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Rothamsted Research
Harpenden, Herts, AL5 2JQ

Telephone: +44 (0)1582 763133
Web: http://www.rothamsted.ac.uk/

Cockbain, A. J. 1961. Water relationships of Aphis fabae Scop. during tethered flight. *Journal Of Experimental Biology.* 38, pp. 175-180.

J. Exp. Biol. (1961), 38, 175–180
With 4 text-figures
Printed in Great Britain

WATER RELATIONSHIPS OF *APHIS FABAE* SCOP. DURING TETHERED FLIGHT

By A. J. COCKBAIN
Rothamsted Experimental Station, Harpenden, Herts

(*Received* 12 *August* 1960)

INTRODUCTION

In a study of fuel used by *Aphis fabae* during tethered flight (Cockbain, 1961 *a*) results were obtained on the water balance of these insects during flight, and form the basis of this paper.

MATERIALS AND METHODS

Materials and methods are described fully in the previous paper. Water contents were estimated by subtracting insect dry weight from live weight; pre-flight water contents of flown aphids were interpolated from graphs relating water content to live weight in unflown control insects.

RESULTS

Water content before flight

Water content in 24 hr. old unflown alatae was directly proportional to total live weight (Fig. 1). The amount of water varied from 64 to 73 % live weight, values which were well within the range found in other insects (Buxton, 1932) and are only slightly lower than those recorded for alatae of *Macrosiphum pisi*, i.e. 74 % (Schaefer, 1938). The highest proportions of water were in aphids reared in the laboratory on broad beans, the lowest in those from a natural infestation of a field bean; variations between batches from the same host were small (Table 1).

Variations in the proportions of water in the aphids from different hosts were mainly associated with differences in the proportions of fat; those aphids with the highest percentage of fat had the lowest percentage of water (Fig. 2). Thus the hydration of fatless dry matter in the aphids from the different hosts was very similar (Table 1).

Water loss during flight

Table 2 gives mean live weights and water contents of batches of aphids before and after flight; pre-flight water contents were interpolated from the appropriate regression in Fig. 1 (mean water content/aphid).

Decreases in water content during flight were recorded in all batches. Fig. 3 (graph A) shows mean decrements per aphid. More water was lost than is indicated by these decrements, however, for some water will have been produced by oxidation of the flight reserves. For the present purposes, decrements in live weight during flight were taken as representing the total amounts of water lost, for the principal fuel used is fat, which yields almost an equivalent weight of water on oxidation. Fig. 3 (graph B) shows mean decrements in live weight.

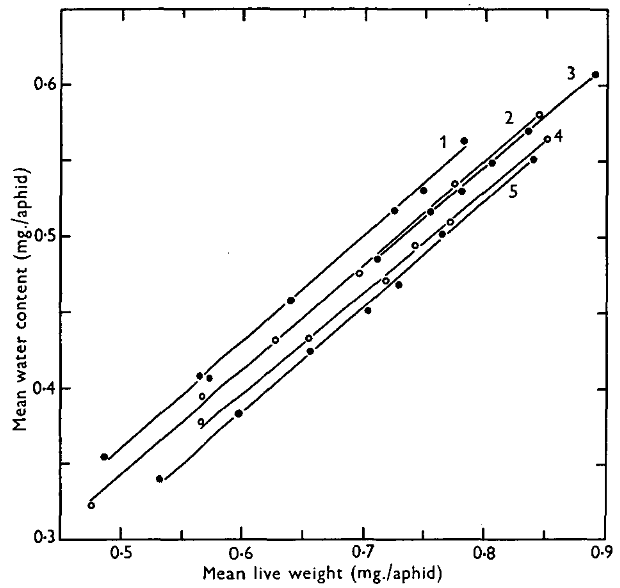

Fig. 1. Relationship between mean water content and live weight in unflown 24 hr. old alatae from different host plants. Numbers refer to experiments; regression coefficients given in Table 1.

Table 1. *Proportions of water in 24 hr. old unflown alatae*

Expt. no.	Host plant	Location	No. of batches × no. of aphids/batch	% water to live weight (min.–max.)	% water to fatless live weight (min.–max.)	Regression coefficient of water to live weight
1	Broad bean	Culture	7 × 10	71·0–72·5	74·3–76·3	+0·699
2*	Spindle	Field	6 × 10	68·1–69·5	74·6–75·7	+0·687
3	Dock	Field	6 × 10	68·2–68·6	73·4–73·8	+0·669
4	Broad bean	Field	6 × 10	65·6–66·5	73·1–74·3	+0·668
5	Field bean	Field	7 × 10	63·7–66·2	71·5–74·0	+0·701

* The alatae were migrantes, not alienicolae as in the other experiments.

The mean decrease in water content during 6 hr. was 0·039 mg./aphid, corresponding to 5·1 % initial body weight, but the mean total water loss was 0·072 mg./aphid, or 9·4 %. Fig. 3 shows that both rate of decrease in water content and rate of water loss were highest during the early period of flight, the rate of decrease in water content gradually falling as flight proceeded but the rate of total water loss remaining fairly constant after the first two hours. Thus a mean of 0·021 mg. water (3·0 % initial body weight) was lost per aphid during the first hour and 0·008 mg. (1·1 %) during the last hour. This apparently high rate of water loss (decrease body weight) during early flight was probably because aphids excreted more often (see below) and used more glycogen (Cockbain, 1961 *a*) during this period; it may also have been because moisture was lost from the surface of the cuticle.

Excretion and evaporation during flight

Water is lost during flight by excretion of honeydew droplets and by evaporation; excretory droplets are considerably smaller than those produced by aphids feeding on a host plant but nevertheless cause water loss; most of the evaporation undoubtedly

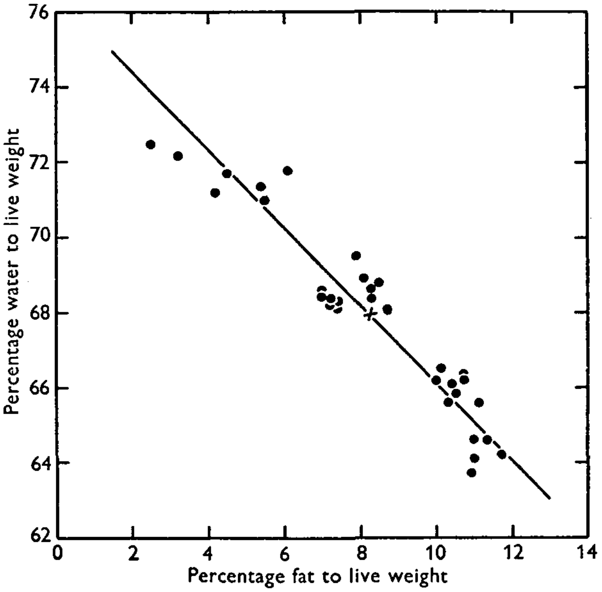

Fig. 2. Relationship between proportions of water and fat in unflown 24 hr. old alatae ($b = -0{\cdot}971$). ×, mean value.

Table 2. *Live weights and water contents of batches of aphids before and after flight*

(Aphids flown at 25–26° C. and at different humidities.)

		Expt. 1 70±6% R.H.		Expt. 2 59±2% R.H.		Expt. 3 80±2% R.H.		Expt. 4 70±4% R.H.		Expt. 5 76±3% R.H.	
Flight uration (hr.)	Aphid condition	Live weight (mg.)	Water content (mg.)	Live weight (mg.)	Water content (mg.)	Live weight (mg.)	Water content (mg.)	Live weight (mg.)	Water content (mg.)	Live weight (mg.)	Water content (mg.)
1	Before flight	5·91 (10)	4·24	6·115 (9)	4·20	6·705 (8)	4·58	5·19 (7)	3·43	7·35 (11)	4·76
	After flight	5·76	4·12	5·89	4·00	6·53	4·465	4·98	3·305	7·21	4·63
2	Before flight	4·41 (8)	3·18	5·16 (8)	3·55	7·18 (9)	4·91	6·15 (8)	4·07	5·455 (8)	3·54
	After flight	4·24	3·06	4·85	3·33	6·805	4·685	5·77	3·82	5·17	3·32
4	Before flight	6·43 (10)	4·61	5·25 (8)	3·62	7·425 (9)	5·08	6·235 (8)	4·12	5·375 (8)	3·48
	After flight	6·00	4·33	4·775	3·275	6·88	4·755	5·72	3·785	4·97	3·24
6	Before flight	5·715 (8)	4·08	5·65 (7)	3·89	7·28 (9)	4·98	5·40 (7)	3·56	5·02 (7)	3·28
	After flight	5·17	3·77	5·07	3·56	6·615	4·655	4·865	3·28	4·605	3·04

Values within parentheses refer to number of aphids per batch.

takes place through the spiracles (Mellanby, 1934), but some may be through the cuticle (Koidsumi, 1934; Church, 1960).

Excretion was not studied in the above experiments but was studied in three experiments in which culture aphids were flown for 4 hr. at 25–26° C. and at different humidities (41–75% R.H.); excretory droplets were collected on pH indicator paper. Table 3 gives the frequency of excretion and the mean diameter of the spots produced by the droplets on the paper (proportional to droplet size). Neither the mean number of droplets excreted nor the mean diameter of the excretory spots was correlated with relative humidity of the air, so humidity differences over this range do not affect excretion during flight.

Excretion was most frequent during early flight, but on the average only one droplet per aphid was produced during 4 hr. It may be inferred from extrapolation of the data in Table 3 that little excretion would occur after 4 hr.; water loss during the last 2 hr. of flight in Expts. 1–5 was therefore almost entirely from evaporation, i.e. 0·008 mg./aphid/hr. Thus evaporation under these conditions probably accounts for *at least* 66 % of the water lost during a 6 hr. flight.

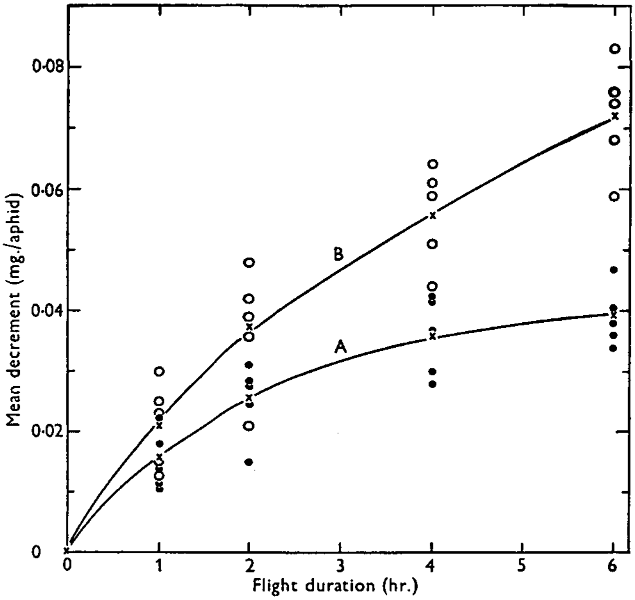

Fig. 3. Decrease in water content (A) and live weight (B) during flight at 25–26° C. and 57–82 % R.H. ×, mean values.

Table 3. *Frequency of excretion during flight at* 25–26° C. *and at different humidities, and sizes of excretory droplets as indicated by spot diameter on* pH *indicator paper*

Expt.	A		B		C	
Relative humidity (%) ...	70 ± 5		64 ± 4		47 ± 6	
Flight duration (hr.)	No. of aphids	Frequency of excretion (drops/aphid/hr.)	No. of aphids	Frequency of excretion (drops/aphid/hr.)	No. of aphids	Frequency of excretion (drops/aphid/hr.)
1	16	0·31	18	0·33	19	0·26
2	16	0·44	18	0·33	19	0·32
3	16	0·06	18	0·11	19	0·21
4	16	0	18	0·22	19	0·11
Mean no. droplets/aphid	—	0·81	—	0·99	—	0·90
Mean spot diameter (μ)	—	589 ± 122	—	535 ± 81	—	583 ± 103

There was a barely significant inverse relationship between the total amounts of water lost (% decrease body weight) during 4 and 6 hr. flights and the relative humidity of the air ($r = -0{\cdot}541$; $P = 0{\cdot}10$). On the average, an increase of 10 % R.H. was associated with a decrease in the amount of water lost of 0·8 % body weight, undoubtedly because humidity affected evaporation. The correlation might have been higher had the experiments been over a wider range of humidities.

Water content during flight

Although absolute water content decreases during flight, the proportion of water in the aphids tends to increase slightly (Fig. 4A), because the percentage of dry matter, i.e. fats and glycogen, used during flight is greater than that percentage of the water content which is lost. The mean increase (67·9–69·4 % body wt.) during 6 hr., however, was not significant ($t = 0{\cdot}83$; $P > 0{\cdot}10$).

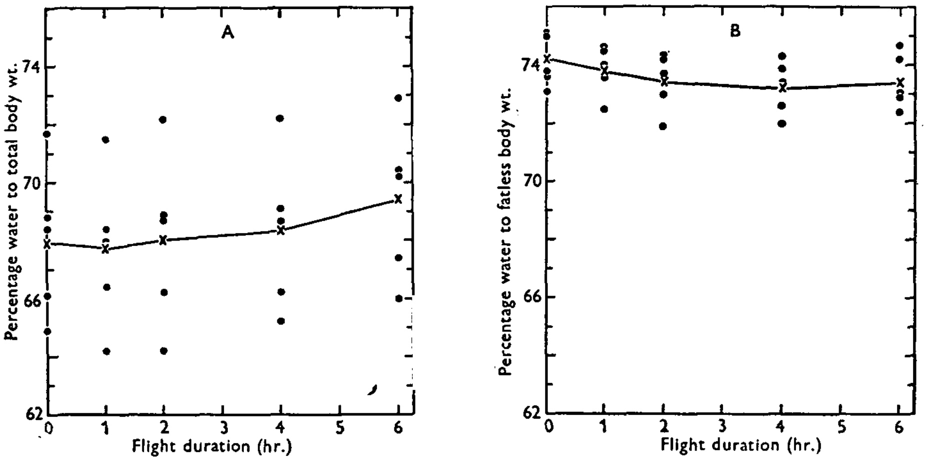

Fig. 4. Change in percentage water content during flight. A, Water content as percentage of total body weight; B, water content as percentage of fatless body weight. ×, mean values.

Hydration of fatless dry matter is probably important in connexion with the water balance, for fats are not associated with water in storage. The percentage of water to fatless body weight shows a tendency to fall during flight, reaching a minimum after 4 hr. (Fig. 4B). Even then the mean percentage has only fallen from 74·2 to 73·2 %; the difference between the means was not significant ($t = 1{\cdot}69$; $P > 0{\cdot}10$). During more prolonged flight the water balance would not alter appreciably, for although water would be lost at a mean of 0·008 mg./aphid/hr. (see above), about 0·005 mg./hr. would be gained by metabolism of fat reserves (see Cockbain, 1961 *a*). The results are similar to those obtained in flight studies on the locust *Schistocerca gregaria*, in which the hydration of non-fatty dry matter remains nearly constant or improves slightly during 5–9 hr. flight (Weis-Fogh, 1956).

CONCLUSIONS

Water was lost by excretion and evaporation during flight, but the proportion of water in the aphids and the hydration of lean dry matter remained almost constant. During more prolonged flight (> 6 hr.) the water balance would not be expected to change appreciably. It is therefore unlikely that water loss would limit the flight capacity of aphids flying tethered at 25–26° C. and 57–82 % R.H., or in more moist atmospheres; in these conditions, flight duration is probably limited by fuel content (Cockbain, 1961 *a*). Results given elsewhere show that the flight durations of culture aphids in humidities as low as 21–27 % R.H., at 25–26° C., do not differ significantly from those of aphids flown in higher humidities (see table 1, Cockbain, 1961 *b*); water loss even in these dry conditions is not a limiting factor to flight. In drier atmospheres, however (saturated deficit > 23 mm. Hg), the amount of water lost by evaporation would probably greatly exceed that gained by metabolism; water loss might then be a limiting factor.

SUMMARY

1. Water content varies from 64 to 73 % of the total body weight and 72–76 % of the fatless body weight of 24 hr. old unflown alatae of *Aphis fabae*.

2. Water loss during flight may be attributed to evaporation and excretion. A mean of 0·07 mg. water is lost per aphid during a 6 hr. tethered flight at 25–26° C. and 57–82 % R.H., corresponding to *c.* 9 % body weight; at least 66 % of the loss (*c.* 1 % body weight/hr.) is by evaporation.

3. Excretion during flight is not affected by relative humidity differences over the range 41–75 % at 25–26° C., but the relative amounts of water lost during prolonged flight are inversely related to relative humidity, because of the effect of humidity on evaporation.

4. Proportion of water in the body does not change significantly during tethered flight. Mean percentage water to total body weight increases from *c.* 68–69 % during 6 hr.; mean percentage water to fatless body weight decreases from *c.* 74 to 73 %.

5. Water loss is evidently not a limiting factor to flight in atmospheres of saturation deficit less than *c.* 23 mm. Hg.

I wish to thank Dr C. G. Johnson, Mr L. R. Taylor and Dr K. Mellanby for criticizing the manuscript.

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