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Original article

Effect of brood production and population size on honey production of honeybee colonies in Alberta, Canada

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Summary — Honey production of 23 honey bee *(Apis mellifera)* colonies was recorded for 2 consecutive years. Brood areas and colony populations were measured during the honeyflow.

One-, 2-, and 3-yr-old queens were used. The mean honey production was 120.2 kg per colony, varying from 60.9 to 210.8 kg. The number of worker brood cells on average was 26 200 (17—18 June), 36 200 (21 d later) and 44 900 (42 d later). The only significant difference in the colonies which depended on the age of the queens was in the number of drone brood cells (drone population 1 700 and 800 with 2- and 1-yr-old colony queens, respectively). Honey production was significantly correlated with the number of worker brood cells of the first measurement ($r = +0.65$), with worker population ($r = +0.62$), with the number of drone brood cells ($r = +0.51$ and $r = +0.41$), and with the drone population ($r = +0.38$), but not with the second measurement of the worker brood cells.

honey production — Canada — colony size

Résumé — Influence de la production de couvain et de la taille de la population sur la production de miel de colonies d'abeilles dans l'Alberta, Canada. *On a utilisé la lignée septentrionale de notre programme de sélection d'abeilles en population fermée. On a étudié en 1985 des colonies possédant des reines âgées de 1 et 2 ans (6e et 5e générations) et en 1986 des colonies possédant des reines de 1 et 3 ans (7e et 5e générations). Les 2 mêmes ruchers, distants de 10 km, ont été utilisés d'une année sur l'autre. En 1985 chaque rucher comptait 6 colonies avec une reine de 1 an et 6 colonies avec une reine de 2 ans. En 1986, l'un des ruchers comptait 10 colonies avec une reine d'un an et deux avec une reine de 3 ans, tandis que dans l'autre les 12 reines étaient âgées d'un an. En 1985 comme en 1986, une reine d'un an a été perdue dans le 2e rucher, ce qui a fait un total de 46 colonies. Les tests ont commencé le 18 juin 1985 et le 17 juin 1986. Les colonies du rucher n° 1 ont été mesurées en premier, celles du n° 2 le lendemain. A l'aide d'une grille en plexiglass on a mesuré la surface de couvain sur les 2 faces de chaque rayon, 2 fois à 21 jours d'intervalle. Les surfaces ont ensuite été converties en nombre de cellules. On a dénombré les ouvrières et les mâles 42 jours après les premières mesures de couvain. On a estimé la production de miel d'après le poids net total de miel produit par la colonie durant les 42 jours du test.*

La production de miel a varié de 60,9 kg à 210,8 kg/colonie, avec une moyenne de 120,2 kg (Tableau I). Le nombre de cellules de couvain d'ouvrières a été de 26 200 en moyenne (17—18 juin) et de 36 200 21 jours plus tard (Tableau I), soit un total de 62 400 pour les 2 périodes (Tableau II). La population moyenne d'ouvrières à la fin des 42 jours a été de 44 900 (Tableau I). La seule différence significative entre les colonies due à l'âge des reines a porté sur le nombre de cellules

de couvain de mâles et sur la population de mâles : 1 700 pour les colonies avec reines de 2 ans et 800 pour celles avec reines d'un an (Tableau I). Le rapport ouvrières/mâles a été de 50,5:1 et 26,9:1 dans les colonies avec reines d'un an et de 2 ans, respectivement (Tableau III). La durée moyenne de la vie productive des ouvrières a été de 30,2 jours, dans toutes les colonies (Tableau II).

La production de miel a été significativement corrélée avec le nombre de cellules de couvain d'ouvrières lors de la 1^re^ mesure (r = +0,65), avec la population d'ouvrières (r = +0,62), avec le nombre de cellules de couvain de mâles (r = +0,51 et r = +0,41) et avec la population de mâles (r = +0,38), mais pas avec la 2^e^ mesure des cellules de couvain d'ouvrières (Tableau IV). La production de miel a significativement augmenté de 2,9 fois toutes les 1 000 cellules d'ouvrières (les 17—18 juin) et de 2,2 fois toutes les 1 000 ouvrières à la fin du test; une régression multiple a modifié ces valeurs en 2,0 et 1,3 respectivement et réduit la constante vers zéro (Tableau V).

Dans l'étude présente, la population des colonies était relativement forte en raison de l'abondance de la production journalière de couvain et de la durée de vie moyenne relativement longue des ouvrières.

production de miel — Canada — taille de la population

Zusammenfassung — Effekt der Brutproduktion und der Populationsgröße auf die Honigproduktion bei Völkern der Honigbiene in Alberta, Kanada. *Zu dieser Untersuchung wurde die Nordlinie aus unserem Zuchtprogramm in geschlossener Population verwendet. 1985 wurden Völker mit ein- und zweijährigen Königinnen aus der sechsten und fünften Generation und 1986 Völker mit ein- und dreijährigen Königinnen aus der siebten und fünften Generation untersucht. In beiden Jahren wurden dieselben zwei (10 km weit voneinander entfernten) Bienengärten verwendet. 1985 umfaßte jeder Garten sechs Völker mit einjährigen Königinnen und sechs mit zweijährigen Königinnen. 1986 standen in dem einen Garten 10 Völker mit einjährigen und 2 mit dreijährigen Königinnen, im anderen Garten waren alle 12 Völker mit einjährigen Königinnen besetzt. In beiden Jahren ging im 2. Garten je eine einjährige Königin verloren, so daß eine Gesamtzahl von 46 Völkern entstand.*

Die Tests begannen am 18.6.1985 bzw. 17.6.86 Die Völker in Garten 1 wurden zuerst und die in Garten 2 am folgenden Tag gemessen. Die Brutfläche auf jeder Seite jeder Wabe wurde mit Hilfe eines Plexiglasgitters zweimal im Abstand von 21 Tagen gemessen. Die so erhaltene Zahl wurde in Anzahl Zellen umgerechnet. Die Anzahl an Arbeiterinnen und Drohnen wurde erstmals 42 Tage nach der ersten Brutmessung bestimmt. Die Honigproduktion wurde aus der Nettogesamtmenge an Honig, die das jeweilige Volk in den 42 Tagen Testzeit produziert hatte, abgeleitet. Die durchschnittliche Honigproduktion belief sich auf 120.2 kg pro Volk und variierte von 60.9 bis 210.8 kg (Tabelle I). Die durchschnittliche Anzahl an Arbeiterinnen-Brutzellen betrug 26 200 (17./18. Juni) und 36 200 (21 Tage später) (Tabelle I), was einer Gesamtzahl von 62 400 in beiden Perioden (Tabell II) entspricht. Die mittlere Zahl an Arbeiterinnen am Ende des 42 Tage, dauernden Test war 44 900 (Tabelle I). Der einzige signifikante Unterschied in den Völkern, der abhängig vom Alter der Königin ist, liegt in der Anzahl Drohnen-Brutzellen und der Größe der Drohnenpopulation mit 1 700 bzw. 800 Brutzellen bei zwei- bzw. einjährigen Königinnen (Tabelle I). Das Verhältnis von Arbeiterinnen zu Drohnen war 50.5:1 bzw. 26.9:1 bei Völkern mit ein- bzw. zweijährigen Königinnen (Tabelle III). Die durchschnittliche Länge des produktiven Lebens der Arbeiterinnen lag bei 30.2 Tagen und war bei allen Gruppen gleich (Tabelle II).

Die Honigproduktion war signifikant korreliert mit der Anzahl der Arbeiterinnen-Brutzellen bei der ersten Messung (r = 0.65), mit der Größe der Arbeiterinnen-Population (r = 0.62), mit der Anzahl an Drohnen-Brutzellen (r = 0.51 und r = 0.41) sowie der Drohnen-Population (r = 0.38) aber nicht mit der 2. Messung der Arbeiterinnen-Brutzellen (Tabelle IV). Die Honigproduktion stieg signifikant um das 2.9 fache für jedes Tausend an Arbeiterinnen-Brutzellen (17./18. Juni) and um das 2.2 fache am Ende des Tests; eine multiple Regression änderte die Werte auf 2.0 bzw. 1.3 und reduzierte den konstanten Term gegen Null (Tabelle V). In der vorliegenden Untersuchung war die Volksstärke relativ groß, da es eine üppige tägliche Brutproduktion und im Durchschnitt eine relativ lange produktive Lebenszeit der Arbeiterinnen gab.

Honigproduktion — Kanada — Volksstärke

Introduction

One of the most important goals in beekeeping is to produce honey. Honey production relative to population size (Harbo, 1986) and average productive life of workers (Woyke, 1981 and 1984) has previously been investigated. The literature related to honey production was reviewed by Woyke (1984). Most honey production research was conducted in areas with relatively low colony yields. The purpose of this investigation was to analyse some factors affecting honey production in an area with high production records.

Materials and Methods

One strain (Northern) of honey bees (*Apis mellifera* L.) from a closed population breeding program was used. One and 2-yr-old queens (sixth and fifth generations) were investigated in 1985, and 1- and 3-yr-old queens (seventh and fifth generations) in 1986. In both years the same two yards, 10 km apart, were used. All colonies were chosen randomly from a group of 100 overwintered colonies. In 1985, each yard contained 6 colonies with 1-yr-old and 6 colonies with 2-yr-old queens. In 1986 one yard had 10 colonies with 1-yr-old queens and 2 with 3-yr-old queens, while in the other yard all 12 queens were 1-yr-old.

Brood survival was not considered in this study. All measurements and counts were taken from 6.00 to 11.00 h when little or no flight activity occurred. By means of a plexiglass grid the area of brood (eggs, larvae, and capped brood) on both sides of each comb was measured twice at 21-d intervals to the nearest 10 cm^2. The measurements were then converted into numbers of cells. There were 397 worker cells per square decimeter and 241 drone cells per dm^2. The number of workers was determined 42 d after the first brood measurements when all the bees were shaken into a box and weighed. Samples of 100 bees taken from each box were frozen, counted, and weighed. The number of workers for each colony was calculated from these two weight records. Average length of productive life of the workers present in the hive on the day / worker number was calculated by dividing total bee-days (number of bees multiplied by 42) by number of bees emerged in the previous 42 days (combined first and second brood counts), as described by Woyke (1984). The drones found on the combs were counted.

Honey production was derived from the net total weight of honey produced by a colony during the 42 d of the test.

A 1-yr-old queen was lost from the second yard in both years resulting in a total of 46 colonies. The tests began on 18 June 1985 and on 17 June 1986. The colonies were measured in No. 1 yard first and in No. 2 yard on the following day.

Statistical procedure

Analyses of variance of the original data were performed; simple and multiple correlations and regressions were computed after adjusting for queens, yards, and years. All analyses were performed with Genstat, release 4.04.

Results

Brood production

The average number of worker brood cells was 26 200 at the first measurement and 21 d later 36 200 (Table I), giving a total for both periods of 62 400 (Table II). There were no significant differences in the number of worker brood cells when the ages of the queens, yards, or years were compared. The only significant differences found were in the number of drone brood cells in the colonies of 1- and 2-yr-old queens. Colonies with older queens had two to three times more brood cells (Table I).

Since all the values given in Table II were calculated from those in Table I, there can be no additional meaningful significant differences, *i.e.* there were no differences in the total worker brood cells, the percentage ratio of worker population

Table I. Number of worker and drone brood cells, adult populations and total honey production in 1985 and 1986 (in thousands).

	Age of queen (yr)	*No. of colonies*	*WB_1*	*WB_2*	*WP*	*THP (kg)*	*DB_1*	*DB_2*	*DP*
1985									
Mean	1	12	23.2	39.1	40.4	92.0	0.2b	1.4b	0.8b
SE			2.1	2.9	3.0	7.2	0.0	0.2	0.1
Mean	2	11	24.9	35.1	45.8	107.2	0.7a	3.0a	1.7a
SE			1.2	1.6	2.5	5.7	0.2	0.3	0.2
1986									
Mean	1	21	28.7	35.6	46.8	144.0	0.4	1.8	1.0
SE			1.8	1.0	2.3	7.2	0.1	0.2	0.1
Mean	3	2	24.9	30.6	46.4	111.7	0.4	1.4	0.5
SE			8.5	1.3	0.4	25.2	0.4	1.1	0.4
Total									
Mean	ALL	46	26.2	36.2	44.9	120.2	0.4	2.0	1.1
Min			12.7	16.4	19.6	60.9	0.0	0.2	0.3
Max			45.9	54.5	75.4	210.8	2.5	4.5	2.6
SE			1.1	1.0	1.5	5.2	0.1	0.2	0.1

Means marked with different letters are significantly different ($P < 0.05$).
Number of worker brood cells (WB1) and drone brood cells (DB1) were obtained from measurements on June the 17th and 18th, and WB2 and DB2 were obtained in the same way 21 d later. Worker (WP) and drone populations (DP) of bees and total honey production (THP) were determined 42 d after the first brood measurements.

Table II. Total worker brood cells (TWB), percent of the ratio of worker population to total worker brood cells (WP/TWB), average productive life of workers in days (AWL), average number of worker brood cells per day (AWB), ratio of number of worker brood cells (from second measurements) to worker population 21 d later (WB_2/WP) and unit honey production by 1 000 workers (UHP).

	Age of queen	*TWB*	*WP/TWB (%)*	*AWL*	*AWB*	*WB_2/WP*	*UHP*
1985	1	62.3	64.9	27.2	1483	0.97	2277
	2	60.0	76.3	32.1	1429	0.77	2341
1986	1	64.3	72.8	30.6	1531	0.76	3077
	3	55.5	83.6	35.1	1321	0.65	2407
Total	ALL	62.4	72.0	30.2	1486	0.81	2677

All numbers were calculated from Table I as follows : TWB = WB_1 + WB_2; WP/TWB = WP/TWB•100; AWL = WP/TWB•42; AWB = TWB/42; UHP = THP/WP•1 000.

to total worker brood cells, or the ratio of second reading of worker brood cells to worker population. The average numbers of worker and drone brood cells per day were 1 486 (Table II) and 50 (Table III), respectively.

Colony population and average length of productive life of workers

The average worker population at the end of the honeyflow was 44 900 (19 600—75 400). There were no significant differences in colonies of 1-, 2-, and 3-yr-old queens, yards, or years (Table I). However, the drone population was more than double, averaging 1 700 in colonies with 2-yr-old queens, compared to 800 in colonies with 1-yr-old queens, $P < 0.01$ (Table I).

The ratios of workers to drones were 50.5:1 and 26.9:1 in 1 and 2-yr-old queen colonies, respectively (Table III).

The average productive life of workers was similar in all groups (30.2 days; Table II).

Honey production

The average honey production per colony was 120.2 kg (60.9—210.8 kg); there were no significant differences associated with the ages of queens, yards, or years (Table I). Honey production was significantly correlated with the number of worker brood cells during the first measurement on 17 and 18 June, with worker population at the end of the experiment, and with the number of drone brood cells throughout the experiment. Honey production was significantly correlated with drone population but not with the number of worker brood cells during the second measurement (Table IV).

Honey production significantly increased 2.9 times for every 1 000 worker brood cell increase (on 17—18 June) and 2.2 times for every 1 000 worker bee increase at the end of the test (Table V); a multiple regression changed these values to 2.0 and 1.3, respectively, and reduced the constant term towards 0 (Table V).

Table III. Total drone brood cells in thousands (TDB), ratio of drone population to total drone brood cells (DP/TDB), number of average daily drone brood cells (ADB) and ratio of worker population to drone population (WP/DP).

	Age of queen	*TDB*	*DP/TDB (%)*	*ADB*	*WP/DP*
1985					
	1	1.6	50	33	50.5
	2	3.7	46	77	26.9
1986					
	1	2.2	46	46	46.8
	3	1.8	28	38	92.8
Total					
	ALL	2.4	46	50	40.8

All values calculated from Table I as follows : $TDB = DB_1 + DB_2$; $DP/TDB = DP/TDB \cdot 100$; $ADB = TDB/48$.

Table IV. Correlations (degrees of freedom = 41) among the number of worker and drone brood cells, population and total honey production from Table I after allowing for queens, yards, and years.

WB_2	0.24 ns					
WP	0.57 ***	0.50 ***				
THP	0.65 ***	0.17 †	0.62 ***			
DB_1	0.49 ***	0.05 †	0.53 ***	0.51 ***		
DB_2	0.60 ***	0.08 †	0.46 **	0.41 **	0.46 **	
DP	0.56 ***	0.02 †	0.30 †	0.38 *	0.42 **	0.86 ***
	WB_1	WB_2	WP	THP	DB_1	DB_2

See notes to Table I for abbreviations.
† not significantly different from 0; * $0.01 < P < 0.05$. ** $0.001 < P < 0.01$. *** $P < 0.001$.

Table V. Partial regression coefficients (standard errors in parentheses) for various models for predicting total honey production (THP) in kilograms from number in thousands of worker brood cells from the first measurements (WB_1), drone brood cells (DB_1), and colony worker population after 42 d (WP).

Constant	*WB_1*	*DB_1*	*WP*	*R^2*	*Error df*
44.6 (3.73) ***	2.9 (0.51) ***	–	–	0.406	40
107.2 (4.22) ***	–	32.8 (8.45) ***	–	0.238	40
22.4 (3.85) ***	–	–	2.2 (0.42) ***	0.365	40
11.0 (3.47) **	2.0 (0.58) **	–	1.3 (0.46) **	0.486	39
52.4 (3.62) ***	2.4 (0.57) ***	16.0 (8.30) †	–	0.441	39
20.5 (3.46) ***	1.8 (0.60) **	9.4 (8.48) †	1.1 (0.49) *	0.489	38

† Not significantly different from 0. * $0.01 < P < 0.05$; ** $0.001 < P < 0.01$. *** $P < 0.001$.

Discussion and Conclusions

The present results are consistent with previous findings that honey production per bee increases as population increases (Farrar, 1937) and, as the weight of a colony population increases, the seasonal weight gain of a colony also increases (Szabo, 1982). The highest correlation, $r = +0.65$, was found between honey production and the first measurement of brood cells on 17—18 June. There was no significant correlation between honey production and second brood cell measurements, which suggests that a large number of the bees emerging during the second part of the honey flow were not involved in nectar and/or pollen collection.

Woyke's (1984) calculations provide data with which to compare the average productive life of workers, the average daily number of worker brood cells, and unit honey production throughout various parts of the world. In the present study, colony population was larger than the given values because daily brood production was greater and the average worker productive life was longer than that of the bees in El Salvador and Poland (Woyke, 1981; 1984). The mean unit honey productions in El Salvador (Woyke, 1981), Poland (Woyke, 1984), and the present study were 464, 392-715 and 2 677 g/1 000 workers, respectively.

Apparently, the average length of productive life of worker bees is very important in the increase of colony populations. According to Neukirch (1982), the lifespan of worker honeybees is determined by the duration of the hive and foraging periods. High daily flight performance decreases maximum flight duration and *vice versa*. In the tropical climate of El Salvador, the bees can probably fly continously, and the foraging population can be decimated by overworking and predators. By contrast, in temperate climates, since bees are sometimes forced to fly at very low temperatures in order to bring water into the hive, many become chilled and lost. During honeyflow conditions in the study area, a very interesting behavioural characteristic was observed. Very little flight activity was usual until approximately 10:00 AM (Szabo, 1980). It seems that by flying only when absolutely essential, the life-span of the worker appears to be prolonged. The colony populations in this study grew to very large numbers of workers, up to 75 400 with a maximum honey production of 210.8 kg.

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