and released at distances of 1, 2, 3, 4, and 5 km. Of 331 drones released, 164 were *di* and 167 were normal. The temperature range and wind speeds (crosswinds) were 28 to 35 C and 2.6 to 3.3 km/h, respectively.

IX. To compare the foraging distribution of normal, Hy-Queen, and diminutive-wing honey bees, three experiments were designed. Inasmuch as the Hy-Queen stock, an experimental hybrid honey bee produced by Dadant & Sons, Inc., of Hamilton, Ill., was also on hand, we opportunistically included it in these experiments. The Hy-Queen bee had been genetically selected for high incidence of pollen collection and a preference for foraging on alfalfa.

IX-1. To study the distribution of bees foraging on onion (Allium cepa L.), safflower (Carthamus tinctorius L.), and carrot (Daucus carota L.), 5000

Fig. 6. Physical layout of fields, tagging sites, and experimental apiary (Experiment IX-2). Williams, Calif.

bees were captured on flowers during a 5-day period (June 21–25, 1971), and tagged (1000 bees/field) in five fields in Solano County, California, near Dixon. Fields were designated as Onion I (3.2 ha), Onion II (4.6 ha), Safflower I (11.1 ha), Safflower II (6.6 ha), and Carrot (13.0 ha). In addition, there was a third onion field in bloom, designated as Onion III (4.9 ha), at which bees were not tagged. All hives were equipped with magnetic traps (Fig. 5).

Five tagging sites (20 × 20 m) were established in a “domino five” pattern within each field. For 5 consecutive days, operators tagged 20 bees/site each

⁹ Wheat is a protein-rich by-product of the manufacture of cottage cheese, produced by a controlled fermentation of selected dairy yeast (*Saccharomyces fragilis*) in fresh cottage cheese whey. It is available from H. V. Nootbaar & Co., 890 So. Arroyo Parkway, Pasadena, Calif. 91105.

morning and afternoon, resulting in a total of 200 tagged bees/day per field. Distances from Onion I to the center of the other fields were: Onion II, 2.1 km; Onion III, 6.4 km; Safflower I, 0.5 km; Safflower II, 1.5 km; Carrot, 3.0 km.

The three bee genetic stocks to be compared were all located in an apiary at the southern edge of Onion I, and included two colonies of *di* bees, four colonies of normal bees, and two colonies of Hy-Queen bees.

IX-2. To study the foraging distribution of bees on alfalfa, safflower, and yellow star thistle, an apiary containing seven three-story hives each of normal and Hy-Queen stock, and five hives of *di* stock, was positioned on the north edge of a 42.7-ha alfalfa field in Colusa County, California, near Williams, on July 8, 1971, (Fig. 6), and equipped with magnetic traps (Fig. 5). Bees were tagged in designated sites (circular; diam 10 m) in the alfalfa and safflower fields (five sites/field), and also in five widely scattered small patches of yel-

low star thistle, on July 8, 9, 12, 13, and 14. During this time, 1000 bees were tagged on alfalfa, 400 on safflower, and 800 on yellow star thistle.

IX-3. To study the intrafield foraging distribution of bees from colonies placed at the edge of a 34-ha field of alfalfa in Glenn County, California, near Artois, 32 colonies were placed in a single apiary at the northwest corner of the field during the early morning hours of July 15–16, 1971. These included 4 *di*, 14 Hy-Queen, and 14 normal colonies (controls), all in three-story hives.

Magnetic traps (Fig. 5) were installed at all hive entrances. There were 40 tagging sites (circular; 10 m in diam) at which bees were captured by net and tagged July 22, 23, 27, and 28, for a total of 100 bees/site (4000 tagged bees). Tags were removed from traps on July 29th and tallied by distance.

Twice a day, samples of incoming bees were captured at hive entrances to determine the frequency of pollen collectors among the three genetic stocks.

RESULTS AND DISCUSSION

I. Morphological Description of the Diminutive-Wing Honey Bee

The measurements made on each specimen are indicated in Fig. 7, and the values obtained are given in Table 1.

Right fore wing: Wing length (C) of the *di* mutant averaged 79.4, 81.6, and 78.4 percent of normal length of workers, queens, and drones, respectively, and covered a median number of 3.4, 2.5, and 4.0 abdominal tergites, respectively. If the wings of *di* bees are examined cursorily, they appear to be miniature replicas of normal honey bee wings. Within each caste, there was no significant difference in the cubital index between normal and *di* bees. However, significant differences ($P < .05$) were found between normal and *di* bees with respect to ratios B/A and E/A.

Consequently, these wings are not simply proportionately smaller than the normal wing; they also have a certain degree of allometry. There were significant differences in ratio C/Q between normal and *di* stocks. The wings of *di* queens are distinctly convex on the longitudinal axis, rather than flat as in normal queens. This character was seen in neither of the other castes.

Right hind wing: Wing length, width, and area were consistently smaller in diminutive wings than in normal wings. In the case of drones, width was measured through the vannal lobe rather than through the remigium, as shown in Fig. 7, inasmuch as the vannal distance is greater. The number of hamuli may be slightly reduced in diminutive wings, but statistical differences from normal were not found in

Fig. 7. Morphological measurements made on the honey bee wing and thorax. (See also Table 1.) *Right fore wing:* A. Length (mm) from base of wing to stigma. B. Length (mm) from stigma to wing tip. C. Total wing length (A + B) (mm). D. Length of radial (marginal) cell (mm). E. Width of wing (mm). G. Cubital index (G_2/G_1). *Right hind wing:* K. Total wing length (mm). N. Number of hamuli (wing hooks). *Thorax:* Q. Length (mm) of true thorax as viewed dorsally (i.e., the alitrunk less the propodeum).

TABLE 1
MORPHOLOGICAL MEASUREMENTS OF NORMAL AND DIMINUTIVE-WING
HONEY BEES

Character measured*		Workers		Queens		Drones	
		normal (n = 30)	<i>di</i> (n = 60)	normal (n = 30)	<i>di</i> (n = 30)	normal (n = 30)	<i>di</i> (n = 30)
A	M†	4.93	3.97	5.57	4.61	6.48	5.27
	SE‡	0.03	0.01	0.08	0.03	0.03	0.04
B	M	4.52	3.53	4.55	3.64	5.79	4.35
	SE	0.03	0.01	0.03	0.03	0.04	0.03
C	M	9.45	7.50	10.11	8.25	12.28	9.63
	SE	0.04	0.02	0.05	0.05	0.05	0.06
D	M	3.40	2.62	3.35	2.67	4.69	3.43
	SE	0.01	0.01	0.02	0.01	0.02	0.02
E	M	3.17	2.48	3.25	2.48	3.98	2.94
	SE	0.01	0.01	0.02	0.02	0.04	0.02
F	M	18.50	11.43	20.98	13.27	31.04	19.41
	SE	4.59	0.01	0.27	0.17	0.35	0.30
G	M	2.56	2.52	3.07	2.93	1.87	1.97
	SE	0.09	0.05	0.13	0.19	0.07	0.09
H	M	0.92	0.89	0.82	0.79	0.89	0.83
	SE	0.01	0.01	0.01	0.004	0.01	0.01
I	M	0.64	0.63	0.58	0.54	0.61	0.56
	SE	0.003	0.003	0.004	0.004	0.02	0.01
J	M	2.68	2.12	2.21	1.76	2.50	1.97
	SE	0.03	0.02	0.01	0.01	0.03	0.26
K	M	6.61	5.32	7.37	5.92	8.34	6.52
	SE	0.03	0.02	0.24	0.03	0.04	0.05
L	M	1.82	1.46	2.15	1.66	3.27	2.62
	SE	0.01	0.01	0.02	0.02	0.03	0.03
M	M	8.91	5.82	12.51	7.67	21.74	14.19
	SE	0.01	0.04	0.16	0.13	0.27	0.26
N	M	21.47	20.88	17.33	16.95§	20.00	19.63
	SE	0.30	0.18	0.30	0.40	0.36	0.30
O	M	60.8	48.8	72.4	57.4¶	80.01	63.9
	SE	0.79	1.38	0.87	0.93	0.98	0.95
P	M	3.64	3.64	3.43	3.57	2.55	2.49
	SE	0.02	0.03	0.03	0.03	0.02	0.02
Q	M	3.53	3.54	4.59	4.67	4.96	4.89
	SE	0.03	0.03	0.04	0.04	0.03	0.02
R	M	27.44	17.25	33.49	20.94	52.78	33.61
	SE	0.22	0.09	0.41	0.70	0.53	0.52

* See Fig. 1 for illustration of certain characters. Other characters, not illustrated, are: F, fore wing area (mm²); H, ratio of B/A; I, ratio of E/A; J, ratio of C/Q; M, hind wing area (mm²); O, mean distance (μ) between adjacent hamuli; P, ratio of K/L; R, total wing area (mm²), right side only (F + M).

† Mean.

‡ Standard error.

§ n = 22.

¶ n = 21.

this study. The mean distance between adjacent hamuli in diminutive wings was significantly smaller than in normal wings in all castes. If the hind wing length in *di* bees is considered as a percentage of normal hind wing length (80.5, 80.3, and 78.2 percent in workers, queens, and drones, respectively), and the mean distance between adjacent hamuli is considered in the same way (80.3, 79.3, and 79.9 percent, respectively), then the two sets of percentages indicate nearly identical proportionate reduction. The ratio of hind wing length to width is the same (3.64) in normal and *di* workers, but significantly different in queens ($P < .01$) and drones ($P < .05$).

Other calculations and observations: Because body size varies with the state of nutrition during development, and of relaxation at time of death, a size index more precise than total body length or weight is required. A satisfactory index was found in the length of the thorax (Q). Within each caste, this value in normal and in *di* bees was not significantly different, lending credence to the ratio C/Q, which relates fore wing length to thorax length. These values for workers, queens, and drones, respectively, were 2.12, 1.76, and 1.97 for *di*, and 2.68, 2.21, and 2.50 for normal bees. Total wing area is an important factor in any consideration of wing-beat frequency, load capacity, flight time, or flight range, and can be obtained by simply doubling the area means given in Table 1. The mean wing area for *di* bees was 62.9, 62.5, and 63.7 percent of normal for workers, queens, and drones, respectively. The difference within each caste was highly significant ($P < .001$). However, even with the great reduction in wing area, *di* workers and drones can fly.

Some *di* workers, and a few *di* queens, were seen in observation hives to uncouple their front and hind pairs of wings. However, this behavior was

noted only once among hundreds of drones observed. Workers with uncoupled wings were capable of normal flight. Attempts to relate wing disengagement to such factors as disease condition, circadian rhythm of activity, and differences in size, shape, or number of hamuli, were unsuccessful. A possible morphological basis for this behavior, however, may be the significant reduction in distance between hamuli in *di* worker bees. Incidence of wing disengagement was most frequent among bees standing motionless in the honey storage area or at the hive entrance. Bees with disengaged wings did not appear until the second day after emergence from their cells. The frequency of wing disengagement among 100 individually marked worker bees increased gradually to a maximum of 17.6 percent (ages 17–24 days), then declined slightly to 14.3 percent (ages 25–32 days).

II. Wing-Beat Frequency of Normal and Diminutive-Wing Honey Bees

The wing-beat frequency of *di* worker honey bees has not been previously studied. However, Sotavalta (1947) removed half the wing of normal workers and found that the average frequency of 224 beats/sec (208–233) was increased to 336 (311–381). Similarly, Wenner (1964) reported that the increase in wing-beat frequency, and decrease in sound intensity, are both in direct proportion to the amount of wing removed.

Stroboscopic analysis of the *di* workers revealed a mean frequency of 251.8 (± 3.23) wing beats/sec. For normal workers, the mean frequency was 206.1 (± 3.16) beats/sec. The 22.2 percent difference was highly significant ($P < .001$), and audibly distinguishable by the human ear.

In addition to the major flight tone, there were also several harmonic over-

Fig. 8. Audiospectrogram of sounds produced by free-flying and fanning worker honey bees. A. Normal bee in free flight. B. Diminutive-wing bee in free flight. C. Normal bee fanning. D. Diminutive-wing bee fanning.

tones, the frequency spectrum of which was within the range of sensitivity of the human ear (Fig. 8). The secondary frequencies, however, were not discernable because of the much greater amplitude of the primary flight tone, represented by the dark band at the lower portion of each audiospectrogram. Frequencies exceeding 300 Hz presumably involved flight muscles or other vibrating structures within the alitrunk, or secondary air vibrations set up by the primary frequency.

III. Loads of Normal and Diminutive-Wing Honey Bees

The size of load carried by a honey bee is affected by interacting factors: morphological, environmental, and behavioral.

Morphological factors include genetically mediated differences in body size and structure (e.g., race and caste), and differences in body size related to larval nutrition and size of cell in which

development occurs. Honey stomach contents of drones are small in comparison with those of workers, because of the smaller capacity of the drone honey stomach (Burgett, 1971). Wells and Giacchino (1968) found that the syrup load volume was positively correlated with the unladen weight of the bee, and that the morphological factor determining syrup load volume seemed to be the honey stomach capacity, a factor that Gontarski (1935) and Ribbands (1953) also considered important.

The most important factors in the environment that affect load size are meteorological variables, principally temperature and wind velocity. Betts (1929, cited by Schuà, 1952), and Gontarski (1935) demonstrated a direct relationship between ambient temperature and volume of sugar syrup imbibed. Risga (1936) found that the average weight of pollen and nectar loads increased as the temperature rose,

TABLE 2
WEIGHTS AND LOADS OF BEES CAPTURED WHILE LEAVING THE HIVE

		Workers*		Drones**	
Item		di	normal	di	normal
Weight of bee (mg)					
Gross weight	M†	88.1	95.4	206.5	219.8
	SE‡	2.6	3.5	2.2	1.9
	N¶	30	30	30	30
After removal of honey stomach contents	M	85.9	90.7	192.0	197.6
	SE	2.6	2.7	1.9	1.8
	N	30	30	30	30
Load (honey stomach contents)					
Volume (μliters)	M	1.9	3.3	11.3	16.2
	SE	0.3	0.5	0.7	1.0
	N	65	45	30	30
Sugar conc (%)	M	20.4	38.2	25.2	36.4
	SE	7.1	3.4	1.9	2.3
	N	30	30	30	30
Load as % of gross weight	M	2.5	4.8	7.0	10.1
	SE	0.5	0.8	0.3	0.6
	N	30	30	30	30

* Period of observation: July 3-4, 1972.

** Period of observation: Aug. 8-16, 1972.

† Mean.

‡ Standard error.

¶ Number of bees included in sample.

but was negatively correlated with wind velocity. Other environmental factors affecting load size may include distance to the food, phagostimulants present, and food quantity and quality. Schuà (1952) reported a slight increase in consumption of sugar syrup with increasing distance of the feeder from the hive, presumably because the bees needed more energy for longer flights. These results, however, seem inconsistent with those of Wenner (1963), who found a shorter imbibing time was utilized by bees at more distant feeders.

A possible example of the influence of behavioral effect on load size is found in the report of Gontarski (1930, cited by Schuà, 1952). Gontarski noted that the average daily nectar loads became larger during several days of foraging activity. Schuà, however, could not reproduce these results. Von Frisch (1967, 1971) and Rau (1970) reported that the volume of the load collected by foragers varied directly with the con-

centration of sucrose provided at the feeding station. However, Wells and Giacchino (1968) stated that the load volume of syrup was not correlated with concentration, scent, or type of sugar in solution.

Experiment III-1. Gross weights of incoming and outgoing bees, and characteristics of their loads

Weights and loads of bees captured when leaving the hive are shown in Table 2. All means for *di* bees were significantly smaller ($P < .05$) than the corresponding values for normal bees. Mean unladen body weights of *di* workers and drones averaged 94 and 97 percent, respectively, of the unladen weights of their normal counterparts. On this basis one might expect the volume carried in the honey stomach to be reduced proportionately. However, the reduction was considerably greater; *di* worker loads were 57 percent, and *di* drone loads 69 percent, of normal volume.

TABLE 3
WEIGHTS AND LOADS OF WORKER BEES CAPTURED WHILE RETURNING
TO THE HIVE

		Nonpollen foragers		Pollen carriers**	
Item		<i>di</i>	normal	<i>di</i>	normal
Weight of bee (mg)					
Gross weight*	M†	87.8	106.9	97.0	107.5
	SE§	1.77	1.38	1.25	1.81
	N¶	30	30	40	39
Unladen weight†	M	77.6	79.1	76.7	82.8
	SE	0.98	0.95	0.66	1.29
	N	30	30	40	39
Load carried (pollen and honey stomach contents)					
Volume (μliters)	M	7.8	25.3	6.2	8.0
of honey	SE	1.49	3.16	1.10	1.55
stomach	N	39	34	40	39
contents					
Sugar conc of	M	41.1	34.0	29.4	30.7
honey stomach	SE	2.55	3.01	1.48	1.77
contents (%)	N	30	30	29	27
Weight of	M	—	—	16.4	18.6
pollen load	SE	—	—	0.93	1.10
(mg)	N	—	—	40	39
Total load††	M	10.8	22.8	20.6	22.4
as % of gross	SE	1.76	2.86	0.99	1.33
weight	N	30	30	40	39

* Gross weight of bee including honey stomach contents and pollen load, if any. For 30 drones returning during the afternoons of Aug. 15–16, 1972, laden weights averaged 199.8 ± 1.66 mg (*di*) and 207.0 ± 1.75 mg (normal).

† Weight of bee after removal of honey stomach contents and pollen load, if any.

‡ Mean.

§ Standard error.

¶ Number of bees included in sample.

|| Period of observation: July 4–5, 1972.

** Period of observation: July 6–7, 1972.

†† Nectar and pollen, if any.

Honey stomach contents (nectar) of returning foragers were significantly less (30.8 percent) for *di* bees than for normal bees. This would seem to eliminate *di* bees from any consideration as potential stock for commercial honey production. The weights and loads of bees captured while returning to the hive are shown in Table 3. Laden weights of *di* workers were significantly less than those of normal workers ($P < .05$). Unladen body weights of returning bees were less than those of departing bees (Table 2) as a result of defecation in flight.

Pollen carriers had nectar loads that were lighter, on the average, than those of nonpollen foragers, probably to compensate for the added weight of the pol-

len. Of 40 *di* pollen carriers, 29 (72.5 percent) also had nectar loads. Similarly, among the 39 normal pollen carriers, 29 (74.4 percent) also had nectar loads. There was no significant difference between the sugar concentrations in the nectar loads of normal and *di* bees. Pollen loads of *di* bees weighed 11.8 percent less than those of normal bees, but the difference was not significant.

Total weight of the honey-stomach load of nectar carriers (without pollen) averaged 10.8 and 22.8 percent of their gross weight (13.1 and 35.1 percent of unladen weight), respectively, for *di* and normal bees, a significant difference ($P < .05$). However, among *di* and normal pollen carriers, the mean load

TABLE 4
RETURN OF ENGORGED, WEIGHT-LADEN BEES FROM A FEEDING STATION
100 M FROM THE HIVE

		26-mg weights		50-mg weights		76-mg weights	
Item		di	normal	di	normal	di	normal
Bees released							
Laden weight	M†	146.4	156.0	159.6	170.4	182.0	185.4
(mg) *	SE‡	2.3	2.4	2.4	2.7	4.5	2.7
	N§	30	30	32	32	11	12
Bees returned							
Number		26	24	8	23	0	6
Percent		86.0	80.0	25.0	71.9	0	50.0
Laden weight	M	102.8	110.0	123.0	130.2		153.3
(mg) *	SE	1.8	3.6	5.0	1.9		1.3
	N	24	21	6	13		3
Volume of	M	0.8	4.1	1.8	1.8		1.0
syrup in	SE	0.5	1.7	1.8	0.9		1.0
honey	N	22	21	6	13		3
stomach							
(μliters)							
Unladen	M	77.3	79.0	68.9	73.0		77.9
weight (mg) ¶	SE	1.5	1.9	4.1	2.0		3.7
	N	22	21	7	22		3

* Includes bee engorged with sugar syrup, plus metal weights.
† Mean.
‡ Standard error.
§ Number of bees.
¶ Weight of bee less weight of sugar syrup and metal weights.

weight (pollen and nectar) was 20.6 and 22.4 percent of the gross weight (26.5 and 29.8 percent of unladen weight), respectively, which did not differ significantly.

Pollens of safflower (*Carthamus tinctorius* L.) and lippia (*Phyla nodiflora* Michx.) accounted for more than 85 percent of the pollen loads of both normal and *di* bees. Both floral sources were accessible within 1 km of the hive, the latter being a ground cover at the apiary site. Other collected pollens included bindweed (*Convolvulus arvensis* L.), legumes, and a few unidentified sources. No attempt was made to identify the plant origins of nectar loads.

Experiment III-2. Maximum weight that bees can carry in sustained flight

Betts (1933) found that bees can carry 111–120 percent of their weight in honey, or 70–85 percent of their weight in nectar. A typical nectar load was 30 mg; 50 mg was exceptional. Kal-

mus (1938) and Rau (1970) attached metal weights to the abdomens of drinking bees, and concluded that the additional weight did not significantly affect the volume of syrup the bees imbibed. However, Schifferer (1952, cited by von Frisch, 1967) found that 55-mg weights applied to a bee's propodeum reduced the amount of sugar syrup imbibed by ca. 25 percent.

The incidence of return to the hive of engorged, weighted bees from the 100-m feeding station is summarized for our experiment in Table 4. The frequency of successful return of normal bees carrying weights of 26, 50, and 76 mg was 80.0, 71.9, and 50 percent, respectively, compared to 86.0, 25.0, and 0 percent for *di* bees. The difference in return between normal and *di* bees carrying 26-mg weights (equivalent to a large pollen load) was not significant, but differences were highly significant for the 50- and 76-mg weights ($P < .001$ and $P < .01$,

respectively). The 76-mg weight approximates that of an unladen bee.

Although bees were fully engorged prior to release, the relatively small volume of syrup remaining in their honey stomachs upon return may indicate partial disgorgement by the bees en route. Many of the bees defecated a clear fluid during the return flight. Food metabolism by the bees during flight, and in the cage prior to release, would account for additional weight loss. Laden weights of normal bees that returned averaged only 70.5, 76.4, and 82.7 percent of their prerelease laden weights (bees carrying 26-, 50-, and 76-mg weights, respectively). Similarly, *di* bees carrying 26- and 50-mg weights returned with 70.2 and 77.1 percent of their prerelease laden weights.

The total burden (syrup plus metal weights) given to the released bees carrying 26-, 50-, and 76-mg weights amounted to 97.5, 133.4, and 138.0 percent of their unladen weights, respectively, for normal bees, and 89.4, 131.6, and 141.7 percent of their unladen weights for *di* bees. The 141.7 percent apparently exceeded the flight-carrying capacity of the *di* bees.

Experiment III-3. Volume of syrup intake as a function of sugar concentration

The effect of sucrose concentration on the mean volume of syrup intake by normal and *di* bees fed in cages or trained to walk to a feeder in the runway of the observation hive is shown in Fig. 9. Thirty bees were used for testing each concentration, except 0 percent (deionized water), which only eight *di* and eight normal bees could be induced to drink. The honey stomachs of outgoing bees in the caged-feeding tests probably contained minimal loads prior to feeding (cf. Experiment III-1), although preexisting load volume was not determined in this experiment in order to avoid adverse effects on subsequent feeding behavior.

Fig. 9. Sucrose syrup intake by normal and diminutive-wing honey bees as a function of concentration.

The syrup volume ingested per bee in the caged-feeding tests ranged from 3 to 72 μ liters, except for one *di* bee (feeding on 50 percent sucrose) that ingested 75 μ liters, the capacity of the capillary tube. In this experiment, the greatest volume of water taken into the honey stomach was 12 μ liters; but one incoming forager, captured in Experiment III-1, had a water load of 31.5 μ liters (as determined by refractometry of the measured honey stomach contents).

Below the 25 percent level, sugar concentration seemed to bear a direct relationship to the quantity of syrup the bees imbibed. However, at higher concentrations, the amount of syrup imbibed per bee was relatively constant (Fig. 9). Thus, with regard to the effect of sugar concentration on syrup uptake, our results agree with those of von Frisch (1967, 1971) insofar as low concentrations (< 25 percent) are concerned. But, for higher concentrations (> 25 percent), our results are more in agreement with those of Wells and Giacchino (1968), who reported they found no relationship between sugar syrup concentration and syrup uptake.

For bees fed in cages, there was no significant difference between *di* and

normal bees in the volume imbibed at any of the concentrations tested. However, for bees trained to feed on syrup at the runway feeder, there was a slight but significant difference between normal and *di* bees with respect to the volume of syrup imbibed at the 62.5 percent concentration, the normal bees imbibing more.

Caged bees generally imbibed more syrup than bees fed at the runway feeder. The major reason was probably because bees competed for access to the food at the runway feeder, whereas there was no competition among individually caged bees.

Experiment III-4. Volume of syrup intake as a function of feeder distance

The effect of feeder distance on the volume of syrup collected per bee is indicated in Fig. 10. The relatively low load volumes carried by normal and *di* bees foraging at the 100-m feeder probably resulted from high competition from bees of other hives in the immediate vicinity of the apiary. During the course of the experiment, 607 untagged bees were killed there, compared to ca. 200 at the 250-m station and none at 1000 m. At 100 m, *di* bees imbibed significantly less syrup (mean, 26.2 μ liters) than did normal bees (mean, 33.5 μ liters; $P < .01$), but a significant difference in load volume was not found at 250 m.

Mean load volumes, expressed as percentages of unladen weight, for syrup collected at 100-, 250-, and 1000-m feeders, respectively, were: normal bees, 49.8, 57.9, and 69.9; *di* bees, 40.0 and 62.5 (100 and 250 m, respectively). Syrup loads in the present experiment were heavier than nectar loads in Experiment III-1, that averaged 35.1 and 13.1 percent of the bee's unladen weight, respectively, for normal and *di* bees. An increase in syrup intake with a corresponding increase in flight distance, as found in this experiment, confirms the

Fig. 10. Intake of sucrose syrup (37.5 percent) by normal and diminutive-wing honey bees as a function of feeder distance.

results of Schuà (1952), and is energetically sound.

IV. Mating Success and Flying Ability of Normal and Diminutive-Wing Queens

Nineteen of the 20 *di* queens emerged, and 16 were accepted. Fourteen of the 20 normal queens emerged and were accepted. By Aug. 15th, 12 of the normal queens had mated and had produced worker brood in the pupal stage. By Aug. 29th, all eight of the surviving *di* queens were laying, but only drone brood was produced, proving that the queens had not mated. The enlarged abdomen, typical of mated queens that are laying, was evident among the normal queens, but not among the *di* queens.

In another experiment, several virgin *di* queens were released in a room, from a height of 1 m. They attempted to fly, but did so on a downward plane, landing on the floor about 2 m away, apparently unable to maintain flight. In contrast, normal virgin queens, even after having been caged in a hive for 3 weeks, flew to a window when released.

The mean dry weight of 30 normal virgin queens (55.2 ± 1.24 mg) was not

TABLE 5

RATIO OF DIMINUTIVE-WING AND CORDOVAN BEES FROM DIFFERENT COLONIES, CAPTURED IN SCENT TRAPS AT VARIOUS DISTANCES FROM THE HIVES ON OCT. 5, 1972, 2:35-3:35 p.m.

Distance from hives to trap (m)	Number of bees captured in trap				Number of bees expected in a sample size of N†			
	<i>di</i>	cordovan	total (N)	ratio	<i>di</i>	cordovan	total (N)	χ^2 ‡
0	118	127	245	0.9:1	192.9	52.1	245	134.94***
50	197	35	232	5.6:1	182.6	49.4	232	4.97*
100	215	28	243	7.7:1	191.3	51.7	243	13.22***
150	168	12	180	14:1	131.4	48.6	180	36.74***
200	58	3	61	19.3:1	48.0	13.0	61	8.82**
250	52	2	54	26:1	42.5	11.5	54	8.95**
300	18	1	19	18:1	15.0	4.0	19	1.98
Total	826	208	1034	4:1	803.7	230.3	1034	2.65

† Computed on the basis of the expected ratio of 3.7:1 (*di*:cordovan), obtained from flight activity counts at hive entrances.

‡ Yates' correction for continuity was applied.

* Observed ratio differs significantly from expected ratio ($P < .05$).

** Observed ratio differs significantly from expected ratio ($P < .01$).

*** Observed ratio differs significantly from expected ratio ($P < .001$).

significantly different from that of 22 dry *di* virgin queens (55.4 ± 1.23 mg). Mean live weights should therefore be about equal. For fourteen 8-day-old normal virgins it was 163.3 ± 3.24 mg (not determined for *di* virgins). One-half of the total wing area (right side of body) of *di* and normal queens averaged 20.94 and 33.49 mm², respectively (Table 1, measurement R). If the weight of both *di* and normal queens is taken as 163.3 mg, then the "static load" (body weight in mg / total wing area in mm²) for normal queens would be 2.44 mg/mm², as compared to 3.90 for *di* queens. It thus appears that the latter ratio exceeds the lift capacity of *di* queens, making sustained flight impossible. However, several years ago Laidlaw (unpub.) found that some normal queens, with both wings shortened by $\frac{1}{4}$ to $\frac{1}{3}$, could still fly and mate. Hence, there must be another reason why *di* queens lack the power of sustained flight. It is our opinion that they are also impeded aerodynamically by the distinctly convex curvature of the wings.

Propagation of successive generations of mated, homozygous, *di* queens, therefore, is totally dependent upon artificial insemination.

V. Ratio of Simultaneously Trained Normal and Diminutive-Wing Honey Bees at Feeders of Various Distances

Experiment V-1. Ratio of simultaneously trained diminutive-wing and normal bees originating from different colonies

The number of bees leaving the hives during five 30-sec hourly flight activity counts on Oct. 4th and two 30-sec counts on Oct. 5th was 245 *di* bees and 66 cordovan bees, a ratio of 3.7:1. Consequently, this was the expected ratio of bees at the feeders, rather than 1:1, despite the apparent equality of colony populations based on equal numbers (14) of frames covered by bees.

The ratio of the two stocks of bees actually trained, as reflected by recovery in the scent traps (Table 5), varied greatly from the 3.7:1 expected ratio. The ratio of bees at the "0-m" distance (directly adjacent to the hives) was essentially 1:1. As distance to feeding stations from the hives increased, the proportion of *di* bees became increasingly greater, until they outnumbered the cordovans 26:1 at the 250-m station. At 300 m, cordovans were outnumbered 18:1.

TABLE 6

RATIO OF NORMAL AND DIMINUTIVE-WING RECRUITED BEES FROM SAME COLONY, CAPTURED AT FEEDERS AT VARIOUS DISTANCES FROM THE HIVE BETWEEN AUG. 8 AND SEPT. 18, 1972

Distance from hive to feeder (m)	Number of recruited bees captured in 70 min				Number of bees expected in a sample size of N†			
	<i>di</i>	normal	total (N)	ratio	<i>di</i>	normal	total (N)	χ^2 ‡
0	19	40	59§	0.48:1	19.1	39.9	59	—
10	305	167	472	1.8:1	153.1	318.9	472	221.60***
100	80	186	266	0.43:1	86.3	179.7	266	0.58
250	8	23	31	0.35:1	10.1	20.9	31	0.37
1000	2	7	9	0.29:1	2.9	6.1	9	0.09
Total	414	423	837	0.98:1	271.5	565.5	837	109.93***

† Computed on the basis of the expected ratio of 0.48:1 (*di*:normal) obtained from 1 h of marking and counting bees taking food from a feeder in the hive runway (0 m).

‡ Yates' correction for continuity was applied.

§ 60-min sample.

*** Observed ratio differs significantly from expected ratio ($P < .001$).

The fact that *di* bees successfully dominated the feeders in this experiment can probably be explained on the basis of their numerical advantage in flight activity. Hence, the *di* bees were better able to defend the feeders against their less abundant competitors, the cordovans. During the entrainment period (Oct. 4th), and during the 30-min exposure of scented sucrose on Oct. 5th, there were intense aggressive encounters between the two stocks at all feeder locations. The encounters were particularly common at locations close to the hives, where there were more bees in the area. Usually, one or two bees grasped with the mandibles a leg of another bee, while the latter pulled away as if attempting to fly. Often one bee clung to the abdomen of another, biting at the wing base while curving the abdomen downward, as if to sting. Also, two bees were sometimes seen clinging together while spinning in flight, falling to the ground. *Di* bees, most numerous at most of the feeders, usually appeared to be the "aggressors," except at the feeder directly adjacent to the hives, where aggressive and defensive behavior seemed equally frequent among both *di* and cordovan bees. No such behavior was seen between bees of like stock.

Although the powers of flight of *di* bees would seem to be increasingly taxed as the distance to food is increased, this factor is apparently negligible at distances up to at least 300 m.

Experiment V-2. Ratio of simultaneously trained diminutive-wing and normal bees originating from the same colony

Although the queen of the observation hive colony produced *di* and normal bees in a 1:1 ratio, the ratio among the foragers at the feeder in the runway (determined during an hour of observation) was 19 *di* to 40 normal (0.48:1), the ratio, therefore, to be expected at the other feeders in this experiment. The 1.8:1 ratio of *di* to normal bees captured at the 10-m feeder (Table 6) greatly exceeded the expected ratio ($P < .001$).

The proportion of *di* bees captured at the stations 100, 250, and 1000 m from the hive decreased slightly as the distance increased. Although the ratios of *di* to normal bees at these distances were not significantly different from the expected ratio of 0.48:1, this could be due to the small sample size.

In this experiment, no aggressive behavior was observed among bees at the feeders, unlike in Experiment V-1. This

can be easily explained. During the period of entrainment, while the feeder was temporarily placed at points intermediate between test stations, the operator killed any alien (untagged) bees coming to the feeder, so that a population of competitors had no opportunity to develop. Few alien bees were attracted to the feeder anyway, owing to their much greater attraction to natural nectar sources, principally the ever present yellow star thistle. The *di* and normal bees recruited to the feeder, being from the same colony, possessed the same colony odor, and were thus mutually recognized as hive-mates. Hence, they did not fight.

In Experiment V-1, the proportion of *di* bees increased as feeder distance increased. In the present experiment, quite the opposite resulted. The differences in results can probably best be resolved on the basis of numerical superiority. In Experiment V-1, *di* bees were superior, whereas in Experiment V-2, normal bees were superior. In both instances, the proportion of foragers of the numerically inferior stock decreased in relation to distance.

VI. Trip Time of Normal and Diminutive-Wing Honey Bees Foraging 1 Km From the Hive

One may predict that *di* workers, with a mean wing area only 62.9 percent that of normal workers (cf. I) would have a flight speed that is proportionately reduced. However, the handicap of reduced wing area is somewhat counterbalanced by a 22.2 percent increase in wing-beat frequency (cf. II).

There were slight but nonsignificant differences between *di* and normal bees with respect to mean trip time from hive to feeder ("empty" bees), and from feeder to hive ("loaded" bees) (Table 7). Likewise, statistical analysis revealed no significant differences between the two groups with respect to round trip time, time spent at the

TABLE 7
TRIP TIME OF NORMAL AND
DIMINUTIVE-WING WORKERS
TRAINED TO A FEEDER LOCATED
1 KM FROM THE HIVE,
AUG. 9, 1972

Time (min)		<i>di</i>	normal
From hive to feeder ("empty" bees)	M*	3.9	3.7
	SE†	0.44	0.19
	N‡	12	29
At feeder	M	1.3	1.9
	SE	0.13	0.75
	N	21	52
From feeder to hive ("loaded" bees)	M	6.1	4.5
	SE	0.88	0.54
	N	13	42
In hive, between successive trips to feeder	M	4.9	7.6
	SE	1.01	1.42
	N	11	29
Round trip (hive to feeder and back)	M	15.5	10.8
	SE	4.16	0.96
	N	12	25

* Mean.

† Standard error.

‡ Number of observations.

feeder, and time spent in the hive between successive visits to the feeder. The mean number of trips to the feeder per hour, 2.9 and 3.2 for *di* and normal bees, respectively, was not significantly different.

VII. Dance Communication of Distance by Normal and Diminutive-Wing Honey Bees

Bees that fed at the feeder in the runway (0 m) did not dance. Bees that walk rather than fly to the feeder apparently are reacting as if food is simply being transferred from one area of the hive to another. Since bees are not known to dance except within the hive, the fact that many dances occurred in the runway rather than on the comb surface supports this interpretation. Increasing the sugar concentration of the syrup from 37.5 to 62.5 percent still did not stimulate dance behavior among bees taking food from the runway feeder. The majority of the trained foragers, however, did dance when returning from the distant stations (70.3 to 100 percent of the normal bees, and

76.2 to 100 percent of the *di* bees).

"Round" dances, known to be associated with food sources near the hive (von Frisch, 1967), were performed by bees that foraged at feeders 10, 100, and even 250 m from the hive. All bees that danced upon returning from the 10-m feeder did round dances. At 100 m, of the 16 dances by *di* bees observed, 11 (68.6 percent) were round dances. This compared to 17 rounds out of 25 dances (65.4 percent) observed for normal bees. The remaining dances observed at this distance were wag-tail dances. At 250 m, two of 17 dances by *di* bees (11.8 percent) were round dances, compared to five of 35 dances (14.3 percent) for normal bees. The majority of the dances observed at this distance were wag-tail dances. However, at 1000 m, only the wag-tail dances were seen among bees of either group.

Analysis of the wag-tail dances (von Frisch, 1967) of *di* and normal bees (Table 8) for the 100-, 250-, and 1000-m feeder distances indicated that, in both groups, the duration of waggle-runs increased, and the dance tempo (number of waggle-runs/15 sec) decreased, with increasing distance to the feeder. However, contrary to expectations that *di* bees would execute dances indicating "longer" distances than would normal bees, there was only a slight, nonsignificant difference between the two groups with respect to either the duration of waggle-runs or the dance tempo, after returning from the same distance. Perhaps this can be best explained on the following basis. Since the wing area of *di* bees averages only 62.9 percent of normal, the wings encounter less air resistance in flight, and thus beat 22.2 percent faster than do normal wings. The load size carried by *di* bees is also reduced (Table 3). Hence, *di* bees probably expend little, if any, more energy in flight than do normal bees, and so do not indicate a "greater distance" in their dance ma-

TABLE 8
ANALYSIS OF WAG-TAIL DANCES
PERFORMED BY NORMAL AND
DIMINUTIVE-WING BEES TRAINED
TO FEEDERS AT THREE DISTANCES

Feeder distance (m) *		Duration of waggle-runs (sec)		No. of waggle-runs/15 sec ("dance tempo")	
		<i>di</i>	normal	<i>di</i>	normal
100	M†	0.51	0.52	8.4	8.3
	SE‡	0.01	0.01	0.10	0.30
	N§	14	16	2	6
250	M	0.60	0.65	7.1	7.9
	SE	0.02	0.02	0.42	0.23
	N	33	64	8	20
1000	M	1.68	1.70	3.8	4.0
	SE	0.03	0.03	0.56	0.75
	N	37	58	8	7

* Only round dances were observed among bees trained to feeders at 10 m.

† Mean.

‡ Standard error.

§ Number of observations. In the case of "duration of waggle-runs," N is the number of waggle-runs timed (usually several for each bee dance); in the case of "no. of waggle-runs/15 sec," N is the number of bee dances observed.

neurers.

Inasmuch as bees learn of the distance and direction to a new food source by following bees that dance (von Frisch, 1967), we paid some attention to the dance followers as well as to the dancers. Normal and *di* bees in the mixed observation hive seemed to follow dancing bees of either group with about equal frequency, showing no preference for the dances of bees of their "own kind."

Results of the survey of dancing bees in the observation hive are indicated in Table 9. There was a much lower frequency of round dances by pollen foragers than by nonpollen foragers, both for *di* and normal bees, indicating that most of the pollen was being gathered at rather great distances. The relatively high frequency of round dances among dancing bees not carrying pollen can probably be attributed principally to nectar foraging by bees on lippia (*Phyla nodiflora* Michx.), which was blooming profusely and in use as a ground cover at the apiary site. Water foraging at sources provided in the api-

TABLE 9
DANCE BEHAVIOR OF NORMAL AND DIMINUTIVE-WING FORAGERS,
AUG. 30-SEPT. 1, 1972

Item	Pollen carriers		Nonpollen foragers§	
	<i>di</i>	normal	<i>di</i>	normal
Dances observed (no. and percent)				
Round	0 (0)	3 (7.1)	17 (50)	30 (36.1)
Wag-tail	12 (100)	39 (92.9)	17 (50)	53 (63.9)
Total	12	42	34	83
Characteristics of wag-tail dances				
Duration of	M*	2.15	2.50	1.19
waggle-runs (sec)	SE†	0.28	0.18	0.15
	N‡	8	30	15
"Dance tempo"	M	2.69	3.23	4.13
(No. waggle-runs/15 sec)	SE	0.31	0.17	0.44
	N	9	28	9

* Mean.

† Standard error.

‡ Number of dances used in making calculations. (Note: for some dances, only the duration of waggle-runs was measured; for others, only the dance tempo. Both parameters were measured if possible; but, in many instances, the bee stopped dancing before this could be done.)

§ Inasmuch as these bees danced, they probably carried a load; but it was not known whether it consisted of nectar or water. (To determine this, the bees would have had to been killed.) The term "nectar carrier" could probably be applied to most of these bees, but the more general term "nonpollen forager" is preferred.

ary may account for other round dances.

In this study, there was only one significant difference in dance behavior between *di* and normal bees, and it was with nonpollen foragers. The ratio of round to wag-tail dances among *di* bees (17:17) was significantly higher ($P < .001$) than that for normal bees (30:53). This would indicate that a greater proportion of *di* bees foraged at close range. For nonpollen foragers that did wag-tail dances, both the mean duration of waggle-runs, as well as the dance tempo, indicated that the average foraging distance was ca. 1 km (calibrated from dances of bees trained to feeders, Table 8), for both *di* and normal bees. For pollen foragers, the mean duration of waggle-runs and the dance tempo indicated a mean foraging distance exceeding 1 km for both groups of bees.

VIII. Return to the Hive of Flight-Experienced Normal and Diminutive-Wing Honey Bees Released at Various Distances

Tag recovery for the bee-release sites is summarized in Table 10. From the

10-m "control" site, 94 percent of the *di* and 84 percent of the normal bees returned. From the 1-km release site, the difference in rate of return between *di* and normal workers (10.0 and 28.9 percent, respectively) was highly significant ($P < .001$). Some drones also returned from this distance (5.0 and 16.3 percent, respectively), but the difference was not significant. From the 2-km release site and beyond, none of the released drones returned to the hives, and the return of workers decreased sharply. The greatest distance from which a *di* worker returned was 2 km, compared to 3 km for normal workers.

Theoretically, a bee familiar with the landmarks in the vicinity of the release site by virtue of having previously foraged in the area (or flown over it, in the case of drones), should be capable of returning to the hive provided its energy reserves are sufficient for the return flight, and weather conditions are favorable. If the distance between hive and release site is visualized as the radius of a circle, it would be expected that the chances of a flight-experienced bee having been previously present at

TABLE 10
RECOVERY, AT THE HIVE ENTRANCE, OF TAGS FROM NORMAL AND
DIMINUTIVE-WING BEES RELEASED IN THE FIELD

Caste	Genetic stock		Distance (km) between hive and release site						Total
			.01	1	2	3	4	5	
Workers	di	Bees released	50	90	90	90	90	89	499
		Tags recovered	47	9	1	0	0	0	57
		Percent	94.0	10.0	1.1	0	0	0	
	normal	Bees released	50	90	90	90	90	88	498
		Tags recovered	42	26	3	1	0	0	72
		Percent	84.0	28.9	3.3	1.1	0	0	
Drones	di	Bees released	—	40	30	32	20	42	164
		Tags recovered	—	2	0	0	0	0	2
		Percent	—	5.0	0	0	0	0	
	normal	Bees released	—	43	38	47	24	15	167
		Tags recovered	—	7	0	0	0	0	7
		Percent	—	16.3	0	0	0	0	

any given point in the field, would diminish rapidly with distance. Since $\text{area} = \pi r^2$, the "area dilution" for the release sites of 1, 2, 3, 4, and 5 km distant would therefore be 3.1, 12.6, 28.3, 50.3, and 78.5 km², respectively. Thus, familiarity with only a tiny fraction of the total area could be expected of each bee, particularly since foraging bees, as individuals, are known to remain constant for many successive foraging trips to the same relatively small "fixation area" of flowers (Butler *et al.*, 1943; Free, 1960, 1966; Singh, 1950; Weaver, 1957).

IX. Foraging Distribution of Normal, Hy-Queen, and Diminutive-Wing Honey Bees

Experiment IX-1. Distribution of bees foraging on onion, safflower, and carrot

At the experimental apiary, 169 tags were recovered: 36 from normal colonies, 68 from *di* colonies, and 65 from Hy-Queen colonies. In addition, 3601 tags were recovered by 396 other known hives within 7.3 km of the experimental apiary.

Of the 68 tags recovered by the two *di* colonies, 19 (27.9 percent) were from Onion I, and 49 (72.1 percent) were from the adjoining field, Safflower I

(mean distance from experimental apiary to Safflower I tagging sites, 473 m; maximum distance flown, 600 m).

Of the 36 tags recovered by the four normal hives, 22 (61.1 percent) were from Onion I; (36.1 percent) from Safflower I (adjoining); 0 from Safflower II (1.4 km); 1 (2.8 percent) from Onion II (1.9 km); and 0 from Carrot (2.8 km).

Of the 65 tags recovered by the two Hy-Queen colonies, 49 (75.4 percent) were from Onion I; 15 (23.1 percent) from Safflower I; 0 from Safflower II; 1 (1.5 percent) from Onion II; and 0 from Carrot.

If all tags recovered in the experimental apiary are considered collectively, disregarding crop, the mean distances the bees flew were: *di*, 331 (± 45.9) m; normal, 222.3 (± 63.4) m; Hy-Queen, 137.3 (± 38.1) m. However, in this experiment, the mean flight distance of neither *di* nor Hy-Queen colonies differed statistically from that of normal colonies.

Experiment IX-2. Distribution of bees foraging on alfalfa, safflower, and yellow star thistle

The number of tags per tagging site recovered by colonies of the three genetic stocks is indicated in Table 11.

TABLE 11
DISTRIBUTION OF DIMINUTIVE-WING, HY-QUEEN, AND NORMAL BEES
FORAGING ON ALFALFA, SAFFLOWER, AND YELLOW STAR THISTLE
IN COLUSA COUNTY, CALIF., JULY 8-14, 1971

Flora	Distance (m) to apiary	No. bees tagged	No. tags recovered			
			Normal colonies (7)	Hy-Queen colonies (7)	<i>di</i> colonies (5)	Total (19)
Alfalfa	61	200	17	33	25	75
	146	200	25	29	18	72
	296	200	26	23	19	68
	443	200	5	16	7	28
	603	200	12	10	11	33
	Total	1000	85	111	80	276
Safflower	232	80	7	9	15	31
	337	80	4	8	2	14
	470	80	1	4	1	6
	623	80	0	2	1	3
	1154	80	0	0	0	0
	Total	400	12	23	19	54
Yellow star thistle	1270	160	0	0	0	0
	1335	160	0	1	0	1
	1365	160	10	0	1	11
	1675	160	0	0	0	0
	2009	160	0	0	0	0
	Total	800	10	1	1	12

(In addition, several other apiaries, not considered part of this experiment, not recovered tags.) In general, the frequency of foragers declined with increasing distance. A notable exception was the concentration of 10 normal bees at the thistle site located 1365 m away, with no tag recovery from two nearer sites. In this particular instance, bees from one colony dominated the area, as 8 of the 10 tags were recovered at one hive. In a large field, however, a more homogeneous mixture of bees from various colonies would be expected, since, in the absence of landmarks, "area defense" by any one colony would appear to be less effective.

The genetic preference of Hy-Queen bees for alfalfa probably may account for their relatively proximal distribution pattern near the apiary (Table 11), and the relatively high rate of tag recovery. In turn, this pattern may have increased the levels of competition

with *di* and normal bees in the area nearest the apiary, causing them to forage farther afield than may otherwise not have been necessary.

Mean distances (in m) that bees flew, disregarding the host plant, were: normal, 363 ± 34.8 ($n = 100$); Hy-Queen, 262.4 ± 16.7 ($n = 135$); *di*, 261.2 ± 18.7 ($n = 100$). There were statistically significant differences ($P < .01$) between means for normal and *di*, and between those for normal and Hy-Queen colonies. Mean distances that bees flew to forage on alfalfa were: normal, 256.9 ± 19.1 ($n = 85$); Hy-Queen, 235.8 ± 16.6 ($n = 111$); *di*, 243.9 ± 20.9 ($n = 80$). The difference between any two means was not significant. For safflower, the mean flight distances were: normal, 286.8 ± 22.1 ($n = 12$); Hy-Queen, 343.9 ± 25.6 ($n = 23$); *di*, 276.2 ± 23.8 ($n = 19$). No differences were significant. For yellow star thistle, too few tags were retrieved

TABLE 12
FORAGING ACTIVITY AND PREFERENCE FOR ALFALFA BY NORMAL,
HY-QUEEN, AND DIMINUTIVE-WING BEES

Kind of bee	No. hives (A)	Flight activity		Tag recovery		
		Index* (B)	Percent of normal (C)	Total (D)	Mean no. tags/hive	
					Uncorrected (E) (D/A)	Corrected† (F)
Normal	14	41.1	100.0	129	9.2	9.2
Hy-Queen	14	37.8	91.3	152	10.9	11.9
Diminutive-wing	4	45.5	109.9	38	9.5	8.6

* Mean no. bees leaving hive entrance/30 sec, based on the ten 30-sec samples taken over a 5-day period (Gary, 1967).

† Adjusted to correct for differences in flight activity, i.e., $F = \frac{100 D}{AC}$. The result should be a theoretical measure of the relative preference for alfalfa foraging by the three genetic stocks.

for a valid statistical comparison of mean flight distances.

Experiment IX-3. Intrafield foraging distribution of bees from colonies placed at the edge of a 34-ha alfalfa field

When the tag recovery frequency data were corrected for differences in flight activity and number of colonies present (Table 12, column F), it was found that a significantly higher proportion of Hy-Queen than normal bees foraged on alfalfa ($P < .05$); but the difference in frequency of alfalfa foraging between normal and *di* bees was not significant.

Although the majority (2841) of the 4000 tagged bees flew to apiaries other than the experimental one (as shown by tag recovery by magnetic traps at 646 hive entrances within a 4-km radius of the field), these are not of concern here. If the mean flight distance is computed by measuring all distances between capture points and the apiary, weighting each distance according to the number of tags recovered, and dividing the result by the total number of tags recovered, then both *di* and Hy-Queen colonies had a shorter mean flight distance than did normal colonies; but the differences were not statistically significant. The mean flight distance (in m) for *di* col-

Fig. 11. Cumulative tag recovery at experimental colonies adjacent to the alfalfa field, as related to the distance from the apiary at which bees were tagged.

onies was 304.3 ± 30.1 ($n = 38$); for Hy-Queen colonies, 237 ± 13.9 ($n = 152$); for normal colonies, 338.2 ± 56.7 ($n = 129$), where n stands for the number of tags recovered. Figure 11 shows how the cumulative percent-tag-recovery increased with a corresponding increase in distance from the hive.

When the twice-daily net samples of bees captured at the hive entrances were pooled, the proportions of returning foragers that were pollen collectors were as follows: *di*, 138/454 (30.4 percent); Hy-Queen, 654/1727 (37.9 percent); normal, 493/1593 (30.9 percent). Thus, the frequency of pollen collectors among *di* bees did not differ significantly from normal ($\chi^2 = 0.04$), but the greater frequency of pollen collectors among Hy-Queen stock was highly significant ($P < .001$).

Discussion of Experiments IX 1-3

The three field experiments presented in this section give indications of the distribution and foraging range of *di* bees under actual field conditions, in comparison with Hy-Queen and normal bees. Both *di* and Hy-Queen stocks appear to have a foraging range that is somewhat restricted, as best shown in Fig. 11. Diminutive-wing bees are "limited" supposedly by their anatomy, whereas Hy-Queen bees supposedly are "limited" by having been selected for a preference for alfalfa and for high frequency of pollen collection. A reduced foraging range by Hy-Queen bees may probably be regarded as an accidental consequence of these factors.

It is notable, however, that, just as with normal bees, many of the *di* and Hy-Queen bees did not remain in the field for which pollination services were intended, even when the hives were located at the field. For example, in Experiment IX-1, many *di* bees were tagged on safflower up to 600 m from their colonies. And a second onion field, 1.9 km from the one at which colonies were located, was not sufficiently isolated to prevent some foraging there by Hy-Queen bees. Similarly, in Experiment IX-2, one *di* bee foraged on yellow star thistle 1365 m from the hive.

A great variety of pollen was collected by bees of all three genetic stocks.

None of the three stocks foraged exclusively within the boundaries of any one field. Perhaps a realistic approach to controlling pollination would be to isolate seed crops of different cultivars from each other by using, at each field, colonies of bees that have a limited foraging range. Minimum isolation distances would have to be determined, but should be less than if normal honey bees were used. This approach, of course, could be used only if all other pollen vectors could be excluded as well. The extent to which pollen transfer occurs from bee to bee within the hive (if at all) is unknown; but if it is significant, it could cause genetic contamination of crops if bees from a colony were foraging simultaneously on two or more semi-isolated cultivars in different fields. Hence, there seems to be potential commercial value for colonies with relatively short bee flight ranges. Such colonies could serve as an additional tool for the producer of certified seed.

The Hy-Queen breeding program of Dadant & Sons, Inc. of Hamilton, Ill., was abandoned after 3 yr of trial. The possibility of using *di* honey bees for pollination of alfalfa or other crops now seems remote for several reasons: First, their flight range is apparently too great to justify using the stock for "limited area pollination." Furthermore, the inability of these colonies to supersede queens (since virgin queens do not naturally mate, but must be artificially inseminated) adds to the problem of colony maintenance by the beekeeper. Nevertheless, the *di* stock remains valuable as a research tool. The theoretical possibility still remains for developing a new strain of honey bees with normal wings and a tendency to forage near the hive.

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