THE POLLINATION ECOLOGY OF COMMERCIAL SUNFLOWER (*Helianthus annuus* L.) IN SOUTH AFRICA WITH SPECIAL REFERENCE TO THE HONEYBEE (*Apis mellifera* L.)

by

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CONTENTS

1. INTRODUCTION

Certain criteria in pollination are necessary for a plant - insect relationship to evolve (Faegri and Van der Pijl, 1979; Kevan, 1983). The bodies of anthophilous insects should be covered with setae, upon which pollen can readily cling. An ability to recognize and imprint plant forms, as well as a communication system is favourable. The pollinator should not be too specialized as specialization towards utilizing a single food source can lead to decreased flexibility in the absence of the particular food source. Insect pollinated plants should have nectar of good quality and quantity available as reward. The nectar of the more advanced bee plants have their nectar hidden in protective narrow tubes, as in the Asteraceae. A nectar reward for pollination has led to various specialized plant - insect relationships as in orchids, pollinated by euglossine bees.

According to Kevan (1983) the Coleoptera as a group are the most primitive holometabolous pollinators. Diptera are also regarded as primitive anthophilous insects. Adult Lepidoptera, which utilize nectar as energy source, play some role in pollination. The Hymenoptera are important pollinators, with the members of the Superfamily Apoidea as the most important. It is estimated that the Apoidea are responsible for 80% of all pollination by insects. Heteroptera are the most common hemimetabolous anthophilous insects but their importance as pollinators is uncertain.

Characteristics of commercial sunflower:

The common sunflower (Helianthus annuus L.) belongs to the Asteraceae, which is the largest plant family. Plants in this family have many small flowers aggregated in the form of a head or capitulum. On the outer side of the capitulum a single row of bright yellow sterile flowers, the ray florets are borne. The rest of the capitulum consists of to 2000 disc florets. Each disc floret has the potential to develop a seed or achene.

The conspicuous sunflower capitulum is a perfect example of botanical adaptation to insect pollination (Kevan, 1983; Faegri and Van der Pijl, 1979). The bright yellow ray florets serve as a visual attraction, while the clustered disc florets provide a highly clumped energy reward. Crowding of the florets ensures that a maximum number of florets are pollinated by a single insect visit.

The sunflower (Helianthus annuus) originates from the southwestern USA and was initially cultivated as an important oil-rich crop in Russia early in the nineteenth century (Heiser, 1955; Hurd et al., 1980; McGregor, 1976). Sunflower breeding intensified in America during the 1940's, mostly for earlier maturity, higher oil content of the seeds and disease resistance. These earlier, open pollinated cultivars were still very variable in development. Different breeding concepts were subsequently applied and these initiated the modern programme of hybrid sunflower seed production. The most revolutionary concept developed since 1970, is the cytoplasmic male-sterile system used in hybridization. A difference is now made between sunflower plantings for commercial purposes and those for hybrid seed production. Sunflower hybrid seed production is totally dependent upon insects to carry pollen from the male-fertile plants to the male-sterile plants (Radford and Rhodes, 1978).

Although the level of self-pollination of modern commercial hybrid sunflowers is better, the level of self-fertility is questioned. According to Lewis (1979) plants have a natural resistance to self-fertilization (autogamy). Self-pollination and self-fertility is controlled in the sunflower by a time difference in the availability of pollen and receptiveness of the stigma of the same floret. Cross-pollination is thus favoured. Pollination and sib-fertilization, i.e. pollen received from another floret on the same head, is possible though. Researchers therefore agree that, in order to achieve a high level of seedset of 70% or more, pollinators are still needed (Birch et al., 1985; Freud and Furgala, 1982; Furgala et al., 1978; Krause and Wilson, 1981).

Pollination of sunflower:

Wind is of little or no importance in the pollination of sunflower as the pollen is heavy and sticky (Robinson, 1978). Insects are the primary pollinators of sunflower as indicated by the following researchers: Cockerell (1914), Free and Simpson (1964), Hurd et al., (1980) and Parker (1981) in the United States, Radaeva (1954) in Russia, Benedek et al. (1972) in eastern Europe, Goyal and Atwal (1973) in India, Diez (1979) in Argentina and Kleinschmidt and Harden (1983) and Radford et al. (1979b) in Australia. Pollinators listed by these authors included not only beneficial insects as honeybees, solitary bees and butterflies, but also agricultural pests such as American bollworm larvae and moths and spotted maize beetles. A wide range of other unimportant insects, including flies and wasps, visit the sunflower capitulum.

The role of honeybees (Apis mellifera L.) as crop pollinators is well established. Researchers quoted above, agree that the honeybee must be considered the major pollinator of cultivated sunflower. Two reasons are given for this fact. Firstly, honeybees are relatively domesticated as they are kept in manageable hives which can be brought into a monoculture otherwise too extensive for pollination. Secondly, the areas planted with sunflower are usually intensively cultivated regions where agricultural activities have led to a reduction in the local honeybee and solitary bee populations.

The leafcutter-bee (Eumegachile pugnata Say) has only recently been discovered as the primary pollinator of wild sunflower in its natural habitat (Parker and Frohlich, 1983). In South Africa the indigenous honeybee (A. mellifera scutellata Lepeletier) should be regarded as the most important pollinator of commercial sunflower (Birch et al., 1985). Reasons for the limitations of indigenous solitary bees as pollinators will be discussed in the course of this thesis.

Economic aspects of sunflower production in South Africa:
Poor seedset is one of the the major factors affecting the sunflower crop in South Africa. Seedset and yield is determined by the separate but vital processes of initiation of flowering, pollination, fertilization and seed development (Birch, 1981). Birch (1981) and Herring (1981) discuss the factors which influence these processes in South Africa. These include climate, cultivar characteristics, insect pollinators and plant nutrition. Birch (1982) revealed that South Africa was the only large sunflower producing country with a lack of relevant research on bees as pollinators. Preliminary research to investigate the influence of honeybees on crop yields was consequently undertaken (Birch et al., 1985), but a survey of pollinating

insects and a study of their behaviour is still lacking.

Commercial sunflower cultivation in South Africa before World War II was entirely for seed production as poultry feed. After the war a worldwide shortage of vegetable oils led to the development of sunflower cultivars with a high oil content. As elsewhere, the production of sunflower seed as a source of vegetable oil resulted in a decline of the production in sunflower seed as food. In 1974 South Africa followed the world trend of using hybrid cultivars which originated in the early 1970's in the United States (Birch and Engelbrecht, 1978). Today more than 40 hybrid cultivars are available on the South African market, developed to suite a wide range of climatic regions.

In spite of the wide assortment of cultivars available, commercial sunflower planting throughout South Africa is not extensive. Most sunflowers are only planted when weather conditions do not favour the cultivation of other fixed-price crops. In South Africa, sunflower is a short-season crop and can therefore be planted late in the growing season. Before 1983 the country was self-sufficient in its local demand for sunflower seed. However, since 1983 demand could not be satisfied, mainly because of drought. Van Zyl (1985) predicted a total dependance on imports, from as early as 1989. His prediction is based on the previous record harvest of 517 000 tons in 1982. The local demand in sunflower seed showed a steady increase from 240 000 tons in 1977 to 430 000 tons in 1986, with an estimated 720 000 tons in 1996. This shortage therefore requires an increase in production per unit area as well as the total area planted.

The aim of this thesis is to investigate the insect - pollinator complex of commercial sunflower in South Africa with special reference to the indigenous honeybee, A. mellifera scutellata Lepeletier. Factors which influence or limit the pollination of sunflower by insects are explored and in conclusion recommendations for better pollinator management will be made.

2. STUDY AREA

The Springbok Flats region extend to about 100 km north of Pretoria. Its favourable climate and black Arcadia soil ('turf') make it one of the major crop producing areas in the Transvaal. In spring large tracts of land are planted to cotton, sorghum, sunflower and maize, as main crops. In autumn, winter wheat is planted. These crops are cultivated mainly under dry-land conditions with a small percentage under flood- or sprinkler-irrigation.

The general weather the Springbok Flats experienced from the 1970/71 to 1984/85 sunflower season is presented in figures 1 to 3. Data are summarized from the S.A. Weather Bureau Report on Meteorological Data (1970 - 1977) and Monthly Weather Report (1978 - 1985) as recorded at Towoomba Research Station (24"54'S, 28"20'E; Altitude 1143m).

In general the Springbok Flats experiences hot summers, as it is protected by the Highveld from cold winds. Mild, dry winters is experienced, though temperature could be minus 7°C on winter mornings. The annual rainfall is 622mm. Heavy down pours occur, usually accompanied by thunder storms. In the late spring hail can be severe. The region is almost frost-free, with frost only on irrigation lands.

Studies on commercial sunflower pollination ecology were conducted on farms surrounding Settlers (27"57'S, 28"32'E), in the Springbok Flats, 20 km east of Towoomba Research Station. A study site was chosen in the Springbok Flats, one of the largest commercial sunflower producing areas in the Transvaal. Furthermore, the severe losses due to hollow seededness during 1979 - 1981, which led to low yields, in spite of exceptionally good weather, favoured the Springbok Flats as the study area.

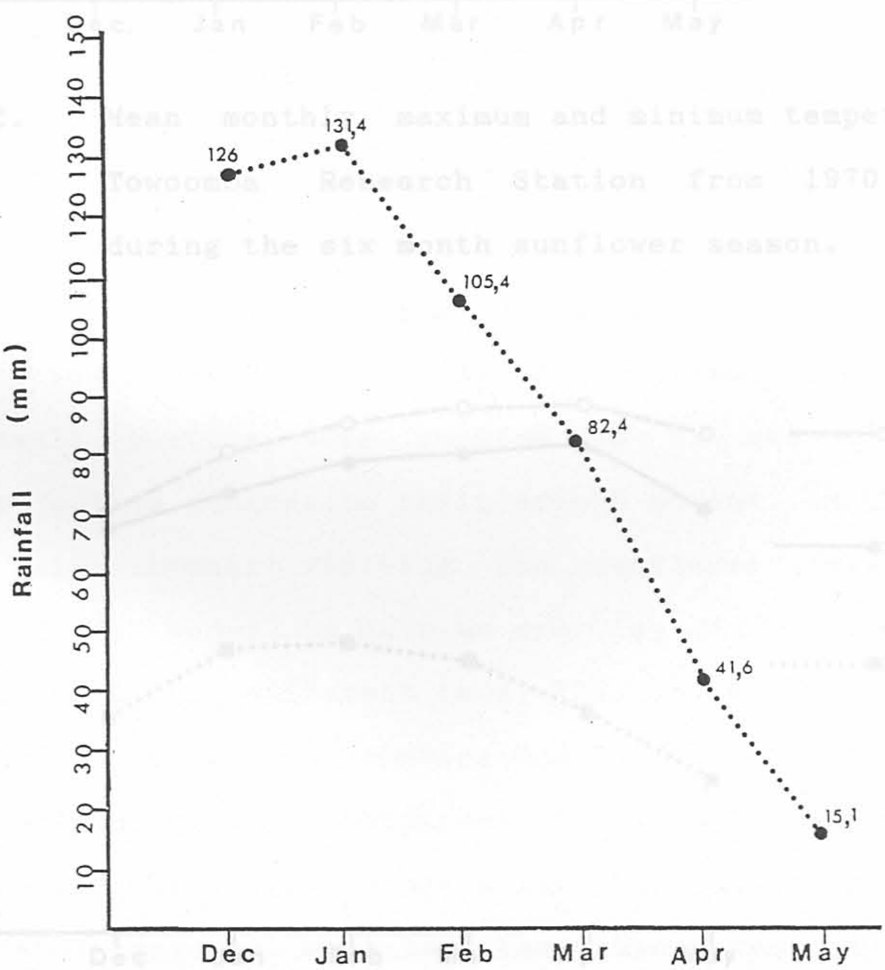

Fig. 1. Mean monthly rainfall at Towoomba Research Station during 1970 to 1985 for the six month sunflower season.

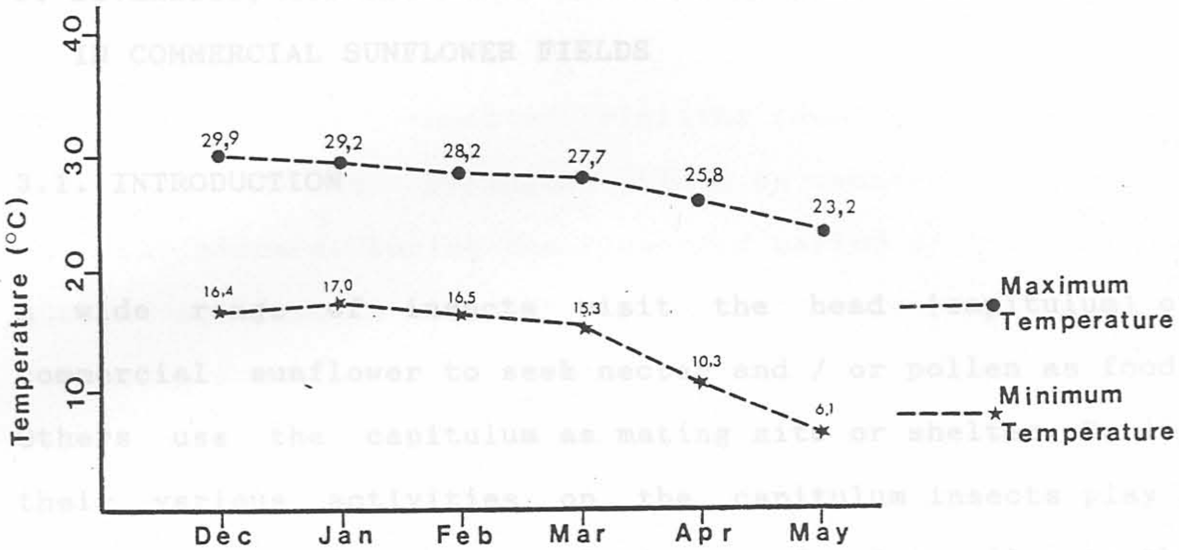

Fig. 2. Mean monthly maximum and minimum temperatures at Towoomba Research Station from 1970 to 1985 during the six month sunflower season.

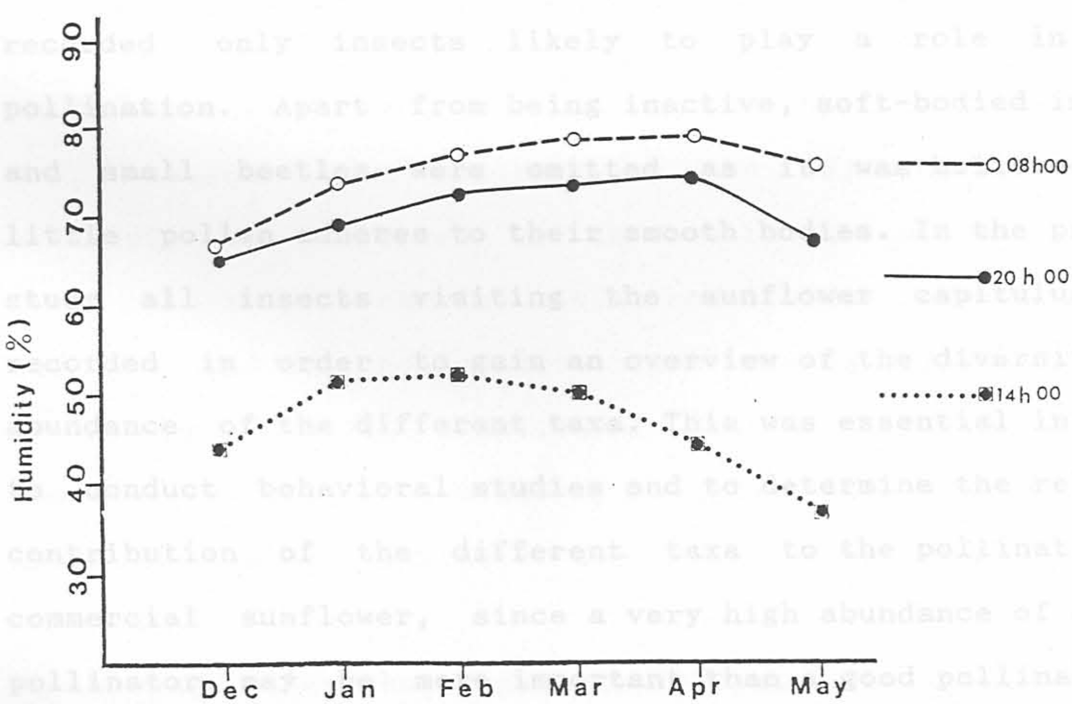

Fig. 3. Mean monthly relative humidity at Towoomba Research Station from 1970 to 1985 during the six month sunflower season.

3. DIVERSITY, ABUNDANCE AND ACTIVITY OF INSECT POLLINATORS IN COMMERCIAL SUNFLOWER FIELDS

3.1. INTRODUCTION

A wide range of insects visit the head (capitulum) of commercial sunflower to seek nectar and / or pollen as food. Others use the capitulum as mating site or shelter. During their various activities on the capitulum insects play a more or less important role in transferring pollen to the stigmas.

In their study on insect pollinators, Radford <u>et al</u>. (1979a) recorded only insects likely to play a role in crop pollination. Apart from being inactive, soft-bodied insects and small beetles were omitted as it was believed that little pollen adheres to their smooth bodies. In the present study all insects visiting the sunflower capitulum were recorded in order to gain an overview of the diversity and abundance of the different taxa. This was essential in order to conduct behavioral studies and to determine the relative contribution of the different taxa to the pollination of commercial sunflower, since a very high abundance of a poor pollinator may be more important than a good pollinator in low numbers.

3.2. MATERIAL AND METHODS

The survey of insects visiting sunflower heads was undertaken on the Springbok Flats on commercial fields of ca. 200 hectare. During the flowering period of the cultivar SO323, all insects visiting the head were recorded for three consecutive seasons. One or two specimens of unknown species were collected for identification, and this removal sampling can certainly be negated in the results. Honeybee colonies were introduced to the sunflower fields by migratory beekeepers at a density of 1 colony per hectare.

Counts of the abundance and diversity of insects per 100 heads receptive for pollination, were made. Rows of sunflowers were selected at random. While walking down a row, insects were recorded on the adjacent row. This procedure was followed so as not to disturb the insects. These counts were carried out at hourly intervals throughout the day and on consecutive days during bloom. General environmental and behavioural data were recorded for all insects visiting the head, by recording observations onto a table using single character abbreviations (table 1).

To compare the insect pollinator fauna with other regions, limited surveys were undertaken in the Western Transvaal (Hartbeesfontein, Klerksdorp district) and on the University of Pretoria Experimental Farm (Pretoria). In the Western

Transvaal with its more arid climate, honey production on sunflower is not as profitable. Commercial beekeepers do not migrate their hives to this area. On the other hand, farming practices are characterized by more restricted use of insecticides and large tracts of uncultivated lands. Consequently more potential natural nesting sites are available for both solitary bees and honeybees.

At the University of Pretoria Experimental Farm, an apiary with 40-50 hives is kept within 400 meters of thirty experimental plots (100 m^2 or 0.01 ha) of commercial sunflower. These plots were surrounded by similar ones of various crop plants and weeds. During the sunflower bloom a dearth of nectar is experienced in Pretoria resulting in an over-abundance of honeybees on the sunflowers, foraging for both nectar and pollen.

The same method for observations of diurnal insect activity was repeated for nocturnal insects. An electric torch was used as source of light. It was found that this weak light neither attracted nor disturbed the insects on the heads. This was also the experience of Radford _et al_. (1979a) working in Australia.

Definitions related to Data sheet for strip counts.

Surrounding forage: This includes commercial crops and weeds which flower at the same time as the target crop to be pollinated, and attracts pollinators. These crops and weeds are regarded as competitors (See Chapter 7, page 95).

Flowering stage of field: Because the disk florets on the sunflower capitulum open in whorls on consecutive days, it is important to indicate the stage of development of capitula in the field. The object of the study was to determine the agents and degree of pollination. Records of flowering stages were therefore determined by the percentage florets on heads that were receptive for pollination (two stigmatic lobes unfolded). The flowering stage was indicated on a 1 - 100% scale, 100% indicating that all florets had opened. A peak in receptive florets is reached at 50% flowering stage. The flowering stage was determined by a visual estimate of the total sunflower field.

Range of honeybees: This denotes the minimum and maximum number of honeybees on heads, within the sample of 100 receptive heads.

Nectar robbers: Denotes honeybees which visit wilting, already pollinated florets with no contact to florets with available pollen. These foragers have learned to visit these florets only and don't contribute to pollination.

TABLE 1. FIELD RECORD DATA SHEET WITH ABBREVIATIONS FOR STRIP COUNTS OF POLLINATORS ON 100 SUNFLOWER HEADS RECEPTIVE FOR POLLINATION.

Date: ____________________

Locality: ____________________

Time: ____________________

Temperature: ____________________

General weather: ____________________

Surrounding forage: ____________________

Flowering stage: ____________________

Natural colonies/Hives: ____________________

Distance from hives: ____________________

Honeybees: ____________________

Range of honeybees: ____________________

Honeybee nectar robbers: ____________________

Anthophoridae: ____________________

Megachilidae: ____________________

Halictidae: ____________________

Wasps and ants: ____________________

Diptera: ____________________

Lepidoptera adults: ____________________

Lepidoptera larvae: ____________________

Spotted maize beetle: ____________________

Other beetles: ____________________

Hemiptera: ____________________

Other insects: ____________________

TABLE 1. (CONTINUED). FIELD RECORD DATA SHEET WITH ABBREVIATIONS FOR STRIP COUNTS OF POLLINATORS ON 100 SUNFLOWER HEADS RECEPTIVE FOR POLLINATION.

General weather	
r - raining	a - directly after rain
s - sunshine	o - cloudy
Surrounding forage	
b - urban area	e - competitor nectar source
l - agricultural activity	f - competitor pollen source
z - natural pasture	
Records of all flower visitors	
n - nectar collector	d - dusted with pollen
p - pollen collector	v - accidental visitor
t - pollen and nectar	w - nectar robber
Other abbreviations	
c - natural colonies	
h - hives	
Unknown species indicated as follows: 5	

Statistics

The standard error of the mean (S.E.) (Van Ark, 1981) was calculated as:

$$S.E. = \frac{S.D.}{\sqrt{n}}$$

S.D. = standard deviation

n = number of observations

3.3 RESULTS

3.3.1. Diversity and abundance of diurnal insects

The results of the survey of insects on commercial sunflower heads near Settlers, Pretoria and Hartbeesfontein for three consecutive years are presented in table 2. The mean numbers of the various insect taxa per hundred heads for the three sites are summarized in table 3, while the parameters which may have influenced the differences between sites are tabulated in table 4.

From the results it is clear that the sunflower capitulum provided food for a wide range of insects (table 2. See also Appendix A, p 136). A mean number of 45 individual insects was counted on 100 sunflower heads at Settlers, while the mean at Pretoria and Hartbeesfontein, was 147 and 64 respectively (table 3). This low presence of insects at Settlers can be attributed to the intensive crop production and chemical crop protection activities in that region (table 4). Honeybees were the most abundant anthophilous insects in all three regions. At Settlers (70,71%) and Pretoria (86,69%) these high representations were the result of introduced, managed hives and that at Hartbeesfontein (46,5%) represented the natural honeybee population.

TABLE 2-1. DIVERSITY AND ABUNDANCE OF DIURNAL ANTHOPHILOUS INSECTS IN COMMERCIAL SUNFLOWER FIELDS AT SETTLERS, 1985 -1987.

Taxon		Total insects 153x100 heads	x̄ / 100 heads (SE)	Range / 100 heads	% of total
Hymenoptera					
Apis mellifera		4836	31,61 (±1,36)	0-71	70,71%
Honeybee nectar robber		116	0,76 (±0,07)	0-4	1,70%
Anthophoridae	(3 spp.)	21	0,14 (±0,04)	0-3	0,30%
Megachilidae		0	-	-	-
Halictidae	(5 spp.)	19	0,12 (±0,04)	0-4	0,28%
Wasps and ants	(5 spp.)	20	0,13 (±0,07)	0-10	0,29%
Diptera	(10 sp)	41	0,26 (±0,05)	0-3	0,60%
Lepidoptera					
Adults	(7 spp.)	10	0,06 (±0,02)	0-2	0,14%
Larvae					
Heliothis armigera		703	4,59 (±0,51)	0-34	10,28%
Trichoplusia orichalcea		35	0,23 (±0,10)	0-12	0,52%
Coleoptera					
Astylus atromaculatus		479	3,12 (±1,07)	0-88	7,00%
Other Coleoptera	(7 spp.)	23	0,15 (±0,05)	0-5	0,34%
Hemiptera	(7 spp.)	530	3,47 (±0,30)	0-23	7.75%
Neuroptera	(1 sp.)	4	0,03 (±0,02)	0-2	0,06%
Mantodea		0	-	-	-
Orthoptera	(2 spp.)	2	0,01 (±0,01)	0-1	0,03%
Total	(50 species)	6839	x̄: 45		100%

TABLE 2-2. DIVERSITY AND ABUNDANCE OF DIURNAL ANTHOPHILOUS INSECTS IN EXPERIMENTAL SUNFLOWER PLOTS AT PRETORIA, 1985-1987.

Taxon		Total insects 67x100 heads	$\bar{x}$ / 100 heads (SE)	Range / 100 heads	% of total
Hymenoptera					
Apis mellifera		8425	127,65 (±4,43)	23-228	86,69%
Honeybee nectar robber		372	5,63 (±1,12)	0-30	3,82%
Anthophoridae	(3 spp.)	4	0,06 (±0,03)	0-1	0,04%
Megachilidae	(2 spp.)	8	0,12 (±0,05)	0-2	0,08%
Halictidae	(4 spp.)	88	1,31 (±0,26)	0-11	0,91%
Wasps and ants	(7 spp.)	32	0,50 (±0,10)	0-4	0,32%
Diptera	(9 spp.)	148	2,24 (±0,24)	0-7	1,52%
Lepidoptera					
Adults	(3 spp.)	22	0,33 (±0,07)	0-2	0,24%
Larvae					
Heliothis armigera		20	0,30 (±0,09)	0-4	0,21%
Trichoplusia orichalcea		0	-	-	-
Coleoptera					
Astylus atromaculatus		548	8,30 (±2,85)	0-120	5,64%
Other Coleoptera	(4 spp.)	12	0,18 (±0,07)	0-4	0,12%
Hemiptera	(5 spp.)	38	0,58 (±0,11)	0-4	0,39%
Neuroptera		0	-	-	-
Mantodea	(1 sp.)	1	0,02 (±0,02)	0-1	0,01%
Orthoptera	(1 sp.)	1	0,02 (±0,02)	0-1	0,01%
Total	(42 species)	9719	$\bar{x}$: 147		100%

TABLE 2-3. DIVERSITY AND ABUNDANCE OF DIURNAL ANTHOPHILOUS INSECTS IN COMMERCIAL SUNFLOWER FIELDS AT HARTBEESFONTEIN, 1985-1987.

Taxon		Total insects 39x100 heads	$\bar{x}$ / 100 heads (SE)	Range / 100 heads	% of total
Hymenoptera					
<u>Apis mellifera</u>		1263	26,60 (±2,42)	10-70	46,50%
Honeybee nectar robber		19	0,49 (±0,12)	0-2	0,70%
Anthophoridae	(3 spp.)	8	0,21 (±0,08)	0-2	0,30%
Megachilidae		0	-	-	-
Halictidae	(2 spp.)	19	0,49 (±0,11)	0-2	0,70%
Wasps and ants	(3 spp.)	10	0,26 (±0,15)	0-5	0,37%
Diptera	(7 spp.)	27	0,69 (±0,12)	0-3	1,00%
Lepidoptera					
Adults	(2 spp.)	2	0,05 (±0,04)	0-1	0,07%
Larvae					
<u>Heliothis armigera</u>		622	15,95 (±1,51)	0-38	22,90%
<u>Trichoplusia orichalcea</u>		0	-	-	-
Coleoptera					
<u>Astylus atromaculatus</u>		406	10,41 (±2,91)	0-75	14,95%
Other Coleoptera	(2 spp.)	3	0,08 (±0,04)	0-1	0,11%
Hemiptera	(6 spp.)	337	8,64 (±1,39)	0-33	12,40%
Neuroptera		0	-	-	-
Mantodea		0	-	-	-
Orthoptera		0	-	-	-
Total	(28 species)	2716	$\bar{x}$: 64		100%

TABLE 3. SUMMARY OF THE MEAN NUMBERS OF ALL INSECT TAXA PER HUNDRED SUNFLOWER HEADS AT SETTLERS, PRETORIA AND HARTBEESFONTEIN, 1985-1987.

Taxon	Settlers	Pretoria	Hartbeesfontein
Hymenoptera			
Apis mellifera	31,61	127,65	26,60
Honeybee nectar robber	0,76	5,63	0,49
Anthophoridae	0,14	0,06	0,21
Megachilidae	-	0,12	-
Halictidae	0,12	1,31	0,49
Wasps and ants	0,13	0,50	0,26
Diptera	0,26	2,24	0,69
Lepidoptera			
Adults	0,06	0,33	0,05
Larvae			
Heliothis armigera	4,59	0,30	15,95
Trichoplusia orichalcea	0,23	-	-
Coleoptera			
Astylus atromaculatus	3,12	8,30	10,41
Other Coleoptera	0,15	0,18	0,08
Hemiptera	3,47	0,58	8,64
Neuroptera	0,03	-	-
Mantodea	-	0,02	-
Orthoptera	0,01	0,02	-
Total	45	147	64

TABLE 4. POSSIBLE PARAMETERS AFFECTING THE DIVERSITY AND ABUNDANCE OF INSECT POLLINATORS IN COMMERCIAL SUNFLOWER FIELDS

Parameter	Locality		
	Settlers	Pretoria	Hartbeesfontein
Main bloom period	Mar - Apr	Jan	Jan - Feb
Average rainfall	moderate	moderate	low
Feral colonies	very few	very few	abundant?
Managed beehives	present	present	absent
Food competition	moderate	moderate	moderate
Pesticides	high	absent	absent
Bird predation	absent	absent?	present?
Arthropod predation	low	low	moderate
Average field size	>200 ha	1-2 ha	50-100 ha

The overall diversity of insect species differed in the three regions not only because of climatic differences, but also because of agricultural practices, such as pesticides applications and extensive cultivation. The number of solitary bees in an area can be regarded as a good parameter for the intensiveness of agricultural practices in that region, as these bees are very susceptible to disturbances in the environment and pesticides. At Pretoria, where the ecologically diverse peri-urban surroundings provide a more lasting environment, a mean of 1,49 solitary bees per hundred heads was recorded. At Hartbeesfontein a mean of 0,7 / 100 heads was found and at Settlers 0,26 / 100 heads (table 3). The most abundant taxa, excluding the Hymenoptera, were Diptera, bollworm larvae (Heliothis armigera Hübner) and spotted maize beetle (Astylus atromaculatus Blanchard) (table 3). In the three regions studied, these taxa also showed differences in numbers.

The presence of honeybee nectar robbers was negligible in Settlers (mean 0,76 / 100 heads and 1,7% of total insects) and Hartbeesfontein (mean 0,49 / 100 heads and 0,7% of total insects). On the other hand, honeybee nectar robbers were the third most abundant group at Pretoria (mean 5,63 / 100 heads, and 3,82% of total insects). This could be the result of honeybees being abundantly present in an area with little forage.

3.3.2. Activity and behaviour of diurnal insects

Activity and behaviour of all insects excluding honeybees is presented in this section, as honeybees are discussed in detail in Chapter 4, page 34.

The long-tongued solitary bees (Anthophoridae and Megachilidae) visited sunflowers for both nectar and pollen. On windless days with temperatures above 15°C these bees were active on the sunflower heads throughout the day. In their search for nectar and pollen, they moved very rapidly over florets of the same head, making contact with a number of stigmas. The movement of these bees between capitula was also very rapid. Generally they did not forage systematically from head to adjacent head but rather skipped five to ten heads or even rows.

The short-tongued Halictidae visited the sunflower only for pollen, as their probosces could not reach the nectar in the tubular sunflower florets. These small bees have to walk over stigmas to reach the next floret. Halictids tend to forage from head to head within the same row.

The most abundant Diptera family on sunflower were the hover flies (Syrphidae). Most of the observed Diptera often sat very still on the capitulum for long periods, and it was difficult to determine whether they were seeking food, perching or simply resting. In the early morning they mainly seemed interested in collecting dew on the florets. Their movements between heads were indiscriminate and no pattern was observed.

While feeding, adult Lepidoptera perched with only their legs in direct contact with the florets. They were not consistent in visiting flowers and most often flew 10 - 50 meters before settling again. Lepidopterous larvae can be

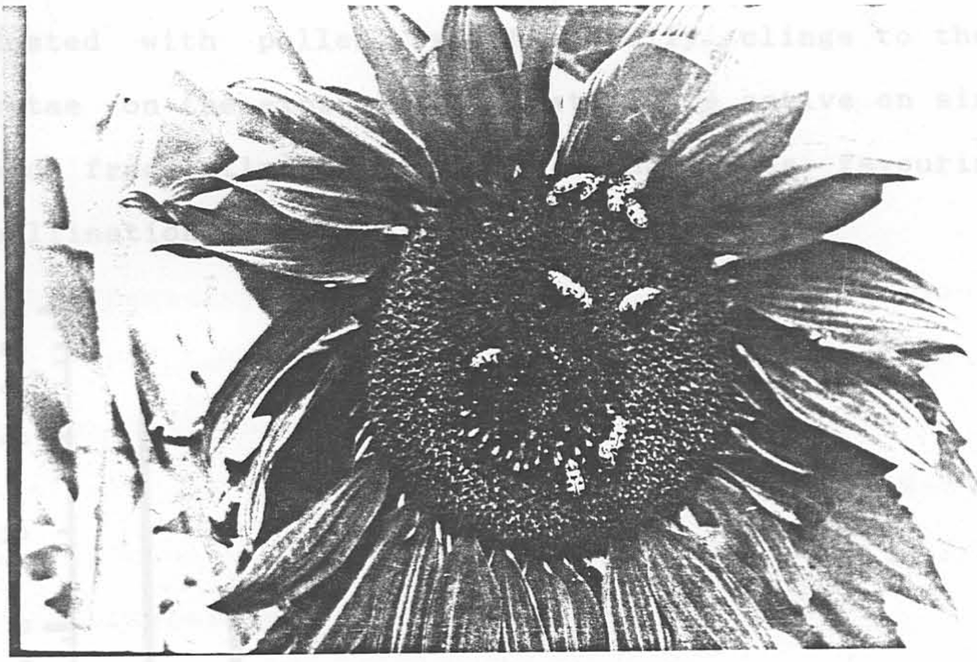

Fig. 4. Spotted maize beetle on a sunflower head at Pretoria, 1986.

regarded as practically passive pollinators, as their movement on the head is extremely slow. No movement between heads was observed.

At the three study sites the numbers of spotted maize beetles was directly influenced by the time of the year. Beetles were present in low numbers and as scattered individuals from January to February. From February to April they formed breeding aggregations with as many as 30 - 40 beetles on a single head (fig. 4). The distribution of spotted maize beetles in a field is given in fig. 5. As adults are pollen feeders they are almost always very well dusted with pollen, which readily clings to the numerous setae on the exosceleton. Beetles are active on single heads and frequently fly between heads thus favouring cross-pollination.

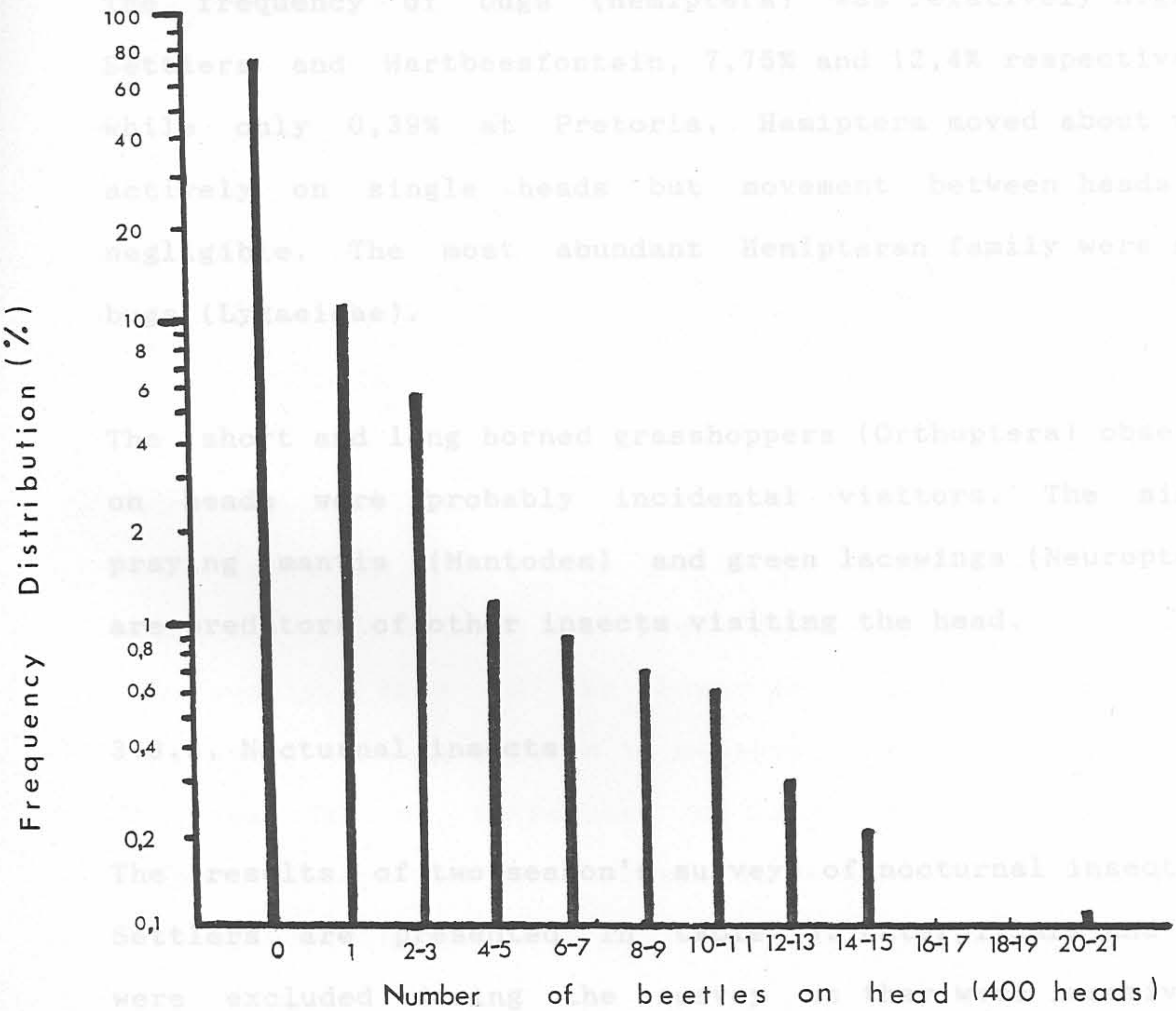

Fig. 5. The distribution of spotted maize beetles in a sunflower field early in the season at Hartbeesfontein, 1987.

The fruit chafers (Cetoniinae) and oil beetles (Meloidae) encountered on heads, behaved very similarly to spotted maize beetles. The flea beetles (Alticinae, Chrysomelidae) and seed weevils (Bruchidae) found on capitula were very small and made little or no contact with stigmas.

The frequency of bugs (Hemiptera) was relatively high at Settlers and Hartbeesfontein, 7,75% and 12,4% respectively, while only 0,39% at Pretoria. Hemiptera moved about very actively on single heads but movement between heads was negligible. The most abundant Hemipteran family were seed bugs (Lygaeidae).

The short and long horned grasshoppers (Orthoptera) observed on heads were probably incidental visitors. The single praying mantis (Mantodea) and green lacewings (Neuroptera) are predators of other insects visiting the head.

3.3.3. Nocturnal insects

The results of two season's surveys of nocturnal insects at Settlers are presented in table 5. Caterpillars and bugs were excluded during the survey as they were inactive at night.

Fourteen species of insects were recorded, of which eleven species were moths (Lepidoptera). <u>Heliothis</u> <u>armigera</u> was the most abundant species (76,63%), with a mean of 6,3 moths / 100 receptive heads. The abundance of the other species was very low, less than 5%, with means 0,02 - 0,41 / 100 flowering heads. Honeybees were the second most abundant taxon (5,16%). These honeybees were however neither active between heads nor on the head itself, because they had been caught foraging in the field after the sun had set.

H. armigera moths were most active between dusk and 20h00. The number of moths then declined with no activity after 24h00 (fig. 6).

3.4. DISCUSSION

According to Faegri and Van der Pijl (1979) the honeybee, Apis mellifera, is a more flexible pollinator than solitary bees. It is active all year round and visits flowers continually. This is why honey production and pollination efficiency with honeybees in managed hives is so successful. Colonies can be introduced at any time to a region where crops flower and will respond, weather permitting, by maximum activity.

Honeybee nectar robbers form an easily recognized group although their numbers are small. However, they contribute little to pollination. These honeybees are just as flower constant as other foragers and will only visit flowers that

TABLE 5. NOCTURNAL INSECTS COUNTED ON 100 RECEPTIVE HEADS OF COMMERCIAL SUNFLOWER AT SETTLERS, 1986-1987.

Taxon	Insects on 46x100 heads	$\bar{x}$ / 100 heads (SE)	Range / 100 heads	% of total
LEPIDOPTERA				
Noctuidae				
Heliothis armigera	282	6,13 (±0,80)	0-17	76,63%
Agrotis segetum	15	0,33 (±0,08)	0-2	4,08%
Agrotis spinifer	10	0,22 (±0,07)	0-2	2,72%
Mythimna loreyi	5	0,10 (±0,05)	0-2	1,36%
3 unidentified species	19	0,41 (±0,13)	0-3	5,16%
Sphingidae (2 spp.)	5	0,10 (±0,05)	0-1	1,36%
Arctiidae				
Utetheisa pulchella	1	0,02 (±0,02)	0-1	0,27%
Pyralidae				
Zinkenia fascialis	10	0,22 (±0,07)	0-2	2,72%
HYMENOPTERA				
Apis mellifera	19	0,41 (±0,11)	0-3	5,16%
ORTHOPTERA				
Tettigoniidae (1 sp.)	1	0,02 (±0,02)	0-1	0,27%
PHASMATODEA				
Phasmatidae (1 sp.)	1	0,02 (±0,02)	0-1	0,27%
Total: 14 species	368	$\bar{x}$: 8		100%

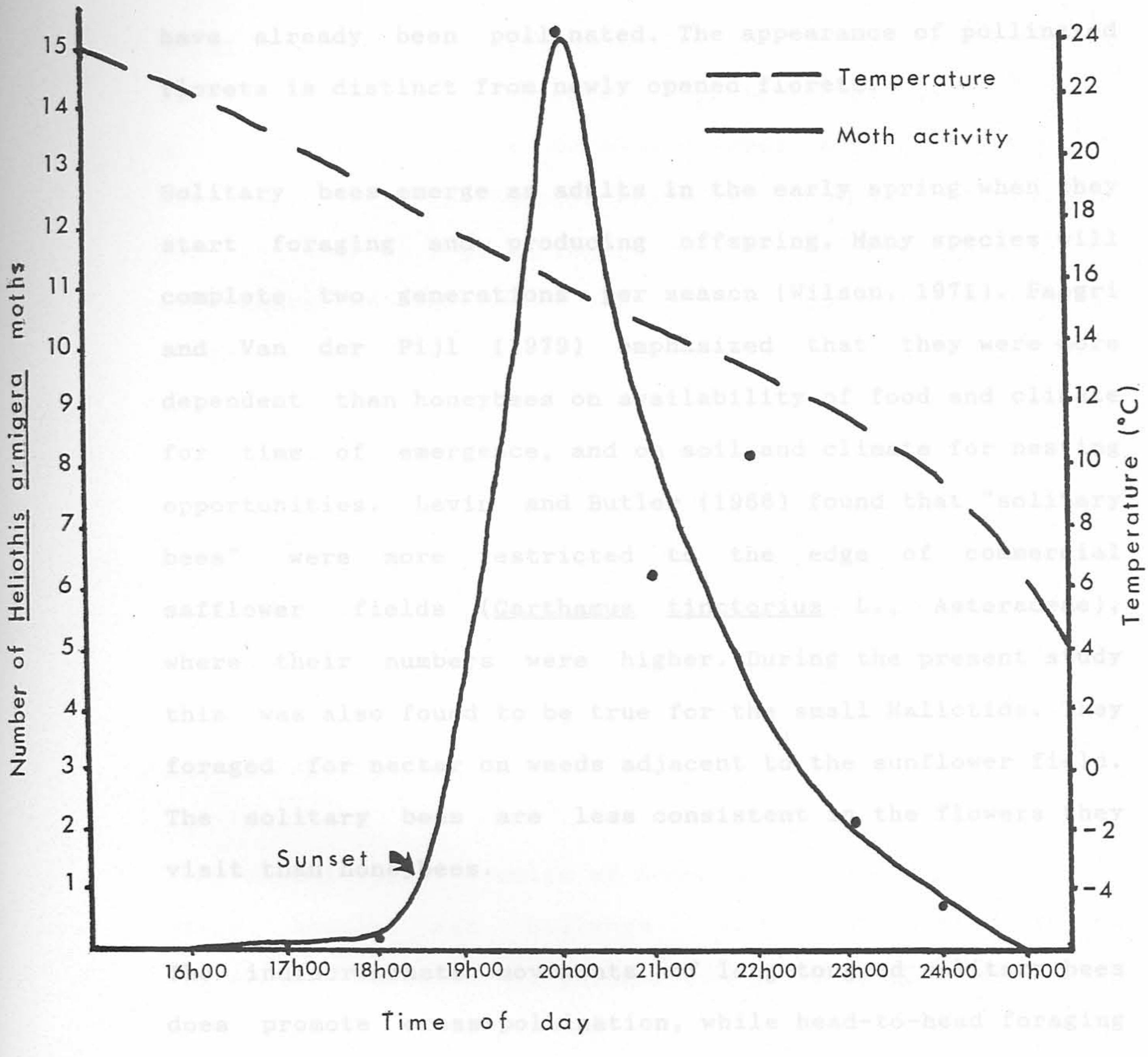

Fig. 6. Activity of <u>Heliothis armigera</u> moths in sunflower fields at Settlers, 1986-1987.

have already been pollinated. The appearance of pollinated florets is distinct from newly opened florets.

Solitary bees emerge as adults in the early spring when they start foraging and producing offspring. Many species will complete two generations per season (Wilson, 1971). Faegri and Van der Pijl (1979) emphasized that they were more dependent than honeybees on availability of food and climate for time of emergence, and on soil and climate for nesting opportunities. Levin and Butler (1966) found that "solitary bees" were more restricted to the edge of commercial safflower fields (Carthamus tinctorius L., Asteraceae), where their numbers were higher. During the present study this was also found to be true for the small Halictids. They foraged for nectar on weeds adjacent to the sunflower field. The solitary bees are less consistent in the flowers they visit than honeybees.

The indiscriminate movements of long-tongued solitary bees does promote cross-pollination, while head-to-head foraging within the same row, as observed in the Halictidae may pose limitations in hybrid seed production of sunflower.

The larvae of both species of Lepidoptera observed are phytophagous and regarded by Annecke and Moran (1984) as agricultural pests. Their abundance on sunflower do not reach levels making chemical control necessary. Though

Heliothis armigera moths can pollinate sunflower, their role as pollinators is regarded as insignificant by Radford _et al_. (1979a). This is because of small populations and low levels of activity. Factors which influence moth populations and activity in a given region are field size, plant density and phase of the moon (Radford _et al_., 1979a). Another factor which could have an indirect influence, is pesticide application to surrounding crops.

Small beetles and other small insects have a negligible influence on seed set (Radford _et al_., 1979a). Morphologically the Hemiptera are not suitable as pollinators. Most species have a hard, smooth exosceleton with little or no setae to which pollen can cling (Faegri and Van der Pijl, 1979).

The actual relative roles of honeybees, house flies, spotted maize beetle and bollworm larvae in pollination of commercial sunflower is further discussed in Chapter 5, page 66.

The total absence of carpenter bees (_Xylocopa_ spp., Anthophoridae) in this study is significant. It was believed that if carpenter bees were significantly as pollinators in sunflower fields, they could possibly be encouraged in and around fields. Herrmann (personal communication, 1985), made only one observation of two _Xylocopa_ _sicheli_ Vachal, in a small sunflower field (less than one hectare) at the Horticultural Research Institute, Roodeplaat. Hurd (1978) reached the conclusion that Xylocopa spp. do not feed on sunflower, though both sunflower and carpenter bees are indigenous in North America. Carpenter bees do use sunflower stalks as nesting sites, however. Goel and Kumar (1981) recorded two species of carpenter bees working on sunflower in India, although in very small numbers.

Working in South Africa in lucerne fields, Watmough (1987) found that carpenter bees were not all that easy to establish as pollinators. Within two years after the initial attempt to concentrate nesting sites around lucerne fields, emigration of these bees took place on such a scale that establishing had to start again. Futhermore their season of activity did not correspond with the main sunflower bloom period which is from February to April (Watmough, personal communication 1987).

The honeybees observed at night on sunflower heads could not play a role in pollination because of their inactivity. According to Radford et al. (1979a) those honeybees were all dying. It is known that African honeybees do forage at night (Fletcher, 1978), but it is not known whether they could successfully spend the night outside the hive. Night temperatures of under 6°C were recorded at Settlers during the sunflower bloom.

4. ACTIVITY AND BEHAVIOUR OF HONEYBEES IN COMMERCIAL SUNFLOWER FIELDS

4.1. INTRODUCTION

The tendency of honeybees to visit flowers of the same specie (flower constancy) make them very efficient pollinators. Large quantities of nectar and pollen are needed for colony survival, which results in very energetic nectar and pollen collection. Branched setae make honeybees morphological well adapted for pollen collection, while their management in hives make them economically imminently suitable as crop pollinators.

While several good accounts of numbers of honeybees in sunflower fields exist (Free, 1964; Krause and Wilson, 1981; Langridge and Goodman, 1974; Parker, 1981; Radford, et al. 1979b), the only accounts of honeybee behaviour on sunflower heads are by Brown and Parker (1984) and Free (1964). Knowledge of honeybee activity and behaviour in fields is essential to maximize their pollination function e.g. better colony management or weed control. It is also needed to calculate the number of honeybees required during pollination. This chapter reports honeybee activity activity as revealed by the conventional strip count method and by observations on returning foragers. The behaviour and movement of bees on and between heads will also be reported, as this is a very important aspect for good cross-pollination.

Temperature and humidity are the most important environmental factors influencing honeybee visits to sunflowers (Birch, 1981; Deshmukh, 1977). Periods of continued low or very high temperatures or rainy weather result in low honeybee activity with a reduction in seed set. Both of these factors also have a direct influence on nectar secretion, thus influencing honeybee foraging indirectly. Other factors include wind, predators, field size, availability of water and competing nectar and pollen sources.

4.2. MATERIAL AND METHODS

Daily and seasonal abundance

The daily and seasonal changes of honeybee numbers on sunflower capitula were recorded by strip counting at hourly intervals as described in Chapter 3, page 12. In the Springbok Flats, 153 strip counts involving 100 receptive heads each were carried out during March 1985-1987. Data of the three seasons were combined to present mean activity graphs.

Foraging activity

Foraging activity of honeybees in managed hives, located adjacent to a commercial sunflower field was determined. Two hives were used 50 meters apart, on the western side of the field and with their entrances facing north-west. The colonies were about equal in size, amount of brood and stores. Sixty production hives were situated a hundred meters away on the northern side of the field. The sixty hectare sunflower field was surrounded on the southern and eastern sides by post-bloom sunflower and on the northern and western sides by natural veld grazed by cattle.

The experimental hives were closed at certain intervals, by inserting a piece of foam plastic into the entrance. Sampling was carried out during the flowering period on days 5 (10% flowering stage; 9 (45%); 12 (65%) and 16 (85%) after flowering commenced. Sixty returning foragers were collected at the entrance by scooping them into a 500 ml glass ethyl acetate killing bottle. Such samples were collected at 07h30 (half an hour after foraging started) and then at two-hourly intervals, viz. 08h30, 10h30, 12h30, 14h30 and 16h30.

To investigate nectar and water foraging, the honey stomachs were pulled out with a tweezer. The content was then identified as either water or nectar with the aid of an Atago 500 hand refractometer. Water loads gave readings of between 0 and 5% dissolved solids, whereas nectar loads had a wide range of sugar concentrations, between 20 and 65%. Honey crop sizes, pollen and propolis loads were estimated using the method of Johannsmeier (in press), fig 7.

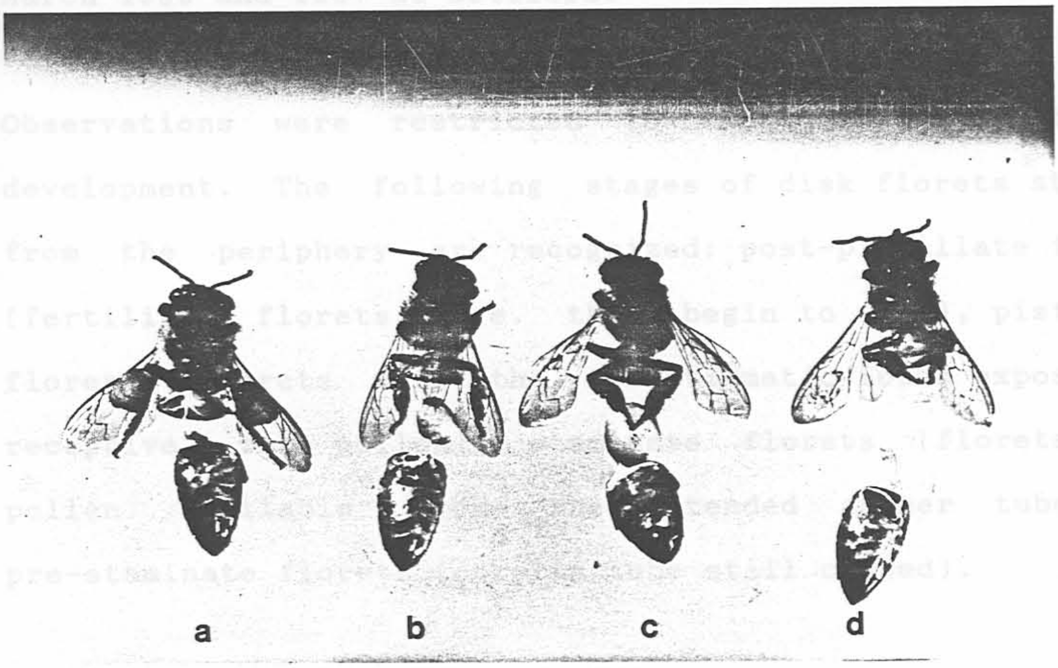

Fig. 7. Honey crop sizes as estimated by Johannsmeier (in press). a. forager with honey crop size 0, but with a size 4 pollen load, b. honey crop size 2, c. honey crop size 3, d. honey crop size 4. 2x life size.

Movement and behaviour of honeybees on the capitulum

The pattern of movement and behaviour of a single honeybee on a head was recorded on a schematic sunflower head drawn on paper (Brown and Parker, 1984). The movements of a hundred honeybees were studied in detail for the entire period from the time they landed on a head until they took for the next head. These observations were carried out on randomly taken heads, at irregular times between 09h00 and 15h00. Observations were made on consecutive days during March 1986 and 1987 at Settlers.

Observations were restricted to heads of the same stage of development. The following stages of disk florets starting from the periphery are recognized: post-pistillate florets (fertilized florets, i.e. they begin to wilt), pistillate florets (florets with the two stigmatic lobes exposed and receptive for pollen), staminate florets (florets with pollen available from the extended anther tube) and pre-staminate florets (corolla tube still closed).

The following events were recorded for honeybee visits: part of capitulum where honeybee lands, time per floret probing for nectar, stage of visited floret, whether collecting pollen, pollen dusted or not, grooming (transferring pollen into pollen basket or discarding pollen), time spend on grooming and whether contact with the stigma is made. The total time of a single honeybee visit was also recorded.

Movement of honeybees between heads
A schematic commercial sunflower field, consisting of three rows with ten plants per row was drawn on paper, to study the movement of a single honeybee between different heads.

This size is convenient for one person to work and will give an indication whether foragers work along a single row of sunflower or change rows frequently. The activity pattern of the honeybee was reproduced on the schematic field, and the following information was recorded: time spend at a single head, collecting nectar or pollen, pattern of movement between heads.

4.3. RESULTS

Daily activity

Daily activity of honeybees in sunflower fields at Settlers is represented in fig. 8. Honeybee activity commenced after sunrise, as soon as flight temperature (10xC) was reached. This occurred as early as 06h30 at Settlers.

The number of foragers in fields showed a rapid increase until 10h00, when a level of 38 foragers / 100 receptive sunflower heads was reached. From 10h00 onwards a slight decrease in foragers was observed, with a mean of 32 foragers / 100 receptive heads between 10h00 and 17h00. At 17h00 foraging activity reached a peak of 40 honeybees / 100 flowering heads. This was followed by a very steep decline in forager numbers, dropping to a level of 4 honeybees / 100 heads at 18h00, with no foraging activity at 19h00. The sun set between 18h00 and 18h30. Honeybees were well dusted with pollen throughout the day. The large deviation of the mean

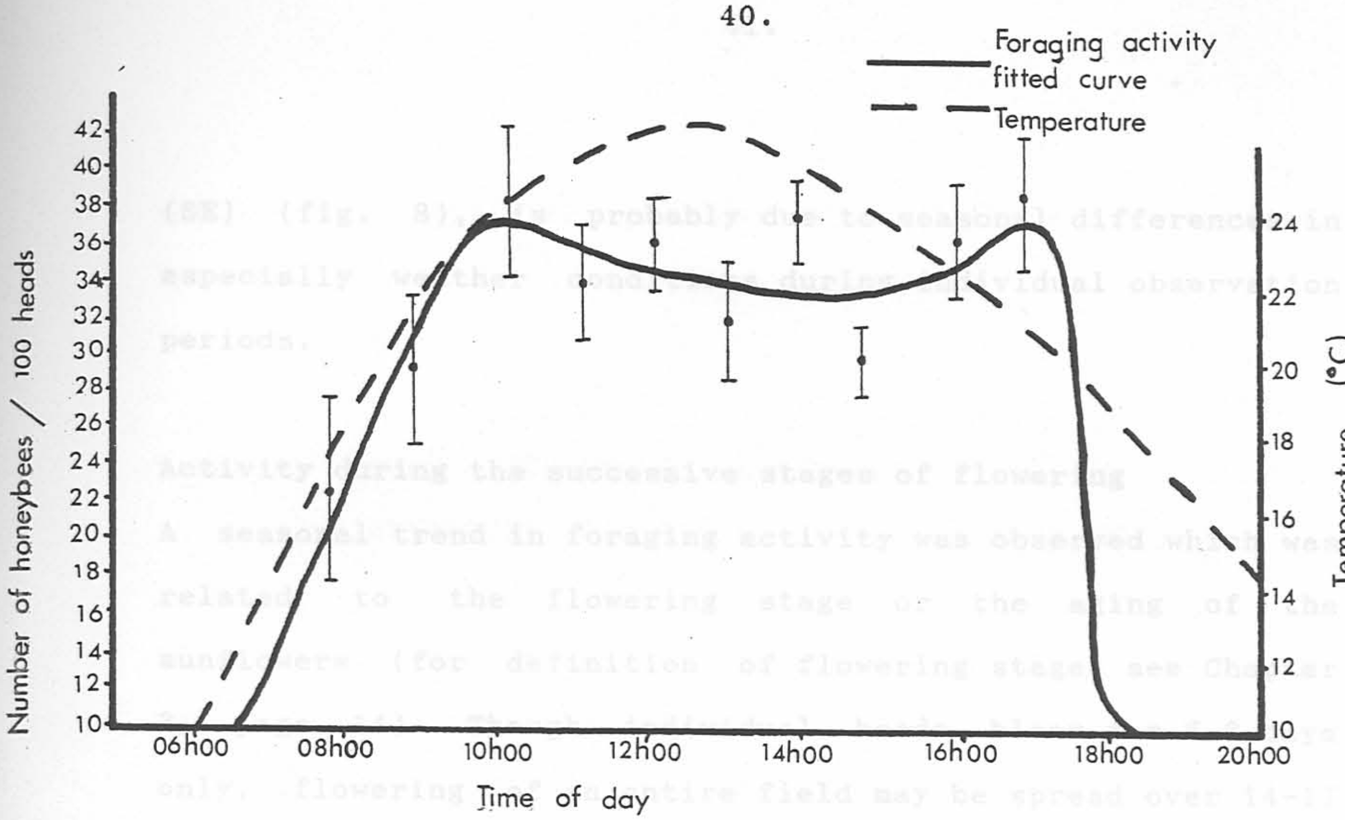

Fig. 8. Mean daily activity of foraging honeybees in commercial sunflower fields at Settlers.

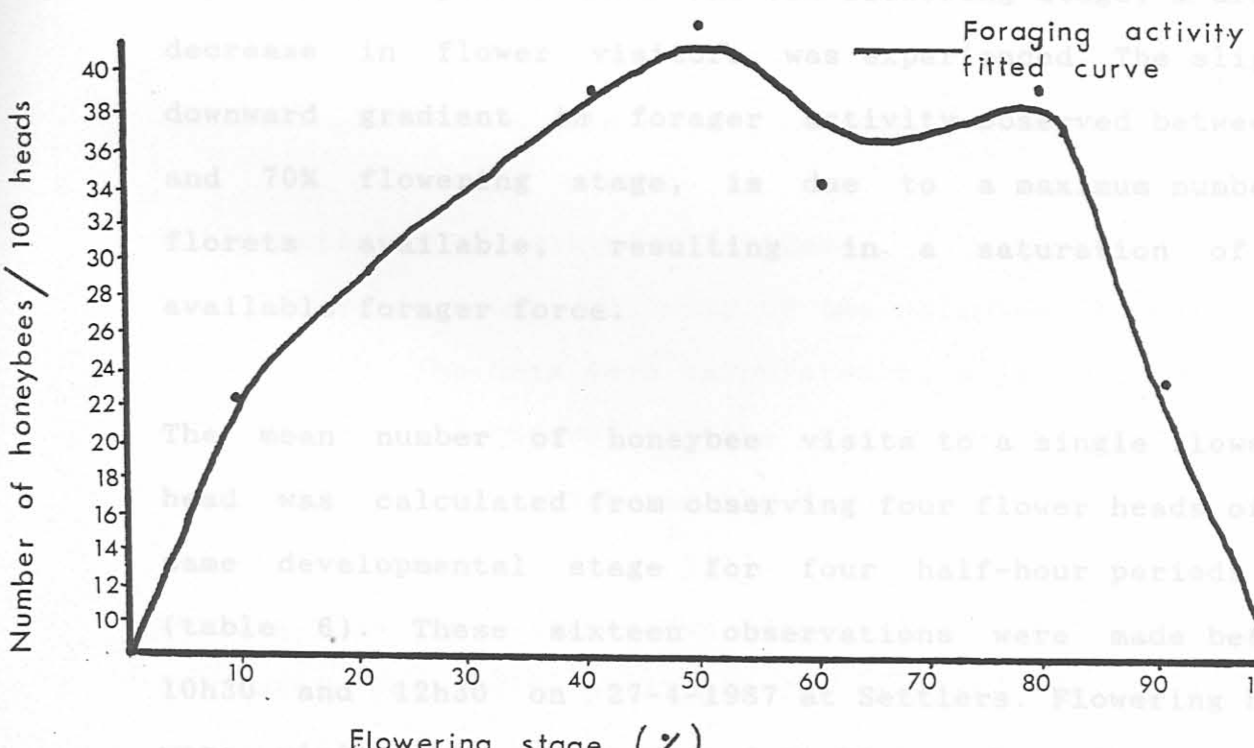

Fig. 9. Mean seasonal activity of foraging honeybees in commercial sunflower fields at Settlers.

(SE) (fig. 8), is probably due to seasonal differences in especially weather conditions during individual observation periods.

Activity during the successive stages of flowering

A seasonal trend in foraging activity was observed which was related to the flowering stage or the aging of the sunflowers (for definition of flowering stages see Chapter 3, page 14). Though individual heads bloom for 6-8 days only, flowering of an entire field may be spread over 14-17 days. With the onset of bloom there were few foragers in the fields (fig. 9), but their numbers increased markedly as more heads opened. After the 80% flowering stage, a drastic decrease in flower visitors was experienced. The slightly downward gradient in forager activity observed between 50 and 70% flowering stage, is due to a maximum number of florets available, resulting in a saturation of the available forager force.

The mean number of honeybee visits to a single flowering head was calculated from observing four flower heads of the same developmental stage for four half-hour periods each (table 6). These sixteen observations were made between 10h30 and 12h30 on 27-4-1987 at Settlers. Flowering heads were visited by an average of 11,25 honeybees (S.D. = 4,34, SE = 1,08, n = 16) during the 30 minute period. From these results a theoretical calculation of the number of honeybees required for efficient pollination can be made (see Appendix B, page 141).

TABLE 6. MEAN NUMBER OF HONEYBEE VISITS TO A SINGLE SUNFLOWER HEAD DURING FOUR 30 MINUTE PERIODS.

Time period	Number of heads observed	Mean	Standard deviation	Standard error
10h30 - 11h00	4	10.25	5.56	2.78
11h00 - 11h30	4	12.75	6.13	3.06
11h30 - 12h00	4	10.50	1.00	0.50
12h00 - 12h30	4	11.50	4.43	2.22
Mean		11.25	4.34	1.08

Daily activity of returning foragers

The daily foraging activity of two colonies is represented in fig. 10. The data were calculated as a mean of the number of returning foragers of the two experimental colonies. Sunflower pollen, which was the main forage source available to the honeybees (fig. 11.), is released in the early morning. As the stigma grows through the anther tube, pollen is pushed out and is available for foraging bees to collect. The availability of pollen early in the morning is reflected in the percentage of pollen gatherers, which was high (57%) when foraging started, and showed a steady decrease until it

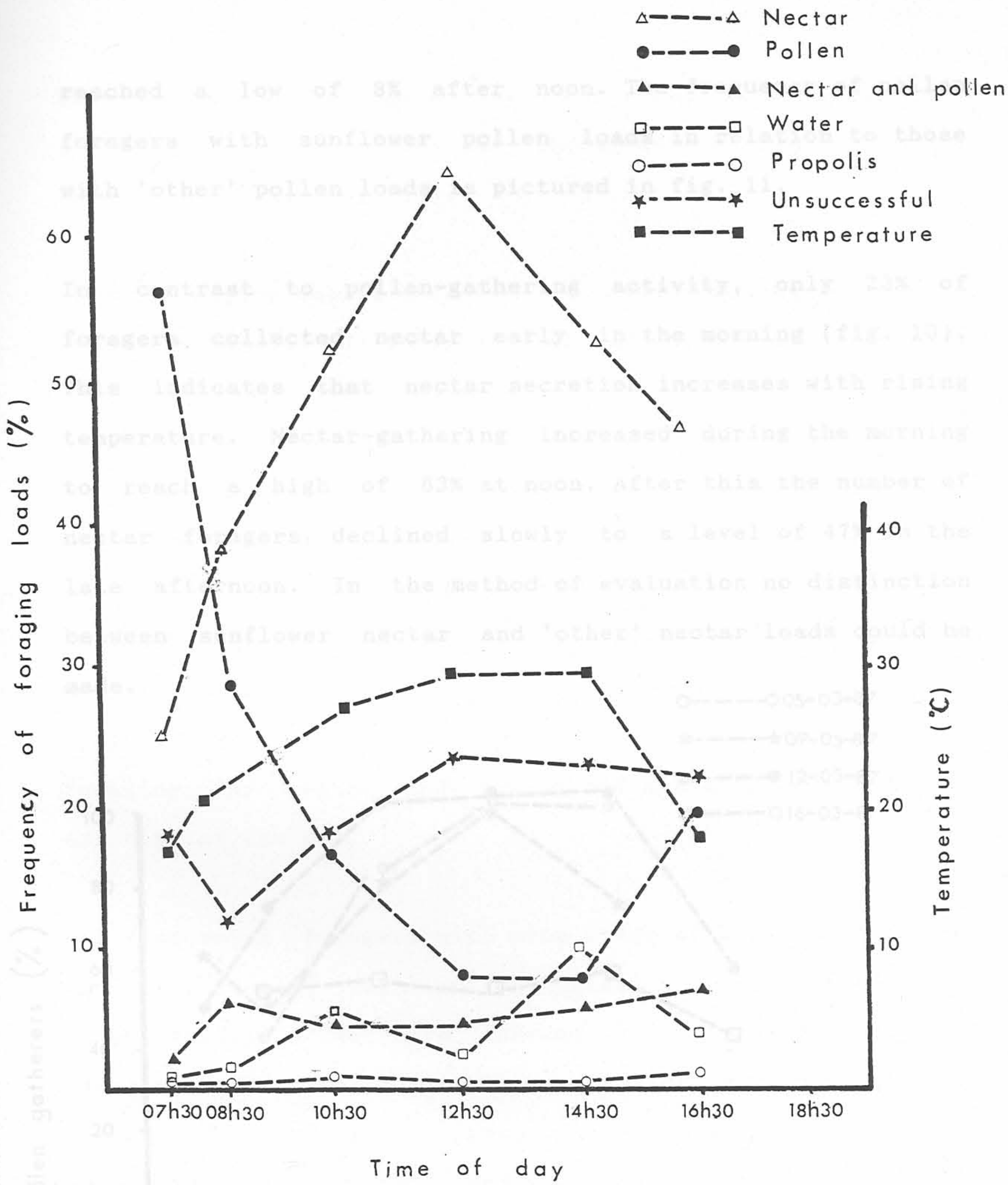

Fig. 10. Mean daily activity of returning foragers throughout the day on sunflowers. Settlers, March 1987.

reached a low of 8% after noon. The frequency of pollen foragers with sunflower pollen loads in relation to those with 'other' pollen loads is pictured in fig. 11.

In contrast to pollen-gathering activity, only 23% of foragers collected nectar early in the morning (fig. 10). This indicates that nectar secretion increases with rising temperature. Nectar-gathering increased during the morning to reach a high of 63% at noon. After this the number of nectar foragers declined slowly to a level of 47% in the late afternoon. In the method of evaluation no distinction between sunflower nectar and 'other' nectar loads could be made.

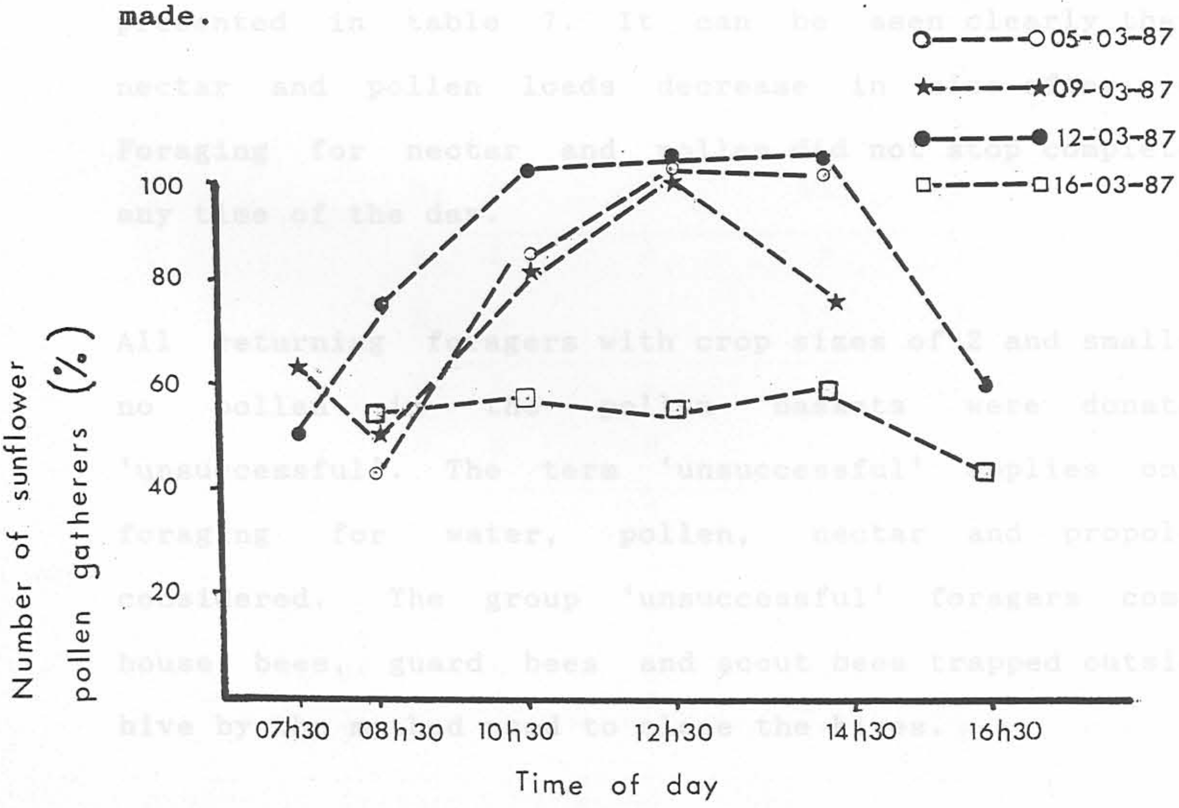

Fig. 11. Returning pollen foragers with sunflower pollen loads in Settlers, March 1987.

TABLE 7. FORAGING LOADS OF RETURNING FORAGERS ON SUNFLOWER AT SETTLERS, MARCH 1987.

Load	time of day		Number of loads					Nectar concentr
			Size 1	Size 2	Size 3	Size 4	Size 5	
Pollen	07h30		5	3	15	81	26	
	08h30		12	10	28	67	33	
	10h30		9	11	18	27	16	
	12h30		3	4	10	15	2	
	14h30		5	7	16	4	1	
	16h30		3	7	9	22	3	
Nectar*	07h30		27	14	34	20	4	38%
	08h30		35	17	58	136	35	38%
	10h30		50	26	90	129	24	44%
	12h30		66	34	121	134	16	46%
	14h30		66	39	114	128	15	47%
	16h30		26	24	40	64	5	37%
Pollen and nectar	07h30	N:	0	0	4	1	0	32%
		P:	0	1	1	2	0	
	08h30	N:	0	0	21	11	0	39%
		P:	4	7	14	2	5	
	10h30	N:	0	0	11	7	0	49%
		P:	3	3	8	2	2	
	12h30	N:	0	0	12	4	0	53%
		P:	5	3	5	3	0	
	14h30	N:	0	0	13	7	0	44%
		P:	7	1	5	7	0	
	16h30	N:	0	0	13	6	0	37%
		P:	4	4	6	5	0	
Water	07h30		0	0	0	0	0	0
	08h30		0	0	3	2	1	3%
	10h30		0	0	6	9	10	1%
	12h30		0	0	7	6	0	2%
	14h30		0	0	14	33	5	2%
	16h30		0	0	0	8	0	2%

Total number of foragers examined: 2280
* All foragers with nectar loads of sizes 1 and 2 were regarded as 'unsuccessful'.

The number of unsuccessful foragers nevertheless showed a predictable pattern. When foraging started, a relatively high percentage of foragers were presumably involved in scouting. Some of the unsuccessful foragers observed at this time could include scouts, resulting in the high of 19% (fig. 10). The number of unsuccessful foragers dropped within the next hour to 11%. Thereafter they showed a steady increase to a noon peak of 23%, a level they maintained for the rest of the afternoon at ca. 22%. This corresponded with the decline in the availability of nectar and pollen in the afternoon.

Activity of returning foragers through the flowering stages

In a single sunflower field a trend in foraging activity was observed as the number of pollen-receptive heads increased (fig. 12). The beginning of flowering is taken as the stage when ray petals of 5% of the heads have unfolded. Five days after flowering started, the heads were in 10% flowering stage. The percentage of nectar foragers was then low (29%). The number of nectar foragers subsequently increased as more florets on heads opened, reaching a high twelve days after flowering started and then declined steadily as more florets on the heads finished flowering (fig. 12). The percentage pollen gatherers was relatively constant throughout the bloom period (fig. 12), with a peak around the ninth day after flowering started (45% flowering stage).

The numbers of foragers that collected both nectar and pollen were fairly constant throughout the day and ranged between 2 and 8% (fig. 10).

Water foraging was at a fairly low level, ranging between 0% with the onset of foraging and 11% during mid-afternoon (fig. 10). Although variable the pattern of water-foraging indicated a slow increase during the day. The number of propolis foragers was very low throughout the day (fig. 10), less than 1% of all foragers.

Sizes of nectar and pollen loads of returning foragers is presented in table 7. It can be seen clearly that both nectar and pollen loads decrease in size after mid-day. Foraging for nectar and pollen did not stop completely at any time of the day.

All returning foragers with crop sizes of 2 and smaller and no pollen in the pollen baskets were donated as 'unsuccessful'. The term 'unsuccessful' applies only if foraging for water, pollen, nectar and propolis is considered. The group 'unsuccessful' foragers comprised house bees, guard bees and scout bees trapped outside the hive by the method used to close the hives.

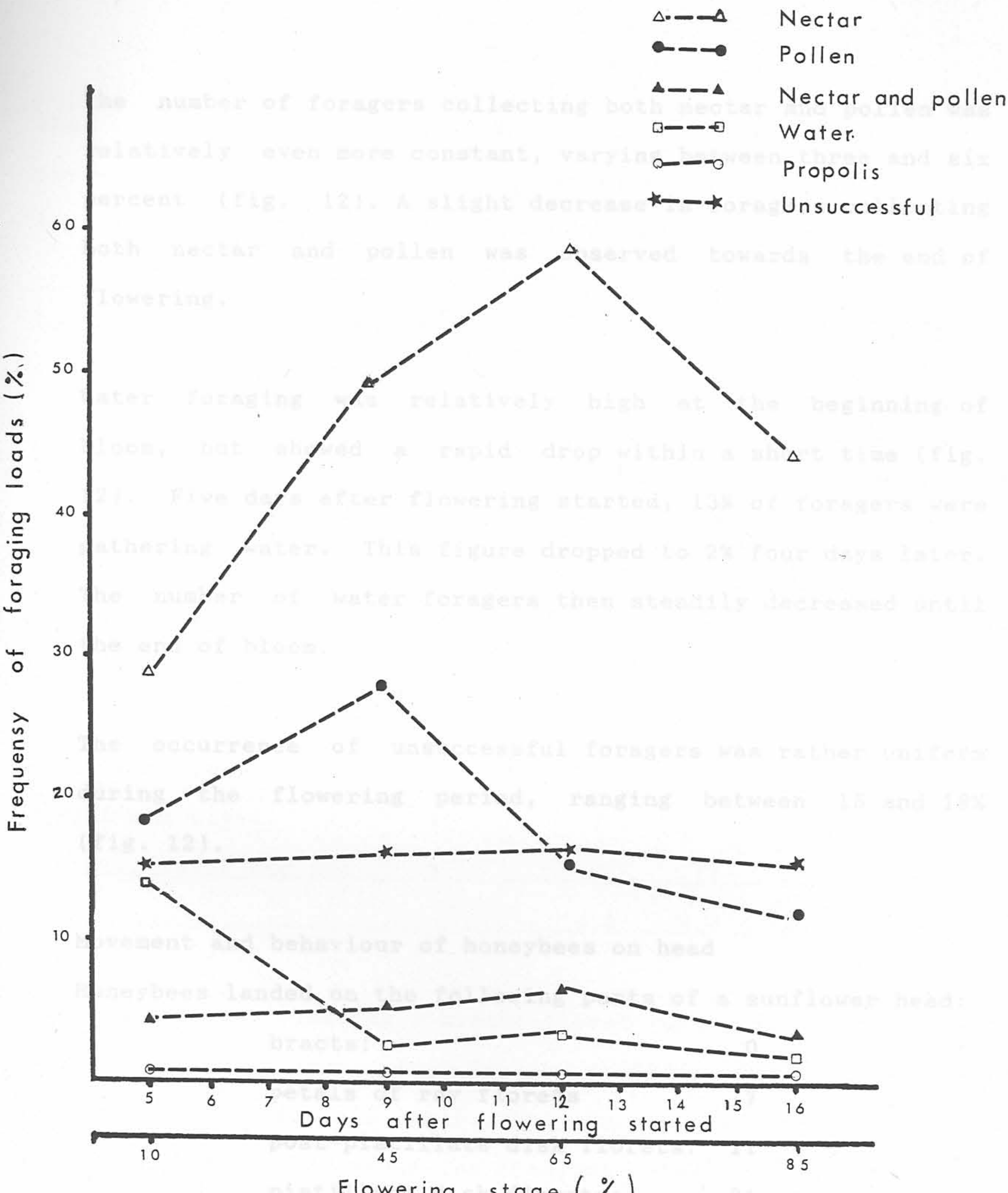

Fig. 12. Mean foraging activity of returning honeybees through the flowering stages of a field of sunflowers. Settlers, March 1987.

The number of foragers collecting both nectar and pollen was relatively even more constant, varying between three and six percent (fig. 12). A slight decrease in foragers collecting both nectar and pollen was observed towards the end of flowering.

Water foraging was relatively high at the beginning of bloom, but showed a rapid drop within a short time (fig. 12). Five days after flowering started, 13% of foragers were gathering water. This figure dropped to 2% four days later. The number of water foragers then steadily decreased until the end of bloom.

The occurrence of unsuccessful foragers was rather uniform during the flowering period, ranging between 15 and 18% (fig. 12).

Movement and behaviour of honeybees on head

Honeybees landed on the following parts of a sunflower head:

bracts:	0
petals of ray florets	7
post-pistillate disk florets:	11
pistillate disk florets:	31
staminate disk florets:	51
pre-staminate disk florets:	0
Total number of observations:	100

The stage of visited florets and the average time of visits are summarized in table 8. The mean time per honeybee visit also included time attributed to walking, grooming and hovering.

TABLE 8. FLORET STAGE AND MEAN NUMBER OF FLORETS VISITED BY A HUNDRED FORAGERS.

Stage of disk floret visited	Number of honeybees	Mean number florets probed per honeybee: p.pist.	pist.	stam.	Mean time per visit (s)
Post-pistillate	1	4	-	-	7
Pistillate	25	-	8	-	29
Staminate	42	-	-	12	47
Pist. and stam.	25	-	6	19	128
P.pist and pist.	4	7	7	-	43
P.pist., pist. and sta	3	2	14	29	271
Mean:		4.3	8.7	20	87.5

The time spent visiting a single floret ranged between 1 and eight seconds with a mean of 2,8s (n = 173). On average visits to post-pistillate florets only, were the shortest (7s), while visits which included florets of the staminate stage were the longest (up to 271s) (table 8). The total time spent at one flowering head ranged between 4 and 893 seconds (14 min. 53s).

Walking occurred mostly after the initial landing, but also included floret to floret movement. Walking is therefore a transitional activity, where the forager relocates herself on the head. Walking occurred as part of 47% of all visits to flowering heads, with a mean of 1,8 walks per visit (range 1-8).

Hovering in front of the capitulum by the forager has three distinct functions. A transitional activity to reorientate herself on the flowering head, to clear herself of pollen, or to pack pollen into the baskets. Hovering was observed as part of 49% of visits to flowering heads, with a mean of 3,2 hovers per visit (range 1-25). Hovering lasted on average 5s (Range 2-10s, n = 44).

Grooming while resting on the flowering head, did occur, but the frequency was much lower than for grooming while hovering. Only 4% of foragers observed groomed while perched. In all of the observed grooming incidents, grooming was to remove pollen from the body. Grooming took place on either the petals of the ray florets or on post-pistillate disk florets. The mean number of grooms per visit was 2, with a range of 1-3. On average a forager spent 18s grooming herself on the flowering head. This was considerably longer than the average time spent on grooming while hovering. All foragers involved in grooming while resting on the flowering head, were also involved in hovering.

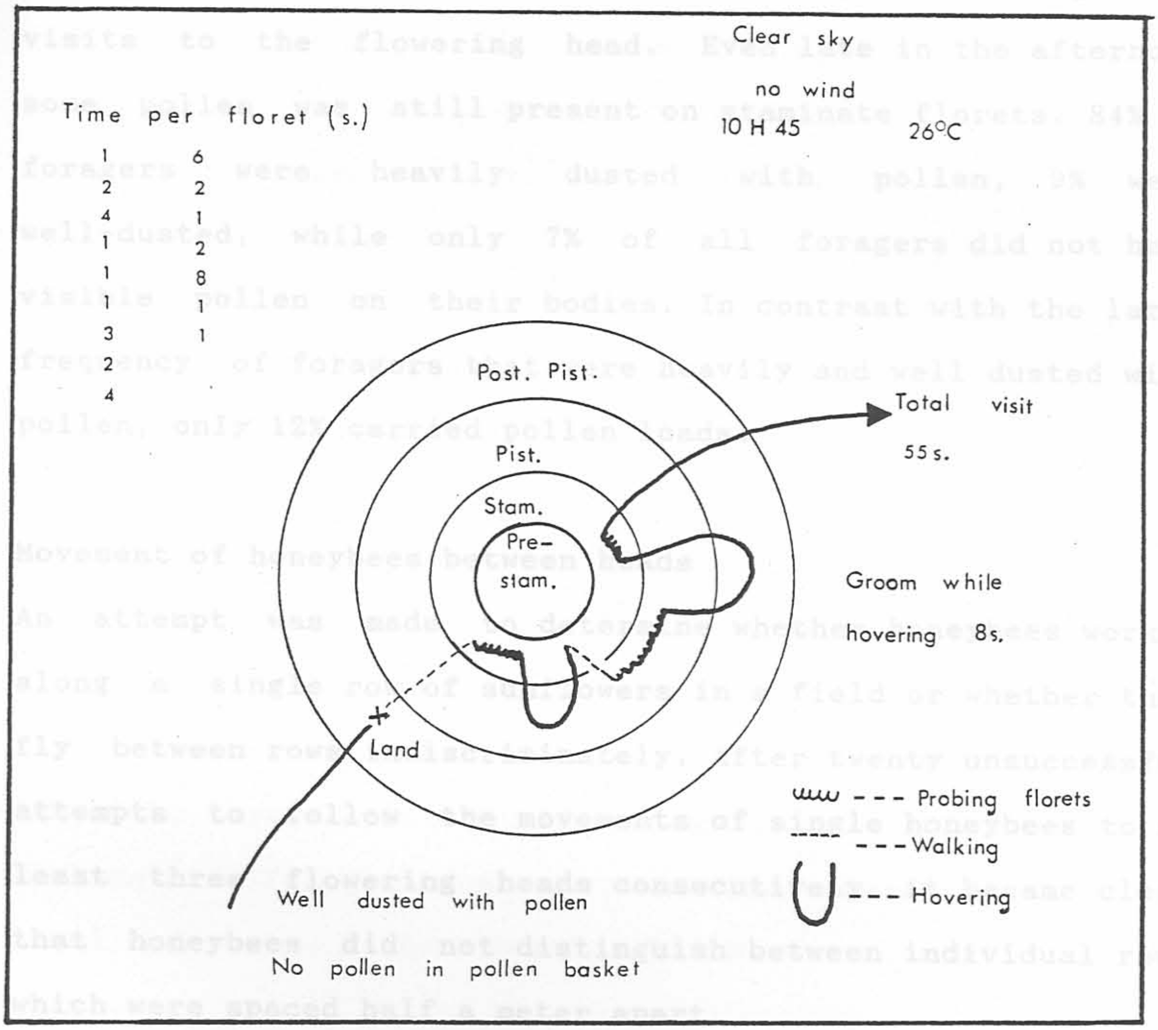

Fig. 13. Datasheet for recording movement and behaviour on a single sunflower head.

No active pollen scrabbling by foragers was observed. Foragers became very well dusted with pollen during their visits to the flowering head. Even late in the afternoon some pollen was still present on staminate florets. 84% of foragers were heavily dusted with pollen, 9% were well-dusted, while only 7% of all foragers did not have visible pollen on their bodies. In contrast with the large frequency of foragers that were heavily and well dusted with pollen, only 12% carried pollen loads.

Movement of honeybees between heads

An attempt was made to determine whether honeybees worked along a single row of sunflowers in a field or whether they fly between rows indiscriminately. After twenty unsuccessful attempts to follow the movements of single honeybees to at least three flowering heads consecutively, it became clear that honeybees did not distinguish between individual rows which were spaced half a meter apart.

4.4. DISCUSSION

In the present study a steep increase in honeybee activity was observed early in the morning after light intensity made flight possible. Temperature rarely seems to restrict flight in the Springbok Flats during the sunflower season. A peak in foraging activity was reached between 09h00 and 10h00, after this activity was fairly constant throughout the day till late in the afternoon when it dropped sharply until it stopped all together. Observations by Krause and Wilson (1981) in Wyoming, USA, showed a stepped increase of foragers to reach a peak only by noon. An unexplained steep decline in forager activity was observed after noon.

Parker (1981) found a seasonal peak of honeybee activity (32 honeybees / 100 heads) eight days after flowering started (40% flowering stage), which then showed a steady decline of foraging numbers to reach a level of 2 honeybees / 100 heads at 80% flowering stage. Krause and Wilson (1981) found less than 5 honeybees / 100 receptive heads until a 35% flowering stage was reached. A rapid increase in forager numbers was then observed to reach a level of 30 honeybees / 100 receptive heads at 50% flowering stage. A very drastic decline in forager numbers was then observed to reach a level of only 5 honeybees / 100 heads at a 60% flowering stage.

In the present study a combination of these various findings, was observed. Honeybee activity reached a peak at 40% flowering, a moderate decline was observed between 50 and 70% flowering, just to reach another peak at 80% flowering, after which a rapid decline is experienced. The moderate decline is believed to be due to saturation of honeybee numbers caused by the large number of open pollen receptive florets at that stage. A high level of foragers is maintained on commercial sunflower in South Africa through the flowering period, where introduced hives are supplied by migratory beekeepers.

Honeybees visiting sunflowers became heavily dusted with pollen, which they either discarded or packed in their pollen baskets. In the present study no honeybees actively scrabbling for pollen was observed, as was observed by Free, 1964. The percentage pollen scrabblers observed by Free (1964) was very low with a mean of 4% throughout flowering. The percentage foragers that collected both nectar and pollen was considerably lower (between 2 - 8%), than the 10 - 25% found by Free (1964).

Free (1964) observed a peak in pollen gathering four days after observations started, when the field had reached a 10% flowering stage. In the present study maximum numbers of pollen gatherers were observed nine days after flowering started (45% flowering stage).

Though grooming to discard pollen was observed in ca. 50% of all foragers, they were nevertheless well dusted with pollen. Good pollen movement which is essential for cross-pollination took place, as not all the pollen was discarded. This is further emphasized by the observation that foragers made contact with a large number of stigmas on the same head, while probing a single floret. This is due to the pumping action of the abdomen while sucking nectar, and also to frequent leg movements.

Free found that between 10 - 12% foragers visited extrafloral nectaries on the bracts when less than 5% of the heads were open. Thereafter it dropped to less than 1%. In this study it was also found that less than 1% of foragers visited extrafloral nectaries after the 5% bloom stage. No counts were made where fewer than 5% of heads had opened.

In his treatise on water requirements of the honeybee colony, Lindauer (1955) stated that water is needed for regulating the temperature and humidity inside the hive. During a nectar flow, the moisture from nectar that is being ripened, may be sufficient for this need. Water collection continues throughout the nectar flow, though on a markedly low level. Water consumption increases with an increase in brood rearing, or after a period of poor weather and flight conditions. Water foraging on any given day is related to the relative humidity of the air. Under normal conditions water foragers will switch to nectar gathering when nectar becomes available (Lindauer, 1955).

Commercial sunflower is rated by Anderson <u>et</u> <u>al</u>. (1983) as a N3P3 honeybee plant, i.e. a good source of both nectar and pollen. When the results of table 7 are evaluated, it becomes clear that modern hybrid sunflower cultivars, grown in the Springbok Flats, can be regarded as N4P4 honeybee plants, i.e. exceptionally good sources of both nectar and pollen. This is due to continuous availability of pollen and climate and soil type probably favouring nectar secretion in the Springbok Flats locality.

Radford et al. (1979b) calculated a theoretical number of 24 honeybees / 100 flowering heads to ensure adequate pollination of commercial sunflower. I made a similarly calculation based on plant density, number of florets visited per honeybee, time of honeybee visits and total time per day available for foraging. A theoretical number of 30 honeybees / 100 flowering heads was calculated, which was then use to calculate the hive density. I made a recommendation of 1 hive / hectare based on these calculations (Du Toit, 1987 - Appendix B, page 141).

Various factors, which influence foraging activity on a daily as well as short-term seasonal basis through the flowering period are demonstrated by graphic models which are based on the fitted curves calculated for foraging activity in figs. 14 to 20. Obviously combinations of these factors are also possible.

The number of honeybees present in a commercial sunflower field is determined by the number of hives placed in the vicinity as well as the presence of feral colonies. As it was established that the number of natural colonies is inadequate to ensure successful pollination in the Springbok Flats (Birch <u>et al</u>., 1985), adequate pollination is largely dependent on the number of hives brought in by beekeepers. A too low number of hives would lead to an inadequate number of foragers for effective pollination either on a daily basis (fig. 14) or seasonal basis (fig. 18).

On a daily basis foraging is influenced by rain showers which occur as short intense thunder showers in the Settlers area (fig. 15). Continuous rain for two or three days will drastically reduce the numbers of foragers to a level of no activity during such a period. This is associated with rings of poor seed set on the flowering head (Birch, 1981). Mechanical irrigation with overhead sprinklers has the same effect on honeybee activity as rain. No honeybee or other insect activity was observed in fields under irrigation in the western Transvaal (09h00 - 12h00, temperature 22 °C).

The direct influence of temperature on honeybee activity in the Springbok Flats is believed to be insignificant as temperatures never reach levels where flight activity will cease (fig. 2 page 10). The indirect influence of temperature on foraging activity is of more significance. Temperature negatively influences nectar secretion by the sunflower plant. Too high mid-day temperatures can lead to foragers switching to gathering water (fig. 16.) Water is

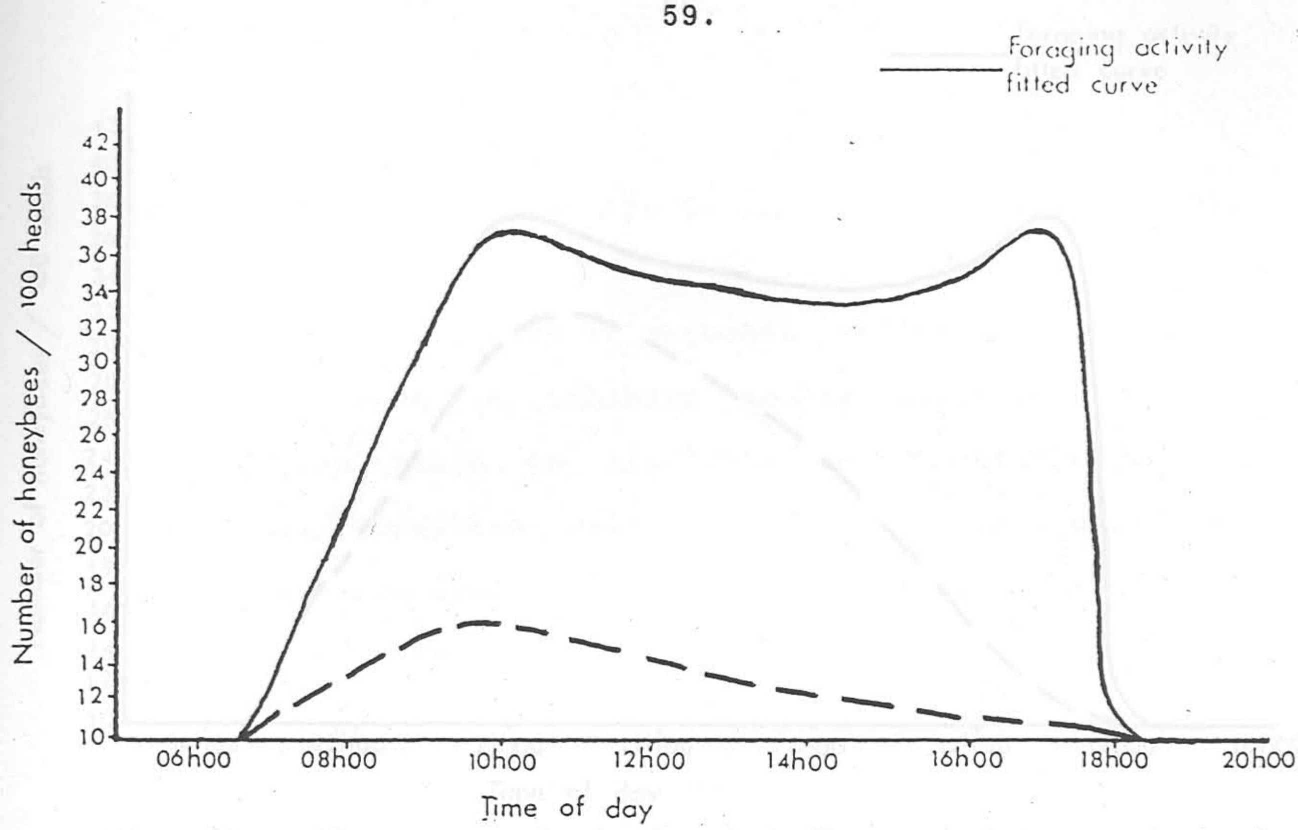

Fig. 14. The effect of a scarcity of foragers on a single day (Herrmann, personal communication 1985). Settlers, 1983-04-24.

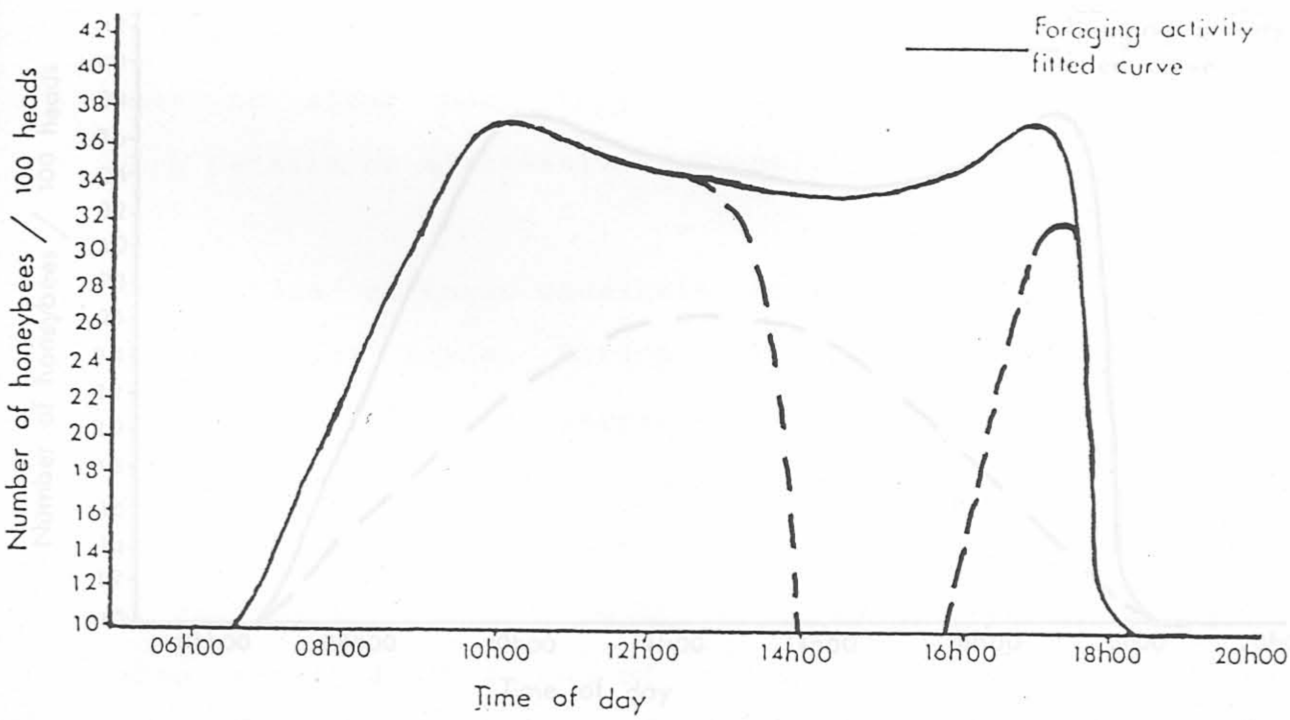

Fig. 15. The influence of a thunder shower on the number of foragers on a single day. Settlers, 1986-03-24 40% flowering stage.

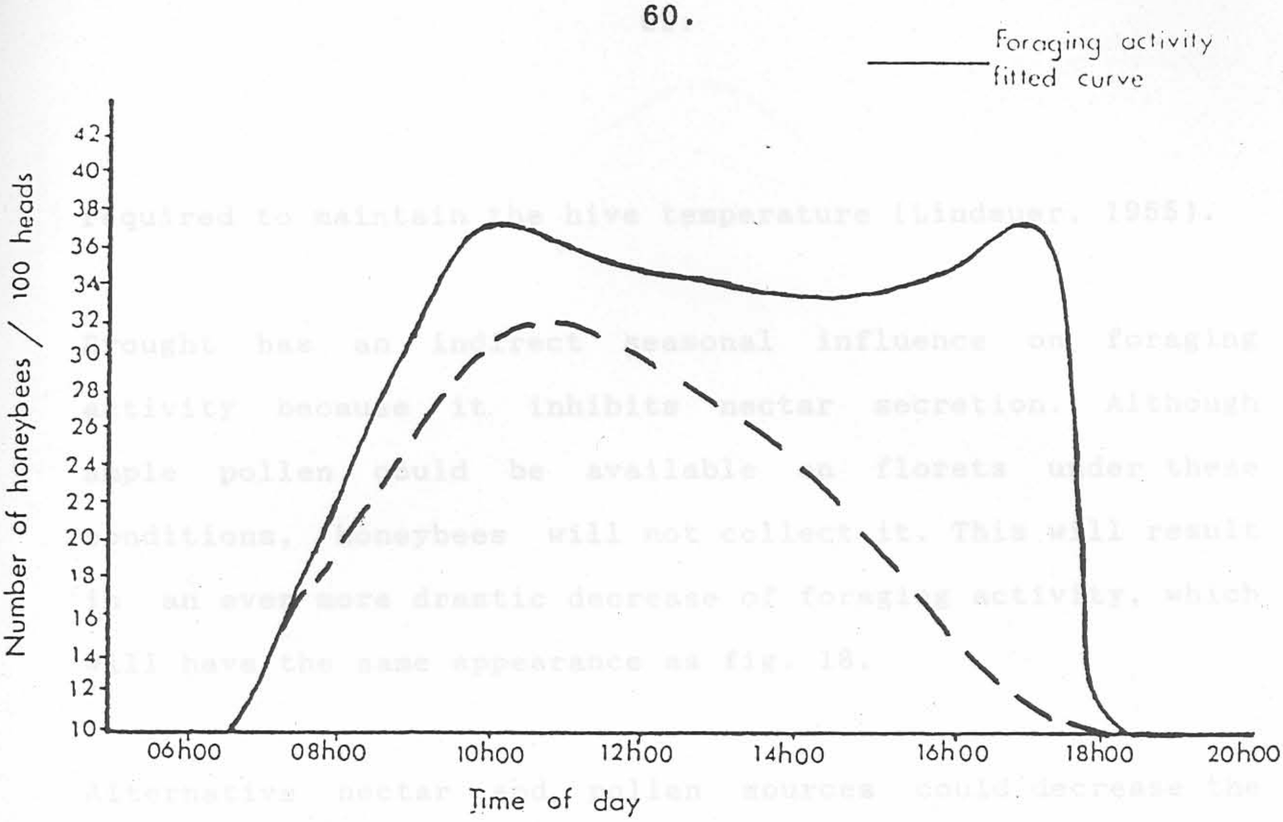

Fig. 16. The assumed indirect influence of temperature on forager activity due to a cease in nectar secretion.

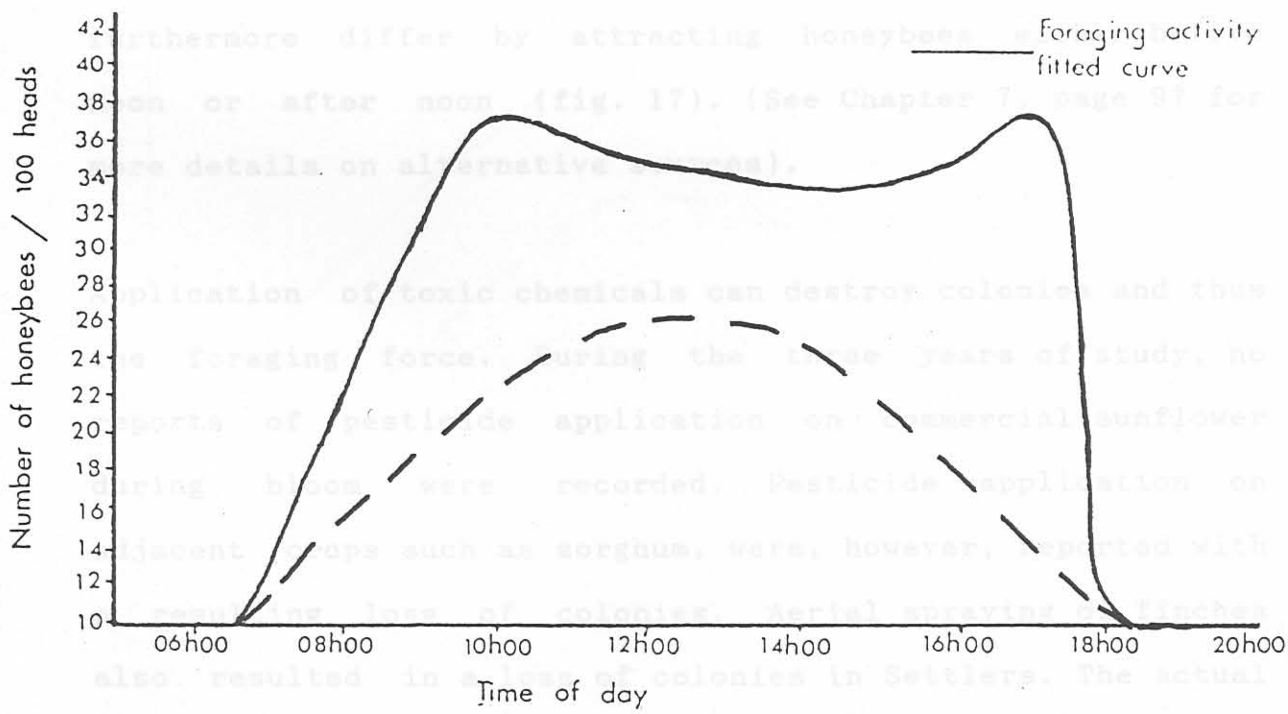

Fig. 17. The influence of alternative nectar and or pollen sources on forager activity. Settlers, March 1987.

required to maintain the hive temperature (Lindauer, 1955).

Drought has an indirect seasonal influence on foraging activity because it inhibits nectar secretion. Although ample pollen could be available on florets under these conditions, honeybees will not collect it. This will result in an even more drastic decrease of foraging activity, which will have the same appearance as fig. 18.

Alternative nectar and pollen sources could decrease the number of foragers on the target crop. These sources influence foraging numbers on the target crop on a daily (fig. 17) or seasonal basis (fig. 19). Their mode could furthermore differ by attracting honeybees either before noon or after noon (fig. 17). (See Chapter 7, page 97 for more details on alternative sources).

Application of toxic chemicals can destroy colonies and thus the foraging force. During the three years of study, no reports of pesticide application on commercial sunflower during bloom were recorded. Pesticide application on adjacent crops such as sorghum, were, however, reported with a resulting loss of colonies. Aerial spraying of finches also resulted in a loss of colonies in Settlers. The actual forager loss for a few days after pesticide application is not known. A model to illustrate possible insecticide action is presented in fig. 20.

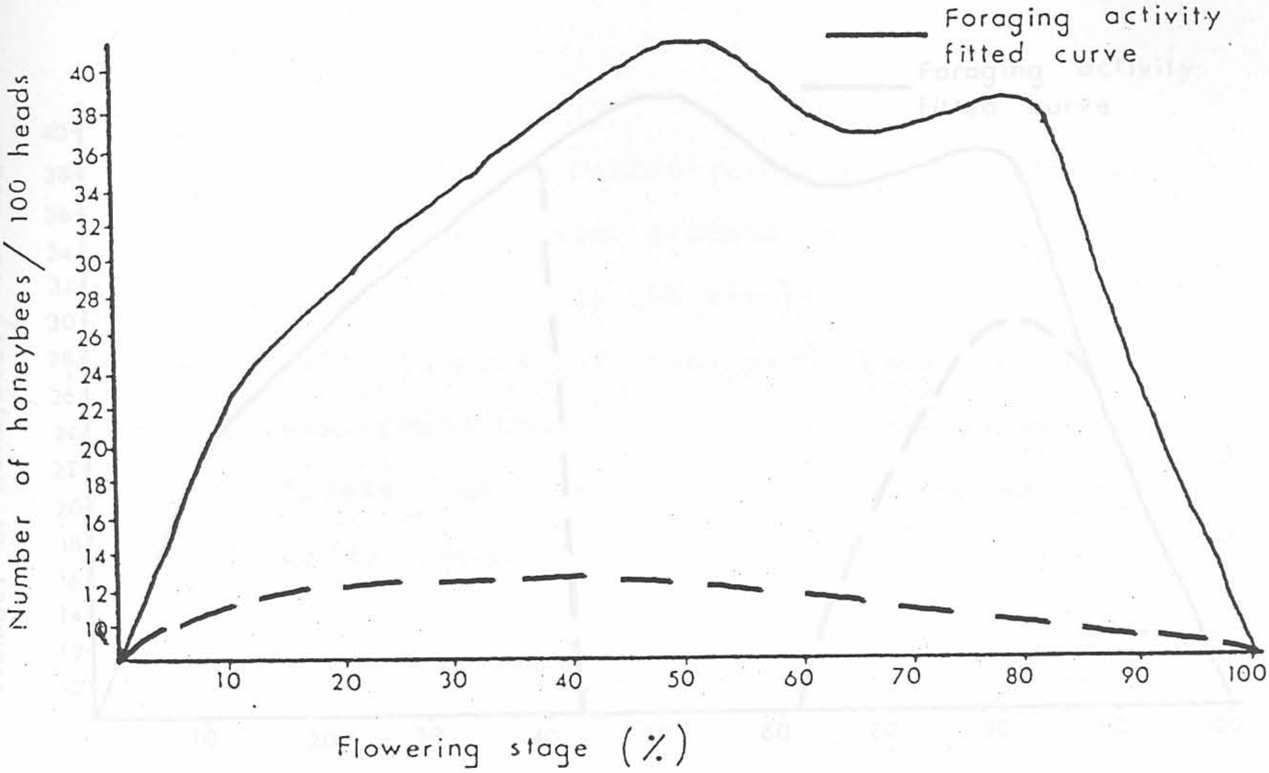

Fig. 18. The influence of a scarcity of foragers during a complete sunflower cycle. (Herrmann, personal communication, 1985. Settlers, April 1984.)

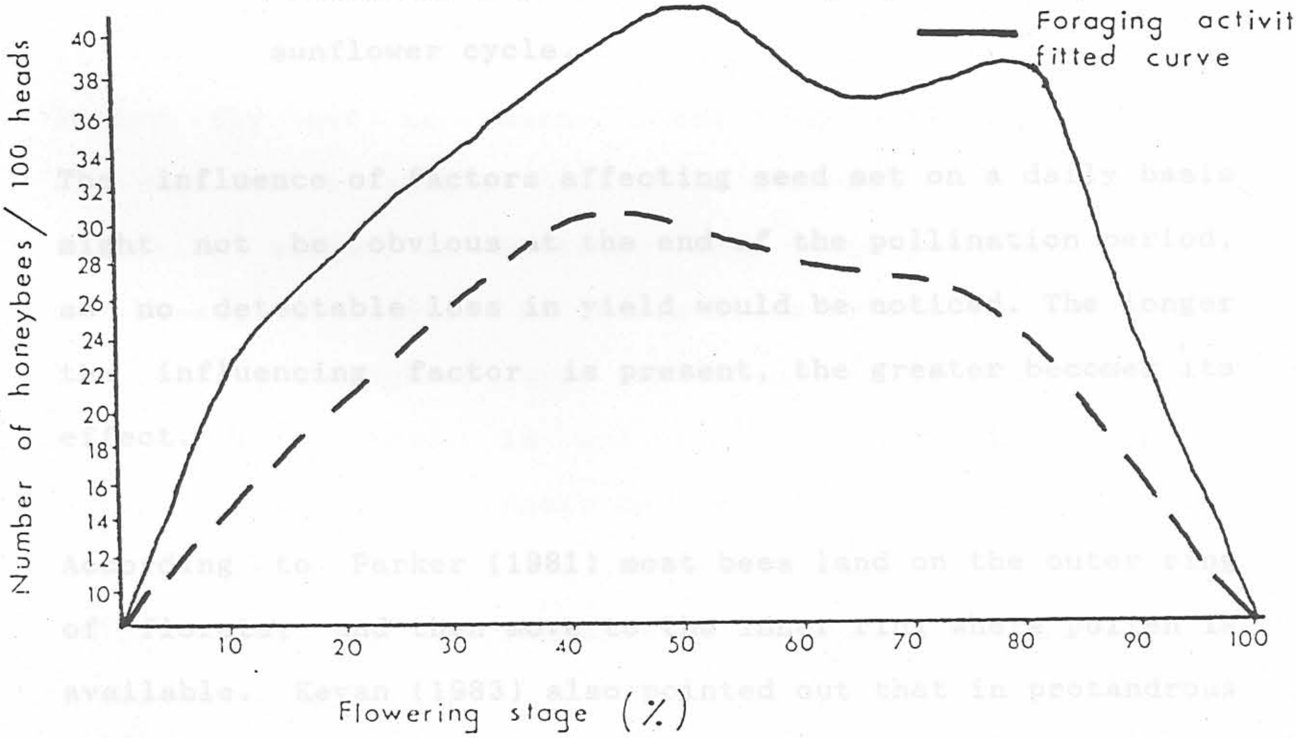

Fig. 19. The influence of alternative nectar and pollen sources during a complete sunflower cycle. Settlers, March 1987.

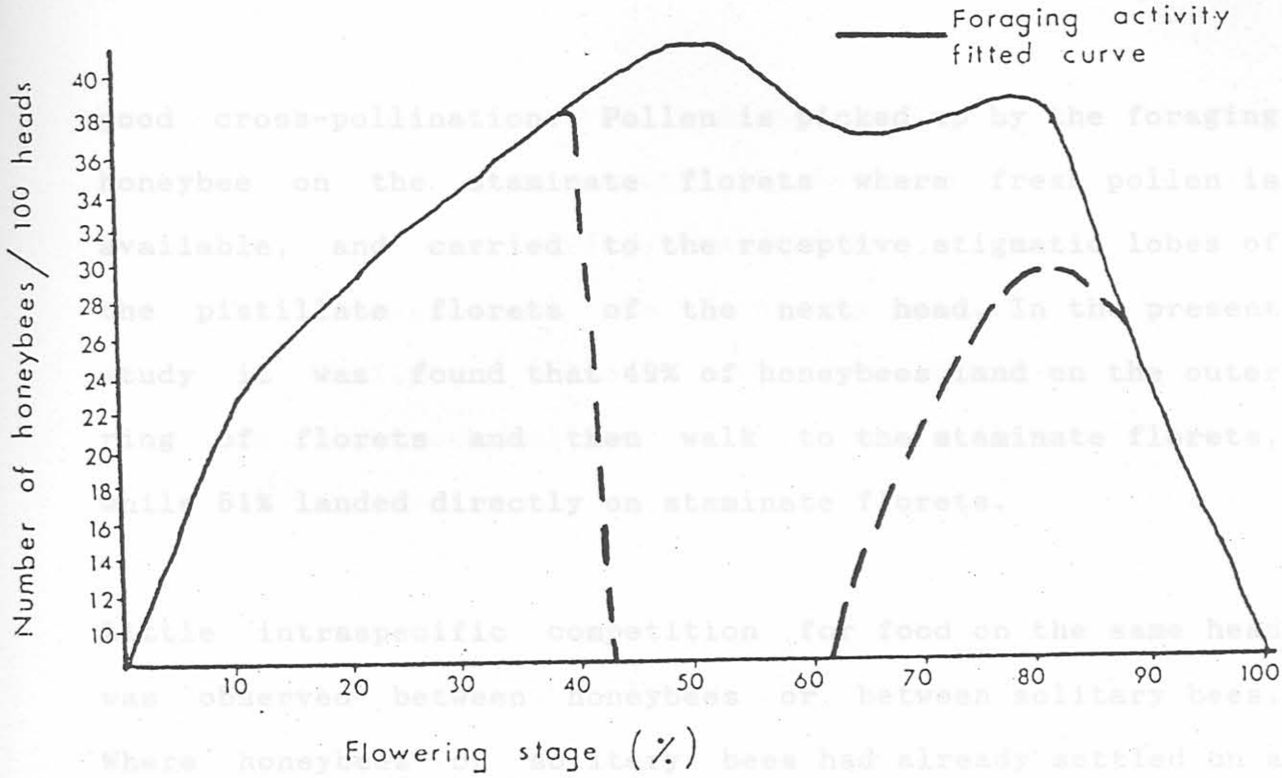

Fig. 18. The assumed influence of pesticides application on the number of honeybees during a complete sunflower cycle.

The influence of factors affecting seed set on a daily basis might not be obvious at the end of the pollination period, as no detectable loss in yield would be noticed. The longer the influencing factor is present, the greater becomes its effect.

According to Parker (1981) most bees land on the outer ring of florets, and then move to the inner ring where pollen is available. Kevan (1983) also pointed out that in protandrous plants such as <u>Helianthus annuus</u>, it is important that bees move from the older florets to the newly opened florets, where pollen is available. This action is very conducive for good cross-pollination. Pollen is picked up by the foraging honeybee on the staminate florets where fresh pollen is available, and carried to the receptive stigmatic lobes of the pistillate florets of the next head. In the present study it was found that 49% of honeybees land on the outer ring of florets and then walk to the staminate florets, while 51% landed directly on staminate florets.

Little intraspecific competition for food on the same head was observed between honeybees or between solitary bees. Where honeybees or solitary bees had already settled on a head, the approach of other honeybees or solitary bees did not disturb the settled ones. Bees which approached a head at the same time did show some interaction and both would rather fly off to another head. Up to 10 honeybees were observed on a single head (head diameter 180 mm., 75-100% flowering stage) at Pretoria (mean range per head: 0 - 5.2 honeybees, n = 64). No interactions between spotted maize beetle and honeybees were observed. It is thus concluded that forager choice is not significantly affected by the presence of other foragers on the head. Tepedino and Parker (1981) reached the same conclusion. No pollen robbing (cleptolecty) by honeybees was observed as described by Thorp and Briggs (1980).

Observations on predators of honeybees were made while conducting the survey of pollinating insects. Only a few incidents of predation on honeybee foragers were observed during the 259 strip counts in Settlers, Pretoria and Hartbeesfontein and during observations on behaviour of individual foragers on the flowering head. Crab or flower spiders (Family : Thomisidae) were observed on four occasions to successfully catch foragers on flowering heads. A robber fly (Family : Assilidae) was once seen to capture a honeybee, similarly an assassin bug (Family : Ruduviidae) positioned on the bracts of a flowering head, was seen feeding on a honeybee. The yellow bee pirate, (Philanthus diadema : Family Sphecidae) was fairly common on flower heads in Pretoria and Hartbeesfontein, though actual attacks on foraging honeybees were never observed. These wasps were only seen to feed on the floral nectar. An exceptional observation was made of eight ants carrying a living honeybee down the stem of a sunflower plant.

5. THE IMPORTANCE OF CERTAIN INSECTS AS POLLINATORS OF COMMERCIAL SUNFLOWER

5.1. INTRODUCTION

Studies by various researchers confirm that the absence of insect pollinators, particularly honeybees, has an adverse influence on the seed set and yield of commercial sunflower (Diez, 1978; Freud and Furgala, 1982; Krause and Wilson, 1981; Langridge and Goodman, 1974). In South Africa, preliminary studies by Birch et al. (1985) also indicate a loss in yield with inadequate numbers of pollinators.

After reviewing the literature, Hurd et al. (1980) emphasized that honeybees should be considered as the most important pollinators of commercial sunflower. They stated that the role of solitary bees should, however, not be ignored, and deserved more attention. The role of insects other than honeybees, has been acknowledged by various researchers, but no studies have been carried out to determine their actual importance. Mostly accounts of their diversity and activity are given (Arnason, 1966; Furgala, 1954; Langridge and Goodman, 1974; Palmer-Jones and Forster, 1975; Parker, 1981). Radford et al. (1979a) have conducted studies to determine the influence of American bollworm moths (Heliothis armigera) on seed set in Australia, where they are the major nocturnal flower visitors. They concluded that their role as pollinators is insignificant.

The two most important methods of studying the influence of honeybees on seed set are the single head bag method (Krause and Wilson, 1981 and Robinson, 1980) and the caged plot method (Birch _et_ _al_., 1985; Langridge and Goodman, 1974; Palmer-Jones and Forster, 1975). Both these methods have advantages as well as disadvantages. With the single head bag method only the influence of the exclusion of pollinators can be assessed. The greatest disadvantage of this method is mechanical pollination occurring as a result of the bag touching the florets in windy conditions. Parker (1981) used this method to study the amount of pollination accomplished by a single bee visit. The influence of a specific insect pollinator species can be studied with the caged plot method, while its main disadvantage is the uncertain influence of shading of the plants. It was decided to use the caged plot method in this study because it offered the widest range of applications.

Radford _et_ _al_. (1979a) made a thorough investigation into the effect of windborne pollen on yields of plants inside cages and those outside. In their research they found 105 sunflower pollen grains per m^{-3} air outside the cage and 115 inside. This windborne pollen inside the cages did not have any influence on the percentage seed set. Putt (1940) and Birch (personal communication, 1988) reached the same conclusion.

After consulting the information recorded during the survey on activity and abundance of insect pollinators (Chapter 3, page 11), it was decided to investigate the pollination efficiency of honeybees, spotted maize beetles, house flies and American bollworm larvae on seed set. Honeybees are believed to be the most important pollinators, while the actual role of the other three species has not been investigated. These specific treatments were compared with those without insect pollinators, as well as with open-pollinated control treatments in the field.

5.2. MATERIAL AND METHODS

Caged plot experiments were carried out in fields of the commercial cultivar SO323 near Settlers on the Springbok Flats during 1986 and 1987. The 200 ha fields were planted on unfertilised black Arcadia soils on 1986-01-10 and 1986-12-10 and started flowering on 1986-03-13 and 1987-02-11 respectively. A final stand of ca. 30 000 plants per hectare was achieved. Production colonies of honeybees were introduced by migratory beekeepers at a density of one colony per hectare.

Insect proof cages were erected at random in the field, each cage covering a similar number of plants of more or less the same size and stage of development (physiological evenness). The cages were made from slotted angle iron, measuring 4,4m long x 3,0m wide x 2,2m high and covered with white nylon parachute netting, providing less than 20% shade. The mesh size of the parachute netting only provided entrance for insects less than 1mm wide. Each cage covered three rows of sunflowers, with 10 to 15 plants in each row. The plots were trimmed at both ends of the rows to avoid contact of sunflower heads with the netting. Three replicates were used for each of the six treatments.

Cages were provisioned as follows: 1. Cages provided with a small colony of honeybees, consisting of three frames of brood (fig. 21). Water was supplied in the cage. 2. Cages provided with 150 spotted maize beetles, which had previously been collected from maize tassels. The beetles were left to settle on the heads by themselves. 3. Cages in each of which 50 house flies was released. 4. Cages where 3 one day old American bollworm larvae were placed on each sunflower head, just after the ray florets had opened. 5. Cages with no insect pollinators. All insects having been removed by hand before bloom. 6. The sixth treatment was an uncaged, open-pollinated 4,4 x 3,0 area in the same sunflower field, which served as a control.

The cages were erected before the ray florets had started opening. The netting was left on the cages until the

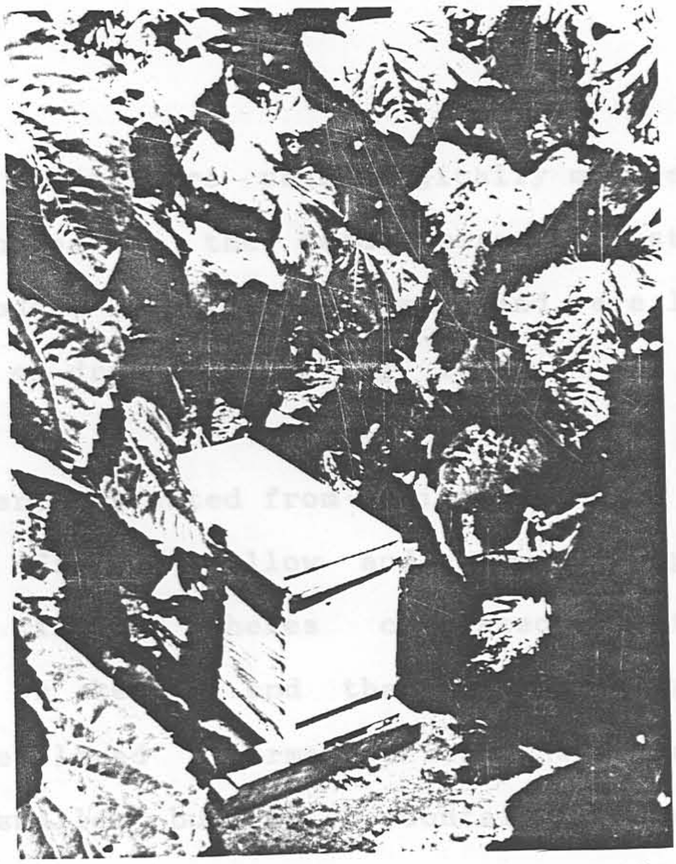

Fig. 21. Small colony of honeybees inside an insect proof cage.

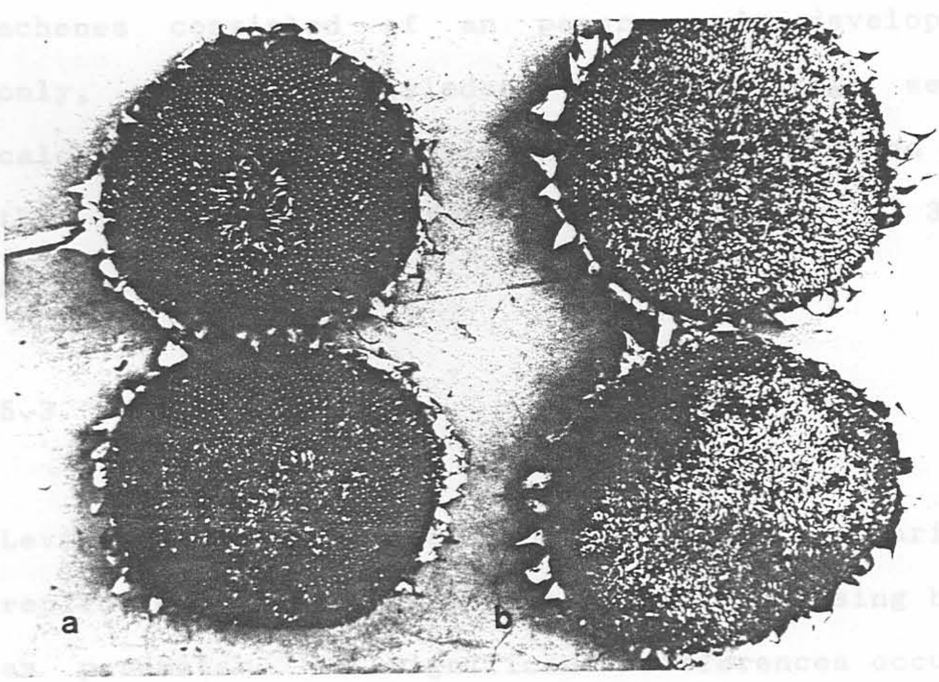

Fig. 22. Sunflower heads harvested from plants inside insect proof cages. a. treatment with honeybees as pollinators, b. treatment with no pollinators.

sunflower heads were physiologically mature (6 weeks after bloom). Thereafter the heads were harvested by hand to prevent rodent or any other damage and were left for another four weeks on drying-racks (fig. 22).

Achenes were harvested from individual heads by hand and the number of filled, hollow and under-developed achenes were counted. Filled achenes consisted of the oil-bearing cotyledon or kernel and the surrounding pericarp. Hollow achenes developed a normal pericarp, which occasionally was somewhat smaller but which contained no cotyledon. These achenes also had a much lower mass and were blown out with the chaff during mechanical harvesting. Under-developed achenes consisted of an papery under-developed pericarp only, with no cotyledon. The percentage seed set was calculated, and the filled achenes were weighed to calculate the crop yield as for the achieved stand of 30 000 plants per hectare.

5.3. RESULTS

Levin's test was used to determine the variance between replicates of each treatment beforehand, using head diameter as parameter. No significant differences occurred between replicates of treatments. For further statistical analysis of data, the replicates of each treatment could thus be combined.

TABLE 9. STATISTICAL RESULTS OF VARIOUS CAGE EXPERIMENTS WITH DIFFERENT INSECT POLLINATORS AT SETTLERS, 1986-1987.

Pollinator		Head diameter (mm)	Number of achenes per head: filled	hollow	papery
Control (Open field)	Mean	165,6	1286,4	82,6	402,2
	S.D.	20,2	310,0	76,5	204,8
	S.E.	1,9	29,4	7,2	19,4
	Max.	210,0	1944,0	603,0	1044,0
	Min.	120,0	568,0	21,0	79,0
	n	111	111	111	111
Honeybees	Mean	158,8	1270,7	74,2	425,8
	S.D.	23,4	327,1	72,4	151,3
	S.E.	02,7	37,7	8,3	17,4
	Max.	215,0	2106,0	419,0	982,0
	Min.	110,0	521,0	11,0	160,0
	n	75	75	75	75
	L. Sign.		0.9094 NS	0.1220 NS	0.0985 NS
Spotted maize beetles	Mean	166,9	1313,0	72,9	343,7
	S.D.	24,3	331,5	68,0	182,3
	S.E.	02,7	37,3	7,6	20,5
	Max.	230,0	2445,0	372,0	957,0
	Min.	110,0	596,0	9,0	68,0
	n	79	79	79	79
	L. Sign.		0.7869 NS	0.0577 NS	0.0498 NS
House flies	Mean	167,8cm	718,8	499,5	676,0
	S.D.	24,1	401,5	469,2	448,7
	S.E.	02,7	46,3	54,1	51,8
	Max.	240,0	1448,0	1771,0	1884,0
	Min.	120,0	14,0	32,0	51,0
	n	75	75	75	75
	L. Sign.		0.0000 **	0.0000 **	0.0000 **
American bollworm larvae	Mean	148,3	870,5	74,9	1021,6
	S.D.	23,8	317,8	48,3	355,2
	S.E.	02,6	34,6	5,2	38,7
	Max.	195,0	1550,0	319,0	2150,0
	Min.	100,0	155,0	17,0	356,0
	n	84	84	84	84
	L. Sign.		0.0000 **	0.7682 NS	0.0000 **
No insect pollinators	Mean	152,0	723,2	199,9	698,0
	S.D.	19,5	294,9	308,4	404,2
	S.E.	02,2	34,0	35,6	46,6
	Max.	195,0	1221,0	1573,0	1986,0
	Min.	100,0	129,0	13,0	152,0
	n	75	75	75	75
	L. Sign.		0.0000 **	0.0160 NS	0.0000 **

Level of significance (L. Sign.): NS - Not significant at 1% level.
** - Significant at 1% level.

n - number of flower heads.

Bonferroni's t-test was first used to determine whether data obtained from the different treatments could be compared with one another. Head diameter was used as the variable (table 9). Based on the means of treatments, honeybee, spotted maize beetle and house fly treatments did not differ significantly from the uncaged control treatments. Treatments with bollworm larvae and without pollinating insects showed a significant difference from the control plots at a 1% level. In the control plots the mean head diameter was 165,6mm, while for cages without insects and cages with bollworm larvae, the mean diameter was 152,0 and 148,3mm respectively.

The Mann-Whitney U-test was used to show the level of significance between the results of the five treatments against the uncaged controls. In terms of mean number of filled, hollow and under-developed seeds, the treatments with honeybees and spotted maize beetles did not differ significantly from the control at a 1% level (table 9). House flies and bollworm larvae treatments differed significantly at a 1% level from the control, except for the number of hollow seeds in the bollworm larvae treatment. In the treatment without pollinating insects the number of filled and under-developed seeds differed significantly from the control, while the number of hollow seeds did not differ significantly (table 9).

TABLE 10. SEED SET, MASS AND YIELD IN CAGE EXPERIMENTS WITH DIFFERENT INSECT POLLINATORS AT SETTLERS, 1986-1987.

Pollinator	Plants per cage	Achenes per head filled	Achenes per head total	Achenes per head mass (g)*	% Seed set		Yield (kg/ha)**
Control (Open plots)	33	1286	1772	59,98 (46,64)	Mean	72,6	1799
					S.D.	11,1	
					S.E.	1,05	
					Max.	92,5	
					Min.	36,2	
					n	111	
Honeybees	34	1270	1763	61,98 (48,80)	Mean	72,0	1859
					S.D.	7,22	
					S.E.	0,84	
					Max.	90,1	
					Min.	50,2	
					n	74	
Spotted maize beetles	36	1313	1728	72,01 (54,85)	Mean	75,9	2160
					S.D.	9,52	
					S.E.	1,07	
					Max.	94,2	
					Min.	53,8	
					n	79	
House flies	33	718	1890	43,66 (60,81)	Mean	37,9	1309
					S.D.	18,68	
					S.E.	2,15	
					Max.	76,9	
					Min.	1,2	
					n	75	
American bollworm larvae	33	870	1967	38,60 (44,36)	Mean	44,2	1158
					S.D.	12,25	
					S.E.	1,33	
					Max.	66,8	
					Min.	8,4	
					n	84	
No insect pollinators	34	723	1621	40,70 (56,28)	Mean	44,6	1221
					S.D.	19,07	
					S.E.	2,21	
					Max.	80,4	
					Min.	6,6	
					n	74	

* Mass of 1000 filled seeds in parentheses.
** Yield as achieved with 30000 plants per hectare.

The percentage seed set (table 10) in treatments with spotted maize beetle was slightly higher than those of the control, while those for honeybees were very much the same. Percentage seed set in house fly, bollworm larvae and no pollinating insect treatments differed significantly at a 1% level from the control. The large standard deviation (S.D.) and error of the mean (S.E.) reflected large variation in percentage seed set between individual heads of this commercial cultivar (table 10).

The number of plants per cage, filled seeds, and seed mass was used to calculate the yield of each treatment (table 10). The level of significance of the treatments and the control is illustrated in table 9, and is again clearly indicated by the differences in yield of treatments (table 10). The yield is dependent on plant density, number of filled seeds and mass of filled seeds. To evaluate the differences in mass of filled seeds of treatments, it is best to recalculate to mass of a 1000 filled seeds (given in parenthesis in table 10). It can be seen clearly that commercial sunflower compensate well for the loss in number of filled seeds where seed set was poor, by producing larger seeds. However, this compensation is not altogether adequate to make up for the poor seed set as shown by the achieved yields.

The yield increase in the open-pollinated control plots against treatments without insect pollinators was 47%. Honeybees produced a 52% yield increase when compared with the treatment without insect pollinators. The yield increase of spotted maize beetles and house flies was 76% and 7% respectively, while a 5% decrease was obtained with American bollworm larvae.

5.4. DISCUSSION

A decrease in seed set in sunflower treatments without pollinating insects was recorded by various researchers (Birch et al., 1985; Freud and Furgala, 1982; Furgala et al., 1978; Langridge and Goodman, 1974). The present study supports the findings of these researchers.

The results clearly indicate that house flies play no role in pollination. American bollworm larvae eat the floral parts and can even effect seed set adversely on a small scale. Damage done by these larvae is less significant in commercial plantings, because larvae are distributed between many plants.

Observations on the behaviour of house flies (Chapter 3, page 24) showed that they did not move as actively on heads or between heads as honeybees do. This may result in slow movement of pollen between florets and between heads. The poor seed set of 37,9% could not be attributed to insufficient numbers of flies, as more than 25 flies per cage were still alive when the bloom period had ended. The fifty house flies were also far more than the highest average of 2,24 flies per hundred heads recorded at Pretoria (table 2-2, page 19).

Though the best seed set and yield were obtained from treatments with spotted maize beetle, the usefulness of these beetles is restricted by biological factors (Chapter 3, page 25). The number of 150 beetles per cage was much higher than the highest natural mean of 10 beetles per 100 heads, observed in the western Transvaal during the survey. This high number of beetles was used, however, to facilitate the maximum range of up to 120 beetles per single head found in the field (see Table 2-2, page 19). Spotted maize beetle may contribute to pollination during certain times of the season or in localized areas, but in large commercial fields the influence of these beetles would be less significant due to clamped and sporadic occurrence. It must therefore be concluded that honeybees are the major pollinator of commercial sunflower in South Africa, though other insects may play a contributing role.

As in this investigation, Freud and Furgala (1982) also found a compensation in seed mass when fewer seeds were set, but this compensation was not enough to make up for the higher seed set in treatments with adequate pollination.

The number of underdeveloped seeds was relatively high, even for treatments with good pollination (table 9). According to Khanna (1972) the number of under-developed seeds is mainly affected by competition for water and nutrient supplies, as a physiological scarcity develops when good set is achieved. Herring (1981) reported on the phenomenon of the sterile head center and stated that this factor is normally overlooked when seed set is determined. Abortion of the central florets is a general phenomenon, and results in poor or no seed set of the central florets (Khadiikar and Mahajan, 1974), though it could also be induced or increased by drought or a boron deficiency.

As the physiology associated with hollow-seededness is still undecided it is difficult to explain the high percentage (24,6%) of hollow achenes in the treatment with house flies. The level of hollow-seededness in the control plots and treatments with other insect pollinators was below 5%. In the treatment with no pollinating insects it was 12,3%. A possible explanation is that where cross-pollination is inefficient, a high level of self-pollination could occur, resulting in either poor fertilization or abortion of the seed after fertilization.

Jain <u>et</u> <u>al</u>. (1978) listed the following factors as contributing to hollow-seededness: insufficient number of insect pollinators, slow movement of pollen, extremes of temperature, humidity and rainfall, heavy dose of nitrogenous fertilizers and large head size. In South Africa, hollow-seededness is usually noticeable when good yields are expected (Birch et al., 1985). In marginal or poor seasons hollow-seededness is hardly noticed as poor crops are excepted by farmers. These findings were confirmed during the present study. Hollow-seededness became most evident when conditions for growth were exceptionally good or when thin stands led to very large head size (mean head diameter larger than 250mm.) or when continuous bad weather results in inadequate pollination because of reduced insect activity.

With adequate numbers of pollinators present and good movement of pollen, the stigma is pollinated within the first 24 hours after it becomes receptive for pollen. In the absence of pollination the stigma can stay receptive for a period of 10 days or longer. During this period the style continues its growth and after ten days it can reach a size of twice its normal length. This elongated style can be an explanation for hollow-seededness, as the overgrown style may not supply the growing pollen tube with enough nutrients to reach the egg cell for fertilization.

6. DIFFERENTIAL ATTRACTIVENESS OF SOUTH AFRICAN SUNFLOWER CULTIVARS TO BEES

6.1. INTRODUCTION

Foraging honeybees discriminate between crops and even cultivars of the same crop when a choice is offered (Free, 1970). These preferences among foragers are determined by quantity and / or quality of nectar (Burmistrov, 1965; Vansell, 1934). Pollination and the eventual crop yield, is indirectly affected as foraging is influenced by availability and quality of nectar.

Factors which influence nectar production are discussed in full by Beutler (1953). These include air humidity, soil moisture, rain and temperature. General plant characteristics which influence nectar secretion include size of nectary, position of flower on plant, diameter of shoot, cultivar and age of flower. Because of these numerous environmental and plant variables, the quantity of nectar secreted cannot be used as an index of the performance of the nectary. The true secretory activity of a nectary can only be estimated from the sugar content of nectar that is secreted by a flower in 24 hours (Beutler, 1953).

Cirnu _et al_. (1974) and Shein _et al_. (1980) indicated that the accessibility of nectar and other morphological cultivar characteristics further influence preferences of honeybees. Corollar tube length is the most important discriminating factor in the case of sunflower as it limits accessibility.

Pigmentation is another important morphological characteristic. The flower heads of cultivars with dark pigmentation of stigmas are very similar in appearance to the heads of cultivars with light coloured stigmas in post-bloom stage. Dark pigmentation might resemble the signal that flowering has finished and nectar is no longer available (Shein et al., 1980). Beutler (1953) reached the conclusion that post-pistillate florets secrete less nectar. This was confirmed by Furgala et al. (1976).

With regard to accessibility of nectar, the tongue lengths was measured of sunflower-foraging bees belonging to three different families. These were the African honeybee, Apis mellifera scutellata (Apidae), a long tongue solitary bee, Anthophora sp. (Anthophoridae) and a short tongue solitary bee, Lasioglossum sp. (Halictidae). In taxonomically related studies of bee tongue lengths, the overall length is measured from the distal point of the submentum to the flabellum on the posterior end of the glossa (Ruttner, 1978 and Winston, 1979).

To determine the effective depth to which the different genera can extend their proboscis in the tubular sunflower floret, both behavioural and morphological phenomena were investigated. The honeybee can insert its proboscis (the labiomaxillary complex) into the narrow disk floret. Penetration was restricted by the broad labrum that covers the mouth opening. The length of the prementum and glossa was taken directly as the effective tongue length, as the prementum can be inserted to some extend into the corollar tube. In the Halictid bee, the total length of the prementum and glossa was also used as the effective tongue length. In the Anthophorid only the length of the glossa was taken into account.

6.2. MATERIAL AND METHODS

Nectar production

After consultation with the Grain Crops Research Institute, seventeen common as well as promising new cultivars of commercial sunflower were selected and grown in a glasshouse for comparative studies on nectar secretion. Five replicates of each cultivar were used.

Single sunflower plants were grown in 0,5 m^3 pots with a surface area of 0,32 m^2. A sandy-loam soil, mixed with 10% humus was used as growth medium. Fertiliser (N3-P2-K3) was applied to pots (0,25g/pot, which is equivalent to 800kg/ha). The plants were watered every day. A micronutrient solution containing i.a. boron was applied once, when the seedlings were one week old. The sunflowers were planted on 1986-11-08 and started flowering on 1987-01-07. The plants achieved heights of 1,80 -2,10 meters, with head diameters between 120 - 190 mm. This compared well with plants in commercial fields. The design of the experiment was a randomized block. Plants were spaced the same distance apart as for stands in a commercial sunflower field with 30 000 plants per hectare (fig. 24).

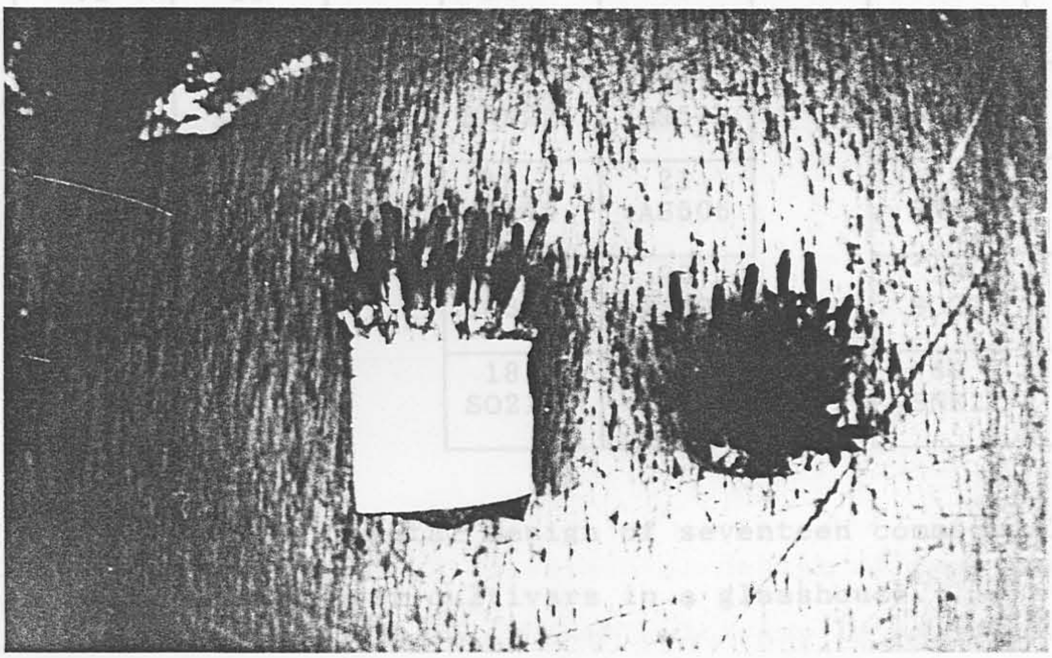

Fig. 23. Disk floret plug as prepared for centrifuging.

The centrifuge technique developed by Furgala <u>et</u> <u>al</u>. (1976) to extract nectar from the floral plug was used with minor modifications (fig. 23). Only floral plugs of the pistillate stage were used in the study, as Furgala <u>et</u> <u>al</u>. (1976) reported that such florets contained more nectar solids than did staminate or post-pistillate florets.

The glasshouse was isolated from all pollinating insects by wire gauze in front of all the ventilation openings.

01 SO306	12 PNR7441	13 AS540	24 AS532	25 AS515	36 SO210
02 SNK22	11 SNK22	14 SUNKING	23 PNR7225	26 SO323	35 AS540
03 PNR7204	10 SO171	15 SNK22	22 AS532	27 SO210	34 SO210
04 AS515	09 SO306	16 AS540	21 AS505	28 SNK26	33 AS532
05 SNK22	08 PNR7441	17 SO323	20 AS505	29 SO222	32 SO306
06 PNR7204	07 PNR7441	18 SO210	19 SO210	30 SNK22	31 SO171

Fig. 24. Experimental design of seventeen commercial sunflower cultivars in a glasshouse.

37 AS540	60 AS532
38 SO323	59 AS505
39 SNK26	58 SUNKING
40 SO222	57 AS515
41 SNK26	56 CAR1006
42 SNK25	55 AS532
43 CAR1006	54 SNK25
44 SO171	53 PNR7225
45 SO306	52 SO222
46 CAR1006	51 AS540
47 CAR1006	50 CAR1006
48 SNK25	49 SUNKING

	85 SNK26
61 PNR7204	84 AS505
62 SNK25	83 SUNKING
63 SO222	82 SNK26
64 SO222	81 SNK25
65 PNR7204	80 PNR7225
66 PNR7204	79 AS515
67 PNR7441	78 SUNKING
68 PNR7225	77 SO306
69 SO171	76 AS515
70 PNR7441	75 SO171
71 AS505	74 PNR7225
72 SO323	73 SO323

Fig. 24. (Continued) Experimental design of seventeen commercial sunflower cultivars in a glasshouse.

The temperature and air humidity in the glasshouse was recorded with a thermo-hygrograph. During the growth period the minimum temperature measured in the glasshouse was 18°C (between 05h00 and 06h00). The highest maximum temperature of 38°C was reached between 12h00 and 14h00. Relative humidity varied between 25% and 75%, during the growth period. During bloom the humidity varied between 35% and 65%, and the temperature between 21°C and 36°C.

One to four whorls of florets opened every night between 02h00 and 04h00. The anther tube had grown out fully by 05h00 but the first pollen was released only between 05h00 and 06h00. The growing style pushed the pollen out of the anther tube. Styles were fully extended by 17h00. The stigmatic lobes open between 17h00 and 24h00, at which time most of the pollen, released early in the morning, was no longer available. It would have been removed by pollen foragers or simply fallen from the floret due to gravitation. It is not uncommon to see pollen grains on the top leaves of the plant.

The pollen was removed twice a day with a light weight, battery operated vacuum cleaner. It was found that the removal of the pollen was essential prior to centrifuging to obtain accurate readings of nectar volume.

In preliminary investigations floral plugs from newly opened florets (staminate stage) were sampled at 07h30 and centrifuged. No nectar was centrifuged from these floral plugs. Plugs cut at 08h30 contained nectar. It was therefore assumed that florets of the pistillate stage, cut at 07h30, would represent nectar secretion over a period of 24 hours.

Floral plugs containing 30 - 40 pistillate florets were cut from the sunflower heads at 07h30, with a cork borer. These plugs were divided into three groups according to their position on the head, namely from the periphery, the intermediary section and the center of the head. The original randomized block with five replicates was subdivided with two to three plugs of each group from the same head over the eight day flowering period of the head. Ten to fifteen variants were thus obtained for each replicate. These plugs were transported in a polystyrene container to the laboratory. All non-pistillate stage florets were removed from the plugs which were then placed in calibrated sedimentation tubes and centrifuged at 1800 to 2000 r.p.m. for 10 minutes.

The volumes of nectar were recorded and the percentage solids were determined with an Atago 500 hand refractometer. The data were converted to volume nectar and mg. solids per 100 florets.

Attractiveness of flower heads and accessibility of nectar

In studies on the variation of morphological characteristics between cultivars which bees can discriminate, the colour of the disk floret corolla tube was estimated on a 1 - 5 point scale (Shein et al., 1980), 1 being the lightest and 5 the darkest. The stigmatic surface was similarly evaluated for colour on a 1 - 5 point scale. Furthermore the disk florets were measured with calipers from the distal section of the corolla tube to the most basal section of the corolla tube opening (fig. 25). The florets used for centrifuging were afterwards used for these measurements.

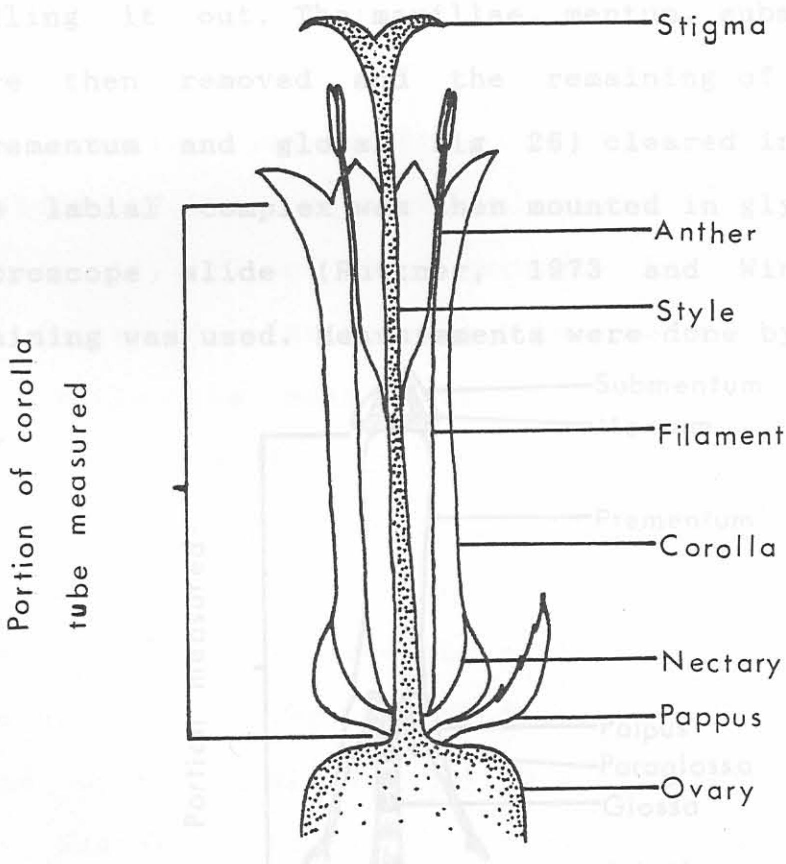

Fig. 25. Sunflower disk floret, to show portions measured.

Bee tongue lengths

Foraging honeybees and the two species of solitary bees were sampled at random while visiting commercial sunflower heads for measurements of tongue lengths. For honeybees this method of sampling is important, as honeybees from one colony might not reflect the true variation in tongue length.

The labiomaxillary complex of the bees being investigated was removed under a dissecting microscope by inserting a tweezer at the lorum, pushing the proboscis forward and pulling it out. The maxillae, mentum, submentum and muscles were then removed and the remaining of the labio complex (prementum and glossa Fig. 26) cleared in boiling 10% KOH. The labial complex was then mounted in glycerine jelly on a microscope slide (Ruttner, 1973 and Winston, 1979). No staining was used. Measurements were done by calipers.

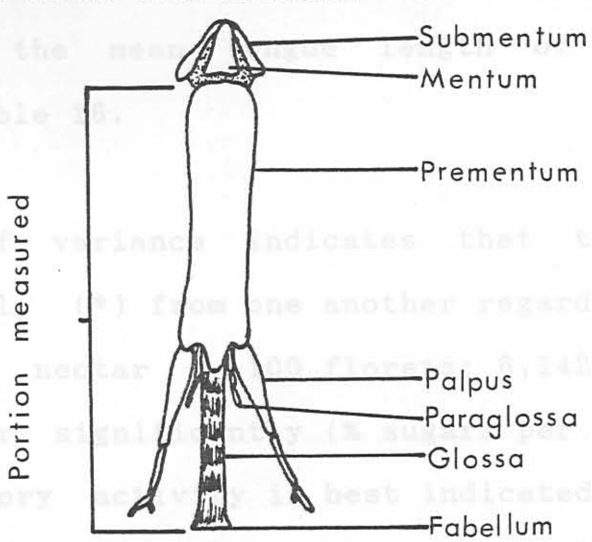

Fig. 26. Schematic drawing of the labial complex of bees, indicating the parts measured.

Statistics

Analysis of variance with random replication was carried out for the following variables: volume of nectar per 100 florets, mg solids per 100 florets and corolla tube length.

Degrees of freedom were: cultivars - 16; positions on head - 2; cultivars x positions - 32; replicates - 4. F-test and Bonferroni's t-test were used during analysis. Standard deviation (S.D.) and standard error of the mean (S.E.) was also calculated.

6.3. RESULTS

The quantity and quality of nectar obtained from pistillate florets of the seventeen evaluated cultivars is presented in tables 11, 12 and 13. Pigmentation of disk florets is given in table 14. The corolla tube length is presented in table 15, while the mean tongue length of three bee genera is shown in table 16.

Analysis of variance indicates that the cultivars differ significantly (*) from one another regarding the quantity of nectar (ul nectar / 100 florets: 6,142 *). Nectar quality also differ significantly (% sugars per 100 florets : 4.596 *). Secretory activity is best indicated by the mass of the solids secreted over a 24 hour period (table 13). A significant difference in secretory activity between

TABLE 11. MEAN VALUES IN ASCENDING ORDER FOR VOLUME OF NECTAR (ul / 100 FLORETS).

Cultivar	Mean	S.D.	S.E.	max.	min.	n
SO 171	188,03	73,00	24,30	321,5	76,9	19
PNR7204	231,94	72,29	20,86	355,3	105,2	29
SNK 25	241,00	78,85	20,36	404,0	129,2	38
SUNKING	247,44	48,70	12,57	358,5	163,3	39
SO 210	250,89	51,98	13,40	337,5	149,3	38
AS 540	255,16	63,47	15,86	383,4	144,7	40
CAR1006	257,58	81,78	23,60	381,8	152,2	29
SO 306	273,52	67,94	17,54	423,5	158,2	40
SO 222	279,82	65,01	16,78	355,6	166,4	36
AS 532	282,63	52,65	15,19	394,3	200,0	32
PNR7225	292,62	75,16	19,40	382,4	198,4	38
PNR7441	294,16	78,36	20,23	435,2	196,2	40
SO 323	310,14	84,17	21,73	519,3	193,2	36
SNK 22	310,74	60,91	40,60	412,6	198,1	40
AS 505	321,22	70,80	18,28	434,2	143,1	40
AS 515	357,78	99,32	33,10	455,9	151,5	21
SNK 26	359,45	86,92	22,44	546,9	221,6	39

TABLE 12. MEAN VALUES IN ASCENDING ORDER FOR CONCENTRATION OF NECTAR SOLIDS (% / 100 FLORETS).

Cultivar	Mean	S.D.	S.E.	max.	min.	n
AS 515	40,64	4,97	1,65	50,95	36,80	21
SNK 22	44,69	2,95	0,76	47,77	37,60	40
SO 306	45,84	4,70	1,21	52,13	38,77	40
AS 505	46,18	4,43	1,14	51,97	34,75	40
SNK 26	46,23	3,92	1,01	52,87	38,90	39
AS 532	46,35	5,67	1,63	51,50	34,70	32
PNR7441	46,96	4,60	1,18	52,03	35,77	40
PNR7225	47,98	7,89	2,03	58,67	32,40	38
SUNKING	48,28	3,84	0,99	54,03	39,90	39
CAR1006	48,39	3,00	0,86	52,65	42,85	29
PNR7204	48,78	2,91	0,84	53,45	42,30	29
SO 171	48,92	7,49	2,49	57,00	38,50	19
SO 323	49,43	4,35	1,12	55,60	42,67	36
SO 222	49,95	4,34	1,12	56,95	43,57	36
SNK 25	50,18	4,41	1,14	55,00	40,03	38
SO 210	50,41	4,30	1,11	57,25	41,73	38
AS 540	51,54	5,33	1,37	57,77	42,10	40

TABLE 13. MEAN VALUES IN ASCENDING ORDER FOR NECTAR SOLIDS (mg / 100 FLORETS).

Cultivar	Mean	S.D.	S.E.	max.	min.	n
SO 171	91,18	35,63	11,87	162,0	40,1	19
PNR7204	111,89	29,86	8,62	150,7	78,1	29
SUNKING	117,92	21,72	5,60	163,1	81,7	39
SNK 25	119,62	36,68	9,47	190,6	59,3	38
CAR1006	122,40	33,56	9,68	166,9	79,0	29
SO 210	125,56	25,19	6,50	170,9	92,0	38
AS 540	129,41	30,39	7,84	184,1	81,1	40
PNR7441	133,68	36,55	9,43	201,0	92,0	40
AS 532	134,38	31,38	9,05	200,2	90,6	32
PNR7225	135,43	21,32	5,50	165,5	103,9	38
SNK 22	138,20	24,06	6,21	185,3	92,4	40
SO 306	138,45	51,67	13,34	303,3	90,3	40
SO 222	138,70	27,49	7,21	191,7	85,0	36
AS 515	141,63	29,73	9,91	165,0	77,7	21
AS 505	146,60	29,36	7,58	186,4	74,0	40
SO 323	151,77	44,16	11,40	286,8	106,5	36
SNK 26	165,60	41,87	10,81	252,7	95,0	39

TABLE 14. MEAN PIGMENTATION VALUES FOR COROLLAR TUBE AND STIGMA OF SEVENTEEN SUNFLOWER CULTIVARS.

Cultivar	Corollar tube pigmentation	Stigma pigmentation	Range of stigma pigmentation
SO 171	1	1,00	1 - 1
SO 222	1	1,00	1 - 1
SUNKING	1	1,00	1 - 1
AS 540	1	1,00	1 - 1
AS 532	1	1,05	1 - 2
PNR7225	1	1,05	1 - 2
SO 323	1	1,08	1 - 2
SO 210	1	1,20	1 - 2
CAR1006	1	1,20	1 - 2
SO 306	1	1,50	1 - 3
AS 505	1	1,70	1 - 3
SNK 25	1	1,80	1 - 3
PNR7441	1	2,00	1 - 3
PNR7204	1	2,10	1 - 3
AS 515	1	2,20	1 - 4
SNK 22	1	2,80	1 - 4
SNK 26	1	4,80	4 - 5

cultivars can be expected, as it is a function of volume of nectar and concentration of sugars present in the nectar.

Corollar tube colouration, as evaluated at the distal portion of the corolla (fig. 21), for the seventeen cultivars were all rated as 1 (table 14). With the exception of PNR7441, PNR7204, AS 515, SNK 22 and SNK 26, all the cultivars were evaluated as less than 2 regarding pigmentation of the stigma (table 14).

A significant difference between corollar tube lengths of the seventeen cultivars was indicated by analysis of variance (16,430 *) (table 15). The shortest corollar tube lenght measured, was SNK 25 (4,93mm), while the longest was SUNKING, measuring 5,80mm. The mean tongue length for honeybees was 5,24mm, against 8,74mm for the anthophorid and only 1,62mm for the halictid.

6.4. DISCUSSION

Quality and quantity of nectar is influenced by a number of factors, as indicated by Beutler (1953). Working in a glasshouse causes some problems but these were outweighed by the need for plants grown under similar conditions for comparable results. The major problem with field experiments is to keep anthophilous insects from utilizing the nectar. It is possible to avoid this but enclosing heads or plants

TABLE 15. MEAN VALUES IN ASCENDING ORDER FOR COROLLAR TUBE LENGTH (mm).

Cultivar	Mean	S.D.	S.E.	max.	min.	n
SNK 25	4,934	0,34	0,08	5,64	4,39	38
SO 171	5,247	0,24	0,08	5,64	4,89	19
CAR1006	5,375	0,13	0,04	5,55	5,04	29
SO 210	5,378	0,29	0,07	5,95	4,95	38
PNR7225	5,399	0,18	0,04	5,71	5,11	38
SO 222	5,432	0,21	0,05	5,78	5,06	36
AS 540	5,422	0,22	0,05	5,75	4,99	40
PNR7204	5,436	0,17	0,05	5,83	5,17	29
SNK 26	5,480	0,29	0,07	5,97	5,00	39
AS 505	5,481	0,19	0,05	5,82	5,05	40
SO 323	5,498	0,30	0,07	5,94	5,09	36
AS 515	5,513	0,20	0,06	5,85	5,23	21
SO 306	5,546	0,25	0,06	5,99	5,16	40
AS 532	5,580	0,28	0,08	6,04	5,09	32
PNR7441	5,615	0,19	0,05	5,93	5,22	40
SNK 22	5,694	0,21	0,05	6,07	5,28	40
SUNKING	5,805	0,25	0,06	6,11	5,27	39

TABLE 16. MEAN TONGUE LENGTH OF THREE BEE GENERA VISITING SUNFLOWER

Taxon	Mean	S.D.	S.E.	max.	min.	n
Honeybee	5,24	0,082	0,015	5,39	5,08	30
Anthophorid	8,74	0,210	0,090	8,95	8,45	5
Halictid	1,62	0,067	0,030	1,70	1,55	5

with exclusion bags introduces a whole series of physical and physiological artifacts.

The significant differences found between nectar yielding capacities of cultivars under glasshouse conditions, suggest that similar differences could be expected under field conditions. Nectar yield in field conditions could further differ in various regions, as soil type and climatic conditions play a major role (Beutler, 1953).

Visual attractiveness of the head seems to be of little importance in modern hybrid cultivars. Pigmentation of the distal portion of the corollar tube and stigma was in an acceptable range with SNK 26 as the only exception.

When the average tongue length of honeybees (5,24mm) is compared to the mean range of corollar tube length (4,93 - 5.80mm), it can be seen that this parameter can be one of the most important discriminating factors. Shein et al. (1980) found accessibility of nectar of sunflower to be directly linked to abundance of foragers in a field. Under conditions where large heads develop, this factor can be of even greater importance. A low number of honeybees visit plants with long corollas, while the abundance on short corolla cultivars are higher (Shein et al., 1980). Long tongue anthophorid bees can reach nectar in all the cultivars and would presumably be able to do so under almost all growing conditions. Short tongue halictids cannot reach nectar in the tubular sunflower disk floret and forage only for pollen on the heads.

Morphological characteristics must be of great importance to sunflower geneticists when breeding cultivars with the most desirable characteristics for forager attractiveness.

Future research on attractiveness should include studies on pheromones released at nectar or pollen sources. Chemical volatiles produced by the plant could also be important pollinator attractants according to Etievant et al. (1984).

7. OTHER PLANTS AS COMPETITIVE NECTAR AND POLLEN SOURCES

7.1. INTRODUCTION

Although individual honeybees are flower-constant (oligolectic), it is seldom found that all foragers from a single colony will utilize the same nectar and / or pollen source (Hurd et al., 1980). It is therefore accepted that a certain percentage of foragers will explore other sources as well, even where colonies are adjacent to large plantings of a reliable and easily accessible food source such as sunflower.

Little is known about the role of surrounding vegetation as competitive nectar and / or pollen sources to sunflower. Weeds and / or other commercial crops within the vicinity of hives could attract honeybees and solitary bees in such numbers that the pollination of the target crop is drastically reduced. Competing nectar and / or pollen sources were mentioned by various researchers as one of the factors influencing the ability of honeybees to pollinate the target crop without, however, giving details (Benedek et al., 1972; Kleinschmidt and Harden, 1983; Krause and Wilson, 1981). Palmer-Jones and Forster (1974) reported hawkbit (Leontodon hispidus L.) and thistle (Cirsium arvense L.) as heavy competitors in New Zealand, though only localised.

To be regarded as a competitor, a plant must co-exist in the same locality and flower at the same time as the plant that it is competing with for pollinating insects. The competitors must also have pollen and / or nectar available as reward to the anthophilous insects. Competitors can attract anthophilous insects from the target crop at specific times of the day depending when nectar and / or pollen is available. In commercial sunflower, where pollen is shed early in the morning and the majority of nectar secreted before noon, plants attracting honeybees and solitary bees during this period, can be regarded as direct competitors. Afternoon competitors can be predicted to be of lesser consequence.

A plant's competitive status can be determined only by taking both the abundance of the plant and the number of pollinators that it attracts into account.

7.2. MATERIAL AND METHODS

Observations on honeybees and solitary bees at competitive plants

Observations on the abundance and diversity of pollinating insects on competitive nectar and pollen sources were conducted at Settlers, Pretoria and Hartbeesfontein during the sunflower bloom for 3 seasons (1985-1987). A general description of the areas is given in Chapter 3 (page 12).

Counts were made on plants surrounding the sunflower field where pollinator activity was observed. The same field record data sheet and methods described in Chapter 3 (p. 12) was used, with only a minor modification in the method of surveying. According to the type of plant involved, either the number of flowers per square meter was calculated and converted to a hundred flowers (as for plants such as the common 'dubbeltjie' and travellers' joy), or a linear route count was used, observing a hundred flowers (as for plants such as sage and sorghum). Data were recorded for each plant species, using table 1 (page 15).

To investigate nectar and pollen loads of honeybees foraging on competitive plants, foragers were caught in a ethyl acetate killing bottle. Honey stomachs were pulled out a tweezer. Nectar volume was determined, using the 1-5 scale developed by Johannsmeier (in press), while sugar concentrations were determined with an Atago 500 hand refractometer. Pollen baskets were investigated for pollen pollen or propolis loads.

A numeric nectar and pollen value was designated according to Anderson et al. (1983), to those competitors where enough data was recorded. This value is influenced by many factors such as quantity and quality of nectar and pollen, weather conditions and the reliability of the source Johannsmeier (in press).

Pollen trapping

An O.A.C.-type pollen trap was fixed onto a honeybee hive during three consecutive sunflower seasons (1985-1987) in Settlers (fig. 27). The pollen pellets trapped from the hive were sorted according to colour, size and texture. Pellets from each group was dissolve in water and grains mounted in glycerine jelly or as semi-permanent water mounts. Pollen grains were identified with a dissecting microscope.

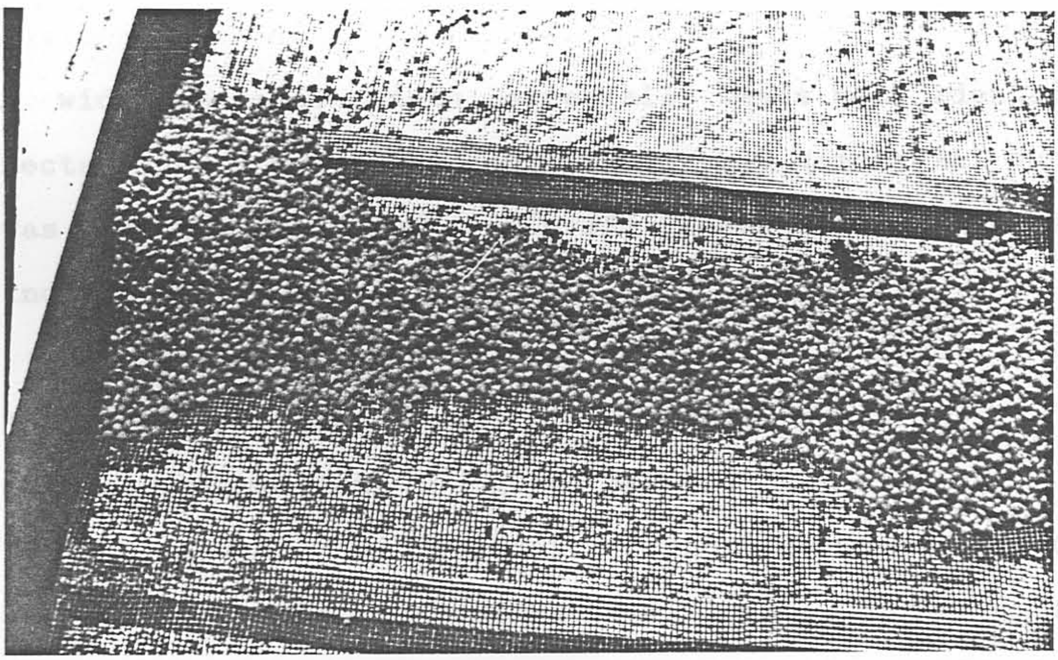

Fig. 27. Pollen pellets trapped by the O.A.C.-type pollen trap.

Mellissopalynology

A sample of 'pure' sunflower honey obtained in cleaned supers at Settlers in 1987, was analysed. The floral origin of the honey was determined by identifying and counting the pollen grains present in the honey with a dissecting microscope. A sample of honey was diluted in water and centrifuged. A permanent, glycerine jelly mounted pollen slide was made from the pollen sediment after staining with basic fuchsin in alcohol.

7.3. RESULTS

A wide range of plants, especially weeds were identified as nectar and / or pollen competitors when commercial sunflower was the target crop (table 17). These plants are discussed individually.

Amaranthus hybridus L. and A. thunbergii Moq.
(Amaranthaceae) Common and red pigweed

These pigweeds are commonly found in commercial sunflower fields. Only one honeybee was seen to collect pollen from A. hybridus during the period of observations at Settlers. No other records of honeybee visits to this weed are known. A. thunbergii pollen was identified from two of thirteen pollen trap samples, though in a very low quantities (less than 0,2%).

Bidens bipinnata L. (Asteraceae) Spanish black jack

Scattered individuals of this annual weed was found adjacent to experimental sunflower plots at Pretoria. Honeybees as well as solitary bees were observed to visit this weed for both nectar and pollen. No other observations were recorded.

Bidens pilosa L. (Asteraceae) Common black jack

Of the two species of black jack this is the more common one. It is nevertheless rarely noticed in commercial sunflower fields, being more common in the surrounding pastures or along roadsides. Two surveys on small 5x20m plots adjacent to sunflower plots of the same size were conducted during 1985 at Pretoria.

Medium to major activity of honeybees was observed before noon (34-44 honeybees / 100 capitula). Eighteen honeybees were each examined for nectar and pollen loads. Only four had nectar crops of size 3 and larger. Mean sugar concentration of the nectar was 27%. Fifteen foragers had pollen loads ranging in size from 1-5. Pollen pellets were of an orange-brown to light-brown colour. Bidens spp. is assigned a N2P2 value by Anderson, et al. (1983), which is confirmed by these limited observations.

Solitary bees of the Family Halictidae, which included the Subfamilies Halictinae and Nomiinae, occurred in numbers of 2-6 / 100 capitula. Other insects found included snout

TABLE 17. COMPETITIVE NECTAR AND POLLEN SOURCES AT SETTLERS, PRETORIA AND HARTBEESFONTEIN, 1985-1987.

Plant species	Settl.	Pta.	Htbfn.
Amaranthaceae			
<u>Amaranthus</u> <u>hybridus</u> (Common pigweed)	X		
<u>Amaranthus</u> <u>thunbergii</u> (Red pigweed)	X		
Asteraceae			
<u>Bidens</u> <u>bipinnata</u> (Spanish black jack)		X	
<u>Bidens</u> <u>pilosa</u> (Common black jack)	X	X	
<u>Flaveria</u> <u>bidentis</u> (Smelter's bush)	X		
<u>Tagetes</u> <u>minuta</u> (Khaki weed)	X	X	X
<u>Xanthium</u> <u>strumaruim</u> (Large cocklebur)	X		
Capparidaceae			
<u>Cleome</u> <u>monophylla</u> (Single-leaved cleome)		X	
Fabaceae			
<u>Sesbania</u> <u>bispinosa</u> (Spiny sesbania)	X		
Lamiaceae			
<u>Salvia</u> <u>reflexa</u> (Sage)	X		
Malvaceae			
<u>Hibiscus</u> <u>cannabinus</u> (Stockrose)	X		
<u>Hibiscus</u> <u>trionum</u> (Bladderweed)	X		
Myrtaceae			
<u>Eucalyptus</u> spp. (Eucalypts)	X	X	X
Poaceae			
grasses	X	X	X
<u>Sorghum</u> <u>vulgare</u> (Grain sorghum)	X		
<u>Zea</u> <u>mays</u> (Maize)		X	
Polygonaceae			
<u>Fagopyrum</u> <u>esculentum</u> (Buckwheat)		X	
Ranunculaceae			
<u>Clematis</u> <u>oweniae</u> (Traveller's joy)	X		
Zygophyllaceae			
<u>Tribulus</u> <u>terrestris</u> (Common 'dubbeltjie')	X		

beetles (Curculionidae), yellow bee pirates Philanthus diadema F. (Sphecidae), other sphecid wasps and bee flies (Bombyliidae).

Of the mean total of 54 insects / 100 capitula, honeybees represented 72%, solitary bees 19% and other insects 9%.

Clematis oweniae Harv. (Ranunculaceae) Traveller's joy
This is an indigenous climber found closely associated with trees such as acacias as supports. It is also commonly found along roadside fences in the Springbok Flats. Five surveys of insects visiting this plant were done at Settlers during the 1985 and 1986 seasons.

Minor to medium honeybee activity was recorded before noon, with no activity in the afternoon. Honeybee numbers ranged between 3 - 20 / 100 flowers. Twenty-four foragers were investigated for nectar or pollen loads. All crop sizes were in the order of 0-2, indicating that this plant is not a source of nectar for honeybees. All foragers had light lemon coloured pollen loads, ranging in size from 2-5. Very minor honeybee activity was observed directly after a rain shower. This plant is assigned a P2 value.

No solitary bees were observed to visit traveller's joy. Other insects included net-winged beetles (Lycidae), flies (Diptera) and African humming moths, Macroglossum trochilus

Hübner (Sphingidae).

The mean total insects on a hundred flowers was 50. Honeybees represented 86% of flower visitors.

Clematis pollen was present in six samples from a total of thirteen pollen trap samples from Settlers (table 18). The frequency ranged between 0,1 - 6,8% with a mean of 1,4%. In pollen analyses of sunflower honey from Settlers, Clematis represented only 0,3% of 636 pollen grains (table 19).

Cleome monophylla L. (Capparidaceae) Single-leaved cleome
Two surveys were done on two small plots (5 x 20m) adjacent to sunflower plots of similar size at University of Pretoria Experimental Farm during 1985.

Minor to medium honeybee activity was observed before noon with no activity after noon. Honeybee frequency ranged from 4-12 honeybees / 100 flowers. Of nine honeybees that were sampled, only one had a medium-sized crop (size 3) with a sugar concentration of 41%. All honeybees carried a khaki to light brown pollen (size range 2-4). A N1?P2 value is given to Cleome.

TABLE 18. POLLEN TRAP ANALYSIS OF POLLEN TRAPPED FROM A HIVE ADJACENT TO COMMERCIAL SUNFLOWER FIELDS AT SETTLERS, 1985-87

Date	Number pellets examined	Sunflower %	Grasses %	Other %
1985: (Yura farm)				
1985-03-15	891	96,3	3,7	0
1985-03-20	1708	72,7	27,2	0,1
1985-03-22	812	78,3	20,8	0,9
1985-03-27	1407	65,7	34,1	0,2
1986: (Yura farm)				
1986-03-20	1786	91,6	7,9	0,5
1986-03-24	1529	95,5	4,0	0,5
1986-04-02	1607	99,3	0,5	0,2
1986-04-11	613	96,6	3,4	0
1987: (Semmelink farm)				
1987-02-23	1414	79,0	20,5	0,5
1987-03-02	1513	83,0	16,4	0,6
1987-03-09	817	67,0	16,8	16,2
1987-03-16	1736	90,5	1,6	6,9
1987-03-31	1449	81,6	0,4	18,0

The frequency and diversity of solitary bees were relatively high, compared to their numbers on sunflower (table 19). The following species were recorded:

Halictidae:	Zonalictus sp.	2-10 / 100 flowers
	Lasioglossum (2 spp.)	2-4 / 100 flowers
	Nomiinae (2 spp.)	4-8 / 100 flowers
Anthophoridae:	Anthophora sp.	2 / 100 flowers

Other insects include sphecid wasps (Sphecidae) and hover flies (Syrphidae).

The mean total of insects on single-leaved cleome was 34 / 100 flowers. Honeybees represented only 24% of the total insect population, with solitary bees 64% and other insects 12% (table 20).

Eucalyptus species (Myrtaceae) Eucalypts

Eucalypts are major nectar and pollen competitors where they flower at the same time as sunflower. Eucalypts with a flowering period overlapping that of commercial sunflower on the Highveld include E. camaldulensis (N3P3), E. viminalis (N2P2) and to a lesser extent E. sideroxylon (N4) and E. melliodora (N4). Eucalypts are commonly seen on Highveld farms as wind shelters or shade trees. During the investigations, only E. sideroxylon was flowering in 1986 during the sunflower bloom in Settlers. Eucalypts in general are considered exceptionally good beeplants (Anderson et al. 1983), and honeybees are known to forsake other forage.

TABLE 19. POLLEN ANALYSIS OF A 'PURE' SETTLERS SUNFLOWER HONEY, APRIL 1987.

n=636

61,6%	<u>Helianthus</u>.
16,3%	<u>Eucalyptus</u>. Small grains: sizes 1 and 1(-). Larger grains punctate.
4,7%	<u>Xanthium</u>.
3,9%	Poaceae. Size 3.
2,5%	Liliaceae. Similar to <u>Aloe</u>.
2,3%	Papilionaceae? Size 2, subprolate, 3-colporate. Thick exine heavily reticulated away from colpi. Faint cross-pori.
1,4%	Unknown. Size 2(+), oval in equatorial view and round in polar view, 3-colporate. Colpi long. Pori +/- square. Exine finely punctuate. Contents sometimes granular. Tiliaceae?
1,4%	Unknown. Size 2, irregularly-shaped, thin clear exine. Long sunken colpi. Pseudocolpi? 3-colporate.
1,3%	Unknown. Size 1, subprolate, 3-colporate. Thin exine. Long colpi.
0,9%	Unknown. Size 1, <u>T. repens</u> habitus, 3-colporate. Exine medium and punctuate.
0,8%	Unknown. Size 2(+), irregularly round, 3-porate? Exine thick and smooth.
0,6%	<u>Sorghum</u>. Size 4.
0,6%	<u>Zea</u>. Size 5.
0,5%	<u>Tribulus</u>.
0,3%	Unknown. Size 2, angulaperturate, 3-colporate. Exine medium, finely punctate, finely striate in OS. Colpi 3/4 to poles, with centre 'ridge'.
0,3%	<u>Clematis</u>. Granular colpi.
0,3%	<u>Acacia</u>. With furrows, 16 cells.
0,2%	Campanulaceae? Size 3(-), round, 3-porate. Thick smooth exine. Pori globular.
0,2%	Acanthaceae. <u>Ruellia</u> type. Size 3-4, round, 5-porate? Fine puncti within reticules.

Honey extracted from three 'clean' supers. A golden honey (61mm Pfund) of medium density (18,6% moisture). Soft, fine, beige-coloured granulation. Bland sweet taste.

TABLE 20. PERCENTAGE FREQUENCY OF SOME ANTHOPHILOUS INSECTS TO COMPETITIVE NECTAR AND POLLEN SOURCES IN RELATION TO SUNFLOWER AT SETTLERS, PRETORIA AND HARTBEESFONTEIN, 1985-1987.

Plant species	Number of insects / 100 flowers	Frequency of insects %		
		honeybees	solitary bees	all other insects
Helianthus annuus *1	45	72	0,6	27,4
Helianthus annuus *2	147	90	1	9
Helianthus annuus *3	64	47	1	52
Bidens pilosa	54	72	19	9
Clematis oweniae	50	86	0	14
Fagopyrum esculentum	14	57	7	36
Flaveria bidentis	12	25	33	42
Salvia reflexa	7	57	14	29

*1 as recorded at Settlers (Table 2-1)

*2 as recorded at Pretoria (Table 2-2)

*3 as recorded at Hartbeesfontein (Table 2-3)

No Eucalyptus pollen was present in any of thirteen pollen trap samples from Settlers. In the pollen analysis of a sunflower honey, Eucalyptus however comprised 16.3% of 636 pollen grains (table 18).

Fagopyrum esculentum Moench. (Polygonaceae) Buckwheat

Two surveys were conducted on this crop during 1986, on 5 x 20m plots next to similar sunflower plots at the University of Pretoria Experimental Farm.

Minor to medium honeybee activity was observed in the morning. Foragers ranged from 4-13 / 100 flowers. Both nectar and pollen were collected. Nectar and pollen loads were not evaluated. Buckwheat is rated by Anderson et al. (1983) as a major foraging source for honeybees (N4P2).

During the period surveyed, only one solitary halictid bee was observed to visit buckwheat flowers. Other insects included spotted maize beetle and yellow bee pirates. The mean total insects on buckwheat was 14 insects / 100 flowers. Honeybees accounted for 57%, solitary bees for 7% and other insects for 36% of the total flower visitors (table 20.)

Flaveria bidentis L. (Asteraceae) Smelter's bush

This is an uncommon weed on disturbed soil around ploughed fields, but is more commonly seen along roadsides. Two surveys were undertaken during 1985 at Settlers. Minor honeybee activity was detected in the morning (2-3 honeybees / 100 capitula). Of three honeybees examined, all had orange pollen in their baskets, pellets ranging in size from 2-4. Foragers had no noticeable nectar crops. Smelter's bush is rated on this limited observations as a N0?P1? pollen plant. No activity was observed after rain.

The frequency of solitary bees on smelter's bush was low, 1-3 / 100 capitula, though the diversity was relatively high. Three genera of the Family Halictidae were recorded from this weed, namely Lasioglossum sp., Sphecodes sp. and Halictus sp. Other insects included net-winged beetles (Lycidae); masarid wasps (Masaridae); paper wasps Belanogaster sp. (Vespidae); yellow bee pirate Philanthus diadema F. (Sphecidae); house flies (Muscidae); bee flies Lomatia sp. (Bombyliidae); African humming moths Macroglossum trochilus Hübner (Sphingidae).

The mean total of insects per hundred capitula was twelve. Honeybees comprised 25%, solitary bees 33% and other insects 42% of the total number of anthophilous insects (table 20).

Grasses (Poaceae)

Other than natural pastures, these also included weeds such as <u>Urochloa panicoides</u> Beauv. (herringbone grass); <u>Cynodon dactylon</u> (L.) Pers. (common couch) and <u>Paspalum notatum</u> Flügge (lawn paspalum). Minor to medium solitary bee activity was observed on all three species at the University of Pretoria Experimental Farm, while honeybees were only seen on the last mentioned. Foraging activity was restricted to early morning when, pollen was collected. No observations were made in the natural pastures.

Grass pollen was present in all of the thirteen pollen trap samples from Settlers. It ranged in frequency from 0,4 - 34,1% with a mean of 12,1%. Pollen pellets from the various grass species differ in colour, being from brown to green. A P3 pollen value is given to grasses based on pollen trapping in Settlers (table 18). Anderson <u>et al</u>. (1983) rated grasses as P1-3.

Although grasses are a pollen source only, they nevertheless comprised a relatively high 3,9% of 636 pollen grains from a Settlers sunflower honey gathered during the period 1987-02-10 to 1987-03-30.

<u>Hibiscus cannabinus</u> L. and <u>H</u>. <u>trionum</u> L. (Malvaceae)

These two annual weed species occur at Settlers in disturbed soil surrounding commercial sunflower fields. During several observations no honeybee or solitary bee activity was noted on their flowers.

Hibiscus pollen was nevertheless present in two of the thirteen samples from Settlers. It comprised a minor part of the total pollen pellets, occurring in quantities of 0,1 and 0,4% respectively, with a mean of 0,25%.

Salvia reflexa (Lamiaceae) Sage

This is an indigenous perennial that occurs commonly as part of the natural vegetation in grass veld. Four surveys were done at Settlers during 1985 and 1986.

Minor honeybee activity was observed throughout the day. Honeybees ranged from 3-6 / 100 flowers. Of the eight honeybees examined, all had crop sizes of 2 and smaller. All honeybees had yellowish pollen loads with sizes of between 2-4. No activity was observed directly after rain. Sage is designated a N0?P1 value based on these observations.

Solitary bees of the Families Halictidae and Anthophoridae were recorded as visiting the flowers. Other insects recorded included hover flies (Syrphidae), butterflies and African humming moths (Sphingidae). The mean total number of floral visitors was 7 / 100 flowers. Honeybees comprised 57%, solitary bees 14% and other insects 29% of the insect visitors (table 20).

Sesbania bispinosa (Jacq.) W.F. Wight (Fabaceae) Spiny sesbania

No honeybees had been observed on this weed of disturbed soil and roadsides during the three seasons of 1985 to 1987. Solitary bees of the Family Anthophoridae, genera Anthophora and Tetralonia, were more commonly observed on this weed than on commercial sunflowers. Bees of these genera are large and capable of opening the sesbania calyx to reach the protected nectar.

Sorghum vulgare L. (Poaceae) Grain sorghum

Two surveys were carried out at Settlers during March 1986 on sorghum regrowth, adjacent to sunflower fields.

Minor to medium activity of 2-14 honeybees / 100 sorghum ears was observed very early in the morning, before 08h00. At this time no honeybee activity was recorded on the adjacent sunflower. Honeybees collected a straw-yellow coloured pollen from the ears. At 10h00 only one honeybee was observed on all of the sorghum. Sorghum is a known source of aphid honeydew honey, when aphids are present in large numbers on the sorghum. No honeydew foraging was observed, as the aphid populations were probable to low. No visible honeydew could be seen. Sorghum is given a P2 value based on these observations.

Two halictid bees / 100 ears were collecting pollen.

A 'pure' sunflower honey sample from Settlers contained 0,45% sorghum pollen (n = 636) (table 19).

Tagetes minuta L. (Asteraceae) Khaki weed

Very minor activity of honeybees was observed on khaki weed capitula in Settlers, Pretoria and Hartbeesfontein during the seasons of 1985 to 1987. The main flowering period of this annual weed is usually after the sunflower bloom. Major activity of yellow bee pirates was observed at Pretoria, where capitula were visited for nectar.

Tribulus terrestris L. (Zygophyllaceae) Common 'dubbeltjie'

Medium honeybee activity was observed at Pretoria and Settlers early in the morning during the three seasons of 1985 to 1987. Both nectar and pollen were collected. Flowers closed by 11h00 in sunny weather, bringing honeybee activity on these flowers to a halt.

Solitary bees of the Family Halictidae were found on flowers of this weed, gathering nectar and pollen. These bees were not recorded on sunflower.

Tribulus comprised 0,5% of 636 pollen grains from a Settlers sunflower honey (table 18).

Xanthium strumarium L. (Asteraceae) Large cocklebur

Large cocklebur pollen was present in three of thirteen pollen trap samples, all from the same locality, viz. Semmelink farm in Settlers, during 1987. It ranged from 0,8 to 12,2%, with a mean of 5,7%. In a pollen analysis of a sunflower honey from the same locality, this pollen comprised 4,7% of 636 pollen grains. No records of honeybee activity on the plants were encountered. According to Johannsmeier (personal communication, 1988) this pollen is collected early in the morning in Pretoria.

Zea mays L. (Poaceae) Maize

Maize pollen was present in a sunflower honey sample obtained from Settlers in 1987 in a very small quantity (0,6% of 636 pollen grains). In Settlers the main maize pollen shed was prior to the sunflower bloom during the seasons 1985-1987. In Pretoria major pollen gathering activity was observed during 1986 and 1987 on experimental maize plots of ca. 10 hectare in total, adjacent to experimental sunflower plots of ca. 2 hectare. According to Anderson et al. (1983) maize has a P4 pollen value.

7.4. DISCUSSION

Pollen trapping during the three seasons of 1985, 1986 and 1987 produced fifteen pollen sources in the Settlers area. The origin of five of these is still unknown. Pellets consisting of propolis (bee glue) and fungal spores were also found. Sunflower pollen was the predominant pollen in all of the thirteen pollen trap samples. It ranged in frequency from 67% - 99,3%. This indicates satisfactory visitation to commercial sunflower pollen gatherers, where adequate honeybees are present due to migrated hives.

Pollen trapping showed grasses to be a major pollen source at certain times during the sunflower bloom period. This was particularly noticeable about two weeks after good rains. Pollen sources other than sunflower and grasses contribute little to the total pollen trapped and can be regarded as insignificant. With the exception of three samples, the 'other' pollens contributed less than 1% of the total sampled (table 16). In the pollen sample of 1987-03-09, the 16,2% 'other' pollen pellets consisted of 12,2% Xanthium and 4,0% represented by six species of minor importance. The 1987-03-16 sample was made up of seven minor pollen sources and propolis, totalling 6,9% of all pellets. Clematis (6,8%) and Xanthium (4,6%) were the major pollen sources, excluding Helianthus in the third sample of 1987-03-31. A further eight 'other' sources contributed to the (6,6%) (table 18).

Johannsmeier (personal communication, 1988) found maize to be the second most important pollen source after sunflower at Settlers (1984) and Moloto (1985 and 1986). This could only have been as a result of sunflower and maize plantings in close proximity, with pollens available during the same period. No maize pollen was found in pollen traps at Settlers during the period studied (table 18) and Moloto during 1987 (Johannsmeier, personal communication, 1988). Kleinschmidt (1986) working in Australia, found maize to be a major pollen competitor to sunflower.

Mellissopalynology of a 'pure' sunflower honey from Settlers, 1987 (table 19) revealed that nineteen plant species were represented in the honey. Ten of these could not be identified. Sunflower contributed 61,6%, an Eucalyptus sp. 16,3%, Xanthium 4,7%, grasses 3,9% and all other species less than 3%.

In an April 1983 sunflower honey from Settlers, sunflower represented 96% of the pollen, grasses 2% and four different weeds a combined total of 2% (Johannsmeier, 1984). The relatively high content of grass pollen (Settlers, April 1987: 3,9% and Settlers, April 1983: 2,0%) in the honey is of interest as grasses are not sources of nectar. Maize and sorghum, which are pollen sources only, each contributed 0,6% to the pollen in the 1987 honey sample. Pollen, from these exclusively pollen producing plants, are believed to be incorporated into honey by either pollen foragers that switch to nectar foraging or by contamination inside the hive. Pollen foragers switch readily to nectar gathering when pollen is no longer available. Foragers, inside the hive, have regular contact with one another resulting in direct exchange of pollen on the setae, but also through grooming.

Observations on the abundance of weeds, natural vegetation and other crops surrounding commercial sunflower fields in the Transvaal, together with the frequency of honeybee and solitary bee activity on these plants, indicated that only a very few plant species can be regarded as competitors of any consequence. The status of all competitive nectar and pollen sources is determined by their abundance, time of flowering, climatic conditions and attractiveness to honeybees and solitary bees.

The more important competitors identified in this study were grasses, maize, eucalypts, traveller's joy and large cocklebur. Though weeds are of lesser importance as forage for honeybees, they could be important nectar and pollen sources to especially the short-tongued Halictid bees, judging by their frequency of occurrence (table 19). Even long-tongued anthophorid bees might prefer a source such as spiny sesbania, to sunflower. In Settlers, no weed control would be recommended or necessary during sunflower bloom other than mowing of the vegetation in the immediate vicinity of sunflower.

8. CONCLUSIONS

1. While a wide range of insects visits the commercial sunflower capitulum. The most important insects contributing to pollination of sunflower are honeybees and spotted maize beetle, as inferred from their numbers and behaviour and morphological characteristics.
2. The diversity and abundance of anthophilous insects in a region is influenced by many factors, such as surface area of cultivated land, pesticide application and competitive nectar and pollen sources.
3. Though certain solitary bees are very efficient pollinators, their numbers are restricted in the study areas, presumably because of low reproductive rates.
4. Various nocturnal insects visits the sunflower capitulum but their role in pollination is of minor significance due both to their behaviour on the head and low numbers.
5. Daily and seasonal activity curves for honeybees indicated that they are present in sufficient numbers for effective pollination where hives are supplied by migratory beekeepers. Strip counting confirmed the theoretical calculation of one hive per hectare required for adequate pollination in commercial fields (Du Toit, 1987). Birch, <u>et al</u>. (1985) concluded that natural honeybee populations are invariably not adequate.
6. Cross-pollination efficiency of honeybees is very good as more than 50% of foragers land on the outer ring of

florets, moving to the inner ring where fresh pollen is available, before taking off for the next head. Movement between heads is indiscriminate, ensuring good pollen movement.

7. Anderson, et al. (1983) recommended a source of water for *Apis mellifera scutellata* where beekeepers migrate to summer crops such as sunflower. Water was present at dams in the vicinity of the hives. The importance of a fresh-water source for honeybees is uncertain, as water foraging reached a level of only 2% during the bloom period. No significant drop in nectar foraging was observed in sunflower fields in the studied regions.

8. The pollination efficiency of honeybees is confirmed by controlled cage plots with honeybees as pollinating insects, evaluated against similar cages with no insect pollinators. Cages with honeybees gave a yield of 1859 kg/ha (72% seed set) against 1221 kg/ha (45% seed set) of cages with no insect pollinators. A 52% yield increase was thus obtained with honeybees as pollinators.

9. With controlled cage studies the role of American bollworm larvae and flies were demonstrated to be insignificant. Spotted maize beetle was proved to be an efficient pollinating insect if present in sufficient populations. Their contribution are further restricted by their seasonality and pest status.

10. While quality and quantity of nectar varied significantly between cultivars, nectar accessibility is the most important factor affecting honeybee visits. Accessibility is influenced by plant growth. Lush vegetative growth of plants during seasons of high rainfall will result in large heads with deeper corollas, putting nectar out of the reach of honeybees. To avoid this, planting density should be increased in high rain seasons or areas to limit head diameter below 200mm.
11. Pollen trapping showed maize, grasses, _Xanthium_ and _Clematis_ as major 'other' pollen sources available to honeybees in vegetation surrounding sunflower fields. Mellisophalynology indicated _Eucalyptus_ spp. as major 'other' nectar sources. With existing farming practices, competition from surrounding vegetation can be disregarded.
12. Surrounding vegetation can be important in attracting solitary bees, as these bees showed a general preference for flowers other than sunflower. This phenomenon could become important where the use of managed solitary bees should be attempted or in fields for hybrid seed production. Short-tongued solitary bees (Halictidae) visit sunflower for pollen only, as they can not reach the nectar in the tubular corolla. This, however, limits rather than enhances good pollen movement.

9. SUMMARY

Problems with hollow seededness experienced in the Springbok Flats resulted in preliminary investigations into the role of honeybees in commercial sunflower. This was followed by the present more comprehensive study of sunflower pollination ecology.

Activity, abundance and diversity of all anthophilous insects on sunflowers were recorded. These revealed honeybees, supplied by migratory beekeepers, to be the most important pollinators of commercial sunflower in South Africa. Adequate honeybee numbers were determined to be at hive densities of 1 colony / ha.

Daily and seasonal honeybee activity in commercial sunflower fields is discussed in more detail. Factors influencing activity are identified and include temperature, rain, pesticides and competitive vegetation.

The pollination efficiencies of various insects were determined in controlled cage studies. 72% Seed set was achieved with honeybees, 76% with spotted maize beetle, 38% with flies, 44% with American bollworm larvae, whereas seed set with no pollinating insects was 44%. A seed set of 72% was achieved in open control plots.

Seventeen popular or promising commercial South African sunflower cultivars were evaluated regarding nectar quality and quantity under similar glasshouse conditions. The tested cultivars differed significantly. Nectar accessibility was determined by measuring corollar tube length. Nectar was generally accessible to honeybees and long-tongued bees, while inaccessible to short-tongued Halictidae. Floral pigmentation amongst the seventeen cultivars, was not a discriminating factor.

Hardly any of the vegetation surrounding sunflower fields can be regarded as competitive. Maize, grasses, <u>Xanthium</u> and <u>Clematis</u> are the most important pollen sources other than sunflower, with the latter comprising between 70 - 99% of the collected pollen. <u>Eucalyptus</u> species were found to be the most important nectar source, excluding sunflower.

10. OPSOMMING

Probleme met betrekking tot holsadigheid in die Springbokvlakte het aanleiding gegee tot 'n voorlopige ondersoek na die rol van heuningbye as bestuiwers in kommersiële sonneblomlande. Dié ondersoek is gevolg deur die huidige, meer uitgebreide studie van sonneblom bestuiwings-ekologie.

Aktiwiteit, getalle en verskeidenheid van alle blombesoekers op sonneblom is aangeteken. Hieruit blyk dat heuningbye wat voorsien word deur migrerende byeboere die mees belangrike bestuiwers van kommersiële sonneblom in Suid-Afrika is. Voldoende bestuiwing is waargeneem by 'n korfdigtheid van 1 kolonie per hektaar sonneblom.

Heuningbye se aktiwiteit en seisoenale verandering in kommersiële sonneblomlande word in meer besonderhede bespreek. Faktore wat aktiwiteit beïnvloed sluit temperatuur, reën, gistowwe en kompiterende plantegroei in.

Uitsluitings-eksperimente is gedoen om die bestuiwings-effektiwiteit van verskillende insekte te bepaal. 72% Saadset is verkry met heuningbye, 76% met bont mieliekewers, 38% met vlieë, 44% met Amerikaanse bolwurmlarwes, terwyl saadset met geen insekbestuiwers 44% was. 'n Saadset van 72% is ook behaal in kontrole-persele uit die res van die land.

Sewentien gewilde of belowende kommersiële Suid-Afrikaanse sonneblom kultivars is geëvalueer om nektar kwaliteit en kwantiteit onder dieselfde glashuistoestande te bepaal. Die ondersoekte kultivars het betekenisvol van mekaar verskil. Nektar toeganklikheid was bepaal deur die blombuis-lengte te meet. Nektar was oor die algemeen toeganklik vir heuningbye en ander lang-tong bye, maar ontoeganklik vir kort-tong bye (Halictidae). Blom pigmentasie van die sewentien ondersoekte kultivars was nie 'n diskriminerende faktor nie.

Weinig van die normale plantegroei rondom sonneblomlande kan as kompeterend vir bestuiwing beskou word. Mielies, grasse, <u>Xanthium</u> en <u>Clematis</u> is die belangrikste stuifmeelbronne buiten sonneblom, waar laasgenoemde tussen 70 - 99% van die versamelde stuifmeel kan uitmaak. <u>Eucalyptus</u> species is die belangrikste nektarbron buiten sonneblom.

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13. APPENDIX A. CHECK LIST OF ANTHOPHILOUS INSECTS FOUND ON SUNFLOWER (HELIANTHUS ANNUUS)

Species	Settlers	Pretoria	Hartbeesfontein
ORTHOPTERA			
Tettigoniidae	(1 sp.)	-	-
Acridoidea	1 sp.	1 sp.	-
PHASMATODEA			
Phasmatidae	(1 sp.)	-	-
MANTODEA	-	1 sp.	-
HEMIPTERA			
Reduviidae	-	-	1 sp.
Coreidae	1 sp.	1 sp.	-
Pyrrhocoridae	1 sp.	-	1 sp.
Lygaidae	2 spp.	2 spp.	2 spp.
Cercopidae	1 sp.	-	-
Cicadellidae	2 spp.	1 sp.	2 spp.
Aphididae	-	1 sp.	-
NEUROPTERA			
Chrysopidae	1 sp.	-	-
COLEOPTERA			
Scarabaeidae:			
Cetoniinae	1 sp.	1 sp.	1 sp.
Lycidae	-	1 sp.	-
Melyridae:			
Astylus atromaculatus	1 sp.	1 sp.	1 sp.

	Settlers	Pretoria	Hartbeesfontein
COLEOPTERA (Continue)			
Coccinellidae	-	1 sp.	-
Tenebrionidae:			
Lagriinae	1 sp.	-	-
Meloidae	1 sp.	-	1 sp.
Anthicidae	1 sp.	-	-
Chrysomelidae:			
Alticinae	1 sp.	-	-
Bruchidae	2 spp.	-	-
DIPTERA			
Asilidae	-	-	-
Bombyliidae:			
Lomatia sp.	1 sp.	1 sp.	1 sp.
Syrphidae:			
Metasyrphus sp.	1 sp.	1 sp.	1 sp.
Eristalinus sp.	1 sp.	1 sp.	1 sp.
unidentified	2 spp.	2 spp.	1 sp.
Tephritidae	1 sp.	1 sp.	1 sp.
Anthomyidae:			
Anthomyia sp.	1 sp.	-	-
Muscidae	1 sp.	1 sp.	1 sp.
Calliphoridae:			
Rhinia sp.	1 sp.	1 sp.	-
unidentified	1 sp.	1 sp.	1 sp.
Tachinidae	-	1 sp.	1 sp.

	Settlers	Pretoria	Hartbeesfontein
LEPIDOPTERA			
Pyralidae:			
Zinckenia fascialis	1 sp.*	-	-
Nymphalidae	2 spp.	1 sp.	1 sp.
Pieridae	2 spp.	1 sp.	-
Sphingidae:			
Macroglossum trochilus	-	1 sp.	1 sp.
unidentified	(2 spp.)	-	-
Arctiidae:			
Utetheisa pulchella	(1 sp.)	-	-
Noctuidae:			
Heliothus amigera	1 sp.*!	1 sp.~	1 sp.~
Agrotis segetum	(1 sp.)	-	-
Agrotis spinifera	(1 sp.)	-	-
Mythimna loreyi	(1 sp.)	-	-
Trichoplusia orichalcea	1 sp.~	-	-
HYMENOPTERA			
Chalcidoidea	-	1 sp.	-
Scoliidae	1 sp.	1 sp.	1 sp.
Pompilidae	-	1 sp.	-
Vespidae:			
Belanogaster sp.	-	1 sp.	-
Polistis sp.	-	1 sp.	1 sp.

	Settlers	Pretoria	Hartbeesfontein
Sphecidae			
Larrinae:			
Philanthus diadema	-	1 sp.	1 sp.
Sphecinae	1 sp.	2 spp.	1 sp.
Halictidae			
Halictinae:			
Halictus sp.	1 sp.	1 sp.	1 sp.
Lasioglossum spp.	2 spp.	2 spp.	2 spp.
Zonalictus sp.	-	1 sp.	-
Sphecodes sp.	1 sp.	-	-
Nominae	1 sp.	-	-
Megachilidae			
Megachile stellarum?	-	1 sp.	-
Creihtoniella sp.	-	1 sp.	-
Anthophoridae			
Anthophorinae:			
Anthophora mimadvena	1 sp.	1 sp.	1 sp.
Tetralonia braunsiana	1 sp.	-	-
Thyreus sp.	1 sp.	1 sp.	1 sp.
Xylocopinae:			
Allodapula sp.	-	1 sp.	1 sp.
Apidae			
Apis mellifera	1 sp.	1 sp.	1 sp.

	Settlers	Pretoria	Hartbeesfontein
Formicidae			
Myrmicinae:			
<u>Pheidole</u> <u>megacephala</u>	1 sp.	-	-
Formicinae:			
<u>Camponotus</u> spp.	2 spp.	-	-

( ) night visitors only * day and night visitors

! adults and larvae ~ larvae only

14. APPENDIX B:

Honeybees as pollinators of commercial sunflower

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The use of honeybees *(Apis mellifera)*, as crop pollinators is well known. Researchers all agree that the honeybee must be considered the major pollinator of cultivated sunflower. Two reasons are given: firstly, honeybees are "domesticated" to some degree as they are kept in manageable hives which can be brought in for pollination at wish. Secondly, the areas planted with sunflower are usually well cultivated regions where agricultural activities have led to a reduction in the local solitary bee as well as honeybee populations.

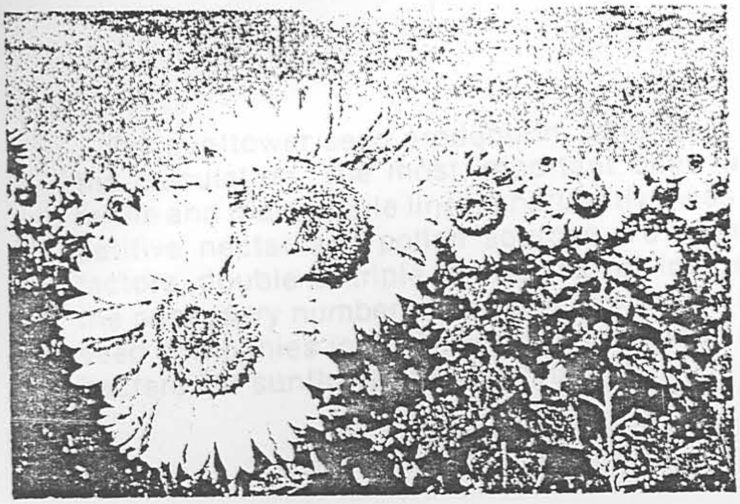
Poor seedset is one of the major factors affecting the sunflower crop in South Africa. Seedset and yield is determined by the separate but vital processes of flowering initiation, pollination, fertilization and seed development. Factors which influence these processes include cultivar characteristics, climate, pollinating insects and plant nutrition.

Since 1983 South Africa has been dependant on imports of sunflower seed because of the drought and an increase in demand. This therefore requires an increase in production per unit area as well as an increase in the total area planted.

After a survey of insects visiting the commercial sunflower heads in the Springbok Flats (Transvaal) it was found that honeybees represented more than 70% of all anthophilous insects. Honeybees were active from 07h00 till dusk. Peak activity was reached between 09h00 and 11h00, though the average number of honeybees per hundred florets was always above 30 honeybees per 100 open heads. 24 - 30 honeybees per 100 heads is accepted by researchers overseas as the minimum number on sunflower. Both nectar and pollen was collected throughout the day. However most of the pollen and nectar was removed before noon. Crop size and pollen pellets decreased in size after noon.

Researchers and extension officers are always confronted with the question of hive stocking rate on sunflowers. To calculate the number of colonies needed for commercial sunflower pollination, various aspects must be kept in mind. The following reasoning could be followed, where a theoretical calculation is made to determine the number of hives needed to pollinate sunflower:

- ★ Sunflowers planted at a density of 35 000 plants per hectare have an average of 1 800 seeds per head.
- ★ Individual heads flower over a period of seven days.
- ★ If it is assumed that all heads flower evenly over a period of seven days, then the number of florets that need pollination on each day will be 1 800 ÷ 7 per head.
- ★ Researchers have determined that each floret must receive an average of 8 honeybee visits to ensure effective pollinatiion.



Sunflower must be regarded as one of the main target crops for members of the new association, POSA North.

- ★ It then follows that the average number of honeybee visits per head per day is (1 800 ÷ 7) x 8.
- ★ The average time of a single honeybee visit per floret was determined as 2.8 seconds.
- ★ The total time required per head per day is then (1 800 ÷ 7 x 2.8) x 8, or 1.6 hours of honeybee activity per head.
- ★ The total time of forager activity in a blooming sunflower field is on average 8 hours per day.
- ★ If 1.6 hours of honeybee activity per head per day is required to ensure effective pollination and foragers are active for an average of 8 hours per day, the percentage time that a single forager must spend on one head to pollinate that head effectively is 1.6 ÷ 8 x 100, or 20% of the available time.
- ★ If it is assumed that honeybees are distributed evenly in a field, then 20% of open flower heads, receptive for pollen, must be occupied with honeybees, in other words 20 honeybees per 100 heads are required.
- ★ As the calculation is based upon mean values, in practice it won't be unrealistic to boost the figure by 50%. A practical number would then be 30 honeybees per 100 receptive heads.
- ★ 30 honeybees per 100 heads represents 10 500 foragers per hectare at any given time at a plant density of 35 000 plants per hectare.
- ★ The average production-colony of African honeybees kept in hives, consists of an average of 50 000 honeybees.
- ★ On average 45% of the bees in a production colony are foragers. This implies that there are 22 500 field workers per hive. Theoretically, 50% of foragers are busy inside the hive unpacking their loads. There would thus be 11 250 field workers at a given time busy to explore florets for food.
- ★ The 10 500 field workers required for adequate pollination is nearly equal to the 11 250 available foragers per hive. According to these calculations an estimated one production colony per hectare is required for adequate pollination of commercial sunflower.

Beekeepers that utilize commercial sunflower as a honey source, usually place one hive per hectare during normal production years while the number of hives may be less during drought seasons.

For sunflower seed production, other sets of factors strongly influence the calculation. The most important ones would be the separated male-fertile and male-sterile lines, unattractiveness of male-sterile lines and competitive nectar and pollen sources. To eliminate the influence of these factors, double or triple the number of foragers are needed to ensure that the necessary number of honeybees visit the male-sterile lines. Most of the seed companies in South Africa recommend a hive density of 2-3 hives per hectare for sunflower seed production.