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THE FUNCTIONAL RESPONSES OF *ANISOPTEROMALUS CALANDRAE* (HOWARD), A PARASITOID OF *CALLOSOBRUCHUS MACULATUS* (F.).

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Keywords: Anisopteromalus calandrae, Callosobruchus maculatus, Functional responses, Random parasitoid search, Searching efficiency.

RINGKASAN

Parasitoid, *Anisopteromalus calandrae* (Howard) didapati mempunyai Holling Type II functional response ke atas ketiga-tiga peringkat anak *Callosobruchus maculatus* (F.), iaitu, instar ketiga, instar keempat dan kepompong. Mengunakan teknik nonlinear least squares, parameter-parameter a' dan T_h dari Random Parasitoid Equation telah dianggarkan. Juga, parameter-parameter yang tersebut telah dianggarkan dari Random Predator Equation. Walau bagaimanapun, bukti-bukti dari kajian ini menunjukkan bahawa tabiat-tabiat pencarian *A. calandrae* mendapati menyerupai tabiat parasitoid tulin.

Kecekapan pencarian, a' bagi *A. calandrae* adalah paling tinggi bagi instar keempat, disusuli pula oleh kepompong dan instar ketiga. Akan tetapi masa penyelenggaran, T_h, sebaliknya bertukar dengan samarata mengikut peringkat-peringkat perumah; paling tertinggi bagi instar ketiga, disusuli pula oleh instar keempat dan kepompong. Tafsiran didapati berbeza daripada tafsiran yang dilihat pada predator-predator tulin oleh penulis-penulis lain. Sebab-sebab yang boleh dipercayai mengenai perbezaan-perbezaan ini dibincangkan.

INTRODUCTION

The theoretical background of predator – prey interactions has been extensively studied. There is now an abundance of mathematical models describing various aspects of these relationships. Some of these works have been reviewed by ROYAMA (1971), HASSELL & MAY, (1973), MURDOCH & OATEN, (1975), BEDDINGTON, *et al.*, (1976), (HASSELL *et al.*, (1976), MAY (1976) and HASSELL (1976; 1978). Two aspects can be distinguished in these interactions (HASSELL, 1976; HASSELL *et al.*, 1976; BEDDINGTON, *et al.*, 1976):

1. the death rate of the prey due to predation or parasitization.
2. the rate of increase of the predator or parasitoid.

To some extent this classification is parallel to that between **functional** and **numerical** responses proposed by SOLOMON, (1949). However, the present classification is broader in that prey density is now only one of the factors affecting parasitoid efficiency or reproductive rate (SOUTHWOOD, 1978).

This paper describes work done on the functional responses of the parasitoid, *Anisopteromalus calandrae* attacking three stages, the third instar, the fourth instar and the pupa, of *Callosobruchus maculatus*, in the laboratory. Search parameters were estimated from the data using both the Random Parasitoid Equation and the Random Predator Equation.

FUNCTIONAL RESPONSES

A functional response may be defined as the change in the attack-rate per parasitoid with variations in the host density (SOLOMON, 1949; HOLLING, 1959; 1968). Assumptions made in this definition is that the parasitoid search is random, the host population is distributed at random and is homogeneous. HOLLING (1959) suggested that functional responses could be divided into three categories (Type I, II and III). For insect predators and parasitoids, the Type II response is most common. Recently, however, the sigmoid Type III response has also been observed in some insect predators (HASSELL *et al.*, 1977; HASSELL, 1978).

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In the Type II response, the number of attacks per parasitoid shows a negatively accelarating rise to an upper plateau. This could be described by Holling's Disc Equation (1959),

$$\frac{NA}{P} = \frac{a'NT}{1 + a'T_hN} \qquad (1a)$$

$$\text{where } T = Ts + T_hNA \qquad (1b)$$

and $\underline{NA}$ = the number of hosts attached; $\underline{P}$ = the number of parasitoids; $\underline{N}$ = the host density; $\underline{a'}$ = the attack rate of the parasitoids or the 'rate of successful search'; $\underline{T_h}$ = the handling time which include time spent pursuing, subduing and resting after oviposition; $\underline{T}$ = the total time that the parasitoid and the host are exposed; and $\underline{Ts}$ = the time that the parasitoid spends looking for the host.

An important point to note in equation (1a) is that no allowance is made for the decrease in available host as they are parasitised (ROYAMA, 1971; ROGERS, 1972). This means the equation is applicable either to situations where re-encounters are completely avoided or situations where the hosts are continually replenished as they are exploited. Since these conditions are not true, further refinements have been made to this attack model. The appropriate attack equations for both the parasitoids and predators were later developed (ROYAMA, 1971; ROGERS, 1972), known respectively as the Random Parasitoid Equation and the Random Predator Equation;

$$NA = N_t \left[1 - \exp\left(- \frac{a'TP_t}{1 + a'T_hN_t} \right) \right] \qquad \text{(for parasitoids)} \quad (2)$$

$$NA = N_t \left[1 - \exp\left(- \frac{a'TP_e}{T - T_h \frac{NA}{P_t}} \right) \right] \qquad \text{(for predators)} \quad (3)$$

where $\underline{N_t}$ = the host density at time $\underline{t}$ and $\underline{P_t}$ = the predator density at time $\underline{t}$.

MATERIALS AND METHODS

Cultures of *Callosobruchus* and *Anisopteromalus*

Laboratory cultures of *Callosobruchus maculatus*, reared on cowpeas (*Vigna unguiculata* (Walp.)) for many generations in Silwood Park at the constant temperature (C.T.) room conditions of 30°C, 70% RH, 16/24 hours illumination were used to begin the experimental cultures. Stock cultures of *C. maculatus* were kept in plastic food boxes, 27.5 cm x 15.5 cm x 9.5 cm, with two layers of cowpeas covering the bottoms of the boxes. Before use, the cowpeas were standardised by placing them in the C.T. room for at least 24 hours. The beetles were removed after 2 or 3 days using a sieve. Two boxes of stock cultures were started every week during the duration of the experiments.

Standard host cultures were initiated using the stock cultures. A layer of standardised cowpeas was placed in a plastic food box, labelled as the oviposition box. Adult beetles were placed in the box with the cowpeas and kept in the C.T. room for 24 hours, after which the cowpeas were removed and placed into a butter dish, 10.5 cm diameter x 4.5 cm. The beetles were reused with another set of cowpeas. This procedure was repeated daily for the duration of the experiments. The *Callosobruchus* beetles were replaced with fresh ones at every 3 or 4 days interval. A schematic diagram of the culture procedures is shown in *Figure 1*.

Stock cultures of *Anisopteromalus calandrae* were initiated from cultures reared on *C. maculatus* in the same C.T. room. For the experiments, the stock cultures were maintained using 16-day old *C. maculatus* larvae as hosts.

With the stock cultures, the standard parasitoid cultures were initiated using only 16-day old larvae. A single layer of cowpeas with the host was placed in a butter dish. After that, the parasitoids were anaesthetised with carbon dioxide and removed using

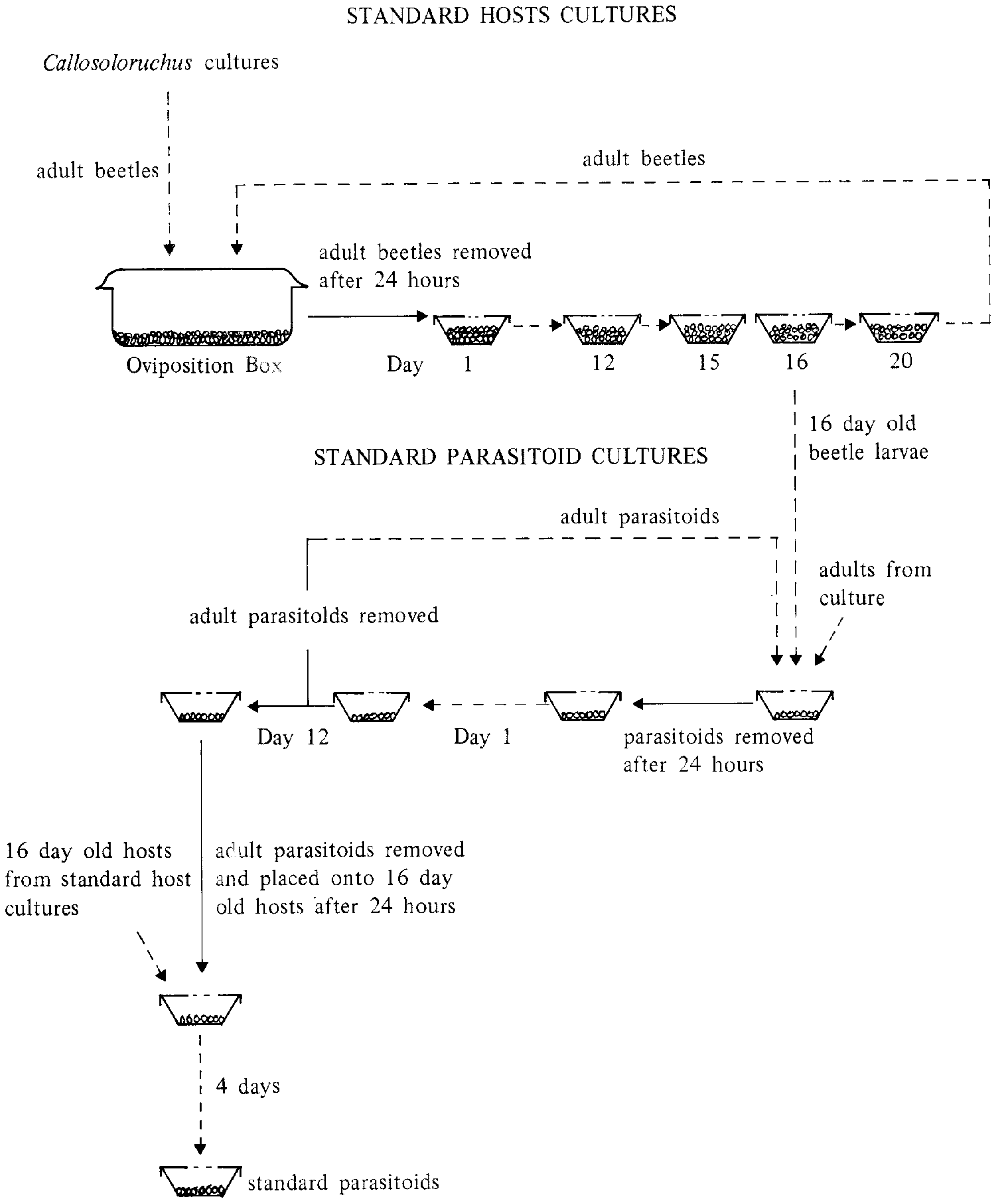

*Figure 1: Schematic diagram of the culture of **Callosobruchus maculatus** standard hosts and standard females of **Anisopteromalus calandrae** for experiments. Temp., 30°C, RH., 70%; 16/24 hours illumination.*

a sieve. The parasitised hosts were kept in the C.T. room and the parasitoids were re-used for the next culture. This procedure was repeated daily. The parasitoids were replaced after 4 or 5 days. To ensure sufficient material for experimentation, 2 dishes of cultures were started each day. The scheme is illustrated in *Figure 1.*

The Standard Parasitoid

On day 12, the parasitoids and beetles that emerged from the parasitoid cultures were removed using a sieve. After 24 hours, the parasitoids that emerged were anaesthetised with carbon dioxide, removed and placed with 16-day old larvae for 4 days. On the fourth day, the standard parasitoids were ready for experimentation. The scheme is illustrated in *Figure 1.*

The Experimental Arena

All the experiments with the parasitoids were carried out using butter dishes as the arena. A hole of 29mm diameter was made in the cover of each dish and covered with a piece of cloth. The dish was filled with 24.5 gm of cowpeas. For the respective experiments, cowpeas were replaced with the same numbers of cowpeas infested with *C. maculatus.*

Experiments on Functional Responses

The host density on each arena was varied by changing the number of infested cowpeas. Infested cowpeas were marked with a coloured wax pencil for easier recognition. One standard female *Anisopteromalus* was used in each arena. Details of the replications are shown in *Table 1.*

Each experiment was set up in the laboratory and kept in the C.T. room for 24 hours. At the end of the experiment, the parasitoids were removed and discarded. The cowpeas with the *Callosobruchus* larvae were dissected and examined for parasitism between 1 to 3 days later. The total number of hosts available ($\underline{N}$) and the number of hosts attacked ($\underline{NA}$) in each arena were recorded.

Third and fourth instar larvae and pupae were used in the experiments. These were animals obtained 12, 15 and 20 days after oviposition, respectively.

Analytical Methods

The parameters, $\underline{a}'$ and $\underline{T_h}$, from the Random Parasitoid Equation (Eqn. 2) can be estimated using two methods. The first method is simple and less time consuming. It involves transforming the data and using linear regression analysis. Rogers (1972) proposed that the Random Parasitoid Equation may be re-arranged into a form suitable for linear regression analysis. In the plot of 1/1n (proportion of hosts surviving) against the host density, the slope of the line can be used to estimate the handling time, $\underline{T_h}$, and the intercept to estimate the searching efficiency, $\underline{a}'$. Thus,

$$\frac{1}{\ln S} = - \left(\frac{T_h}{TP} N \right) \quad \left(\frac{1}{a'TP} \right) \quad (4)$$

where S = (N − NA)/N.

Subsequently, this method has been used extensively and is still being used by many authors. However, it was pointed out by Cock (1977) that the method violates the assumptions of regression analysis, and is thus statistically unsound.

The second method is by the use of a nonlinear least squares technique. A computer program, FRESAN, was developed by Bellows (1979) for this purpose. The program was run through a time-sharing terminal at Silwood Park which was connected to a CDC 6500 computer in the Imperial College Computer Centre, London. The program could provide:

1. the best fitted curves to the data using the Holling Type II and Type III functional response models of both a parasitoid and a predator.
2. the estimates of $\underline{a}'$ and $\underline{T_h}$ values of the models.
3. the analysis of variance tables.

TABLE 1: REPLICATIONS OF THE EXPERIMENTS ON THE FUNCTIONAL RESPONSES OF *ANISOPTEROMALUS CALANDRAE* ATTACKING DIFFERENT INSTARS OF *CALLOSOBRUCHUS MACULATUS*

Number of infested cowpeas per arena	Number of replicates		
	3rd instar	4th instar	Pupa
1	–	20	7
2	–	5	13
3	10	10	20
4	–	5	7
5	10	15	10
7	–	–	6
8	5	5	5
15	10	10	5
19	5	5	4
25	5	5	5
30	5	–	5
50	5	–	5
70	5	–	5

4. the plots of the residuals against the host densities.

The usual tests used in linear models are, generally, not appropriate when the model is nonlinear (DRAPER & SMITH, 1966). Thus, the F – statistic cannot be used to obtain conclusions at any stated confidence level. However, an approximate idea of possible level of fit may be obtained by the mean squares ratio (MSR) of:

$$\frac{\text{Mean squares due to 'lack of fit'}}{\text{Mean squares due to pure error}}$$

The sum of squares due to 'lack of fit' is obtained by the difference between the unexplained variation (residual) and pure error sum of squares. The latter can be obtained from the repeated observations.

DRAPER & SMITH, (1966) also described ways to check the model by examining the residual plots. Residuals are defined as:

$$e_i = Y_i - y_i ; i = 1, 2, ...$$

where $\underline{Y_i}$ is an observation and $\underline{y_i}$ is the corresponding fitted value.

In this paper, the functional response parameters were estimated from both the Random Parasitoid Equation and the Random Predator Equation using the computer program, FRESAN. Residual analyses were used to check for deviations from the models.

RESULTS

The functional response data of the three stages of the host, *C. maculatus,* when plotted showed forms typical of the Holling Type II response. *Figure 2* shows the curves of the Random Parasitoid Equation fitted using the least squares technique. The MSR

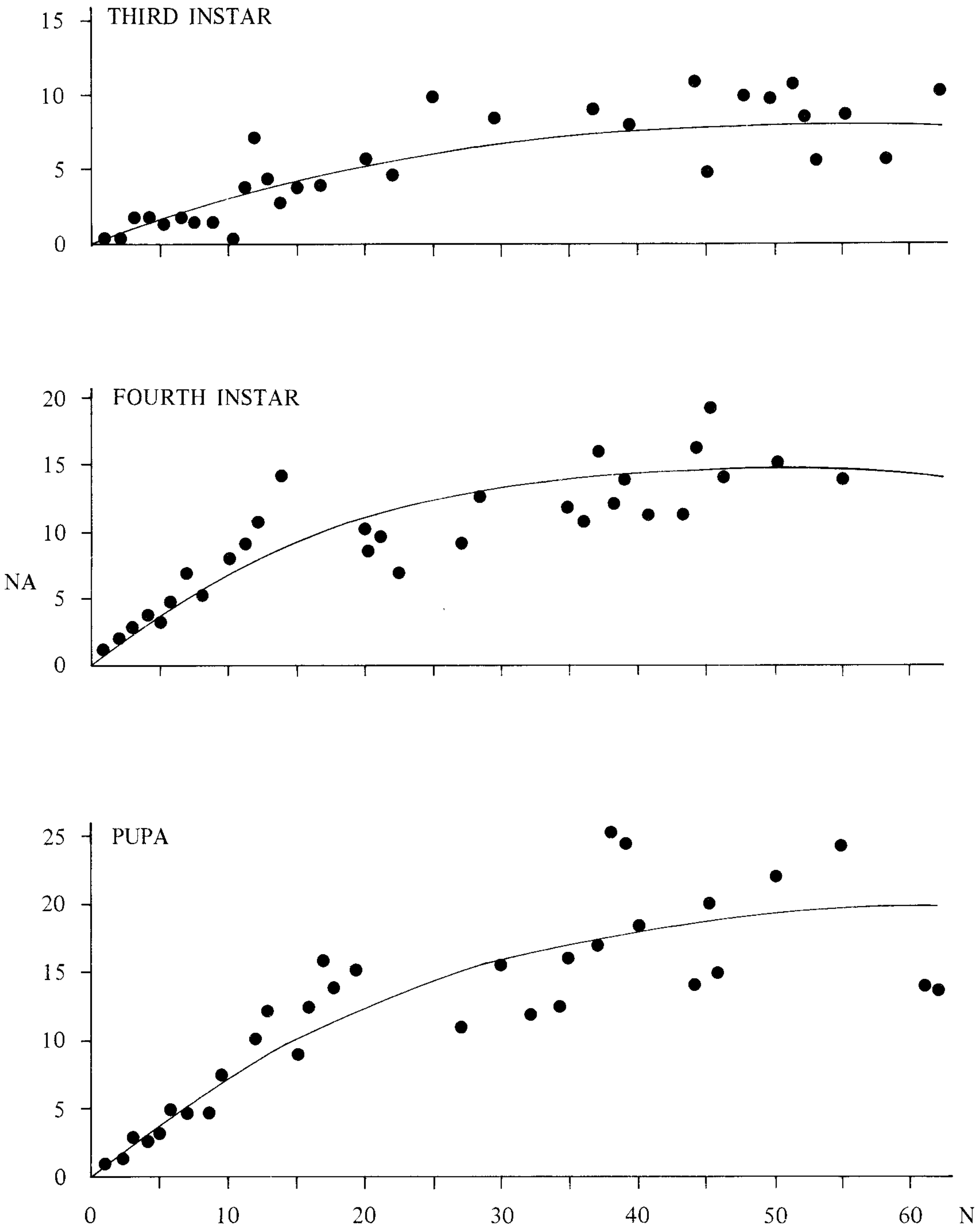

Figure 2: Functional responses of ***Anisopteromalus calandrae*** *to the different stages of* ***Callosobruchus maculatus***

The curves are best fit curves fitted to the Random Parasitoid Equation using least squares.

values were rather small indicating that the data fitted the model satisfactorily. In the plots of the residuals against the independent variable, N, an overall impression of a horizontal band of the residuals could be recognised in each of the three cases. This implied that there were no abnormalities in the data and thus no reason to suspect that the data did not fit the model (DRAPER & SMITH, 1966). The estimated values of the parameters, a' and T_h, are presented in *Table 2*.

The data were also fitted to the Random Predator Equation. In all the three cases, the MSR values were also small indicating satisfactory fits. The residual plots also showed no abnormalities in the data. Estimated values of a' and T_h from the Random Predator Equation are shown in *Table 3*.

DISCUSSION

The searching efficiency of a parasitoid is influenced by the climate, the host density (the functional response), the host distribution, the density of the parasitoids and alternative hosts or competing parasitoid species present (HASSELL, 1978). Thus, in a homogenous environment, the functional response is the prime factor. This is well expressed by the Random Parasitoid Equation (ROYAMA, 1971; ROGERS, 1972; HASSELL *et al.*, 1976) which is:

$$NA = N \left[1 - \exp \left(\frac{-a'TP}{1 + a' T_h N} \right) \right] \quad (5)$$

where NA = the number of hosts attacked
P = the number of parasitoids present
N = the host density
a' = a constant, the searching efficiency
T_h = a constant, the 'handling time'
T = total time the parasitoid and host are exposed.

The assumptions implicit in the equation have been discussed by ROGERS (1972) and HASSELL (1978). It assumes that:

1. every host has equal probabilities of being encountered by the parasitoids

2. the parasitised hosts remain exposed to encounters by the searching parasitoid. The re-encounters will lead to exactly the same period of handling time as the first encounter. Thus, more time is spent on handling than an equivalent predator.

Parasitoids have been known to be able to avoid superparasitism (DOUTT, 1964; VINSON, 1976). They may do this in one of several ways. The pteromalid, *Nasonia vitripennis* for instance, can distinguish between a live and dead host (EDWARDS, 1954). Females of *Trichogramma* rejecting hosts on which other females had walked over is another well known example (SALT, 1937). The parasitoid in this case approaches the predator situation, i.e. re-encounters are completely avoided. This can be expressed by the Random Predator Equation (ROYAMA, 1971; ROGERS, 1972; HASSELL, *et al.*, 1976; HASSELL, 1978).

The available evidence suggests that there is some avoidance of superparasitism by *Anisopteromalus calandrae.* Although at low host densities, more than one egg per host is commonly found (as many as 7 eggs were found in a situation with the 4th instar as hosts), at higher host densities, only one egg per host generally occurs. On the host, *Sitophilus,* it is rare for more than one egg to be oviposited on a larvae (COTTON, 1923; GHANI & SWEETMAN, 1955). On the one hand it is not entirely realistic to assume that avoidance of superparasitism is complete, but neither is it true to assume that superparasitism is complete. Thus, *Anisopteromalus* females probably behave in a manner intermediate between the two extremes. The a' and T_h values estimated from both the models appear rather similar. Thus, the Random Parasitoid Equation can

TABLE 2: PARAMETER ESTIMATES OF THE FUNCTIONAL RESPONSES OF *ANISOPTEROMALUS CALANDRAE* TO THE DIFFERENT STAGES OF *CALLOSOBRUCHUS MACULATUS* USING THE RANDOM PARASITOID EQUATION

Stages	Parameters		MSR
	a'	T_h	
3rd instar	0.6745	0.0738	1.82
4th instar	4.8126	0.0542	3.58
Pupa	3.8729	0.0374	5.30

a' = searching efficiency
T_h = handling time (day)
MSR = mean square ratio

TABLE 3: PARAMETER ESTIMATES OF THE FUNCTIONAL RESPONSES OF *ANISOPTEROMALUS CALANDRAE* TO THE DIFFERENT STAGES OF *CALLOSOBRUCHUS MACULATUS* USING THE RANDOM PREDATOR EQUATION

Stages	Parameters		MSR
	a'	T_h	
3rd instar	0.6273	0.0780	1.77
4th instar	2.5529	0.0613	3.53
Pupa	2.1786	0.0410	5.03

a' = searching efficiency
T_h = handling time (day)
MSR = mean square ration

be considered adequate in describing the searching behaviour of *Anisoptromalus calandrae*.

The variations in the a' and T_h values with the increase in prey size in predators have been discussed by THOMPSON (1975) and HASSELL, *et al.*, (1976). It is interesting to note that for the parasitoid, *A. calandrae*, the two parameters respond differently with the host age *(Figure 3)*. In the case of the damselfly, *Ischura elegans*, feeding on *Daphnia magna*, T_h increases with the increase in prey age (THOMPSON, 1975). Similar response was also observed in the predator, *Notonecta glanca* (HASSELL, *et al.*, 1976). Since smaller prey will, in general, be easier to subdue, consume and digest, T_h is dependent on other factors as well, such as, host acceptance and host location. Host size and age also play important roles in host acceptance. Examples of such behaviour are found in VINSON, (1976).

Odours from the host are also important when locating a host. Such examples are given by VINSON (1976). These odours, in contrast to the more long-range

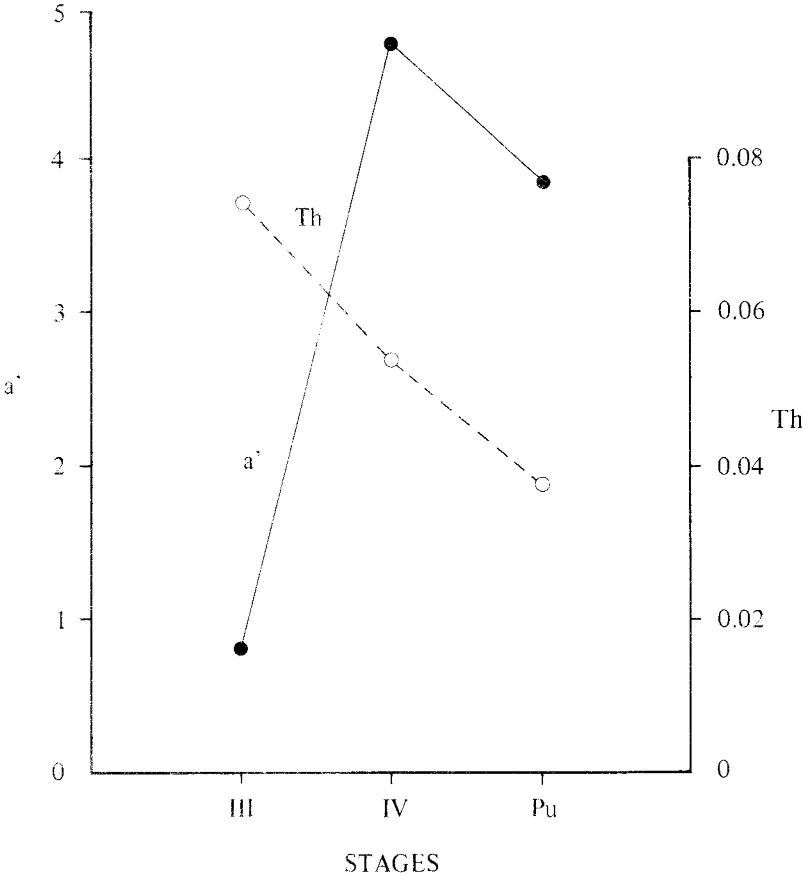

Figure 3: The searching efficiencies, a' and handling times, Th, of Anisopteromalus calandrae attacking the 3rd instar (III), 4th instar (IV) and pupa (Pu) of Callosobruchus maculatus

volatile chemicals that attract the parasitoid to the host habitat, appear to influence the parasitoid only when it is a short distance (2–20 cm) away (HENDRY, *et al.*, 1973; SCHMIDT, 1974). The existence of such odours, called *kairomones* (WHITTAKER & FENNY, 1971), in *C. maculatus* has, however, not been investigated. Host location with respect to its position in the substrate is also important. For instance, a host located deep in the cowpea may cause an increase in handling time because the parasitoid may spend more time 'trying to get at it'.

The feeding cells of the early stages of the larvae are usually quite deep beneath the testa of the cowpeas. At the fourth instar, the feeding cell is extended until a part of it is just beneath the testa, creating a 'window' on the surface of the cowpea. A large proportion (84%) of the third instar of *C. maculatus* were found deep beneath the surface of the cowpeas. No 'windows' were formed by these larvae. Some of the third instar larvae were feeding near the surface, but the 'windows' formed were very small (0.03 – 0.24mm diameter). Hosts located nearer the surface and with larger 'windows' will probably require less handling time. Lower $\underline{T_h}$ values in the fourth instar and pupae which are located nearer the surface of the cowpea are thus to be expected.

In true predators, a' decreases with the increase in prey age (THOMPSON, 1975; HASSELL, *et al.*, 1976). For parasitoids, there is still insufficient evidence in the literature on this relationship. However, the experimental results tend to suggest that the situation is probably different in parasitoids. Smaller hosts may be less nutritious and are thus less preferred. Host locations are also important. This probably explains the lower a' for the third instar in the case of *C. maculatus* and *A. calandrae*.

Figure 3 shows that a' increases and then decreases. This may represent experimental errors. However, it is highly probable that a' is maximum for the fourth instar. Several authors have shown that as larval hosts reach the pupal stages, they become less acceptable (VINSON, 1976). Such changes in acceptance may be related to hormones or to alterations in the factors necessary for acceptance.

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SUMMARY

The parasitoid, *Anisopteromalus calandrae* (Howard) was found to have Holling's Type II functional responses to the three immature stages, third instar, fourth instar and pupa, of *Callosobruchus maculatus* (F.). Using the nonlinear least squares technique, the parameters a' and T_h of the Random Parasitoid Equation were estimated. These parameters were also estimated from the Random Predator Equation. However, the evidence obtained indicated that the searching behaviour of *A. calandrae* was closer to that of a true parasitoid.

The searching efficiency, a', of *A. calandrae* was highest for the fourth instar, followed by the pupae and the third instar. The handling time, T_h, on the other hand, varied uniformly with the stage of the host; highest for the third instar, followed by the fourth instar and the pupa, respectively. These observations differed from those found in the true predators by other authors. Possible reasons for these differences are discussed.

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SUITABILITY OF FIVE PREEMERGENCE HERBICIDES FOR CASSAVA (*MANIHOT ESCULENTA* CRANTZ)

[illegible] HANG[1]

Keywords: Cassava, Weeding, Herbicides, Phytotoxicity, Field Experiment

RINGKASAN

Dua percubaan telah dijalankan untuk menentukan kesesuaian lima racun herba pracambah bagi ubikayu. Percubaan pertama menunjukkan alachlor [2-chloro-2^{1}, 6^{1}-diethyl-N (methoxymethyl)-acetanilide], fluometuron [1, 1-dimethyl-3-(a,a,a-trifluro-m-tolyl) urea], dan oryzalin (3, 5-dinitro-N^{4}, N^{4}-dipropylsulfanilamide) adalah selamat bagi ubikayu pada kadar 1.5 kg/ha dan memberi kawalan rumpai yang memuaskan. Pada kadar 1.5 kg/ha diuron [3-(3,4-dichlorophenyl)-1, 1 dimethylurea] mengakibatkan kesan buruk pada tumbuhan, manakala tebuthiuron [N(5-(1, 1-dimethylethyl)-1, 3, 4-thiadiazol-2-yl) N, N^{1}-dimethylurea] memberikan kawalan rumpai yang amat baik dan lama tetapi mengakibatkan kesan yang sangat teruk pada tumbuhan. Percubaan kedua membuktikan bahawa alachlor, fluometuron dan oryzalin adalah sesuai dan mempunyai kadar selamat yang tinggi bagi ubikayu. Diuron didapati agak sesuai dan mungkin tidak selamat jika digunakan pada kadar lebih daripada 1.5 kg/ha. Akan tetapi ia boleh digunakan dengan campuran alachlor pada kadar yang rendah. Adalah dirumuskan bahawa racun herba yang sesuai bagi ubikayu adalah alachlor, fluometuron dan oryzalin.

INTRODUCTION

Weeds are a major problem in crop cultivation. In cassava, serious weed infestation normally occurs during the initial months before the crop canopy is fully developed and at the later stage when the plants shed some of their leaves, allowing a greater light penetration. Apart from competing for the growth factors, weeds seriously interfere with the harvesting operation. Many farmers are aware of the weed problem and have practised weed control measures accordingly (TUNKU MAHMUD, 1979). Normally, manual weed is carried out at the early stage followed by post-emergence herbicides a few months later and, if necessary, near harvesting (CHAN, 1971; TUNKU MAHMUD, 1979).

Preemergence herbicides may be used for weed control in cassava. DOLL and PIEDRAHITA (1976) have screened many preemergence herbicides for their selectivity to cassava. The herbicides reported to be suitable for the crop include some of the locally available ones such as alachlor, fluometuron, chloramben and diuron. However, little work has been reported locally on the suitability of these herbicides for the local cassava clones and their levels of selectivity (CHEW *et al.*, 1976). Two experiments were thus designed to evaluate the efficacy of some of the locally available preemergence herbicides and their levels of selectivity to a popular local cassava clone (Black Twig).

MATERIALS AND METHODS

Experiment I

This experiment was conducted to evaluate the efficacy of the selected pre-emergence herbicides which included alachlor, diuron, fluometuron, oryzalin and tebuthiuron for weed control in cassava. They were applied alone or in combination at the rate of 1.5 kg/ha (alone) and .75 kg/ha (combination) as preemergence (*Table 1*).

The experiment was sited on a heavy soil (Sogomonas Soil Series) in Syarikat Ubiyu Plantation near Sitiawan, Perak.

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[1] Field Crops Branch, MARDI, Serdang, Selangor

TABLE 1: TREATMENT DESCRIPTIONS FOR EXPERIMENT I

Entry	Herbicide		Rate (a.i.) kg/ha
	Common name	Formulation*	
	Oryzalin	Surflan 80 WP	1.5
2	Tebuthiuron	Perflan 80 WP	1.5
	Diuron	Karmex 80 WP	1.5
	Fluometuron	Cotoran 80 WP	1.5
5	Alachlor	Lasso 4.8 EC	1.5
6	Alachlor + Diuron	Lasso 4.8 EC Karmex 80 WP	.75 .75
7	Alachlor + Fluometuron	Lasso 4.8 EC Cotoran 80 WP	.75 .75
8	Control I	Monthly weeding	
9	Control II	– No weeding	

* WP — Wettable powder

EC — Emulsified concentration

The cassava was planted in March of 1978 on 4-row beds spaced at a meter between plants and rows. The herbicides were applied one day after planting with a spraying volume of 800 L/ha and on a plot-by-plot basis to ensure even distribution of the chemicals. Fertilizer was applied a month after planting at the rate of 400 kg of CCM 44 (12:6:22:3) per hectare.

Crop injury and weed conditions were observed at the 6th and 10th week from planting. Visual weed ratings were made based on a scale of 0 to 100%, where 0 represented no weed and 100% represented complete weed cover. However, angular transformation was used in the statistical analysis. The crop was harvested at 12 months after planting from a sampling area of 4m by 10m from the center of the plots, fresh weights of the vegetative positions and tubers were determined.

The experimental design was Randomized Complete Block with 4 replications.

Experiment II

This experiment was laid out to evaluate the herbicides found to be promising in experiment I for their levels of selectivity to cassava clone Black Twig. The herbicides and the rates used in the investigation are described in *Table 2*.

The cassava was planted in January, 1979 at MARDI Research Station, Serdang, Selangor, on a medium textured soil (Bungor Soil Series). The method of planting was the same as in Experiment I but no bed was constructed. The herbicides were applied one day after planting.

Plant injury ratings were assessed at one month after planting based on visible phytotoxic symptoms and the general physical appearance of the crop seedlings. The ratings were classified under five categories: 1) None to very slight injury; 2) Slight injury; 3) Moderate but acceptable injury; 4) Severe injury; 5) Very severe to complete death. All the treatments were replicated 4 times and

TABLE 2: TREATMENT DESCRIPTIONS FOR EXPERIMENT II

Entry	Herbicide		Rate (a.i.) kg/ha
	Common name	Formulation*	
1	Alachlor	Lasso 4.8 EC	2
2	,,	,, ,, ,,	4
3	,,	,, ,, ,,	6
4	Diuron	Karmex 80 WP	1
5	,,	,, ,, ,,	2
6	,,	,, ,, ,,	4
7	Fluometuron	Cotoran 80 WP	1
8	,,	,, ,, ,,	2
9	,,	,, ,, ,,	4
10	Oryzalin	Surflan 80 WP	2
11	,,	,, ,, ,,	4
12	,,	,, ,, ,,	6

* WP = Wettable powder
EC = Emulsified concentration

arranged in a Randomized Complete Block Design. The plot size was 4m by 5m.

RESULTS

Experiment I

Weed Control

The common weeds observed in the experimental plots were *Axonopus compressus* (Sw.) P. Beauv., *Echinochloa colonum* (Linn.) Link, *Eleusine indica* (Linn.) Gaertn, *Digitaria ciliaris* (Rez.) Koel, *Imperata cylindrica* (Linn.) P. Beauv., *Paspalum conjugatum* Berg, *P. commersonii* Sensu RidL, *Stachytarphelia indica* (Linn.) Vahl., *Borreria latifolia* Schum., *Cleome rutidosperma* D.C., *Croton hirtus* L' Herit, *Ipomoea* sp., *Physallis minima* Linn..

Ratings for the general weed conditions are presented in *Table 3*. The experiment site was selected on the area which had a serious weed infestation history. However, during the course of the experiment, the weed population was observed to be not as dense as expected probably due to the prevailing dry weather conditions. In the first six weeks, all the plots were practically free of weeds as reflected by low weed ratings. Weed ratings at the 10th week gave an average of 66% for no weeding plots and a range of 4% to 28% for the herbicide treated plots. Among the herbicides, tebuthiuron gave exceptionally good weed control; weed rating of 4% was recorded at the 10th week. It also provided a long residual control as indicated by the weed conditions observed during crop harvesting. The other herbicides, alone or in combination, gave a satisfactory weed control.

Crop Performance

Cassava was found to be susceptible to tebuthiuron. The crop seedlings in tebuthiuron treated plots showed severe leaf chlorosis and stunting, and some

TABLE 3: THE EFFECTS OF FIVE PREEMERGENCE HERBICIDES ON CASSAVA PLANTS AND WEEDS

Herbicide	Rate (a.i.) (kg/ha)	Pnytotoxicity	Plant Stand (%)	Weed (%)	
				6th week	10th week
Oryzalin	1.5	NIL	100	3	23
Tebuthiuron	1.5	Severe	43	1	4
Diuron	1.5	Slight	100	5	26
Fluometuron	1.5	NIL	100	4	20
Alachlor	1.5	NIL	100	3	16
Alachor + Diuron	.75 .75	NIL	98	5	28
Alachor + Fluometuron	.75 .75	NIL	99	5	21
Control I –	Monthly weeding	–	100	8	11
Control II –	No weeding	–	99	14	66
		L.S.D.* 5%	–8	1	3
		C.V.	–6%	26%	24%

eventually died. Only 43% of the affected seedlings survived and recovered. Diuron at the rate of 1.5 kg/ha induced some phytotoxicity. The affected seedlings exhibited wilting symptoms, but no plant casualty was recorded. However, when mixed with alachlor at half the rate, no visible toxic symptoms were observed. The other herbicides were safe for the crop at the rates tested *(Table 3)*.

The vegetative and tuber yields are shown in *Table 4*. They ranged from 73 kg to 137.1 kg/plot and 71.3 kg to 141.5 kg/ha for vegetative and tuber yields, respectively. The lowest yields came from the tebuthiuron treated plots, and these were explained by the loss of 57% plant stand. The highest yields came from oryzalin treated plots. Among the herbicides, diuron produced one of the lowest vegetative and tuber yields. The no weeding plots produced vegetative and tuber yields comparable to that of the monthly weeding plots probably because of low weed infestation.

Experiment II

Cassava Tolerance

The crop tolerance to the various herbicides was assessed based on the responses of cassava seedlings one month after planting. The results of the study, presented in *Table 5*, indicate that cassava had a high level of tolerance to alachlor, fluometuron, and oryzalin. Treated with as high as 6 kg/ha for alachlor and oryzalin and 4 kg/ha for fluometuron, the crop seedlings exhibited little visible toxic symptoms, indicating a high level selectivity of the chemicals. However, cassava had a low level of tolerance to diuron; rates higher than 1 kg/ha produced severe yellowing of leaves and stunted seedlings. This was in agreement with the responses to diuron observed in the earlier experiment.

DISCUSSION

The efficacy of preemergence herbicides is highly regulated by the availa-

TABLE 4: THE EFFECTS OF FIVE PREEMERGENCE HERBICIDES ON CASSAVA VEGETATIVE AND TUBER YIELDS

Herbicide		Rate (a.i.) (kg/ha)	Shoots (kg/plot)	Fresh tuber (kg/plot)
Oryzalin		1.5	137.1	141.5
Tebuthiuron		1.5	73.0	71.3
Diuron		1.5	100.1	112.9
Fluometuron		1.5	114.0	128.3
Alachlor		1.5	136.8	123.3
Alachlor + Diuron		.75 + .75	119.5	124.5
Alachlor + Fluometuron		.75 + .75	124.0	120.7
Control I –	Monthly weeding –		116.1	120.6
Control II –	No weeding		107.9	109.3
	L.S.D. @ 5% =		9.8	37.1
	C.V. =		14%	[illegible]

TABLE 5: THE TOLERANCE LEVELS OF CASSAVA TO FOUR PREEMERGENCE HERBICIDES A MONTH AFTER PLANTING

Herbicide	Rate (kg/ha a.i.)	Phytotoxicity
Alachlor	2	Slight
	4	Slight
	6	Slight
Diuron	1	Slight
	2	Severe
	4	Severe
Fluometuron	1	Very slight
	2	Slight
	4	Slight
Oryzalin	2	Very slight
	4	Slight
	6	Slight

bility of soil moisture. Under wet condition, the herbicidal properties of the chemicals are usually enhanced. And in the tropics, such as this country, where the weather is generally hot and wet with unpredictable rainfall, the suitable herbicides for a crop therefore should not only be safe at the rate applied but should have an acceptable margin of safety. This is even more important when considering the tradition of herbicide application (manual) in this country whereby accurate calibration is often difficult, and over application may occur.

Hence, the suitable preemergence herbicides for cassava, among the five tested, are alachlor, fluometuron, and oryzalin. Alachlor and fluometuron have also been reported to be highly selective to cassava elsewhere. The herbicides induced no harmful effects even when applied at double the recommended rates (DOLL and PIEDRAHITA, 1976). The investigations with the local cassava clone produced similar results. Similarly, oryzalin is also highly selective to the crop. In the first experiment, the herbicide applied at 1.5 kg/ha induced no visible phytotoxicity and produced the highest tuber yield. The subsequent trial confirmed the safety of the herbicide to the crop and also revealed the high level of tolerance of the crop.

Diuron is one of the most widely used preemergence herbicides in the country. Research elsewhere showed that diuron was selective to cassava and the crop treated with double the recommended rates exhibited no harmful effects (DOLL and PIEDRAHITA, 1976). In these experiments, however, diuron was found to be partially selective to cassava. In the first experiment, the crop treated with 1.5 kg/ha of diuron expressed some phytotoxicity. However, the later experiment showed that diuron was safe at 1 kg/ha but with 2 kg/ha or higher resulted in severe phytotoxicity. These results suggest that diuron may not be safe at a rate more than 1.5 kg/ha for cassava. However, diuron may be used in combination with alachlor at a lower rate. The contradiction on the selectivity of diuron as reported elsewhere and in this study is probably due to the different levels of susceptibility among cassava clones.

For tebuthiuron, the rate used in this study may be too high. This was indicated by the excellent and long duration of weed control. And the surviving plants from the 1.5 kg/ha of tebuthiuron treatment totally recovered and produced some yields. But in view of the local environment, though the herbicide may have a potential at lower rate, it should be avoided for use due to the sensitivity of the crop.

Although in the experiments weed competition was not serious and the herbicides gave a satisfactory degree of control. However, some less susceptible weeds still emerged as reflected by the weed ratings. In fact an application of preemergence herbicide would usually require a supplementary weed control measure to remove the escaped weeds for high crop yields (DOLL and PIEDRAHITA, 1976). But in this study, the effectiveness of the herbicides to control weeds was not reflected by the crop yield responses. This was probably due to low weed population which did not significantly reduced crop yields in the 'no weeding' control plots. The crop yield responses do indicate that herbicides produced no detrimental effects to the crop tuber development. Nonetheless, these herbicides have been widely employed in many crops cultivation, and their efficacy to control weeds is well established.

CONCLUSIONS

Suitable preemergence herbicides for cassava, among the five tested in this study, were alachlor, fluometuron, and oryzalin. These herbicides were selective and had a wide margin of safety to cassava. On the other hand, diuron was partially selective and may not be used for more than 1.5 kg/ha for medium to heavy textured soils. Tebuthiuron was non-selective and should be avoided for use in cassava cultivation.

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SUMMARY

Two experiments were conducted to determine the suitability of five preemergence herbicides for cassava. The first experiment showed that alachlor [2-chloro-2', 6'-diethyl-N-(methoxymethyl)-acetanilide], fluometuron [1, 1-dimethyl-3-(a, a, a-trifluro-m-toly) urea], and oryzalin (3, 5-dinitro-N^4, N^4-dipropylsulfanilamide) were safe to cassava at 1.5 kg/ha and produced a satisfactory weed control. Applied at 1.5 kg/ha, diuron [3-(3, 4-dichlorophenyl)-1, 1-dimethylurea] induced some phototoxicity; tebuthiuron [N (5-(1, 1-dimethyl-ethyl)-1, 3, 4-thiadiazol-2-yl)-N, N'-dimethylurea] gave a long and excellent weed control but induced severe phytotoxicity. The second experiment confirmed that alachlor, fluometuron and oryzalin were selective and had a wide margin of safety to cassava. Diuron had been found to be partially selective and may not be safe if applied more than 1.5 kg/ha. However, it may be used in combination with alachlor at a reduced rate. It is concluded that suitable herbicides for cassava were alachlor, fluometuron and oryzalin.

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