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Original article

The influence of hive location on honeybee foraging activity and fruit set in melons grown in plastic greenhouses

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Summary — Melon (*Cucumis melo* L) is a very important winter crop in Israel, especially in the extremely hot Arava Valley. The melons are grown in 120 m long plastic tunnels, which creates problems in terms of pollination. Because of local southern windstorms, the long plastic tunnels can only be oriented in one direction, from north to south. Beekeepers disagree as to the best site to locate the bee hives. Observation of bee foraging behavior and analysis of wind direction in the experimental plots revealed that placing hives at the northern end of the tunnel allows for higher bee activity in the morning. This results in a higher yield compared with that obtained when hives are located at the southern end of the tunnel.

***Apis mellifera* / *Cucumis melo* / greenhouse / pollination / wind direction**

INTRODUCTION

Melon (*Cucumis melo* L), a common Israeli crop, used to be grown in the summer in open fields throughout the country. During the last 10 years, growth of this crop has been shifted to the desert (Arava Valley), where it is still grown in open fields in autumn and spring (Orr and Eisikowitch, 1988). However, in the late winter, because of the low temperature, the crop is grown in specially designed greenhouses, which have the form of long, walk-through tunnels. The tunnels are built in a north to south direction, to enable the structure to withstand the common southern windstorms. The openings at the 2 ends of the tunnel allow the air to flow through the structure, in accordance with the direction of the outside wind.

Previous studies have shown that honeybees can pollinate melons under polyethylene sheets in the form of 'row covers' (Gaye

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et al, 1991) or in high greenhouses (Iselin *et al*, 1974; Spangler and Moffett, 1979). In Israel the only pollinator used for melon pollination in greenhouses is the honeybee (*Apis mellifera* L) (Dag *et al*, 1992). When placing the bee hives for pollination, the beekeeper cannot reach the area between the tunnels, which is too narrow for the passage of vehicles. The hives can therefore only be placed at the southern or northern ends of the tunnel.

Disagreement exists among the beekeepers as to the most advantageous location for the bee hives. The purpose of this study was to learn which of the locations (north or south of the tunnel) gives maximum foraging activity and fruit set.

MATERIALS AND METHODS

The research was conducted in Ein-Yahav, a settlement in the center of the Arava Valley, in the southern part of Israel (30.5° latitude and 35.5° longitude).

The experiment was carried out at 2 different sites: site A with 12 tunnels and site B with 6, separated from one another by 5 km. The walk-through tunnels used in this work were made of metal arches covered with a 0.12 mm layer of polyethylene (UVA, IR, anti fog; Polygar, Israel).

All tunnels were 120 m long, 2.2 m high at their highest point and 4.8 m wide, holding 3 rows of melon plants (1 700 plants per dunam; 0.1 hectare). Plants were drip-irrigated with local well water. The cultivar used was 'Arava', an andromonoecious variety selected for desert conditions (Karhi, personal communication). This cultivar, like most commercial melon cultivars, is self-compatible and needs zoophilic pollinators to transfer pollen and set fruit (McGregor and Todd, 1952; Dag *et al*, 1992; Free, 1993).

The hives were placed outside the tunnel, near a round hole in the plastic wall, thereby allowing some of the bees to forage within the greenhouse and others to forage in the open field. This method enabled us to keep the colony active and vigorous during the long period of crop pollination under greenhouse conditions (Free and Racey, 1968; Free, 1993).

At each site tunnels were divided into 2 blocks; in 1 block, hives were located at the southern end of the tunnels and in the other block, they were located at the northern end. Each tunnel was divided into three 40 m sections: its northern, middle and southern thirds.

The hives were brought into the pollination area at the beginning of January. All colonies had the same starting strength: 4 combs with brood out of 8 bee combs. Preliminary observations revealed no significant pollinators other than the honeybees pollinating the greenhouse melons.

Honeybee foraging activity in the greenhouse was determined by counting bees during their active period (0900 to 1400 hours) by means of a mechanical counter while walking at a normal pace; each 40 m section / 2.5 min. Only honeybees which had landed on flowers were counted. Results are given as the average number of bees per section.

Fruits were counted for each treatment in 2 tunnels per site. The count was performed on 2.7 m segments from the middle row; 15 segments per section per tunnel. The average fruit set per segment per treatment in each section was calculated from 30 segments (15 segments x 2 tunnels). The smallest melons counted were the size of chicken eggs. Fruits reaching this size are beyond the dropping stage, and therefore represent fruit that will reach the harvest stage.

Wind direction data were obtained from an Israeli Meteorological Service station located 4 km away from the experimental field.

RESULTS

Honeybee foraging activity

Bees foraging data from site A (January 15, 1992) are presented in figure 1. Data were analyzed by χ^2 for the 1:1 expected ratio between average bee numbers in the different sections for the 2 hive locations (north and south). Figure 1 clearly indicates that the tunnels with hives located at their northern end contained higher bee activity in the northern and middle thirds, as compared to

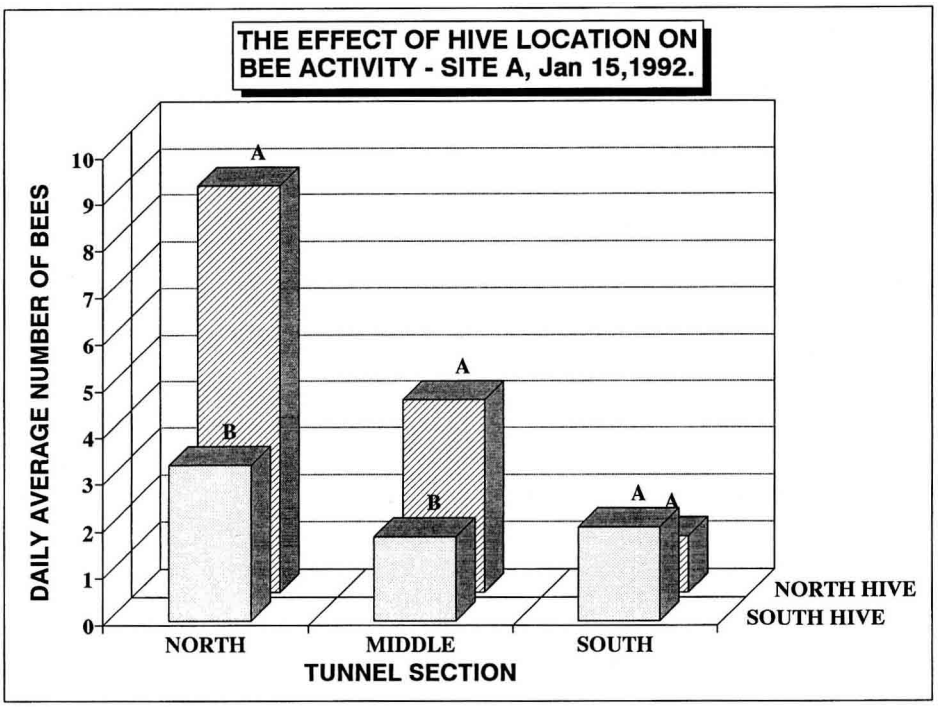

Fig 1. The effect of hive location on honeybee foraging activity; site A, January 15, 1992. Different letter heading the columns in a section represents a significant difference ($p < 0.05$) between the 2 hive locations (north and south).

tunnels with hives located at their southern end. However, no such difference was found in the southern third of the tunnels.

Bee foraging data from site B (January 23, 1992) are presented in figure 2. Data were analyzed as above. Higher bee foraging activity was found in all 3 sections of the tunnels with hives at their northern end. However, the difference was significant only in the tunnel's northern section.

Figure 3 presents the hourly foraging activity at site A on January 23, 1992. In the morning, the tunnels with hives located at their northern end had higher bee activity in all 3 sections, compared to tunnels with hives placed at their southern end.

Fruit set

Average fruit counts for each third of 2 tunnels at site A are presented in figure 4. The results were analyzed by 2-way ANOVA (table I). The average fruit number was found to be significantly different between tunnels with different (north or south) hive locations, and significantly different between the different sections of the tunnels. There was a strong interaction between the 2 parameters (hive location and tunnel section) in terms of their effect on fruit set.

Figure 5 presents the fruit set data from site B. Data analysis by 2-way ANOVA

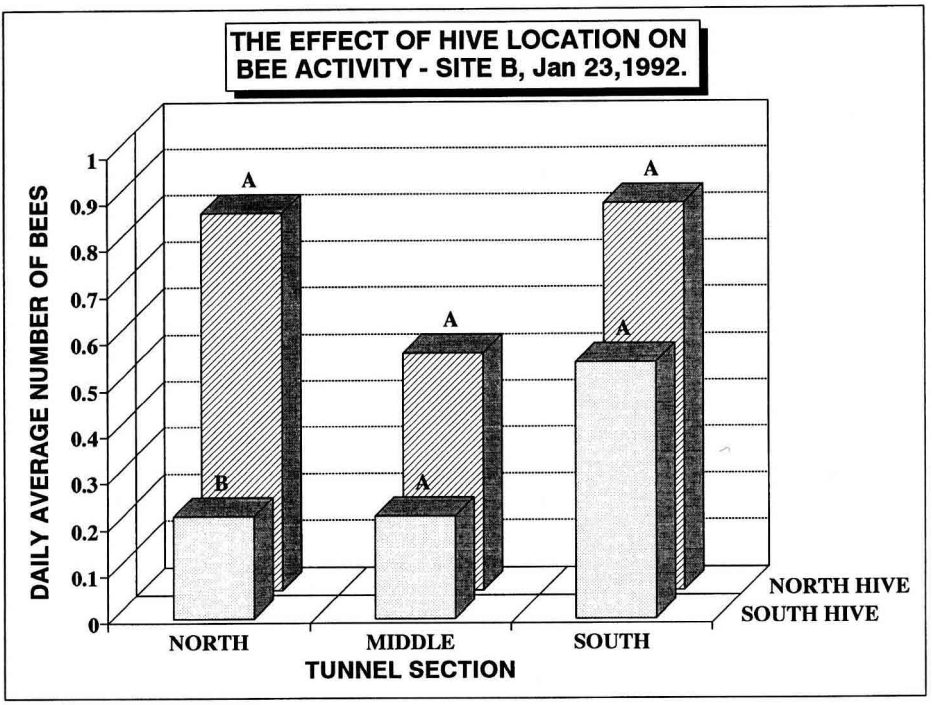

Fig 2. The effect of hive location on honeybee foraging activity; site B, January 23, 1992. Different letter heading the columns in a section represents a significant difference ($p < 0.05$) between the 2 hive locations (north and south).

is presented in table II. There was a significant difference in fruit number between the tunnels with different hive locations.

Wind direction

Wind direction data from the Israeli Meteorological Service are given for 8 directions

Table I. Statistical analysis of fruit counting data in site A.

	DF	*Sum of squares*	*Mean square*	F-*value*	*P-value*
Hive	1	1 186.537	1 186.537	116.220	0.0001
Area	2	70.859	35.429	3.470	0.0337
Hive x area	2	297.084	148.542	14.550	0.0001
Residual	146	1 490.571	10.209		

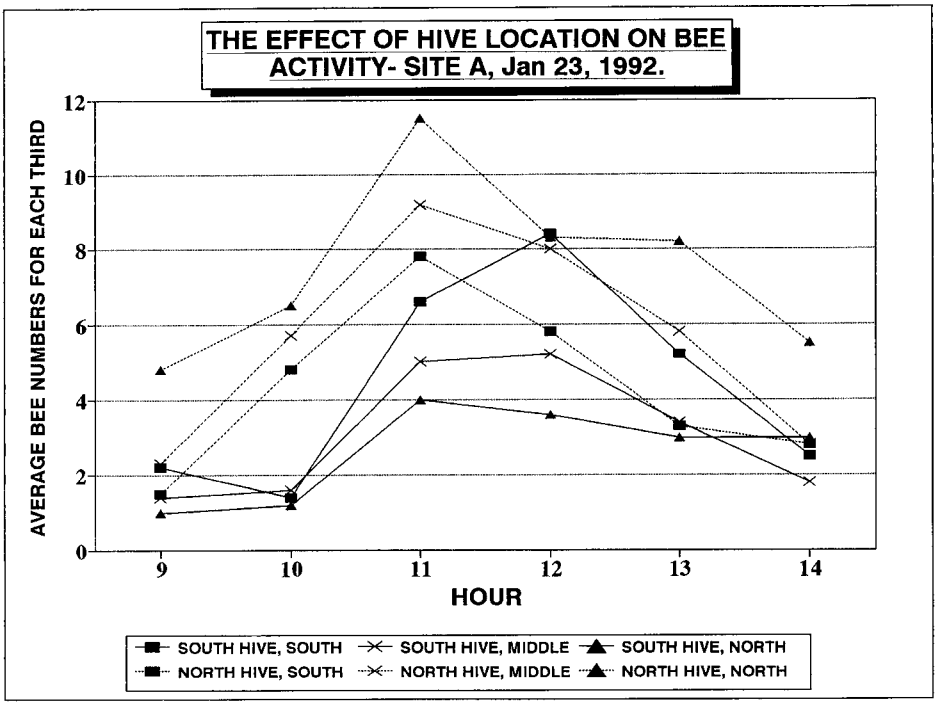

Fig 3. The effect of hive location on honeybee hourly foraging activity; site A, January 23, 1992.

(west, south west, south, *etc*). Frequency of the different wind directions and their highest speeds are provided for 2 periods of bee activity (table III).

The tunnel's north-south direction together with the outside wind direction, create a situation in which southwesterly, southerly and southeasterly winds caused

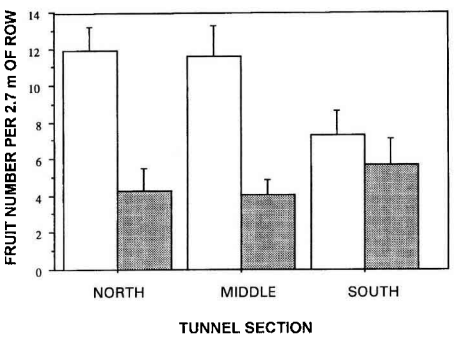

Fig 4. The effect of hive location on fruit set; site A, January 30, 1992. Error bars represent a 95% confidence interval. North hive: white; south hive: grey.

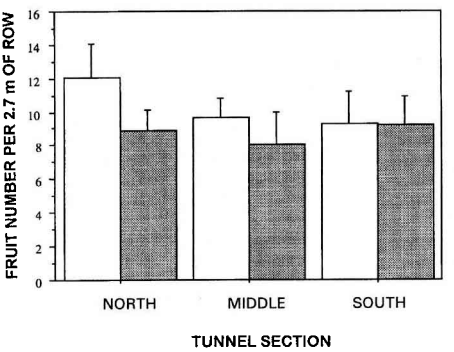

Fig 5. The effect of hive location on fruit set; site B, January 30,1992. Error bars represent a 95% confidence interval. North hive: white, south hive: grey.

Table II. Statistical analysis of fruit counting data in site B.

	DF	*Sum of squares*	*Mean square*	*F-value*	*P-value*
Hive	1	124.274	124.274	6.022	0.0151
Area	2	85.805	42.902	2.079	0.1281
Hive x Area	2	70.863	35.432	1.717	0.1826
Residual	175	3 611.460	20.637		

Table III. Wind speed and direction data for the experiment period (from the Israeli Meteorological Service)

Time (hours)		*Wind direction*							
		West	*South west*	*South*	*South east*	*East*	*North east*	*North*	*North west*
0900-1100	Relative probability [a]	22%	53%	9%	2%	–	9%	4%	–
	Wind speed (km/h)[b]	< 30	< 20	< 20	< 12	–	< 20	< 20	–
1100-1300	Relative probability [a]	4%	28%	6%	2%	6%	42%	6%	6%
	Wind speed (km/h)[b]	< 20	< 60	< 20	< 12	< 20	< 30	< 20	< 20

[a] Relative probability: the probability of the specific wind direction during the hours examined. [b] Wind speed: the high limit of wind speed in the specific direction.

air flow in the tunnel from south to north, whereas northeasterly, northerly and northwesterly winds caused air to flow in the tunnel from north to south.

From 0900 to 1100 hours, 64% of the time there is southerly (south to north) air flow in the tunnels and 13% of the time, a northerly air flow. From 1100 to 1300 hours, 36% of the time air flowed through the tunnels in a southerly direction, and 54% of the time, it flowed in a northerly direction.

DISCUSSION AND CONCLUSIONS

To achieve maximal fruit set, each hermaphrodite melon flower requires the visits of at least 10 bees during its one day of blooming (Free, 1993). For various reasons, greenhouses are not the preferred environment for bee foraging, making it important to find a way to improve bee activity. This work examines the influence of hive location on bee activity and subsequent fruit set in a greenhouse setting.

Locating the hives at the northern end of the tunnel improved bee activity in comparison to locating them at the southern end (figs 1–3). This improved foraging activity was followed by better fruit set (figs 4 and 5).

It also seems that the shorter distance from the tunnel section closest to the hive played an important role in increasing bee activity. This same phenomenon of increasing bee activity and fruit set in greenhouses

close to hives has also been found in *Freesia refracta* (Free and Racey, 1966). The curves in figure 3, representing bee activity in the different thirds of the tunnel relative to a particular hive location, are parallel. On the other hand, if we compare the 3 curves representing hives located at the northern end to those representing the southern hive location, we find the following: until about 1100 hours, the activity from the northern hives is higher than that from the southern hives; after 1100 hours, the activity in the tunnels with northern hives decreases rapidly while the activity in those with hives located at their southern end increases.

The local meteorological data (table III) indicates air flow from south to north (a southern air flow) in the tunnel from 0900 to 1100 hours, at which point it changes direction, becoming a northern air flow (from north to south).

From the meteorological information and the data in figure 3, the following scenario is proposed. In the morning, the bees in the hive located at the northern end of the tunnel are exposed to a southern air flow from the greenhouse, which increases their activity inside. At the same time, bees from hives located at the southern end of the tunnel are exposed to air flow from the open field, which reduces their pollination activity inside the tunnel.

At 1100 hours, the wind changes its direction, causing the opposite situation to occur. As a result, bee activity in tunnels with hives at their northern end starts to decrease, whereas the activity in tunnels with hives at their southern end increases.

The activity in tunnels with hives at their southern end never reaches the level of activity in the northern-hive tunnels, probably because the natural foraging activity of bees on melon flowers peaks before noon (McGregor and Todd, 1952).

The tendency to forage upwind is known in honeybees (Wenner, 1963; Friesen, 1973; Ish-Am, 1995), as well as in bumblebees (Woodell, 1978).

Fruit set in the tunnels with hives at their northern end was higher than that in tunnels with hives at their southern end (figs 4 and 5). This is due not only to higher bee foraging activity, but also to the timing of that activity. In melon, stigmas have been found to be very receptive from 2 h before anthesis to 2–3 h afterwards (morning). Pollen fertility decreases during the day, and pollination is more successful earlier in the day than later (Nandpuri and Brar, 1966). We conlude, therefore, that bee activity early in the morning (in tunnels with northern hives) is more efficient than noontime activity (tunnels with southern hives).

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Résumé — L'influence de l'emplacement des ruches sur l'activité de butinage des abeilles et la fructification des melons cultivés sous serre en plastique. Le melon (*Cucumis melo* L) est une culture commune en Israël, répandue dans tout le pays. Cependant, au cours des dernières années, le développement de cette culture s'est déplacé vers le sud, dans la vallée de l'Arava. Le principal cultivar utilisé est «Arava» qui est un cultivar autocompatible andromonoïque qui nécessite un pollinisateur pour la fructification. Ces melons sont cultivés l'hiver dans des serres ayant la forme de longs tunnels recouverts de polyéthylène, de 120 m de long, 2,2 m de haut et 4,8 m de large. Ces tunnels sont orientés du nord au sud afin de résister aux tempêtes de vent. Pour des raisons techniques, les ruches utilisées pour la pollinisation ne

peuvent être disposées qu'aux entrées sud ou nord des tunnels. Les apiculteurs de cette région sont en désaccord quant au choix du meilleur emplacement. Le but de cette étude est d'analyser l'influence respective de chacun de ces emplacements, et de recommander l'utilisation de celui qui induit l'activité de butinage la plus intense, et donc la meilleure fructification. L'expérience a été réalisée à Ein-Yahav, dans 2 sites différents : le site A avec 12 tunnels et le site B avec 6 tunnels. Chacun de ces sites a été divisé en 2 secteurs : dans l'un, les ruches étaient situées à l'extrémité sud de chaque tunnel, tandis que, dans l'autre, elles étaient situées à l'entrée nord. Toutes les ruches contenaient des colonies de force identique (4 cadres de couvain sur 8). Pendant l'expérience, les abeilles ont été comptées chaque heure durant leur période d'activité, et seules les abeilles qui ont atterri sur les fleurs ont été considérées comme étant des visiteuses. Le comptage des fruits a été réalisé sur une longueur de 2,7 m dans la rangée du milieu (sur 3 rangées) dans 2 tunnels de chaque secteur. Les mesures de la direction du vent provenaient d'une station météorologique située à 4 km. Au cours de la période étudiée, les vents dominants étaient orientés du sud au nord tous les matins jusqu'à 11 h et changeaient de direction (nord-sud) par la suite. Les tunnels comportant des ruches à leur extrémitré nord ont présenté une activité de butinage significativement plus élevée dans les 2 tiers nord du tunnel que les tunnels dont les ruches étaient situées à l'extrémité sud (fig 1, pour le site A). Cependant la différence n'était pas significative dans le tiers sud. La figure 2 montre la même tendance, en plus marquée, pour le site B. La figure 3 présente les données horaires et montre que les ruches disposées au nord entraînent une meilleure activité des abeilles le matin. Les figures 4 et 5 montrent qu'une activité de butinage élevée avait pour conséquence une meilleure formation des fruits quand les ruches étaient situées au nord. En conclusion, nos résultats démontrent que 3 facteurs au moins interviennent dans l'activité de butinage et la fructification : i) la distance entre les ruches et les plantes : plus les ruches sont proches plus l'activité des abeilles est importante et meilleure est la fructification ; ii) la direction du vent : les abeilles préfèrent voler contre le vent ; iii) l'heure : la pollinisation du melon est plus efficace quand elle se situe tôt le matin.

***Apis mellifera* / *Cucumis melo* / serre / pollinisation / direction du vent**

Zusammenfassung — Einfluß des Stellplatzes von Bienenvölkern auf Sammelaktivität der Bienen und Fruchtansatz bei Melonen in Plastiktunneln. Die Melone (*Cucumis melo* L) ist eine in Israel weit verbreitete Feldfrucht und wird meist im Sommer angebaut. In den letzten Jahren wurde der Anbau jedoch überwiegend in Richtung des Arava Valley im Süden verlagert. Hauptsächlich wird die Varietät "Arava", eine andromonözische (männliche und Zwitterblüten auf einer Pflanze), selbstkompatible Form angebaut, die für den Fruchtansatz auf Bestäubung durch Insekten angewiesen ist. Die Melonen im Arava Valley werden im Winter in speziellen Plastiktunneln angebaut. Diese Tunnel sind 120 m lang, 2,2 m hoch und 2,8 m breit. Sie werden aus Metallbögen gebaut, die mit 0,12 mm dickem Polyethylen überzogen sind. Die Tunnel erstrecken sich in der Nord-Südrichtung, damit diese Konstruktion den im Arava Valley häufigen südlichen Windstürmen standhält. Aus diesen technischen Gründen können die Bienenstöcke nur im Norden oder im Süden der Tunnelöffnungen aufgestellt werden. Die Meinung unter den Imkern ist widersprüchlich, welche der beiden Seiten erfolgreicher ist. Ziel dieser Arbeit war es, den Stellplatz zu bestimmen, an dem die Sammelaktivität und der Fruchtansatz am höchsten ist. Der Versuch wurde in Ein-Yahav an zwei verschiedenen Orten durch-

geführt: Platz A hatte 12, Platz B 6 Tunnel. Beide Plätze waren in je zwei feste Blöcke unterteilt: In einem Block wurden die Bienenstöcke am südlichen, im anderen am nördlichen Ende der Tunnel aufgestellt. Die Völker waren gleich groß und bestanden aus 8 Waben, davon waren jeweils 4 Brutwaben. Während des Experiments waren alle Tunnel dem Bienenbeflug ausgesetzt. Die Bienen wurden während ihrer Aktivitätsphase stündlich gezählt. Nur die Bienen, die auf den Blüten landeten, wurden als Besucher gewertet. Die Fruchtzahl wurde in 2 Tunneln auf einem 2,7 m Abschnitt der mittleren von 3 Reihen ermittelt. Daten über die Windrichtung wurden von einer israelischen meteorologischen Station in 4 km Entfernung vom Feld ermittelt. Die Winde kamen bis 11.00 Uhr morgens meist aus südlicher Richtung, später wechselte die Richtung und sie kamen mehr aus dem Norden. In Tunneln am Platz A war eine größere Aktivität im nördlichen und mittleren als im südlichen Abschnitt zu beobachten (Abb 1), wenn die Bienenstöcke an der Nordöffnung standen. Allerdings war diese Differenz im südlichen Drittel nicht signifikant. Abbildung 2 zeigt den gleichen aber deutlicheren Trend am Stellplatz B. Abbildung 3 gibt die stündliche Bienenaktivität während des Tages an und zeigt, daß die Aufstellung im Norden eine höhere Aktivität am Morgen aufweist. Abbildungen 4 und 5 zeigen, daß die höhere Sammelaktivität bei Aufstellung der Völker an der Nordöffnung der Tunnel einen höheren Fruchtansatz zur Folge hat. Die Ergebnisse zeigen, daß mindestens 3 Faktoren die Sammelaktivität und den Fruchtansatz bestimmen: i) Entfernung zwischen Volk und Pflanzen: je geringer der Abstand zwischen Völkern und Pflanzen ist, desto höher ist der Bienenbeflug und der Fruchtansatz. ii) Windrichtung: die Bienen fliegen bevorzugt gegen den Wind, deshalb ist die Bestäubung besser, wenn die Bienenvölker an der dem Wind abgekehrten Seite aufgestellt werden. iii) Tageszeit: die Bestäubung der Melonen ist am Vormittag effektiver als um die Mittagszeit.

***Apis mellifera* / *Cucumis melo* / Gewächshaus / Bestäubung / Windrichtung**

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