STUDIES ON *Oliarus atkinsoni* Myers (HEM. CIXIIDAE), VECTOR OF THE "YELLOW-LEAF" DISEASE OF *Phormium tenax* Forst.

III—RESISTANCE OF NYMPHAL FORMS TO SUBMERGENCE-CONTROL BY INUNDATION

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Summary

The conditions under which the nymphal populations of *Oliarus atkinsoni* exist in the field are outlined.

Laboratory experiments to test the ability of the nymphal stages to resist drowning are described. These experiments indicated the probability that 90 per cent of the nymphs would be killed by an indundation lasting 14 days.

Field trials are described in which a complete kill of nymphal forms by inundation was obtained.

INTRODUCTION

Experimental work commenced by the writer in December, 1949, showed that the so-called "yellow-leaf" disease of the native fibre-producing plant *Phormium tenax* could be induced by enclosing on seedling material adult bugs of the Cixiid *O. atkinsoni*, collected from areas showing a high percentage of infected bushes (Cumber, 1952a). Studies on the biology and ecology of the insect (Cumber, 1952b, 1952c) have been undertaken so that various possible methods of control may be formulated and tested. It is probable that populations of this insect are controlled in nature by the frequency and degree of inundatiodn by flood waters. The present work was carried out to obtain information necessary in planning the control of the bug by inundation.

CONDITIONS UNDER WHICH NYMPHAL POPULATIONS OCCUR IN THE FIELD

The adult stage of *O atkinsoni* is found on the aerial portions of *Phormium* from mid-November until mid-March. For the remainder of the year, the bug is present in the egg or nymphal stages which are found at the base of the plants, where they remain hidden amongst the dead-leaf material and feed on the *Phormium* roots.

Accurate estimations of the numbers of nymphs present in an area are difficult to obtain. Often several hundred nymphs will be found on one fan and its rhizone. In one area where an estimation of the number of nymphs present was attempted, it appeared that there would be at least 400,000 to the acre.

Throughout the nymphal stages the bugs produce copious amounts of a mealy substance which issues dorsally from several of the posterior abdominal segments. This substance lines "galleries" in which the nymphs live, hidden away within the dead material that invests the rhizome. A powdery substance also covers the nymphs themselves, and both this and the mealy substance that lines the galleries are highly water-repellant, so that an air bubble surrounds each submerged individual, and there is often a relatively spacious gallery which resists wetting.

The life cycle of the bug occupies two years, nymphal stages being present at all times.

RESISTANCE OF NYMPHS TO SUBMERGENCE-LABORATORY TESTS

It was considered that several factors might influence the ability of nymphs to survive field inundations. The most favourable submergence from the control aspect was expected to be submergence to enclose the nymph in the minimum air space—that is, in its investing air bubble only. Under field conditions, some of the individuals would be submerged in air pockets in the galleries, and the number of such pockets present would vary with depth and duration of inundation. It is also conceivable that under field conditions submerged nymphs might be able to feed on the roots while in the enclosed air bubble or space, and thereby prolong their life. In an attempt to reproduce these three conditions, insects were—

- submerged in the air bubble that enclosed them (minimum air and no food);
- submerged with a limited known quantity of air (limited air, no food);
- submergence by placing fans with undisturbed basal material and nymphs in their galleries in drums of water (maximum air likely, plus possible food supply).

In addition, the period of survival of nymphs floating upon the surface of water was also determined.

Nymphs for the tests were taken from *Phormium* bushes by collecting the dead material at the base of the plants and submberging this in a water bath. The nymphs floated to the surface, where they were collected with a camel-hair brush.

At the time that this work was carried out (August–September), the majority of the nymphs present belonged to one of two age groups, i.e., the second and third instar group from eggs deposited during the last adult flight season, and the fifth instar group from eggs deposited during the season before. It was considered possible that the ability to resist submergence might vary with the size or age of the nymphs, so individuals of these two groups were included in the experiments.

Survival of Nymphs Submerged with Minimum Air Supply and No Food

Nymphs were held in $2\frac{1}{2}$ x $\frac{1}{2}$ in. glass tubes. Two fifth-instar and two second- or third-instar nymphs were placed in each tube. Water was added to bring the level up to the lip of the tube and a wet cotton-wool plug applied. This forced the nymphs below the surface of the water and enclosed them solely in the air film which closely surrounded them. All tubes were then completely submerged in a larger body of still water to a depth of four inches. This arrangement ensured that the oxygen content of the water enclosing the nymphs was not restricted by the capacity of the tube. At intervals, numbers of these tubes were removed from the water, and the nymphs transferred to petri dishes containing moist filter papers; previous experiments showed that the recovery of nymphs following submergence was often a slow process, and assessment of results could not be made immediately the bugs were removed from the water. Assessment of recoveries was therefore based on the ability of the nymph to show movement after a recovery period of four days. Table I shows the numbers and percentages of nymphs surviving after varying submergences, together with survival times for a control series of nymphs set up in petri dishes containing moistened filter papers but no food.

TABLE I.—Survival Rates of Nymphs Enclosed with Minimum Air

Period of submergence (days)	Total No. of nymphs		No. of nymphs surviving		% Nymphs surviving		% Control* nymphs surviving	
	Instar 2, 3	5	Instar 2, 3	5	Instar 2, 3	5	Instar 2, 3	5
3	72	72	36	37	50	51	96	93
4	72	72	20	20	28	28	96	88
6	72	72	14	9	19	13	96	86
7	72	72	12	3	17	4	96	86
10	72	72	0	2	0	3	96	86
13	48	48	0	3	0	6	94	84

*Controls comprised 52 second- and third-, and 56 fifth-instar nymphs.

Survival of Nymphs Submerged with a Limited Quantity of Air and No Food

In this experiment, nymphs were enclosed in an air-space of 1 cc. capacity. Two second- or third-instar nymphs and two fifth-instar nymphs occupied the one space, and a small piece of cork was supplied to give foothold for the bugs. Glass tubes $2\frac{1}{2}$ in. x $\frac{1}{2}$ in. were filled with water. One cubic centimetre of water was removed with a syringe, then the bugs and piece of cork were inserted. The tube was then covered with a finger and inverted so that the air space with the enclosed cork and bugs rose to the bottom of the tube. The tube was then immersed in water on cotton-wool so that the size of the tube did not restrict the oxygen supply of the water within it. Four inches of water covered the tubes. At intervals, a number of bugs were removed and survival rates assessed as in the previous experiment. This experiment attempted the reproduction of conditions which might exist owing to the formation of air pockets in the galleries when submergence occurred. Results are indicated in Table II,

TABLE II.—Survival Rates of Nymphs Enclosed in Limited Air Space (1 cc. per 4 Nymphs)

Period of submergence (days)	Total No. of nymphs		No. of nymphs surviving		% Nymphs surviving		% Control* nymphs surviving	
	Instar		Instar		Instar		Instar	
	2, 3	5	2, 3	5	2, 3	5	2, 3	5
9	40	40	2	0	5	0	95	93
14	40	40	0	0	0	0	93	90
15	80	80	0	0	0	0	93	90

*Control nymphs comprised 40 second- and third-instar nymphs and 40 fifth-instar nymphs held in petri dishes on moist filter paper and with no food.

Survival of Nymphs Submerged with Fans

Fans on which numbers of nymphs were living were dug out, care being taken to leave undisturbed the dead basal sheathing leaves overlying the bugs. These were then placed in 40-gallon drums of water, the fans being submerged to an average depth of 12 inches.

It was considered that this method approached field conditions during inundations. The bugs would have their water-resistant galleries undisturbed, and possibly could obtain nourishment by feeding on roots traversing the galleries. Fans were removed at intervals, all bugs present being placed in petri dishes containing moist filter papers to allow recovery prior to the assessment of survival rates. Results of this experiment are given in Table III.

TABLE III.—Survival Rates of Nymphs Submerged with Fans

Period of submergence (days)	No. of fans examined	No. of nymphs found at exam.		No. of nymphs surviving		% Nymphs surviving	
		Instar		Instar		Instar	
		2, 3	5	2, 3	5	2, 3	5
7	3	30	15	5	1	17	7
14	4	129	19	0	0	0	0

The nymphs rising to the surface of the water following submergence of fans were collected during the first seven days. Only four individuals (2 per cent) were taken. It is probable that in natural flooding or field inundation, where basal material would be little disturbed, an even lower percentage would escape to the surface.

Survival of Nymphs Floating on the Surface—No Food

This experiment was carried out to ascertain survival rates of bugs that floated on the surface of the water without food. Glass tubes, 4 in. x 1 in., were half-filled with water, the bugs added (10 bugs per tube), and cotton-wool stoppers pushed into the mouths of the tubes. Bugs were removed at intervals and recoveries assessed as previously. Results are summarized in Table IV.

TABLE IV.—Survival Rates of Nymphs Floating on Water

Period of flotation (days)	Total nymphs		No. nymphs surviving		% Nymphs surviving		% Control* nymphs surviving	
	Instar 2, 3	Instar 5	Instar 2, 3	Instar 5	Instar 2, 3	Instar 5	Instar 2, 3	Instar 5
4	10	20	10	18	100	90	95	93
8	10	20	9	4	90	20	95	93
12	10	20	5	4	50	20	95	90
16	10	20	3	1	30	5	88	90

*40 second- and third-instar and 40 fifth-instar nymphs.

It is possible that mass flotation as used in this experiment would result in greater disturbance amongst the individuals than would occur in the case of single flotations.

CONTROL OF NYMPHAL POPULATIONS: FIELD TRIALS

Two field trials were set up to test the application of the results obtained from laboratory experiments. These trials demonstrated the effectiveness of inundation as a means of controlling nymphal populations.

FIG. 1.—Field trial to test inundation as a means of controlling *O. atkinsoni*. The nymphal stages are restricted to the material at the base of the plant.

Two areas of approximately a quarter of an acre each were selected. On these the *Phormium* bushes showed a heavy infestation, with the nymphal forms belonging to all except the first instar (October–November). Holding banks 3 ft. to 4 ft. high were bulldozed up around the areas, and water from the Manawatu River was pumped in to a depth of 2 ft. to 3 ft. and maintained for a period of 14 days (Fig. 1). The water took an additional two to three days to seep away. Two weeks later (period allowed for recovery of nymphs), the trial was examined. Dead nymphs were observed in hundreds, not a single living individual being found. Other insect species had also largely been cleared from the base of the plants.

DISCUSSION

A comparison of Tables I and II shows that the survival of bugs submerged in the minimum air space is not less than the survival in an air space of 1 cc. capacity. This is not what might be expected, but such factors as restriction of activity, exchange of oxygen with the surrounding water, etc., probably contribute to the result. Table III indicates that the influence of any survival aid afforded by air pockets in the galleries and the feeding from such galleries may not be very great. It is possible that decomposition of basal material results in a fairly rapid destruction of such galleries. The percentage of bugs forsaking the base of the plant for the surface of the water is low, the majority being trapped within their galleries. Table IV shows that nymphs, more especially the smaller ones, may live on the surface of the water for some time without food. It is probable that moving water would transport a low percentage of the nymphs quite satisfactorily.

Although a complete kill of nymphal forms was obtained in the field inundation trials, the bushes were recolonized with adults from the surrounding infested areas within two weeks of the draining away of the water, and egg-laying at the base of the plants had commenced.

O. atkinsoni appears generally to be restricted to *Phormium*, and it is natural that it should withstand the conditions under which the host plant thrives—i.e., the periodic changes in water table, and floodings. But it seems likely that these floodings have always been a factor controlling the populations of the bug, for it is apparent that the *Phormium* is able to withstand a longer inundation than the bug.

The remaining areas of *Phormium* in the Manawatu district are induced—i.e., drained swamps, or plantation, and the periodic floodings of the river do not reach them now. The natural control of *O. atkinsoni* has thus been removed, and great populations of the insects have built up. Consequently, the spread of the yellow-leaf condition has reached epidemic proportions. It has long been realized that the stop-banking of rivers and the overdraining of the induced areas results in a gradual die-back of the *Phormium* from those parts which become dry and no longer receive the periodic inundations. Only now that the disease is known to be transmitted by *O. atkinsoni* is it possible to link up this long-held belief with the causal factors.

There appears to be no reason why the bug may not be controlled by inundation. The flood waters of the Manawatu River may be utilized to cover large *Phormium* areas. In addition, the beneficial effects of flood waters are many—e.g., destruction of other harmful insects and weeds, increased soil fertility, etc. It will be necessary to remove *Phormium* from the higher parts which cannot be flooded unless some other satisfactory method of exterminating the bug in such areas is devised.

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