CHAPTER 6

PREDICTION OF DAMAGE WITH REFERENCE TO JUVENILE LARVAL MORTALITY

Introduction

A fundamental aim of economic entomologists is to be able to predict damage early enough to initiate control procedures. With this aim in mind, Watt (1964) proposed the development of predictive mathematical models based on mortality data to forecast population levels for several generations ahead. Although this is theoretically possible, given the appropriate data, in practice it is of limited use, except within the environment of a long term, extensive monoculture such as forest and grassland. Even under such conditions, problems will arise with attempts to achieve long term prediction, because some factors which affect population levels, such as weather, cannot be adequately forecast.

The same problems arose when prediction of porina population levels was attempted. It has already been shown that very dry weather during the early stages of the life cycle is a significant and variable mortality factor. For this reason alone, porina population prediction would only appear feasible for one generation ahead. Depending on when the prediction was made, this may or may not allow adequate time to initiate control measures.

In order to forecast porina damage, information is required for the following.

1. Susceptibility of different areas.
2. Prediction of population levels.
3. When damage occurs.

It has been shown in this study that the surface dwelling larval period is a key mortality stage. It was also hypothesized that the mortality factors responsible were microclimatic variables on the soil surface. To test this hypothesis it was decided to measure the most important of these factors and to determine whether significant correlations exist between them and subsequent larval population densities.

Determination of areas susceptible to porina infestation

Introduction

Soil type was known to be highly variable in some of the many paddocks sampled early in the study to determine larval distribution patterns (Chapter 4). As larval populations were found to be aggregated the following hypothesis was postulated.

'That soil type differences influence the distribution pattern of larval populations.'

It is known that some soil characteristics influence the microclimate at the soil surface, and consequently must affect porina survival. For example, different soil types have different moisture retention ability which directly or indirectly affect soil surface temperature, soil surface moisture and plant growth (Ives, pers. comm.). All these parameters have been found to influence egg and surface dwelling larval survival. It was decided that quantitative evidence for or against the above hypothesis was required if delimitation of susceptible areas within a paddock or over a farm were to be feasible.

There is much merit in the concept of using a basic, universally applicable, standard unit (the soil type) as a means of determining porina susceptible areas.

Method and results

During the years 1968-69-70 over twenty porina infested pastures were sampled to determine larval population distribution patterns using the method described in Chapter 4, page 142. Thirteen pastures were selected in those localities which were considered to cover a range of soil types. The location and description of each site is given in Table 32 (see also Figures 34-46). Mr D. Ives of Soil Bureau, D.S.I.R., Lincoln, kindly surveyed each paddock and drew a detailed soil map of each paddock to an appropriate scale. The porina distribution patterns were then superimposed over the thirteen detailed soil maps prepared (Figures 34-46). A key to the abbreviations used on each map is given in Table 30.

The Kruskal-Wallis non-parametric test (Sokal and Rohlf, 1969) was used to determine quantitatively whether there were statistically significant differences between soil types in

Table 30 Key to abbreviations used in soil type maps in Figs 34 to 46 and in Tables 31, 33 and 34.

Soil type	Abbreviation
YELLOW-GREY EARTHS	
Dry-hygrous	
Wakanui silt loam	W1
Wakanui silt loam, weakly mottled phase	W1a
Wakanui silt loam, strongly mottled phase	W1b
Wakanui silt loam on fine sandy loam	W2
Wakanui silt loam on fine sandy loam, weakly mottled phase	W2a
Wakanui silt loam on fine sandy loam, strongly mottled phase	W2b
Wakanui fine sandy loam; weakly mottled phase	W3a
INTERGRADES BETWEEN YELLOW=GREY EARTHS AND YELLOW-BROWN EARTHS	
Hygrous	
(Associated yellow-brown shallow and stony soils)	
Ruapuna silt loam with stones	R1
Ruapuna stony silt loam	R2
Ruapuna very stony silt loam	R3
LOWLAND YELLOW-BROWN EARTHS	
Hygrous	
Gorge silt loam	G1
Gorge shallow silt loam	G1h
Gorge silt loam with stones	G1s
Gorge silt loam on fine sandy loam	G2
GLEY SOILS	
Hygrous	
Temuka silt loam	Tk1
Temuka silt loam on fine sandy loam	Tk2
Temuka silty clay loam	Tk3
Temuka silty clay loam on clay loam	Tk3a
Temuka shallow silty clay loam on clay loam	Tk3h
Temuka silty clay loam on fine sandy clay	Tk4
RECENT SOILS	
Waimakariri silt loam	Wk1
Waimakariri shallow silt loam	Wk1h
Waimakariri silt loam on fine sandy loam	Wk2
Waimakariri sandy loam	Wk3
Waimakariri stony sandy loam	Wk3s
Templeton silt loam	Tm1
Templeton silt loam on fine sandy loam	Tm2
Templeton silt loam on fine sandy loam, deep topsoil phase	Tm2d
Templeton shallow silt loam on fine sandy loam	Tm2h
Templeton silt loam on sand	Tm3
Paparua fine sandy loam	P1
Paparua shallow fine sandy loam	P1h
Paparua fine sandy loam with stones	P2
Eyre shallow silt loam	E1h
Eyre fine sandy loam	E2
Eyre fine sandy loam, deep topsoil phase	E2d
Eyre fine sandy loam with stones	E2s
Eyre very stony fine sandy loam	E3
Selwyn fine sandy loam	S1
Selwyn shallow fine sandy loam	S1h

Table 31 Scoring of certain soil characteristics for use in the Kruskal-Wallis nonparametric test to determine susceptibility of soil types to porina infestation.

Soil type	Moisture retention score 1-6	Drainage score 1-6	Water logging score 1-5
W1	5	4	3
W1a	5	4	3
W1b	6	5	4
W2	4	4	2
W2a	4	4	2
W2b	5	5	3
W3a	4	4	2
R1	5	3	2
R2	4	3	2
R3	3	3	1
G1	5	3	2
G1h	4	3	2
G1s	4	3	2
G2	5	4	2
Tk1	6	6	4
Tk2	5	5	4
Tk3	6+	6	5
Tk3a	6+	6	5
Tk3h	6+	6	5
Tk4	6+	6	5
Wk1	4	3	2
Wk1h	3	2	1
Wk2	2	2	1
Wk3	3	2	1
Wk3s	1	1	1
TM1	3	3	2
TM2	2	3	2
TM2d	3	3	2
TM2h	2	2	1
TM3	2	2	1
P1	3	2	1
P1h	2	2	1
P2	2	1	1
E1h	3	2	1
E2	2	2	1
E2d	3	2	1
E2s	2	2	1
E3	1	1	1
S1	4	4	2
S1h	3	3	1

Key

Moisture retention ability 1 — 6 poor — good

Amount of drainage 1 — 6 excessive — poor

Amount of water logging 1 — 5 high — nil

see Table 30 for explanation of soil type abbreviations.

Table 32   Key to sites given in Tables 33 and 34 and discussed in text (p.228)

Site	Farmer	Locality	Spring management	Management at time of sampling
1	Clark	Southbridge	lax grazing	grazed
2	Maw	Methven	hayed	"
3	"	"	lax grazing	"
4	Bruce	Rakaia	lucerne hay	lucerne hay
5	Jarmen	Darfield	moderately grazed	grazed
6	"	"	lightly grazed	"
7	"	"	lax grazed shut for white clover	"
8	Dept. of Ag.	Templeton	shut for grass seed	"
9	Lord	Eyreton	" " white clover	"
10	Robert	Russley	" " " "	"
11	Tucker	Ladbrooks	" " " "	"
12	College	Lincoln	heavy grazed	"
13	D.S.I.R.	"	shut all the time	not grazed

Note: see also Figs. 34 - 46

Table 33 The relationship between soil type and susceptibility to porina infestation tested by the Kruskal-Wallis non-parametric test (Sokal and Rohlf, 1969)

Part A

Rank	Site 1	2	3	4	5	6	7	8	9	10
1	Tm2 (165)	G2 (195)	G1s(170)	R1 (223)	P1 (222)	P1 (151)	Tm1(180)	Tm3 (316)	W3a (341)	S1h(211)
2	Tm2h(159)	G1 (192)	G1 (167)	R3 (211)	E2s(216)	Tm1(143)	Tm2(161)	Tm2h(267)	Wk1 (286)	S1 (181)
3	E2d (124)	G1h(182)	G1h(120)	G1h(191)	Tm2(186)	Tm2(142)	P1 (111)	Tm2 (238)	Wk2 (262)	
4	Tm1 (120)	G1s(180)		G2 (179)	Tm2(163)	Tm3(140)		Tm1 (186)	Wk3s(253)	
5	E2 (93)			R2 (166)	E3 (162)	P2 (134)			Wk3 (252)	
6	E1h (83)			G1 (158)		E3 (89)			Wh1h(193)	
No. of samples per site	242	378	326	377	396	279	343	520	552	398
Stat.sig.	**	N.S.	**	**	*	N.S.	*	**	N.S.	*

Rank		Site 11	12	13
1		W1b (158)	W2a(198)	Tk2(170)
2		Tk3h(147)	Tm2(188)	Tk1(97)
3		Tk3a(126)	W2 (172)	
4		W2b (85)	W1a(166)	
No. of samples per site		265	361	295
Stat.sig.		N.S.	**	**

contd.

Part B

Soil Moisture Retention Ability Scores (refer to Table 31)													
Rank	1	2	3	4	5	6	7	8	9	10	11	12	13
1	2	5	4	5	3	3	3	2	4	3	6	4	5
2	2	5	5	3	2	3	2	2	4	4	6+	2	6
3	3	4	4	4	2	2	3	2	3		6+	4	
4	3	4		5	2	2		3	1		5	5	
5	2			4	1	2			2				
6	3			5		1			3				

<u>Key</u>

** = significant at P < .01
* = significant at P < .05
N.S. = non significant
1-6 = order of ranking according to relative degree of porina susceptility
( ) = the rank number obtained from the statistical test used to correlate porina density and soil type

* Key to soil type abbreviations and locality of sites given in Tables 30 and 32 respectively

Table 34 The relationship between soil type and susceptibility to porina infestation tested by the Kruskal-Wallis non-parametric test (Sokal and Rohlf, 1969) after arranging the soil types into groups sampled in the one season.

Seasonal groupings

Sites sampled in 1968				
5	8	9	10	3
Ranked soil type (from Table 33A)				
P1 (222) E2s (216) Tm2 (186) Tm3 (163) E3 (162)	Tm3 (316) Tm2h(267) Tm2 (238) Tm1 (186)	W3a (341) Wk1 (286) Wk2 (262) Wk3s(253) Wk3 (252) Wk1h(193)	S1h (211) S1 (181)	Tk2 (170) Tk1 (97)

Moisture retention ability score

3 2 2 2 1	2 2 2 3	4 4 3 1 2 3	3 4	5 6

Overall ranking

		Statistical rank	Moisture score
1	W3a	341	4
2	Tm3	316	2
3	Wk1	286	4
4	Tm2h	267	2
5	Wk2	262	3
6	Wk3s	253	1
7	Wk3	252	2
8	Tm2	238	2
9	P1	222	3
10	E2s	216	2
11	S1h	211	3
12	Wk1h	193	4
13	Tm1	186	3
14	Tm2	186	2
15	S1	181	4
16	Tk2	170	5
17	Tm3	163	2
18	E3	162	1
19	Tk1	97	6

contd.

Table 34 contd.

Sites sampled in 1969				
1	2	3	6	7
Ranked soil type (from Table 33A)				
Tm2 (165) Tm2h(159) E2d (124) Tm1 (120) E2 (93) E1h (83)	G2 (195) G1 (192) G1h (182) G1s (180)	G1s (170) G1 (167) G1h (120)	P1 (151) Tm1 (143) Tm2 (142) Tm3 (140) P2 (134) E3 (89)	Tm1 (180) Tm2 (161) P1 (111)

Moisture retention ability score

2 2 3 3 2 3	5 5 4 4	4 5 4	3 3 2 2 1	3 2 3

Overall ranking

		Statistical rank	Moisture score
1	G2	195	5
2	G1	192	5
3	G1h	182	4
4	G1s	180	4
5	Tm1	180	3
6	G1s	170	4
7	G1s	167	5
8	Tm2	165	2
9	Tm2	161	2
10	Tm2h	159	2
11	P1	151	3
12	Tm1	143	3
13	Tm2	142	2
14	Tm3	140	2
15	P2	134	2
16	E2d	124	3
17	Tm1	120	3
18	G1h	120	4
19	P1	111	3
20	E2	93	2
21	E3	89	1
22	E1h	83	3

contd.

Table 34 contd.

Sites sampled in 1970			
4	11	12	
Ranked soil type (from Table 33A)			
R1 (223) R3 (211) G1h (191) G2 (179) R2 (166) G1 (158)	W1b (158) Tk3h(147) Tk3a(126) W2b (85)	W2a (198) Tm2 (188) W2 (172) W1a (166)	

Moisture retention ability score

5 3 4 5 4 5	6 6 6 5	4 2 4 5	

Overall ranking

		Statistical rank	Moisture score
1	R1	223	5
2	R3	211	3
3	W2a	198	4
4	G1h	191	4
5	Tm2	188	2
6	G2	179	5
7	W2	172	4
8	W1a	166	5
9	R2	166	4
10	G1	158	5
11	W1b	158	6
12	Tk3h	147	6
13	Tk3a	126	6
14	W2b	85	5

FIG. 34
Site 1

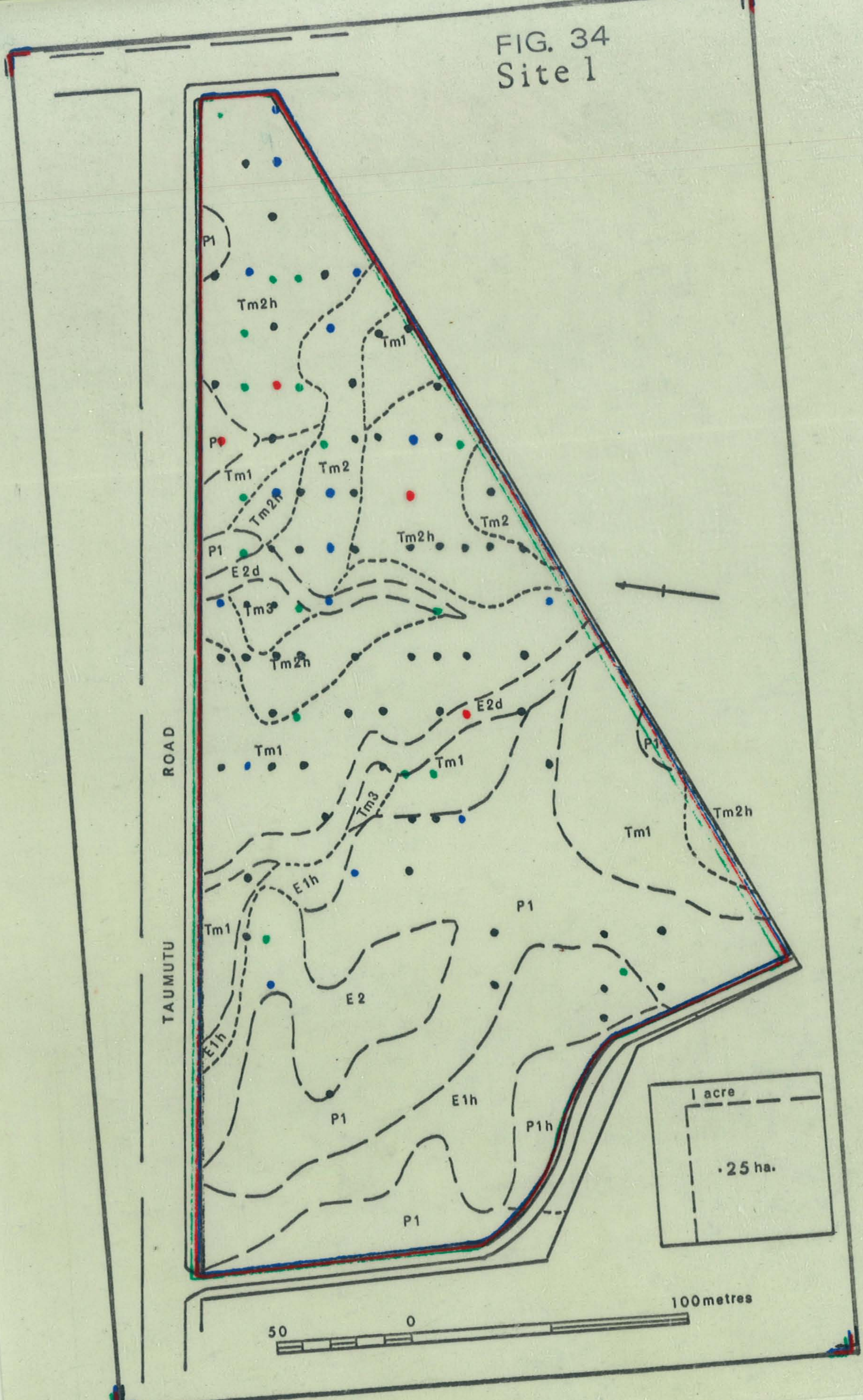

ROAD
TAUMUTU
P1
Tm2h
Tm1
Tm2
E2d
Tm3
E1h
E2
P1h
I acre
·25 ha.
100metres
50
0

FIG. 35
Site 2

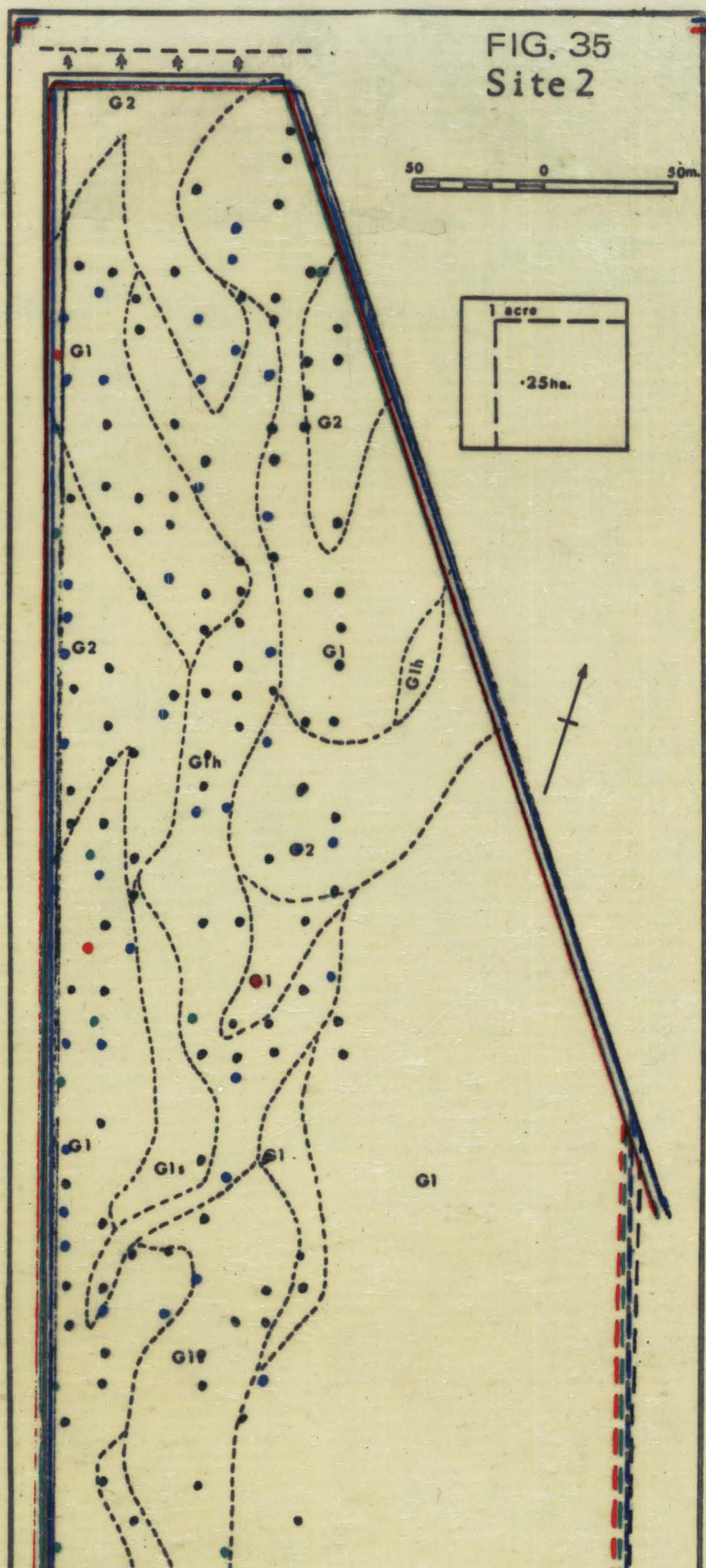
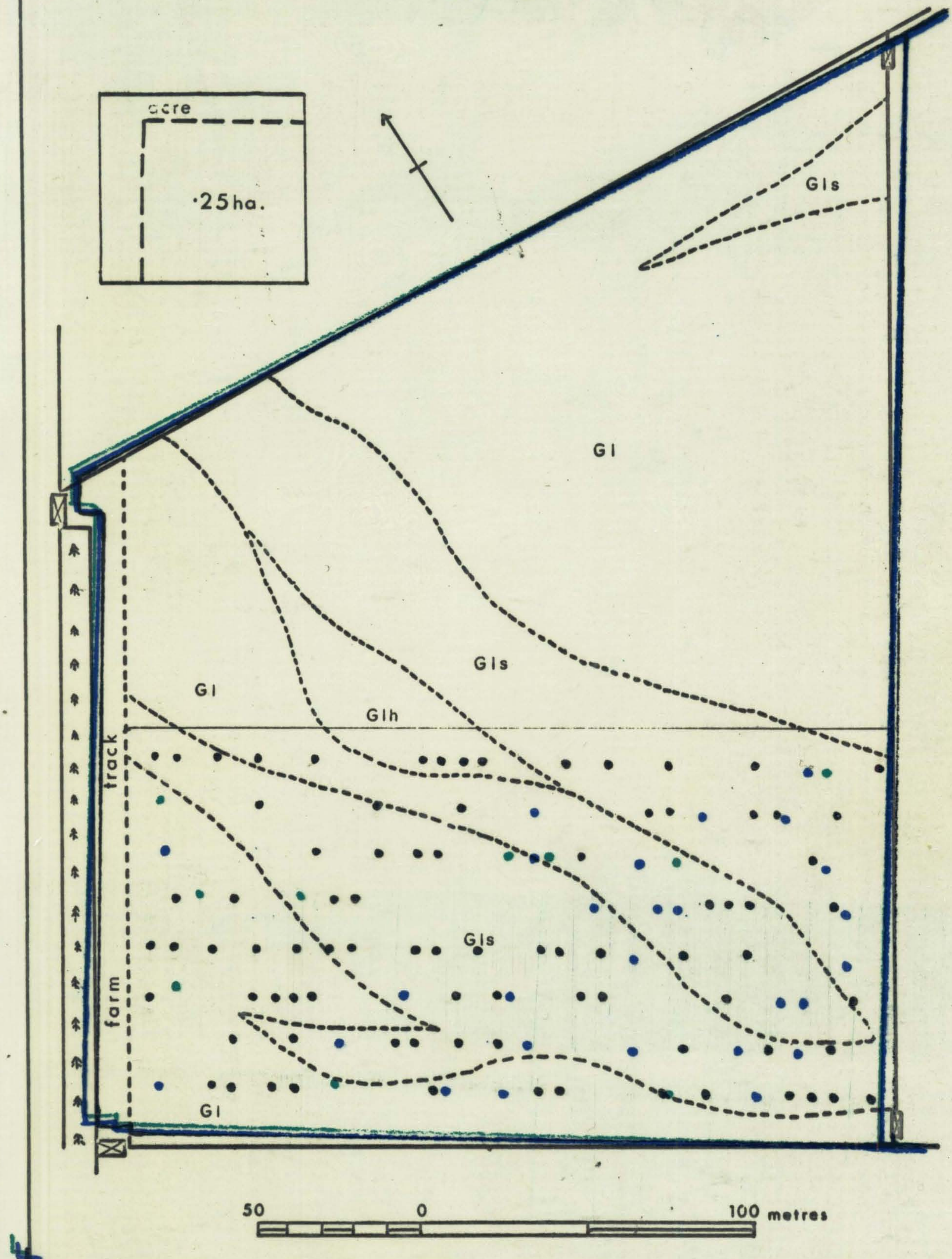


FIG. 36
Site 3



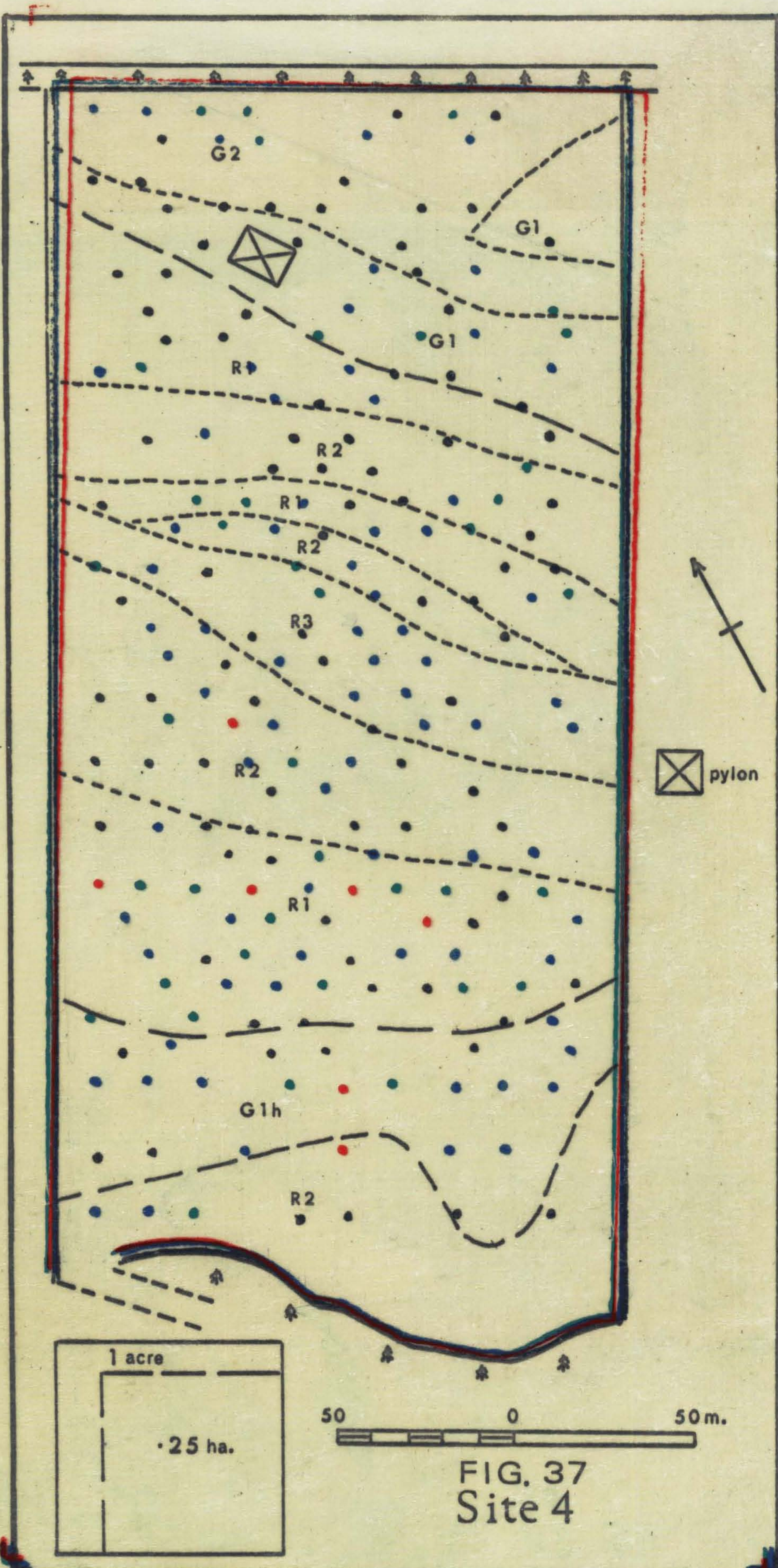


FIG. 37
Site 4

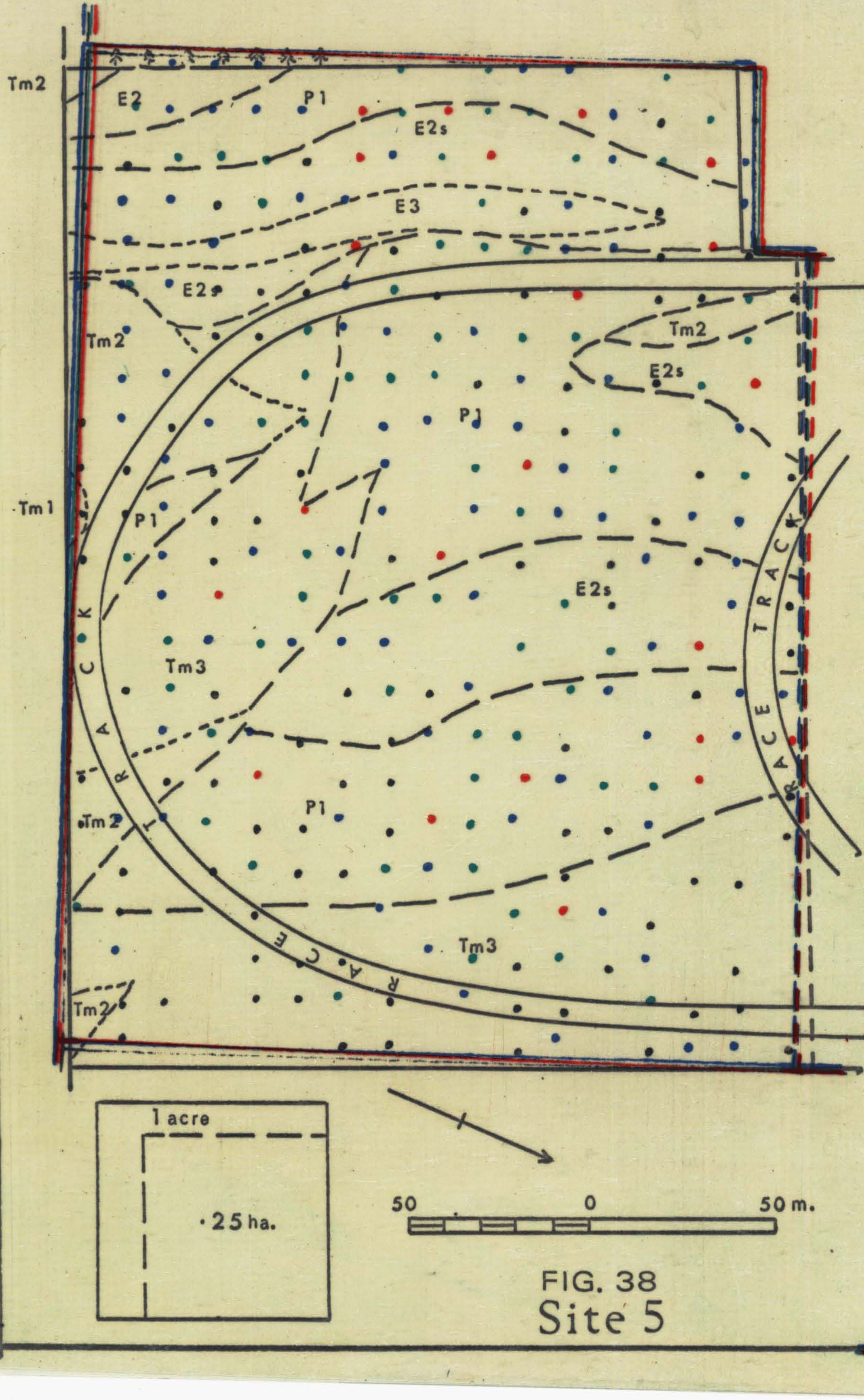

Tm2
E2
P1
E2s
E3
E2s
Tm2
Tm2
E2s
P1
Tm1
P1
E2s
Tm3
Tm2
P1
Tm3
Tm2
RACE TRACK
RACE TRACK
1 acre
·25 ha.
50
0
50 m.

FIG. 38
Site 5

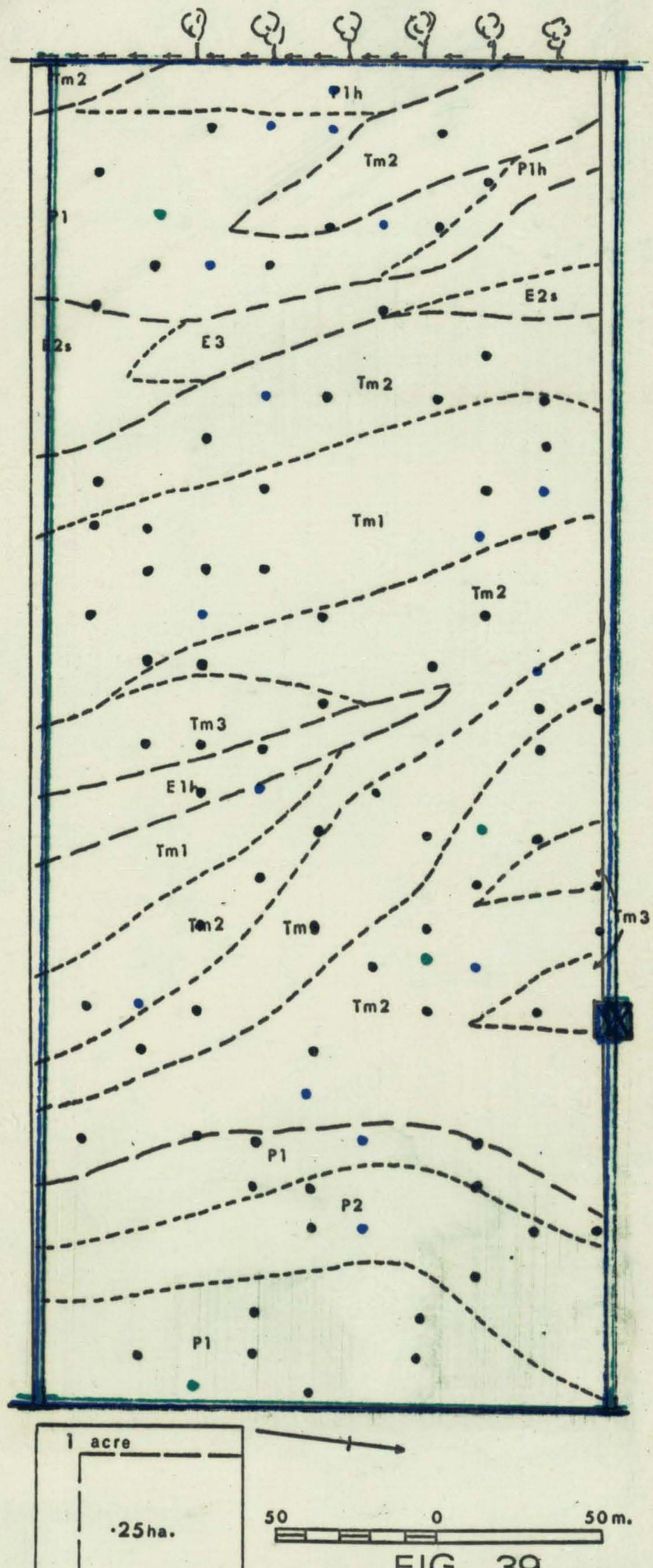

Tm2
P1h
Tm2
P1h
P1
E2s
E3
E2s
Tm2
Tm1
Tm2
Tm3
E1h
Tm1
Tm2
Tm3
Tm2
P1
P2
P1
1 acre
·25ha.
50
0
50m.

FIG. 39
Site 6

FIG. 40
Site 7

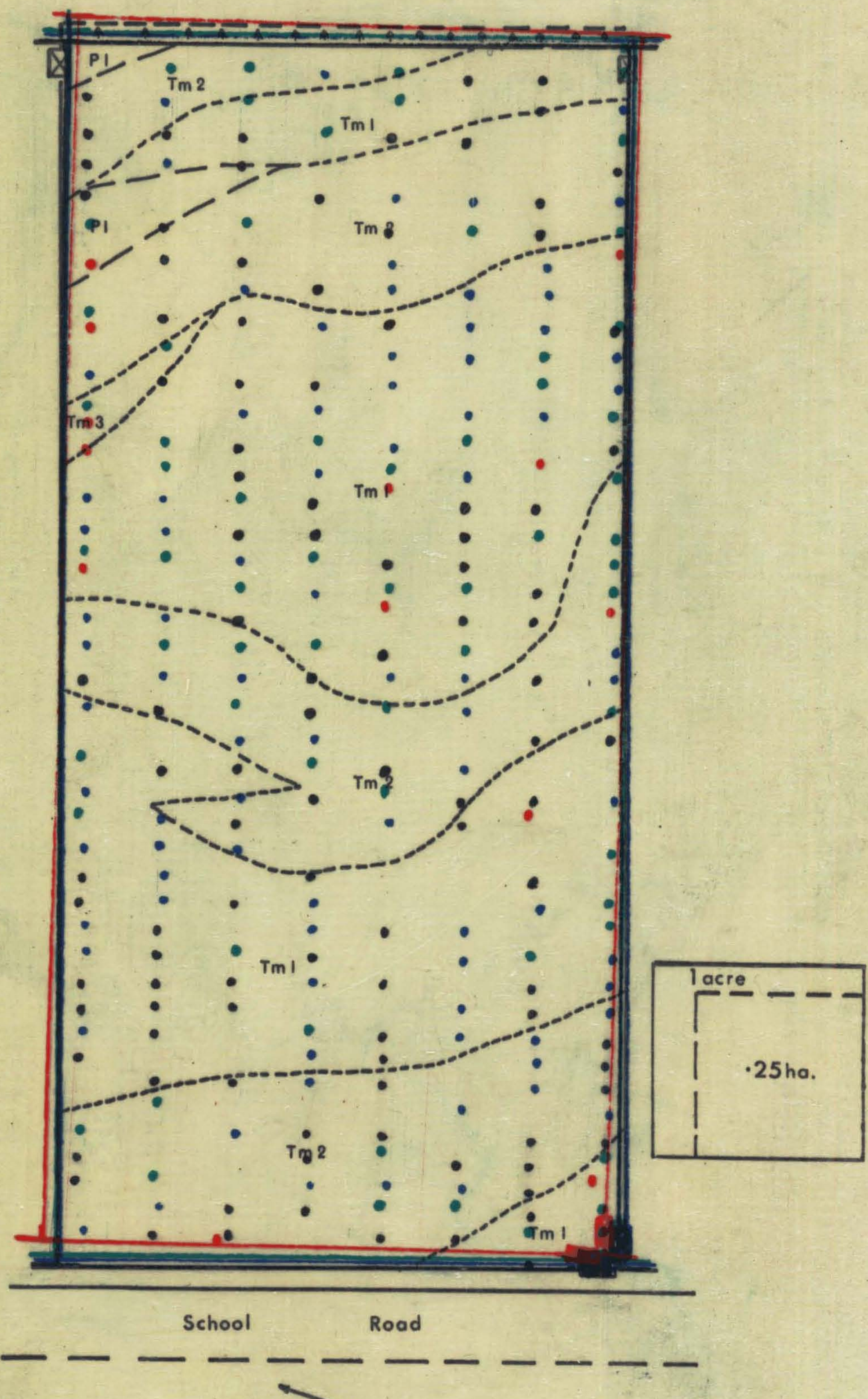

P1
Tm 2
Tm 1
P1
Tm 2
Tm 3
Tm 1
Tm 2
Tm 1
Tm 2
Tm 1
1 acre
·25 ha.
School Road
50
0
100 metres

FIG. 41
SITE 8

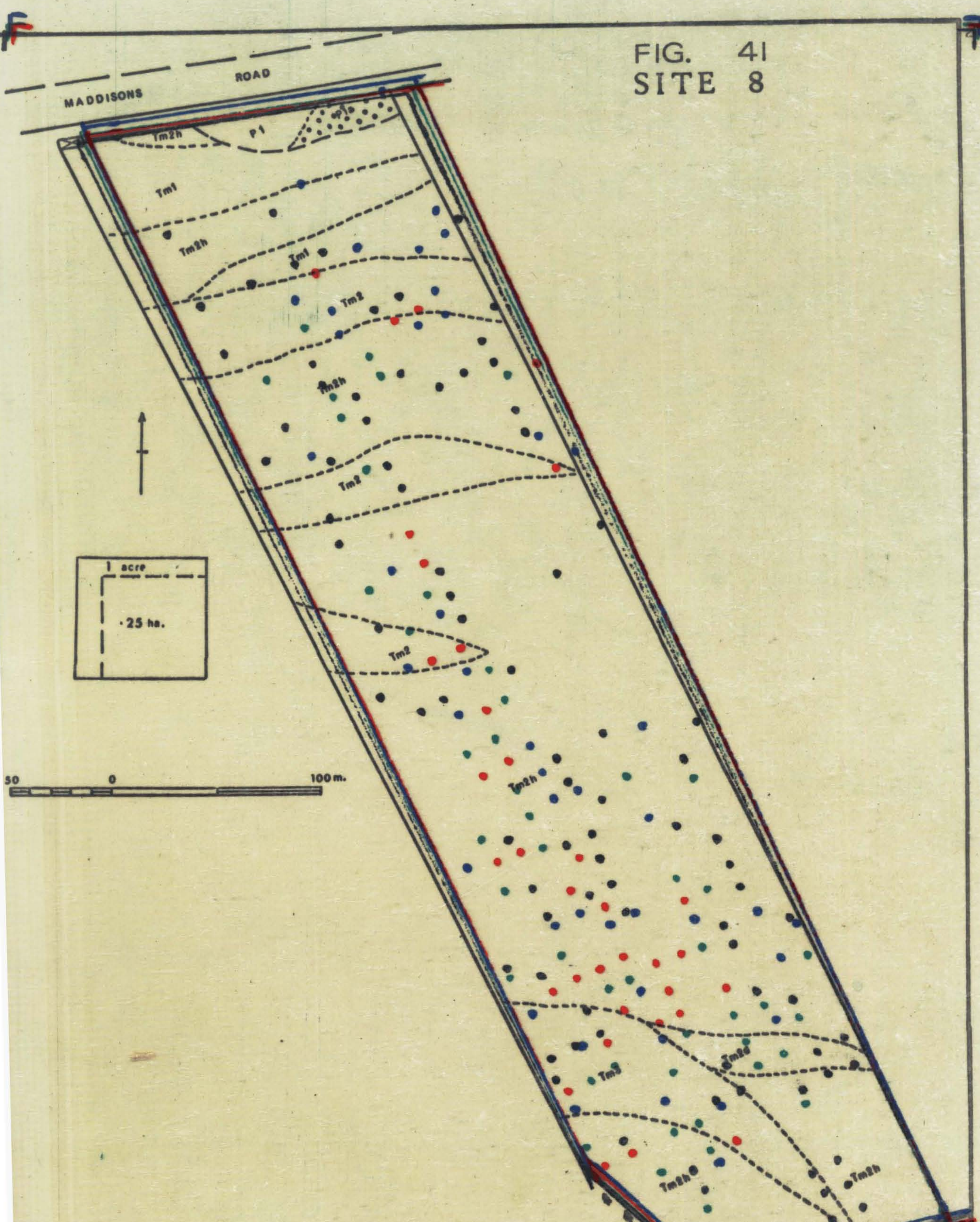

MADDISONS ROAD
Tm2h
P1
spib
Tm1
Tm2h
Tm1
Tm2
Tm2h
Tm2
Tm2
Tm2h
Tm3
Tm2h
Tm2h
1 acre
·25 ha.
50
0
100m.

FIG. 42
Site 9

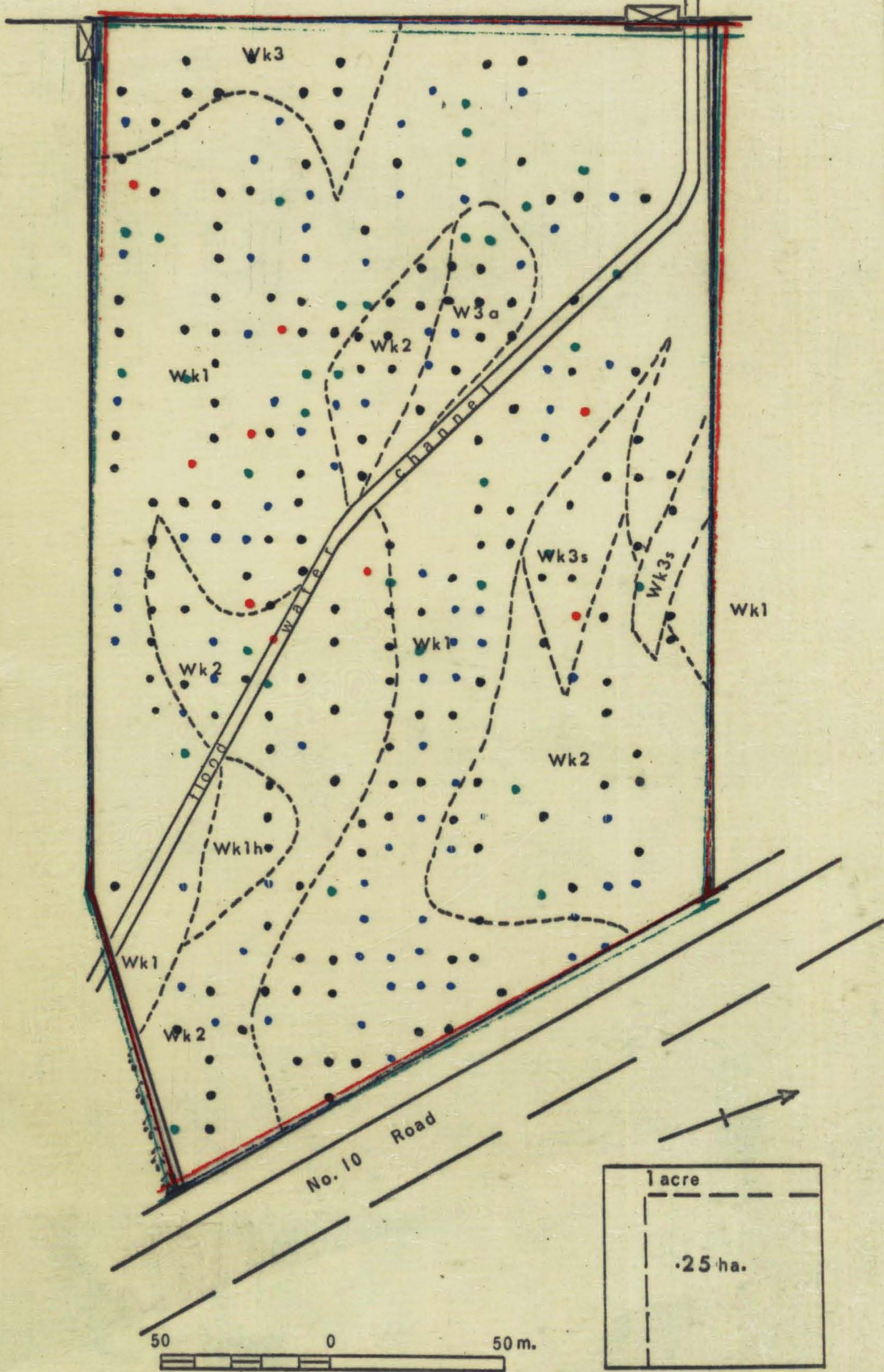
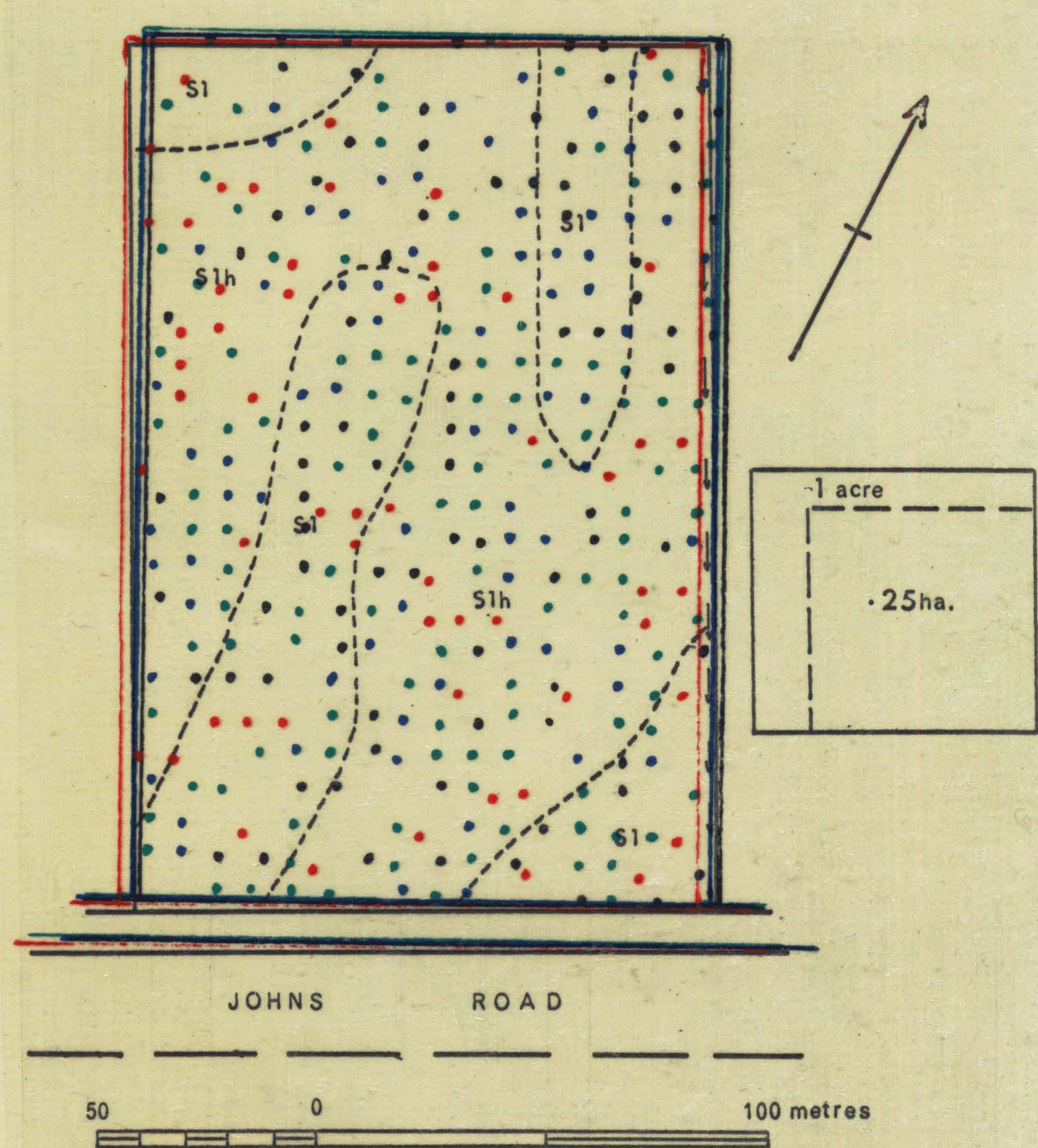

Wk3
W3a
Wk2
Wk1
channel
water
flood
Wk3s
Wk3s
Wk1
Wk1
Wk2
Wk2
Wk1h
Wk1
Wk2
No. 10 Road
1 acre
·25 ha.
50
0
50 m.

FIG. 43

Site 10



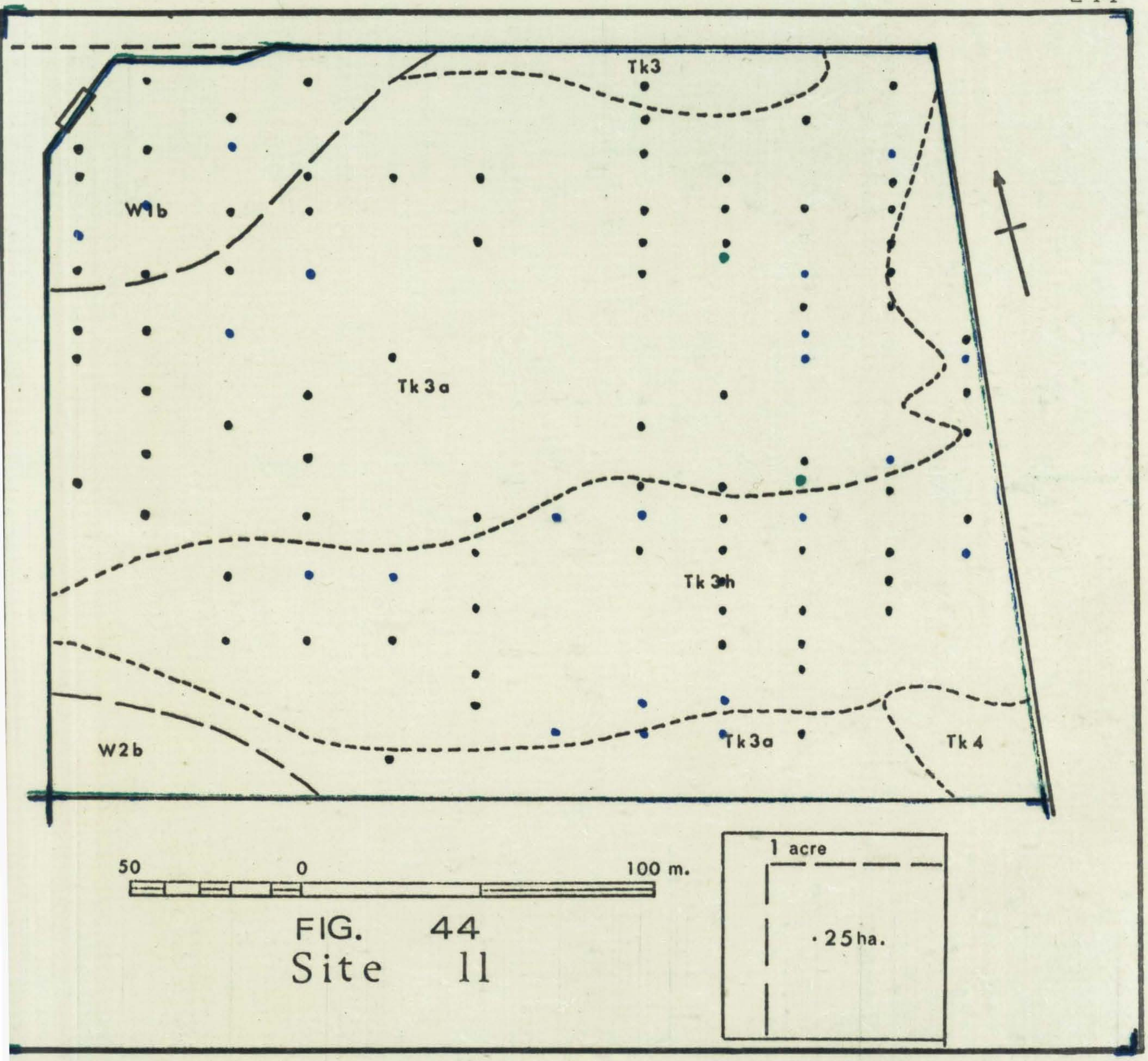


FIG. 44
Site 11

FIG. 45
Site 12

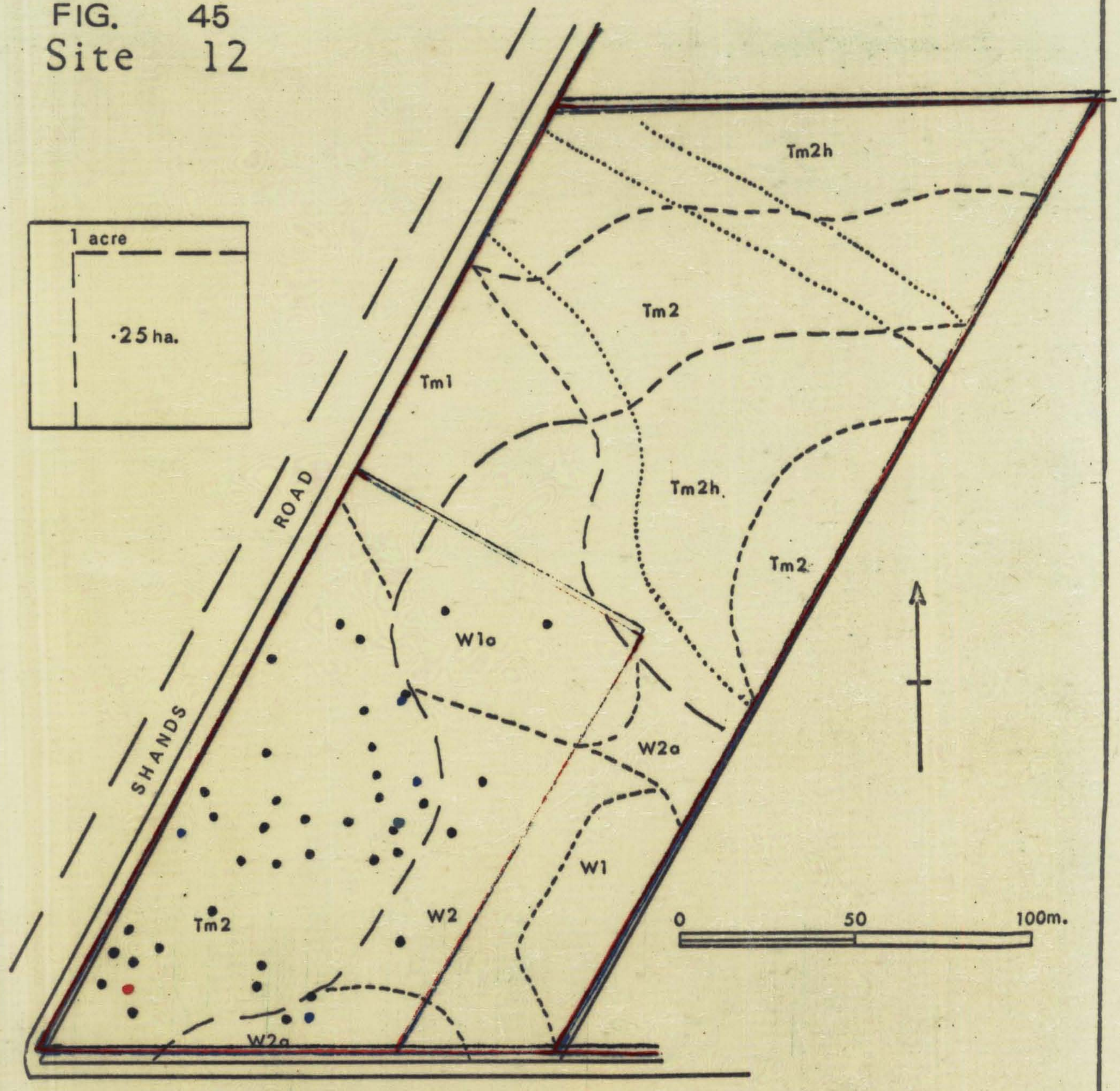
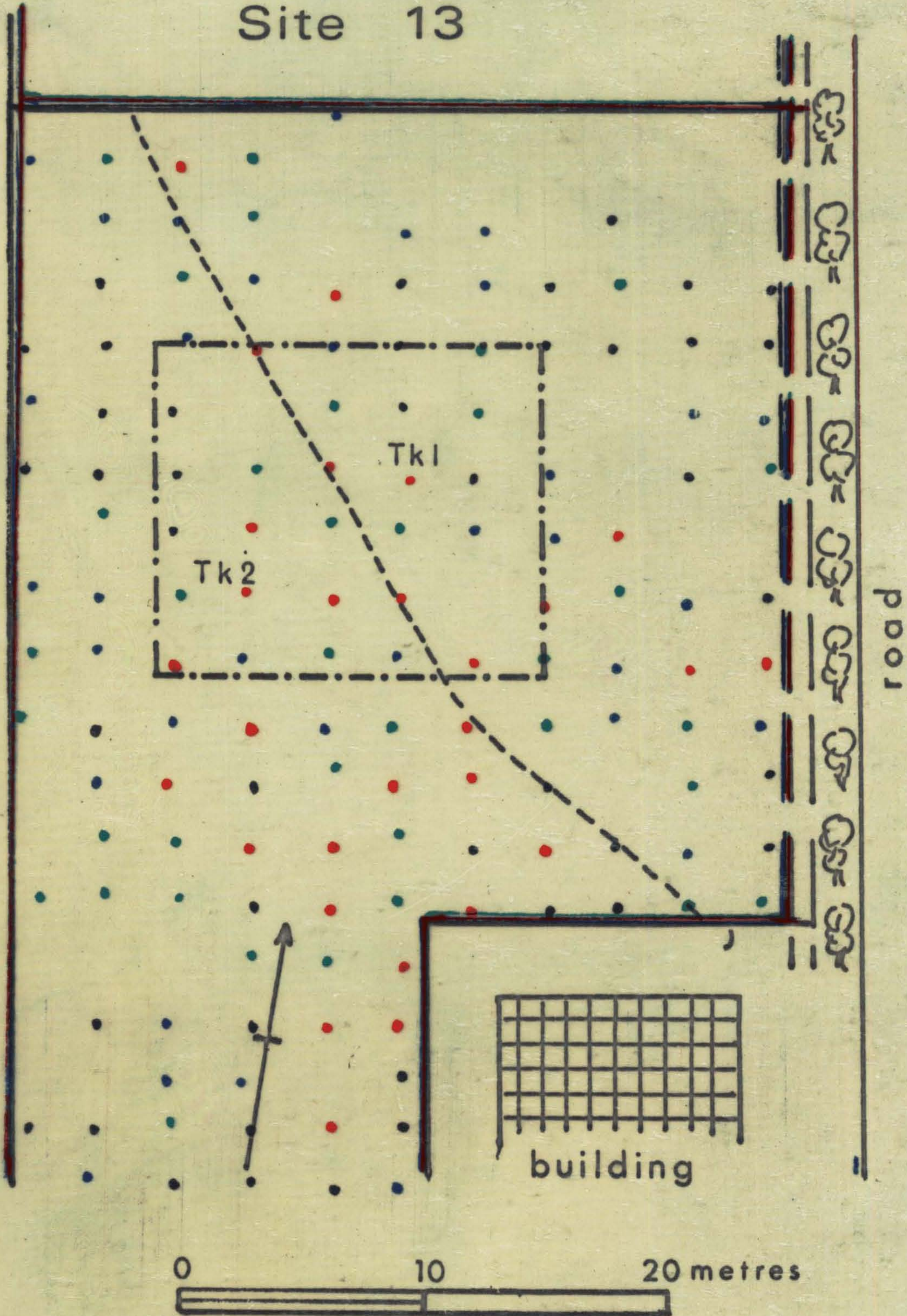


FIG. 46

Site 13



each paddock. This test was chosen because of its applicability to the analysis of a wide range of different distribution series. In this test the null hypothesis is not concerned with specific parameters but only with the distribution of the variates.

The test was used firstly to indicate whether there were real differences between the soil types in each paddock. This was achieved by ranking each soil type within a paddock, according to the larval density within the mapped boundaries of the soil type. Larval population frequency distributions were used to determine the ranking score.

The next step involved assigning a figure to each soil type representing a physical characteristic. Each soil type was firstly rated on a one to six scale according to its moisture retention ability (Table 31). The soils were then arranged in descending order in each paddock according to the statistical ranking, based on porina density. The moisture retention score was then allocated. These results are given in Table 33.

Rearrangement of these figures was carried out in an attempt to find other statistically meaningful and logical arrangements. For example, seasonal grouping was attempted (Table 34) but was not successful.

Other arrangements were tested after making allowance for sample number in each paddock by dividing each soil type rank number by the total sample number per paddock. A percentage infestation for each soil type was also calculated and analysed using the original information rather than frequency data.

In either case little or no improvement towards a meaningful sequence was obtained, even after using a composite figure consisting of a combination of soil characteristics which are given in Table 31.

Discussion on the effect of soil type
<u>on the pattern of porina infestation</u>

It was not possible to conclusively prove the hypothesis that soil type differences influenced larval distribution patterns. An encouraging trend was initially revealed at Site 1 (Figure 34) where the heavier the soil type, the greater the density of porina (Table 33 part A). The Kruskal-Wallis test gave significant differences in nine of the thirteen paddocks studied (Table 33 part A) but anomalies became apparent. For example, the ranking of the soils at Sites 4 and 12 (Figures 37 and 45) was contrary to the expected trend. At these sites the lighter soils seemed to have the greater porina density. Similar anomalies became apparent when moisture retention ability was tested (Table 33 part B). A meaningful sequence was revealed at Site 6 but the original differences between the soil types were statistically non-significant (Table 33 part A).

It became apparent that either there was no relationship between porina infestations and soil type, or the statistical test was not appropriate and would not reveal differences between the soil types even if they existed. It appeared, therefore, that soil type may have a less important and direct effect on the microclimate with regard to porina survival than was first thought, while variations in plant cover and prevailing weather conditions may have more influence. For example, a dense irrigated hay crop could provide an ideal and uniform microclimate, regardless of paddock soil type differences.

Whatever the explanation, however, the fact remains that it was not possible, with the present results, to categorically rank soil types according to their susceptibility to porina infestation. Nevertheless, it was intuitively felt that the general approach has much merit and that more detailed work should be attempted to ascertain the influence of soil type on the soil surface microclimate.

Conclusion

Although it was not possible to develop a system to delimit susceptible areas, general trends could be outlined. For example, in a dry spring, those areas most likely to harbour porina infestations, other factors being equal, are the Gorge, Wakanui, Ruapuna and Temuka soil groups.

In a wet spring, soil type probably has little effect, although it is possible for some soils to become too wet. This could cause high surface dwelling larval mortality (Fenemore and Allen, 1969). The high moisture retentive Temuka group could contain such soils and this may explain why some of the soil types within this group ranked very low in the statistical analysis.

There was a trend towards higher porina densities in most of the silt loam soil types, especially within the drier soil groups, i.e. Waimakariri, Templeton, Paparua, Eyre and

and Selwyn. For an example see Table 33, Sites 6 and 7).

The above trends could be applied on a farm scale to determine where porina are likely to be present, although consideration would have to be given to seasonal and management variations.

As the information was inconclusive it would be inadvisable to apply the findings outside the Canterbury province.

Prediction of porina population levels

Introduction

Information from the life table studies (Chapter 5) showed how egg and surface dwelling larval mortality influenced population trend. In view of the catastrophic nature of the larval mortality (Figures 15 to 19 and Tables 19 to 21) especially during drought, microclimatic factors were considered worth studying. Dumbleton (1945) had already stressed the importance of these factors in relation to early larval mortality (see page 42).

Furthermore, the calculation of Arbous and Kerrich's (1951) dispersion parameter (page 160) indicated the importance of environmental factors influencing population distribution (= population mortality/survival).

Methods

In order to carry out microclimatic studies, very precise and usually complex measurements are required. This negates using large areas, for practical reasons. It was therefore thought desirable to intensively study a large number of small plots. A large plot number would also allow inter-plot variability to be assessed and the results obtained could be extrapolated to larger areas.

It was decided to measure soil surface temperature and soil surface moisture, plant cover and rainfall. All of these factors were easily measured and previous work presented in Chapters 4 and 5 indicated their importance.

To measure the porina populations a life table technique would have yielded the most information. Pilot trials showed, however, that the problems involved in sampling for a number of age intervals on very small plots, were insurmountable. It was finally decided to sample the surviving larval population at the time they assumed the tunnelling stage. The aim was to find a relationship between microclimatic variations in spring and the surviving larval population at the tunnelling stage.

Design of field experiments

A distinct disadvantage when working with a univoltine insect is the time factor involved when studying a particular age interval and trying to obtain temporal replication. Much of the information obtained from the first two years' work was inadequate, as the time was spent on pilot trials which were used to perfect techniques.

Pilot trials conducted during 1969 at Ladbrooks and Prebbleton

The study area for each of these two trials consisted of eighteen 53 cm x 79 cm plots. The study area at Ladbrooks was on a Temuka silt loam soil (Ives, *pers. comm.*) and was located 4 km north east of Lincoln. The study area at Prebbleton was situated on a Wakanui shallow silt loam soil (Ives, *pers. comm.*) and was located 1.6 km east of Prebbleton.

The cover consisted of white clover shut for seed, and grassland, respectively.

The plots were sited randomly in each paddock, which were 6 ha and .8 ha in area, respectively. Each plot was split, one half retaining the original cover and the other bared of cover. The vegetative half was allowed to grow normally.

The trials commenced in mid-October and finished in late December.

Soil surface moisture and plant cover were measured as described below.

One,continuous recording earth thermograph instrument with three probes was available for each study area. The instrument was installed centrally in the paddock and the soil surface temperature readings obtained were assumed applicable to all 18 plots on the study area. This assumption was found acceptable after the thermocouple, described below, was used to measure soil surface temperatures on each plot.

Pilot trial conducted during 1970 at Ladbrooks This experiment consisted of four clusters of three plots (106 cm x 158 cm) sited in a white clover seed crop (Plate 21). An earth thermograph was placed in the centre of each cluster with one of the three probes being placed in the centre of each plot. (Plate 21). One of the following treatments was applied to one plot in each cluster.

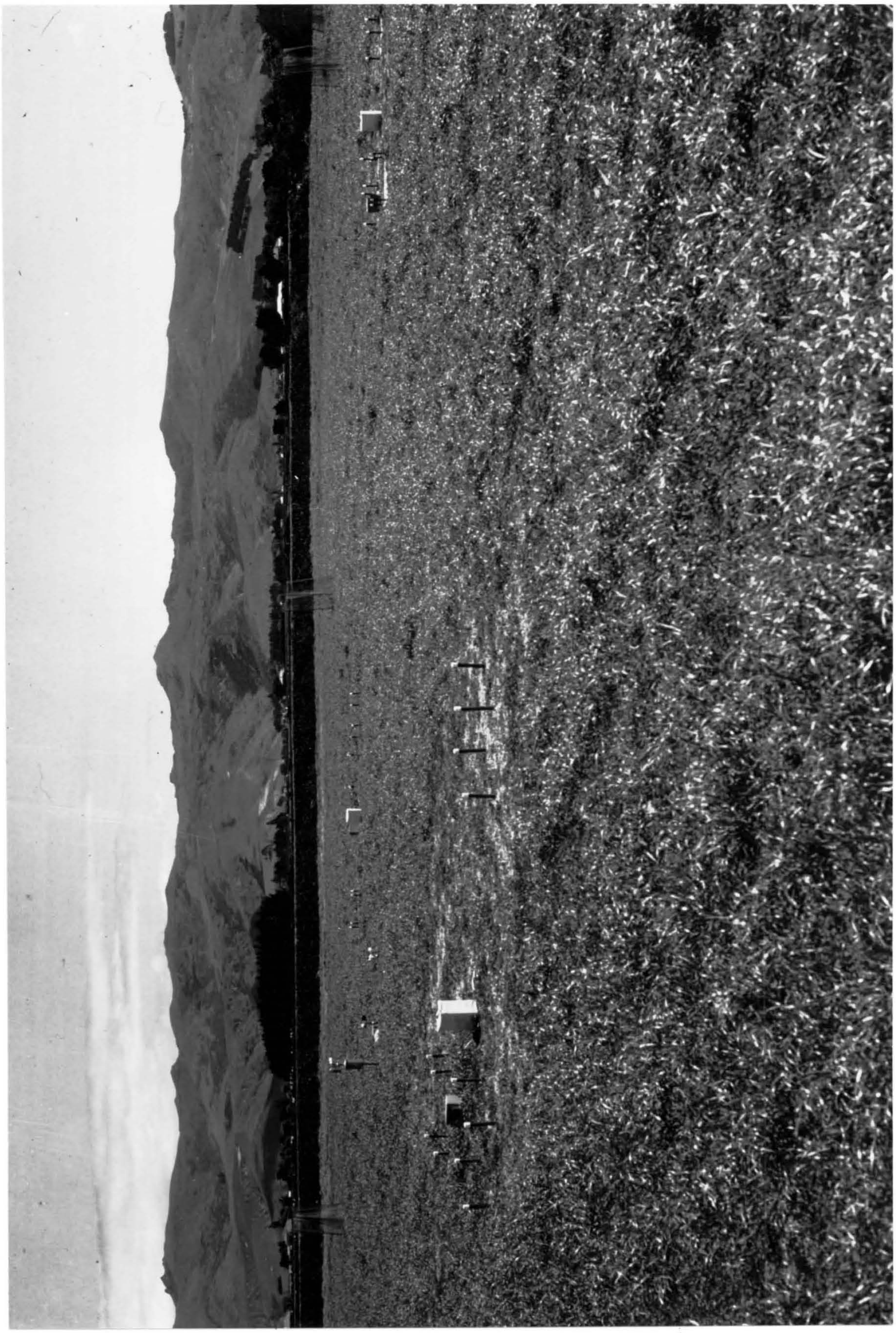


Plate 21 General view of the microclimate study area at Ladbrooks in the 1970 season. Note the baffle traps used for flight experiments and the meteorological instruments.

1. Bared soil.

2. Bared soil covered with thin transparent plastic sheeting, held against the soil surface with nails securing the perimeter of the sheet. This treatment was later found to be ineffectual and the results were included with those from treatment 1.

3. Original cover trimmed to a height of approximately 50 mm.

4. Original cover left to grow normally.

The experiment was carried out between mid-October and late December.

Trial conducted during 1971 at Ladbrooks This experiment was basically the same as the previously described pilot trial. Two white clover paddocks were used, with two clusters of three plots in each paddock. The experimental design differed from the 1970 experiment in that each cluster had different plot treatments.

1. Bared soil.

2. Original cover trimmed to 50 mm.

3. Original cover allowed to grow normally.

Measurement of soil surface temperature A copper/constantine thermocouple connected to a Wheatstone potentiometer was used in the pilot experiments. The disadvantage of this technique was that it allowed only spot readings to be taken.

It was, however, very accurate ($\pm$ .1^{o}C) and was used to determine temperature variations under grass plants and calibrate the earth thermographs.

It was found that variation within each plot or treatment (bared soil or covered soil) was negligible (see Table 35).

During the 1970 and 1971 trials, constant recording earth thermographs were used. The instruments had three probes each of which was placed in the centre of a plot, just beneath the soil surface.

Measurement of soil surface moisture Soil surface moisture was measured gravimetrically. Samples were taken by using a 13 mm diameter copper tube onto which a washer was soldered to prevent penetration into the soil beyond 7 mm. Two soil samples, each consisting of four randomly taken cores, were taken from each plot, per week.

Measurement of plant cover A photographic technique was used to assess plant cover (Evans, pers. comm.). It was a modification of a stereoscopic method developed by the New Zealand Forest Service at the Forest and Range Experimental Station, Rangiora.

A reflex camera was supported by a tripod at a height of 1.5 m above ground level. This gave a field of view of 53 cm x 79 cm. This area was used as the plot size during the pilot trials. Later the plot size was doubled, which necessitated taking two photographs for each enlarged plot.

Colour positive film was used throughout the experiments. The slides were projected onto a micro-screen, on which

Table 35 Soil surface temperatures (^{o}C) recorded from the Prebbleton and Ladbrooks microclimate study areas in 1969 using a thermocouple

	A			B		
	$\bar{x}$	n	S.D.	$\bar{x}$	n	S.D.
Ladbrooks						
17/10/69	17.7	4	.45	15.4	4	.53
20/10/69	18.7	9	1.11	16.3	9	.78
22/10/69	24.1	6	1.13	20.0	6	1.36
23/10/69	24.1	6	.78	20.8	6	.27
24/10/69	16.2	4	.3	14.1	4	.72
3/11/69	20.6	6	1.00	18.1	6	.58
7/11/69	28.2	4	.52	24.2	5	1.29
28/11/69	32.7	10	1.60	30.2	10	1.50
Prebbleton						
15/10/69	29.8	13	.92	24.8	13	.79
17/10/69	16.2	12	.86	15.4	12	1.08
20/10/69	21.6	7	.67	18.0	7	.96
22/10/69	26.2	6	.97	23.2	6	.27
23/10/69	24.9	9	2.00	21.9	9	1.28
13/11/69	22.3	6	.57	19.9	6	.63

Key

Readings taken between 10 a.m. and 3 p.m.

Measurement recorded from A = bared soil

B = under plant cover

200 small, black dots were painted, arranged in a grid and covering the area of the image. Each slide was systematically studied and the type of vegetation under each dot was recorded. The result was a point analysis from which the percentage of clover, grass, weeds, debris and bare ground in each plot could be estimated.

Measurement of rainfall A standard 127 mm diameter rain-gauge was placed in each paddock and daily rainfall recorded over the experimental period. The gauge was also used to determine how much water was applied during periods of spray irrigation.

Sampling the eggs and surviving autumn subterranean larval population

In the pilot trials an egg sample was taken on each plot using twenty 13 mm diameter white plastic lids 10 m deep and implanted flush with the soil surface. This gave satisfactory results but was discontinued as the technique was time consuming. All the lids (400 in total) had to be looked at, at least once every two days, over a period of four to six weeks. It was realised, however, that by not measuring egg populations, the actual numbers in each of the following age intervals could not be predicted. However, indirect methods discussed later allowed an estimate of egg numbers to be made.

To measure the autumn subterranean larval populations it was decided to use a modification of the metal plate technique discussed in Chapter 4.

At the end of January or early February when all surviving larvae were assumed to be in tunnels, each plot was bared of all surface vegetation and the soil levelled and packed gently. About four litres of water were sprinkled on each plot, over which a moistened sack was pegged down.

After two days the sacks were lifted and the area examined. Previously blocked porina tunnels which were reopened were easily seen. A flat-headed drawing pin was placed in each tunnel entrance and the entire plot photographed (Plate 22). Projection of the coloured slide allowed the tunnels to be counted and their position determined. Previous pilot trials showed that by using this technique 80 to 90 per cent of the population was accounted for. If necessary, a correction factor could have been applied. It was determined, however, that any difference was well within the inter-plot sampling variation and for comparative purposes was not significant.

Design of indoor experiments

To supplement the information obtained from field trials, glasshouse and shadehouse micro-climatic studies were conducted. They were basically similar in design to the field trials. The methods of measuring the microclimate variables were similar to those described above.

Results of microclimate studies

The results from all studies, except from Ladbrooks (1970) and the glasshouse trial , are given in Tables 36 and 37. Rainfall is given as that received naturally, plus an estimate of irrigation and that applied manually in the shadehouse. Soil surface temperatures have not been given in

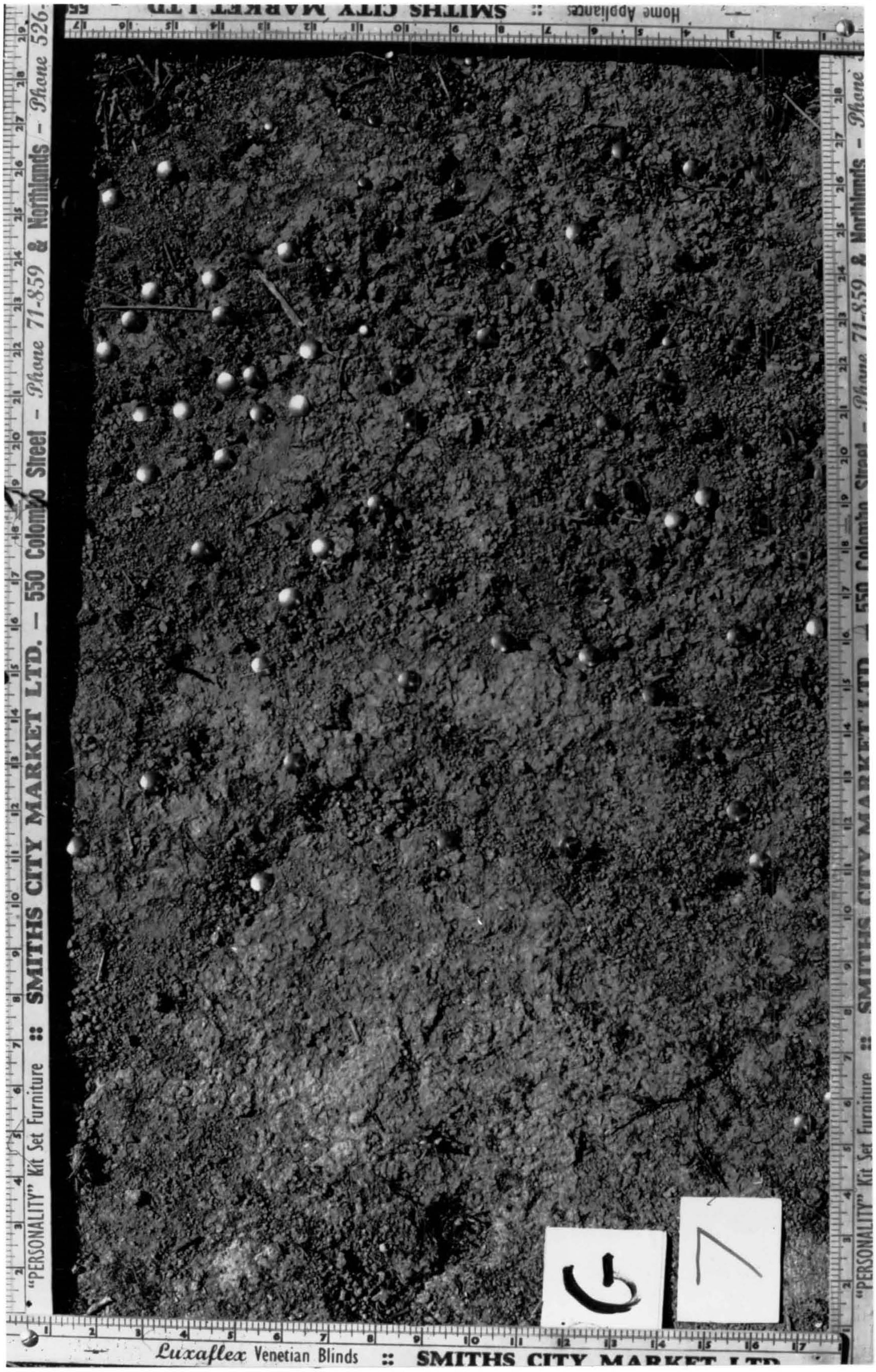


Plate 22 Example of autumn subterranean larval tunnel counts obtained from Ladbrooks in 1969. Each drawing pin represents a tunnel entrance Note: The greater number of pins on the half originally covered by pasture.

Table 36 Climatic, pasture and autumn subterranean larval population records from the microclimate study areas in 1969 and 1970

	Glasshouse 1970			Ladbrooks 1969		Prebbleton 1969	
	Bare soil	Covered soil		Bare soil	Covered soil	Bare soil	Covered soil
No. of days for experiment	45	45	45	57	57	73	73
Rainfall and irrigation (mm)	88	88	88	152	152	88	88
Total P.E. (mm)	232	225	227	256	178	291	247
Mean daily P.E. (mm)	5.2	5.0	5.1	4.5	3.2	4.0	3.2
Total P.E.-rainfall (mm)	144	138	140	105	26	203	159
Mean daily total P.E.-rainfall (mm)	3.20	3.06	3.11	1.84	.46	2.78	2.17
Mean soil moistures (%)	17.5	22.9	22.1	10.4	22	8.8	21.5
Accumulated heat (degree days)	1227	876	1161	1585	1120	1362	1058
Mean daily accumulated heat (degree days)	27	20	26	22	16	19	15
Mean cover (%)	0	100	98	9	99	11	90
Larval number per $4m^2$	0	0	0	304	788	1	4
Log of larval number + 1	.0001	.0001	.0001	2.4843	2.8971	0.3010	0.6990

Table 37 Climatic, pasture and autumn subterranean larval population records from the microclimate study areas in 1971

	Shadehouse		
	Covered soil		Bare soil
No. of days for experiment	74	74	74
Rainfall and irrigation (mm)	141	131	131
Total P.E. (mm)	247	242	253
Mean daily P.E. (mm)	3.3	3.7	3.4
Total P.E. - rainfall (mm)	116	111	122
Mean daily total P.E. - rainfall (mm)	1.57	1.50	1.66
Mean soil moistures (%)	26.2	22.4	13.5
Accumulated heat (degree days)	1162	1196	1300
Mean daily accumulated heat (degree days)	16	16	18
Mean cover (%)	98	99	39
Larval number per $4m^2$	1	0	0
Log of larval number + 1	0.3010	0.0001	0.0001

contd.

Table 37 contd.

	Ladbrooks 1971											
	Bare soil				Covered soil							
. of days for experiment	73	73	73	73	73	73	73	73	73	73	73	73
infall and irrigation (mm)	204	204	204	204	204	204	2 4	204	204	204	204	204
tal P.E. (mm)	344	313	315	297	279	284	276	290	302	259	232	283
an daily P.E. (mm)	4.7	4.3	4.3	4.1	3.8	3.9	3.8	4.0	4.1	3.5	3.2	3.9
tal P.E. - rainfall(mm)	140	109	111	93	75	80	72	86	98	55	28	79
an daily total P.E. - rainfall (mm)	1.92	1.50	1.52	1.28	1.02	1.09	.98	1.18	1.35	.76	.39	1.08
an soil moistures (%)	8.7	8.5	10.8	9.9	16.7	12.9	20.5	19.0	19.6	26.3	24.4	20.4
cumulated heat (degree days)	1532	1462	1477	1386	1176	1324	1233	1420	1416	1222	1130	1339
an daily accumulated heat (degree days)	21	20	20	19	16	18	17	19	19	17	15	18
an cover (%)	42	50	49	46	100	96	100	100	98	100	99	99
rval number per $4m^2$	0	0	10	0	38	0	201	181	29	96	124	77
g of larval number + 1	.0001	.0001	1.0414	.0001	1.5910	.0001	2.3054	2.2601	1.4771	1.9868	2.0969	1.8921

degrees celcius but have been converted into accumulated heat, expressed in "degree days" (Baskerville and Emin, 1969) and potential evaporation (Toebe, 1970). Both these indices were calculated from daily maximum and minimum soil surface temperature readings. The soil surface moistures are given as means calculated from a number of weekly measurements. Likewise the percentage cover.

Surviving autumn subterranean larval populations are given as numbers per four square metres, for comparison if required, with previous life table data.

To help normalize the variability of the larval population data and smooth out seasonal differences, the logarithmic transformation of larval number, plus one, is given and was used in all correlations. A list of the correlations and related information is given in Table 38.

Analysis of results

Preliminary analysis involved determination of real differences between treatments. An analysis of variance (ANOVA) carried out on the results from the trials at Ladbrooks (1969 and 1971) showed that there were real differences between treatments (Table 38).

Simple linear regressions were then carried out between some of the variables given in Tables 36 and 37 and the transformed autumn subterranean larval counts. To compensate for the varying duration of each experiment, mean daily values were used for the microclimate variables.

The results from the Ladbrooks trial carried out in 1970

Table 38 Details of the correlations carried out between microclimatic variables and larval survival

First preliminary analysis

2 way ANOVA Ladbrooks 1969

	d.r.	M.S.	F		
Treatments	1	2.0405	68.24	**	F, at P < .01 = 8.40
Replications	17	.3338	11.16	**	F, at P < .01 = 3.40
Error	17	.0299			

2 way ANOVA Ladbrooks 1971

	d.r.	M.S.	F		
Treatments	2	3.1019	9.09	**	F, at P < .05 = 5.14
Replications	3	.6553	1.92	N.S.	F, at P > .05 = 4.76
Error	6	.3410			

contd.

Table 38 contd.

Second preliminary analysis (see Figs 47 - 52)

Linear regression

1	Log. larval number	vs. mean daily P.E.	r = -.152	N.S.	F = .404	N.S.
2	" " "	vs. total P.E.-rainfall	r = -.660	**	F = 13.13	**
3	" " "	vs. mean soil moisture	r = .456	*	F = 4.46	*
4	" " "	vs. mean daily accumulated heat	r = -.156	N.S.	F = .425	N.S.
5	" " "	vs. mean % cover	r = .364	N.S.	F = 2.61	N.S.
6	P.E.	vs. total accumulated heat	r = .871	**	F = 100.1	**
7	"	vs. mean soil moisture	r = -.429	*	F = 7.2	*
8	"	vs. mean % cover	r = -.570	**	F = 15.43	**

contd.

Table 38 contd.

Final analysis

Stepwise multiple regression

Variable 1 = P.E. - rainfall
" 2 = mean soil moisture
" 3 = mean % cover
Y = log larval number

1 Predetermined level of selection set at F = .5

Y = 2.491-0.0167 (P.E.-rainfall)+.0858 (mean soil moisture) -.0156 (mean % cover)

T values for coefficients T_1-2.9163* T_2 1.5693 N.S. T_3-1.3760 N.S.

Summary of statistics

	Step	d.f.	mult. corr. coeff.(r)	Goodness of fit (F)
1	P.E. - rainfall	17	.632	11.335 **
2	add mean soil moisture	16	.649	5.843 *
3	add mean % cover	15	.697	4.744 *

2 Predetermined level of selection set at F = 1.5

Y = 2.663-0.0156 (P.E.-rainfall)

T values for coefficient T_1-3.3667**

Summary of statistics

	Step	d.f.	mult. corr. coeff.(r)	Goodness of fit (F)
1	P.E. - rainfall	17	.632	11.335

3 Calculation of confidence limits for means of equation Y = 2.663-.0156 (P.E.-rainfall) see Sokal and Rohlf (1969) p. 424

95% confidence limits calculated and presented in Fig. 48

$b = \pm .0098$

$Y \text{ (at } \bar{x}) \pm .4003 = (1.128 \pm .4003)$

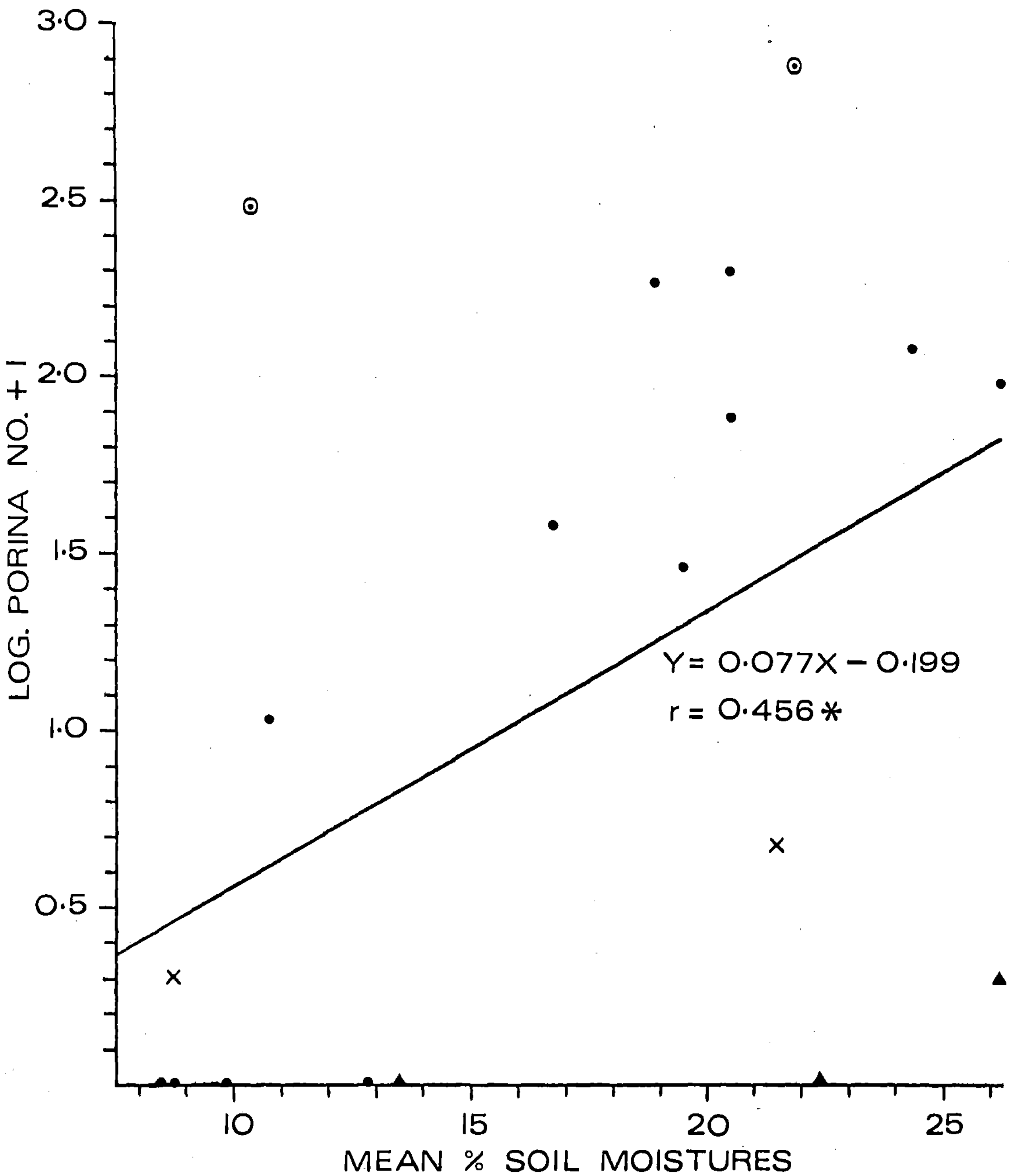


FIG. 47

The relationship between the density of autumn subterranean larval populations and soil surface moisture using results from the microclimate studies.

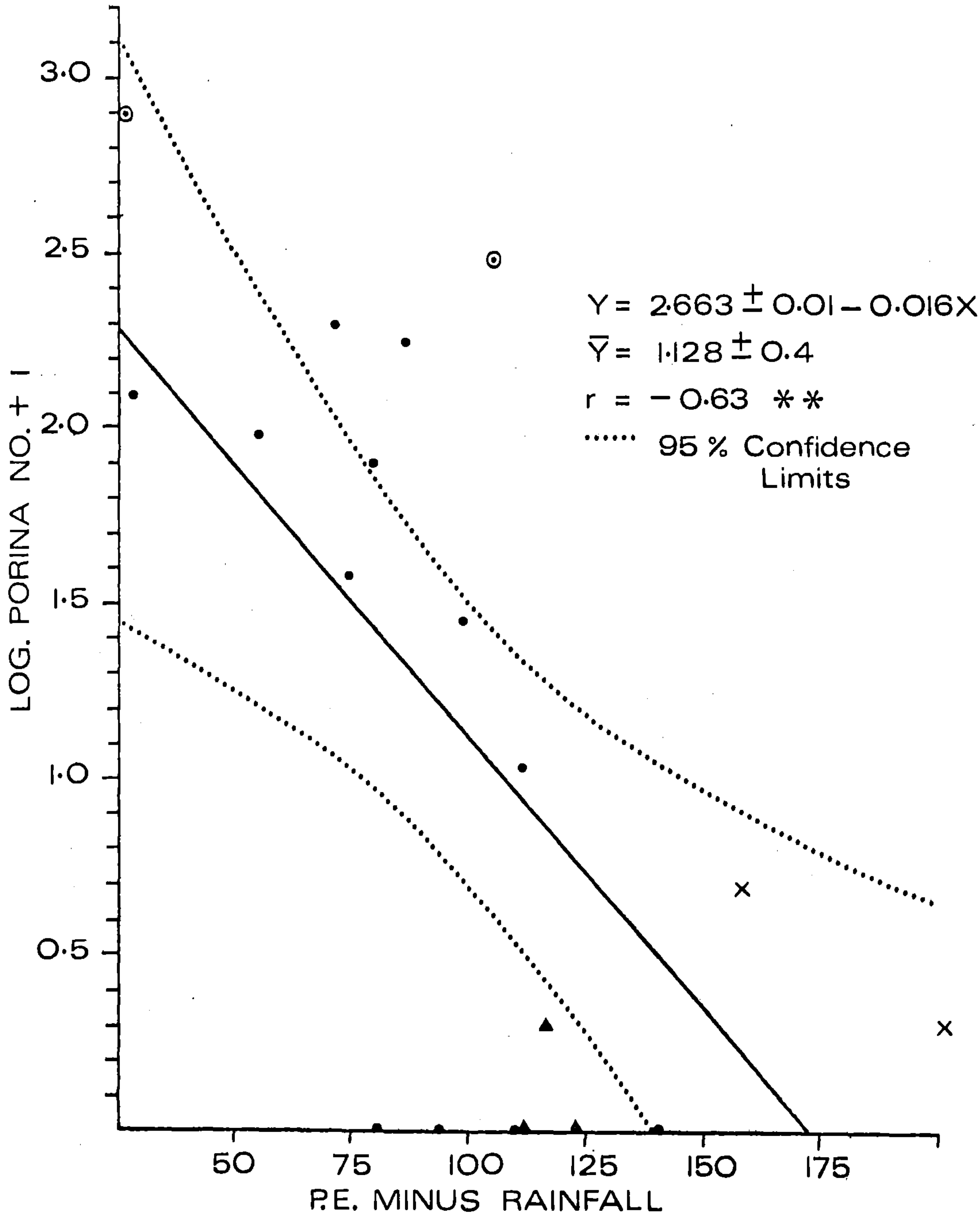


FIG. 48

The relationship between the density of autumn subterranean larval populations and potential evaporation minus rainfall using results from the microclimate studies. Key as for Fig. 47.

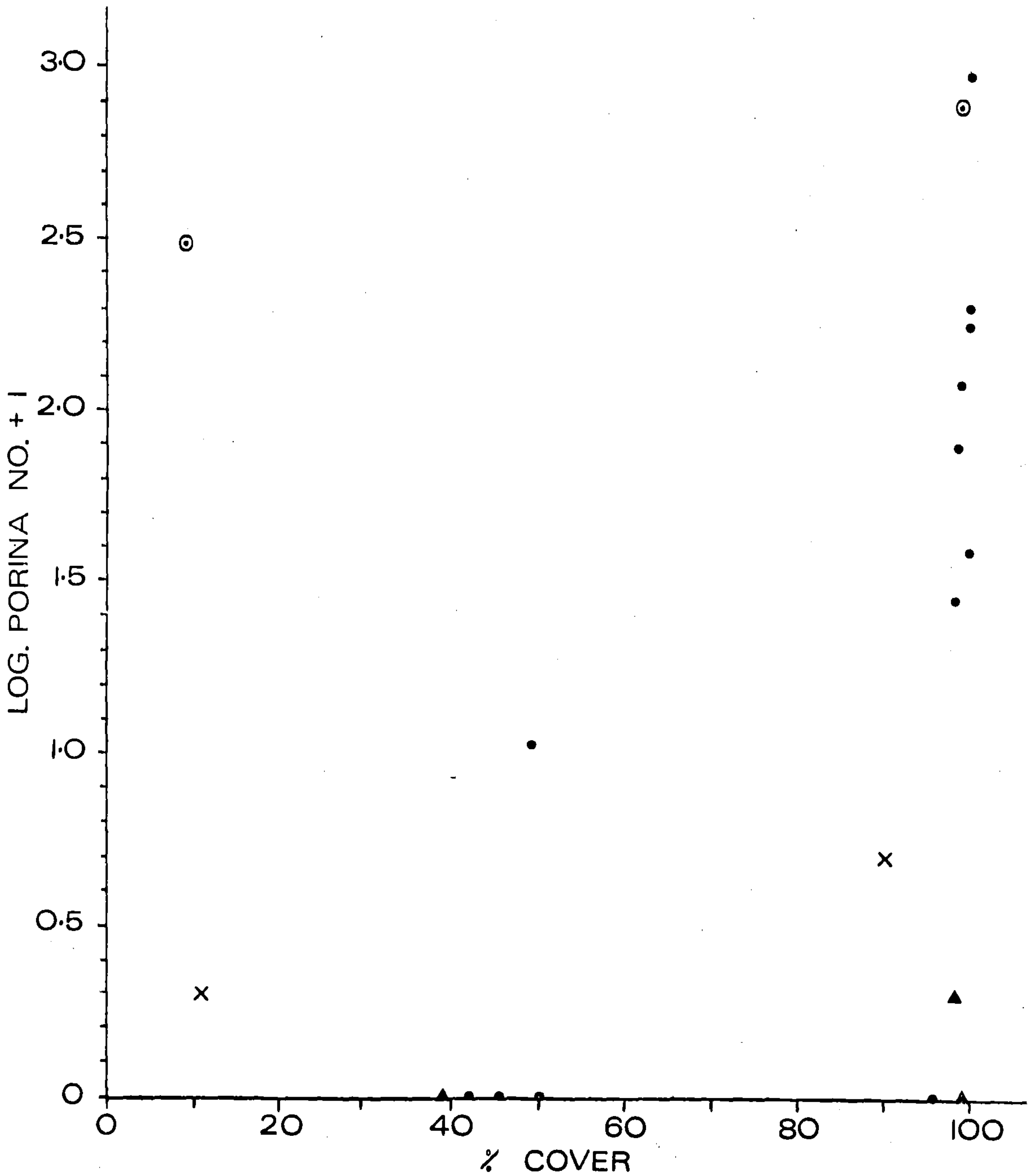


FIG. 49

The relationship between the density of autumn subterranean larval populations and plant cover using results from the microclimate studies. Key as for Fig. 47.

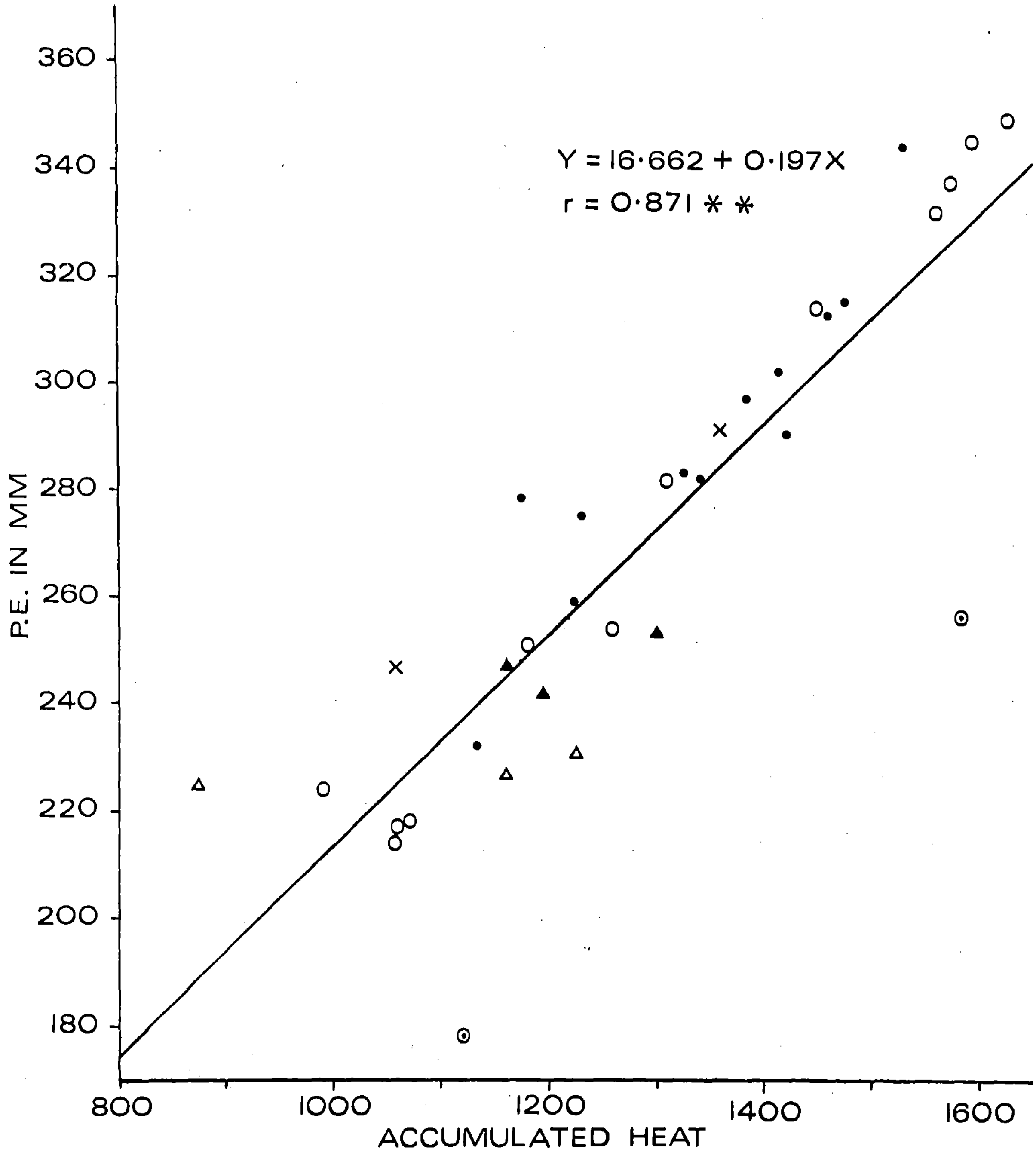


FIG. 50

The relationship between potential evaporation (P.E.) and accumulated heat (in "degree days") using results from the microclimate studies. Key as for Fig. 47.

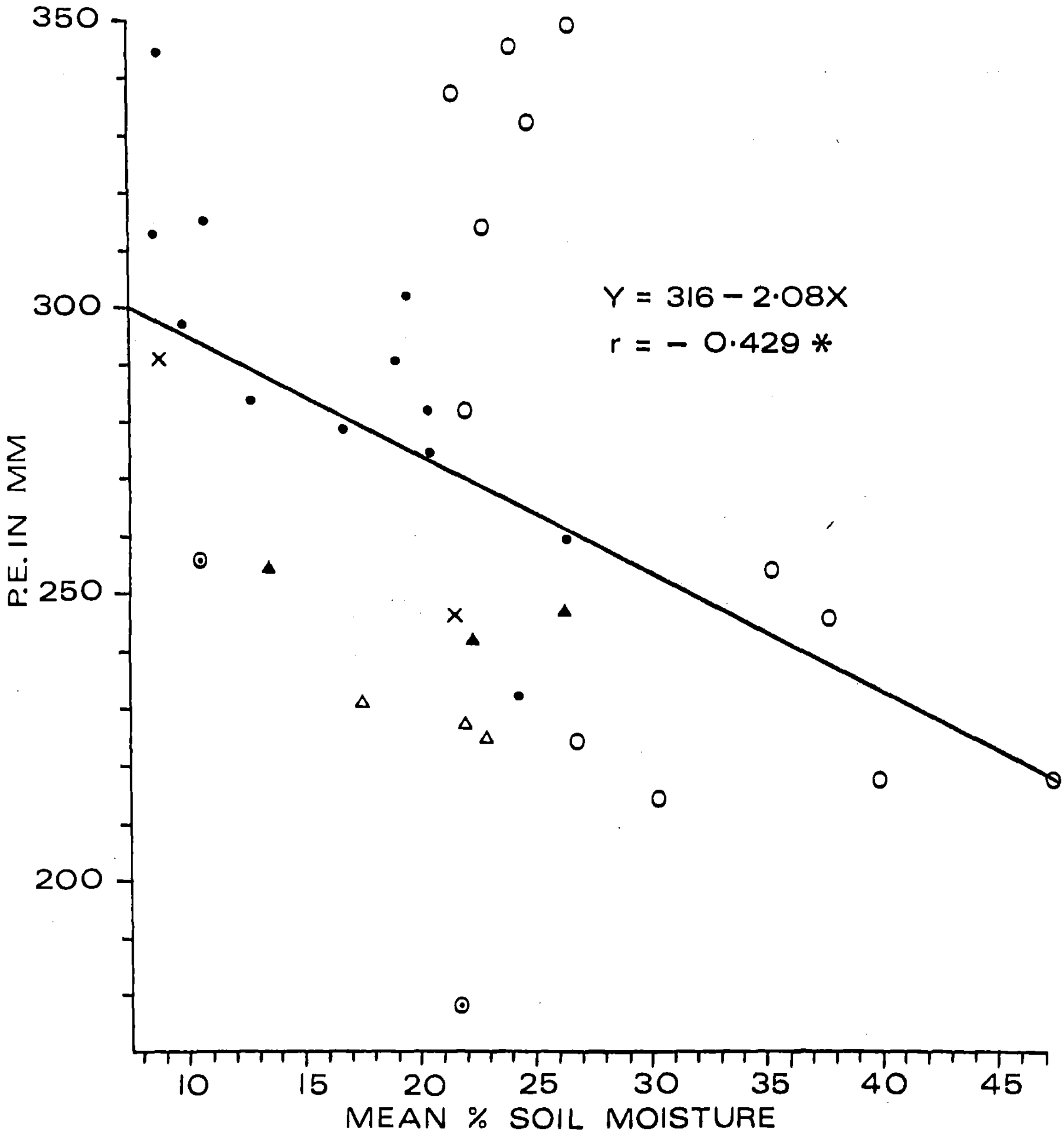


FIG. 51

The relationship between potential evaporation (P.E.) and soil surface moisture using results from the microclimate studies. Key as for Fig. 47.

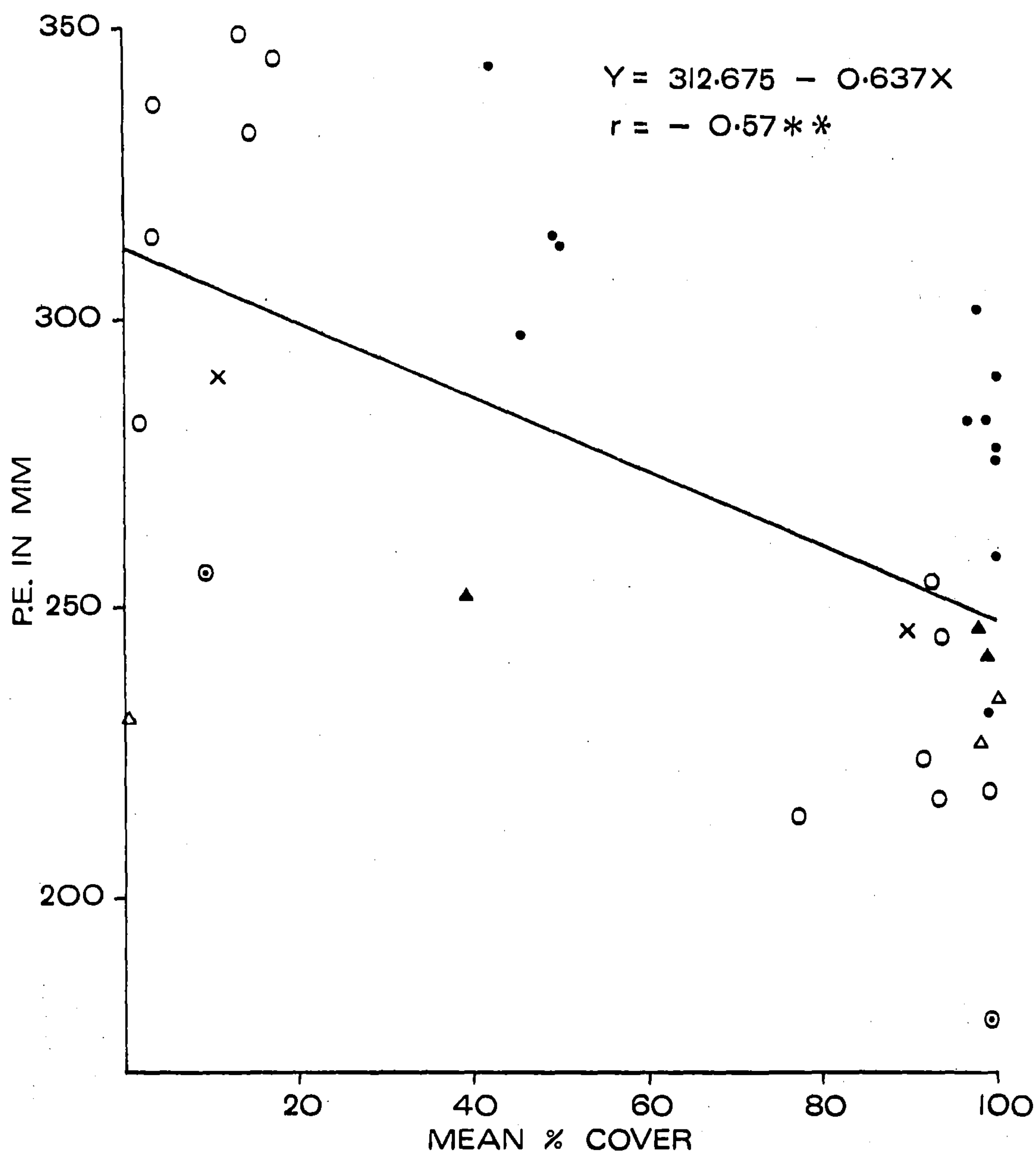


FIG. 52

The relationship between potential evaporation (P.E.) and plant cover using results from the microclimate studies. Key as for Fig. 47.

and the glasshouse trials were not included in the main analyses because dry conditions completely destroyed the porina juvenile populations and therefore correlations were not possible. The microclimatic data from these trials was, however, included in Figures 50, 51 and 52.

A statistically significant relationship (P .05) was found between mean soil moisture and the autumn subterranean larval population density (Figure 47). The other measured variable unaccounted for in the analyses was rainfall. As there was insufficient data for correlation, it was decided to use rainfall as a weighting factor for potential evaporation (P.E.). This gave an index of "P.E. minus rainfall", and this resulted in a very good correlation (P .01) with the larval population (Figure 48). This index, in effect, partially quantifies the "mortality-inducing" effect of the surface soil temperature on the surface dwelling larval stages, modified by the "survival-inducing" rainfall.

As expected, there was no significant lineal relationship between percentage cover and the autumn subterranean larval population density (Figure 49). This was due to lack of variation between the covered plots. Thus, the treatments, which consisted only of bared soil versus covered soil, gave a clumped appearance to the data. Furthermore, any subtle variations within the covered plots may not have been measured.

The next series of analyses was aimed at showing the interdependence of the variables measured, in an effort to simplify the development of predictive models. Statistically significant correlations were found between P.E. and accumulated heat (Figure 50), P.E. and mean soil moisture (Figure 51), and P.E. and percentage plant cover (Figure 52).

It became obvious that to obtain a more biologically meaningful understanding of a complex and interrelated system, some form of multivariate statistical analysis was required. The 'path analysis' technique described by Scott (1966), would have been ideal had the experiments been suitably designed. Instead, a computerised, step wise, multiple regression technique was applied. The results are summarised in Table 38. These show that, as expected, the "P.E. minus rainfall" index gave the best correlation. If mean soil moisture and plant cover were included there was an improvement in the r value, but the increase was statistically insignificant.

When damage occurs

Results of light trapping presented in Table 2 have indicated the dates when adult peak moth flights occur, over various areas in New Zealand. This information could be used to predict when damage will appear. For example, in Canterbury a peak flight will occur sometime between October 16 and October 31. Assuming the eggs take four to five weeks to hatch, and that the surface dwelling larval period lasts for seven to eight weeks, then the time when the subterranean larval stage appears can be estimated. It is important to know when this age interval appears as field observations have indicated that these larvae start to consume significantly increasing amounts of pasture green matter, after forming tunnels. Significant damage becomes apparent about March in Canterbury, but differs in other areas according to when peak flights occur (Table 2). If timing is correct, the application of some control measure prior to occurrence of significant damage would be most economic.

Although the results in Table 2 give an approximate idea of when significant damage is likely to occur, the information must be used with care. For example, some care must be exercised when dealing with mixed and late populations which can occur in different paddocks on the one farm. Mixed populations occur when two races of porina temporally separated, coexist in the one pasture. The larvae of one race cause significant damage during winter, while the other causes damage to spring pasture (Allen, 1968). Although a certain amount of variation is normal in even a "pure species porina population", mixed populations of two distinct races occasionally occur, especially in areas not susceptible to summer drought, e.g. West Coast and around the foothills in Canterbury. Where such mixed populations exist, prediction of when damage will appear is difficult as significant damage can extend over a long period. Because of these exceptions Table 2 should only be used as a guide.

As a check, infested pasture should be sampled in August or September to determine the proportion of small and large larvae and pupae. The age structure of the population can then be easily determined and the approximate period of adult activity can be estimated.

Normally, the early flying race is the most common.

However, it is important to ascertain the presence of other races in order that control measures can be optimally timed.

Discussion with reference to predicting damage

The above analyses supported the hypothesis that micro-climatic factors cause significant mortality in the egg and surface dwelling larval stages. This should now be the basis for future discussion and research and form the framework on which to develop a practical but quantitative system to predict porina damage. For example, by using certain equations in Table 36 and equating Y = 0, it can be calculated that the "P.E. minus rainfall" index is approximately 170. If this figure was used as a base, it should be possible to predict whether porina damage is likely to occur, by comparing it with other indices based on field measurements.

There is, however, insufficient information at present to adequately develop a very sophisticated mathematical model. More extensive data are required as the material presented here is only applicable to one area (Ladbrooks) and covers only two seasons.

Although it is possible to give a "yes/no" prediction for the likelihood of porina damage in a given paddock, it is much more difficult to predict population densities. There is also the question of the practicability of doing this.

If a deterministic type mathematical model was developed, the density of the damaging larval population could only be predicted after certain events had occurred. This would mean that the relevant information would only be obtained about mid to late December (for the early races), leaving very little time to carry out control measures on the susceptible, surface dwelling larvae, before they formed tunnels.

What is required is the knowledge of porina infestation levels one generation ahead. This implies that an attempt should be made to develop a stochastic mathematical model, based on the probability of occurrence of certain significant mortality factors. This, at present, seems an almost impossible task.

For example, it has already been shown how moth mortality, vis-a-vis migration, significantly affects generation levels (Table 24), and that wind speed is probably the factor responsible. Because of the state of meteorological knowledge, it is impossible to predict, one year ahead (Wright, 1972) what the weather is likely to be during the peak flight periods. This would make it impossible to predict the final egg density in any given paddock, one generation hence.

It would be more realistic in fact to actually sample for eggs during October and November (perhaps using sequential techniques) and then calculate possible mortality thereafter, by estimating (or guessing) what sort of weather will be experienced over the following two months.

Another method of predicting autumn subterranean larval population densities would be to use the information on mortality given in Tables 25 and 26. For example, if dry conditions were likely to occur in a given paddock, (say a "P.E. minus rainfall" index, significantly greater than 170) then over 95 per cent of the egg and surface dwelling larval populations would be destroyed. This would result in an extremely low and insignificant autumn subterranean larval population, even if high egg numbers were originally deposited. On the other hand, with reasonable conditions ("P.E. minus rainfall" index significantly less than 170) only 3o to 40 per cent of the egg population would be destroyed and perhaps a further 50 to 60 per cent of the surviving surface dwelling larval population. By using these gross estimates it should be possible to calculate (albeit with wide confidence limits) the densities of the damaging autumn and winter subterranean larval populations.

Whether this type of information would be timely or useful is debatable. Most farmers could not be bothered with sampling paddocks for porina eggs, let alone soil surface temperatures. Basically, all the farmer needs to know is whether porina will be present in any given pasture each year and, if so, what can be done to prevent it.

Using the system outlined in the following conclusion plus a certain amount of meteorological guesswork, the former can be achieved. The latter is discussed in some detail in Chapter 8, but briefly, the method involves heavy mob-stocking of infested pasture during the surface dwelling larval stage.

Why, then, should the development of a predictive model be pursued when a simple yes or no answer to the question of whether or not porina damage will occur, is all that is required? The main reason lies in the stimulating challenge of attempting to understand animal population regulation. At present, however, there is insufficient information to even attempt sophisticated mathematical modelling for porina populations, a major limitation being the inability to make long range meteorological forecasts.

CONCLUSIONS FROM RESULTS OF MICROCLIMATE STUDIES

Using the techniques discussed above, together with careful observations, it should be possible to predict whether a porina infestation will occur in any pasture. To determine this, the following steps should be used.

1. Sample damaged pastures in August to determine what race of porina is present (early or late). Use the information given in Table 2, Figures 6 and 7 and mean daily field temperatures, to calculate when the majority of eggs will hatch. This date is the base upon which to decide whether spring or winter damage will occur, and therefore to time control procedures if necessary.

2. The soil types should be mapped in each paddock to determine the most susceptible areas, keeping in mind that in a wet spring with much pasture growth, soil type differences will be masked. In a dry spring, the greater the moisture retention ability of the soil, the greater the chances of porina infestation.

3. The egg population should be estimated by using either the implanted funnel technique (page 115). Timing is very important for the latter and should be carried out about two weeks after peak oviposition. The

appropriate mortality figure given in Tables 25 and 26 should be applied to the egg population depending on what sort of weather is predicted or eventuates for November and December. If the conditions are expected to become very dry, or a "P.E. minus rainfall" index greater than 170 was calculated after measuring soil surface temperature and rainfall, then more than 90 per cent mortality will occur in the egg and surface dwelling larval populations. If a wet spring is forecast, or if the index was calculated to be considerably less than 170, then a 30 to 60 per cent egg mortality and a 50 to 60 per cent surface dwelling larval instar mortality can be expected. The estimated number of larvae remaining should represent the density of the autumn subterranean larval population. Ideally, confidence limits should be calculated but considerably more life table information, suitably replicated in time and space, would be required before this could be attempted.

Unless highly motivated, however, it is doubtful whether farmers would use the above scheme. Perhaps its most practical use would be in those cases where insecticides are commonly used to control porina, because for the best economic use chemicals should be applied before any significant pasture damage takes place. This means applying insecticide in January or February to control a population of small larvae which are difficult (but not impossible) to sample.

The use of this scheme should assist farmers to select pastures which are likely to become damaged without the need to sample for juvenile larvae. This system would therefore indirectly help to not only reduce the amount of insecticide used, but should enable a better economic return if chemicals are used at the most appropriate time.

CHAPTER 7

ECONOMIC STATUS OF PORINA

Introduction

The term "economic entomologist" is rarely used in New Zealand, even today. Yet there are many entomologists employed whose job is to control economic pasture pests. Economic pasture pests are defined as those insect populations which, if unchecked, cause enough damage to pasture growth to significantly reduce farm and national production of meat, milk and wool.

Obviously, one of the first objectives of the entomologists concerned should have been to assess this damage. It is surprising that they have seldom made any serious quantitative attempt in New Zealand to do so. Instead, it has been assumed by all concerned that these "pests" are directly responsible for significant decreased production. A bad drought or stock diseases can, however, have the same effect and the question can be asked, which is the greater or most significant problem?

Because of their specific nature to a given set of circumstances, estimates of insect populations in relation to economic parameters are difficult, time consuming and subject to changes in the economic outlook. The work is, however, by no means impossible, given time and money.

Fundamentally, the first thing required of economic entomologists is to assess insect damage as accurately as possible, and interpret this information in the light of present and future economic trends, in production. This was carried out for porina in this study as follows.

1. The determination of larval food consumption and feeding behaviour under field conditions.

2. The application of this information to the agroecosystem and interpretation of its economic significance.

DETERMINATION OF LARVAL FOOD CONSUMPTION AND FEEDING BEHAVIOUR

Method

The experiment was situated on a Temuka silt loam soil and located at the Lincoln station of the Department of Scientific and Industrial Research.

In early April 1969 the metal plate technique was used to find 50, single, well isolated porina tunnels. After ascertaining that the larvae were active (as determined by the appearance of webbing and casting), green painted metal sleeves, 16 cm in diameter and 18 cm high, were placed over each tunnel entrance and pushed into the soil to a depth of three to four cm. An eight gauge metal outer cylinder was then placed over each sleeve to prevent bird predation (see

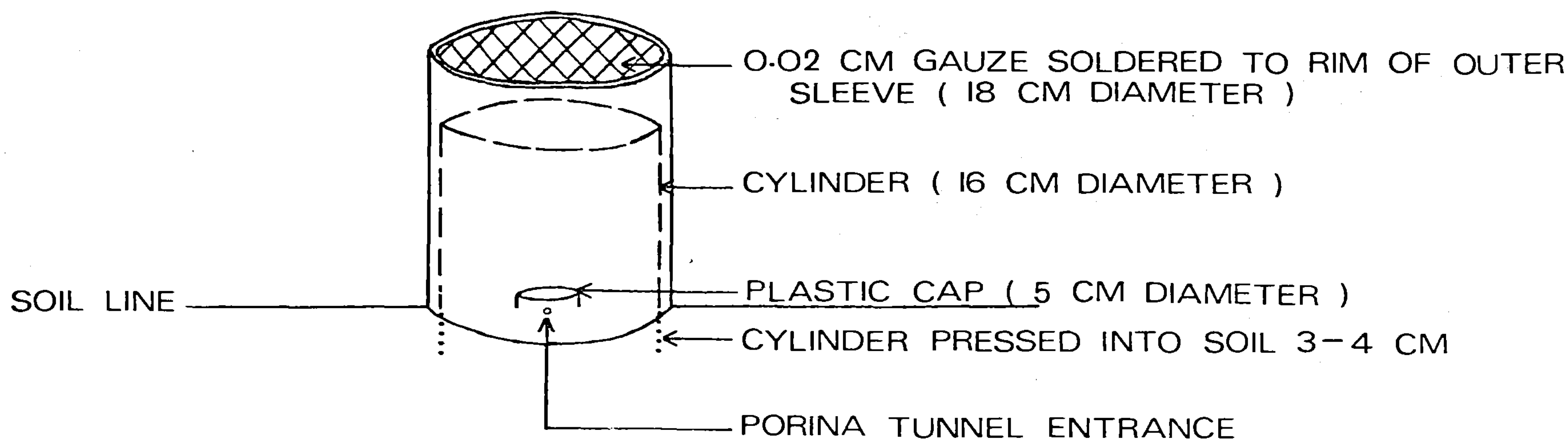


FIG. 53

Diagram of field cage used for larval feeding experiments at D.S.I.R., Lincoln.

Figure 53).

Every afternoon a fresh supply of white clover leaves (Trifolium repens) was gathered. Fifty trifoliate leaves of approximately the same size were weighed individually to three decimal places.

Each evening, one trifoliate leaf was placed directly above each tunnel entrance. A white opaque plastic cap five cm in diameter and 12 mm high, was placed over the leaf to prevent movement of the leaf by wind and to reduce leaf dehydration.

Because the experiment was unattended over the weekends an extra two trifoliate leaves were placed out on Fridays. At no time during the trial was either the weekend or daily allocation of clover leaves fully consumed by any of the larvae.

Each morning the untouched clover was carefully removed and signs of feeding activity assessed. The leaves were then accurately weighed after surplus water on the surface had been removed.

A loss of leaf weight normally occurred due to dehydration, particularly at weekends. On rare occasions, however, i.e. frosty nights, there was a weight increase due to the leaf absorbing condensed moisture. To allow for these deficiencies the mean daily percentage loss or gain of weight was calculated from untouched leaves. This percentage was then added to, or subtracted from, the initial weight of each partially consumed leaf before the individual daily consumption rates were calculated.

Occasionally the larvae webbed around the leaf but did not eat it. This was expressed as untouched green matter. If, however, some portion of the leaf was actually severed and partially pulled into the tunnel entrance it was classified as consumed.

The larvae had no access to any other green matter. This was ensured by continual careful weeding within the cylinders and adjacent areas.

During the experiment some re-siting of the cylinders was necessary to maintain the original population level. As expected from the information obtained from life table work, natural mortality was relatively high.

The experiment was stopped in late October when feeding by most caterpillars had ceased. The soil was removed beneath each cylinder to a depth of 18 cm and examined. A record was kept of any porina remains and diseased cadavers.

The experiment was repeated in 1970, commencing in February and finishing in late October.

Meteorological instruments were sited on the area for most of the trial period and the following variables measured.

1. Daily rainfall.
2. Weekly soil moistures taken to depth of five cm.
3. Continuous air temperature and humidity readings taken 8 cm above the soil surface in a modified Stevenson screen.
4. Continuous soil temperatures taken at the following depths - .7 cm, 4.0 cm, 7.5 cm, 11.5 cm, 15.0 cm and 19.0 cm.

The readings at each depth were replicated three times.

Results

Figures 54 and 55 show the relationship between mean larval food consumption and time, in each study year. In order to smooth the curves the results for each day were bulked into weekly intervals. A single common regression line (Rao, 1967) was then constructed, by bulking the results gathered over the two years (Figure 56). This was done because each year was considered a random sample in time. Consequently, bulking should give a more precise estimate of food consumption because of increased temporal replication.

It is stressed that the results shown in Figures 54, 55 and 56 are mean food consumption figures, based on the number of larvae known to be alive each evening. These results therefore included larvae which had not fed on a particular night, for various reasons. It was felt that the use of this figure was realistic as it reflected the feeding behaviour of a normal larval population.

Figure 57 shows the feeding behaviour of a number of larvae over a six month period. The small vertical lines depict the nights when some feeding took place. The dots indicate nights on which no feeding occurred although this does not imply that larvae did not emerge.

The fate of all porina larvae used in the two experiments is summarized in Table 39.

Discussion on the variability of larval food consumption

Although a statistically significant relationship was found

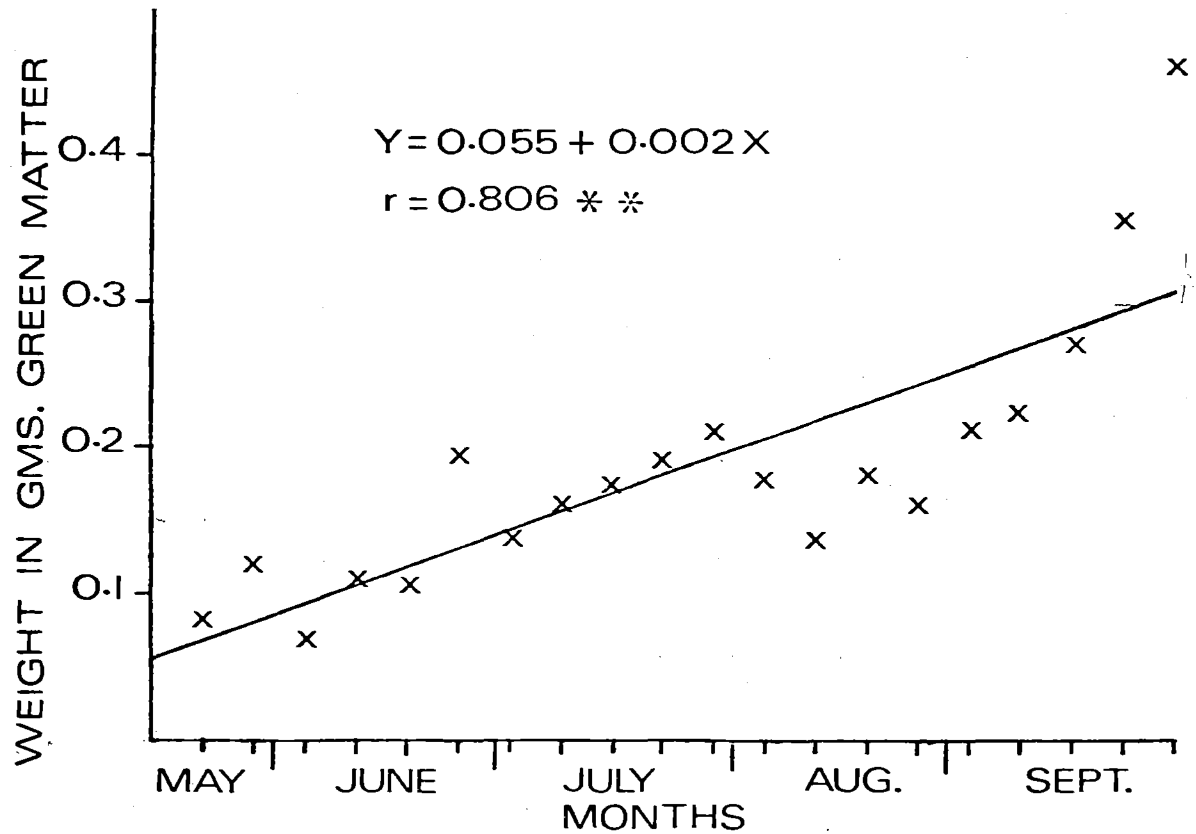


FIG. 54

The relationship between the weekly rate of increase in larval food consumption and time, 1969 study period.
Note: The equation will give the weekly larval food consumption between X and X-7 days.

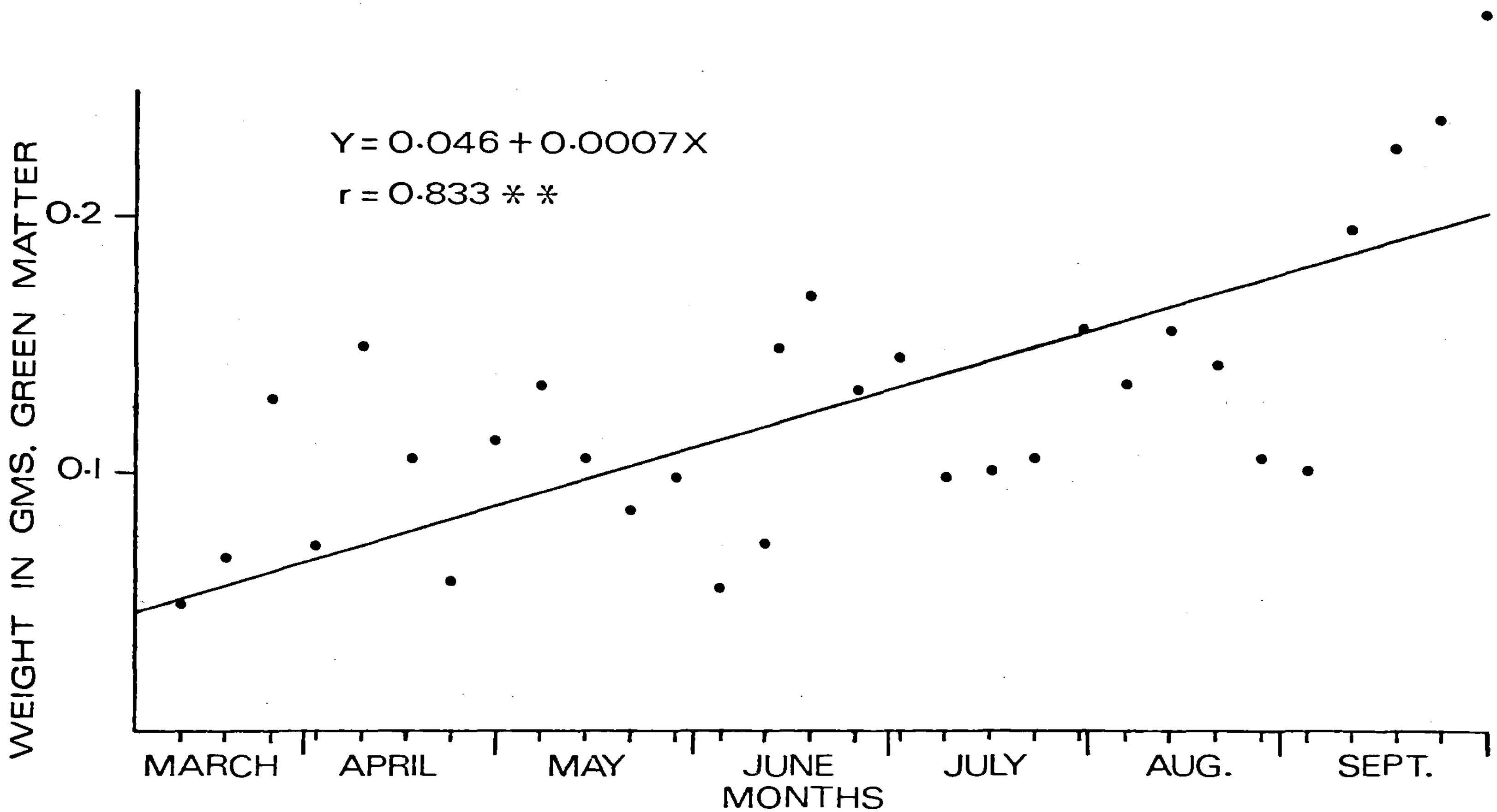


FIG. 55

The relationship between the weekly rate of increase in larval food consumption and time, 1970 study period.
Note: The equation will give the weekly larval food consumption between X and X-7 days.

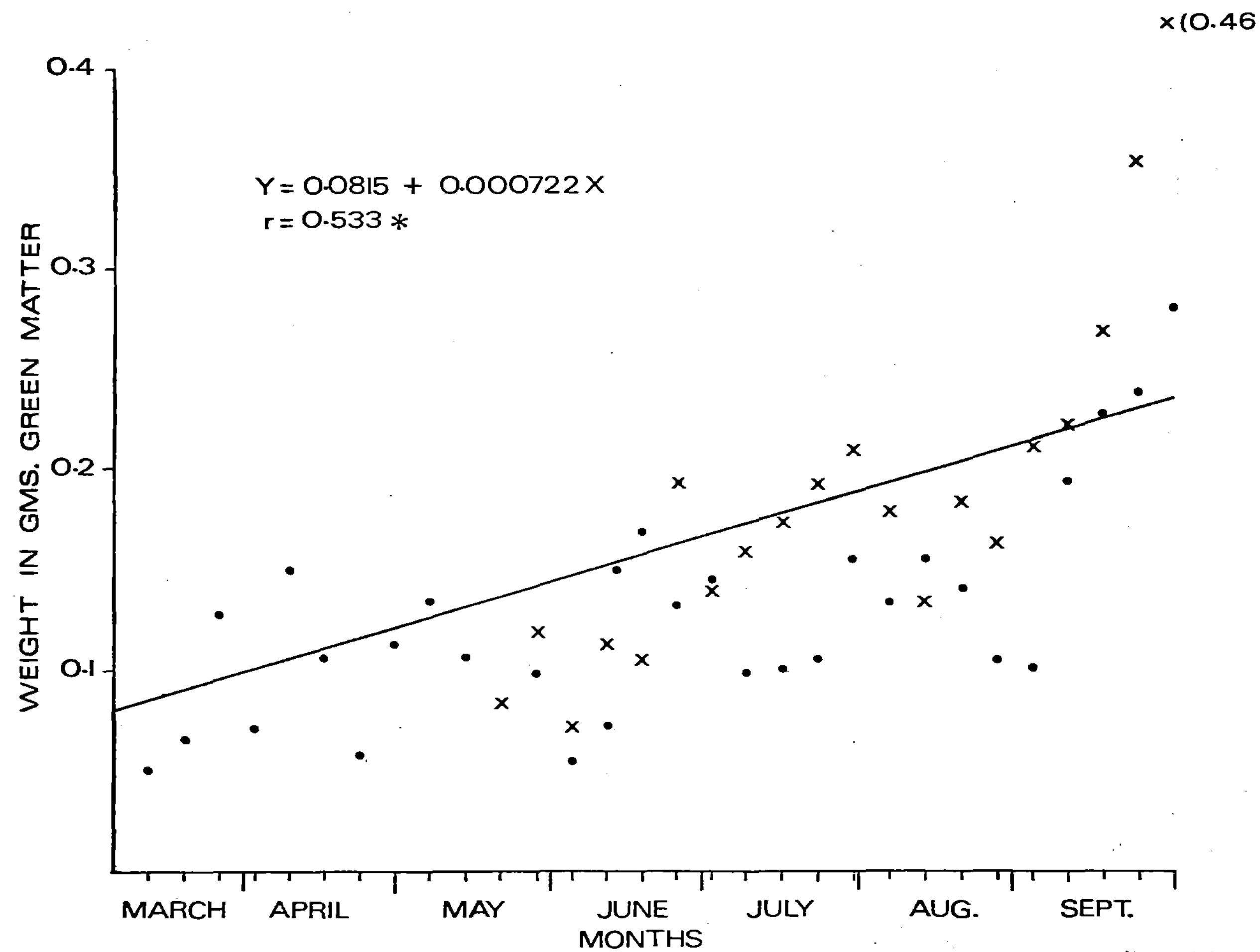


FIG. 56

The relationship between the weekly rate of increase in consumption and time, after bulking the results from the 1969 and 1970 study periods.

Note: The equation will give the weekly larval food consumption between X and X-7 days.

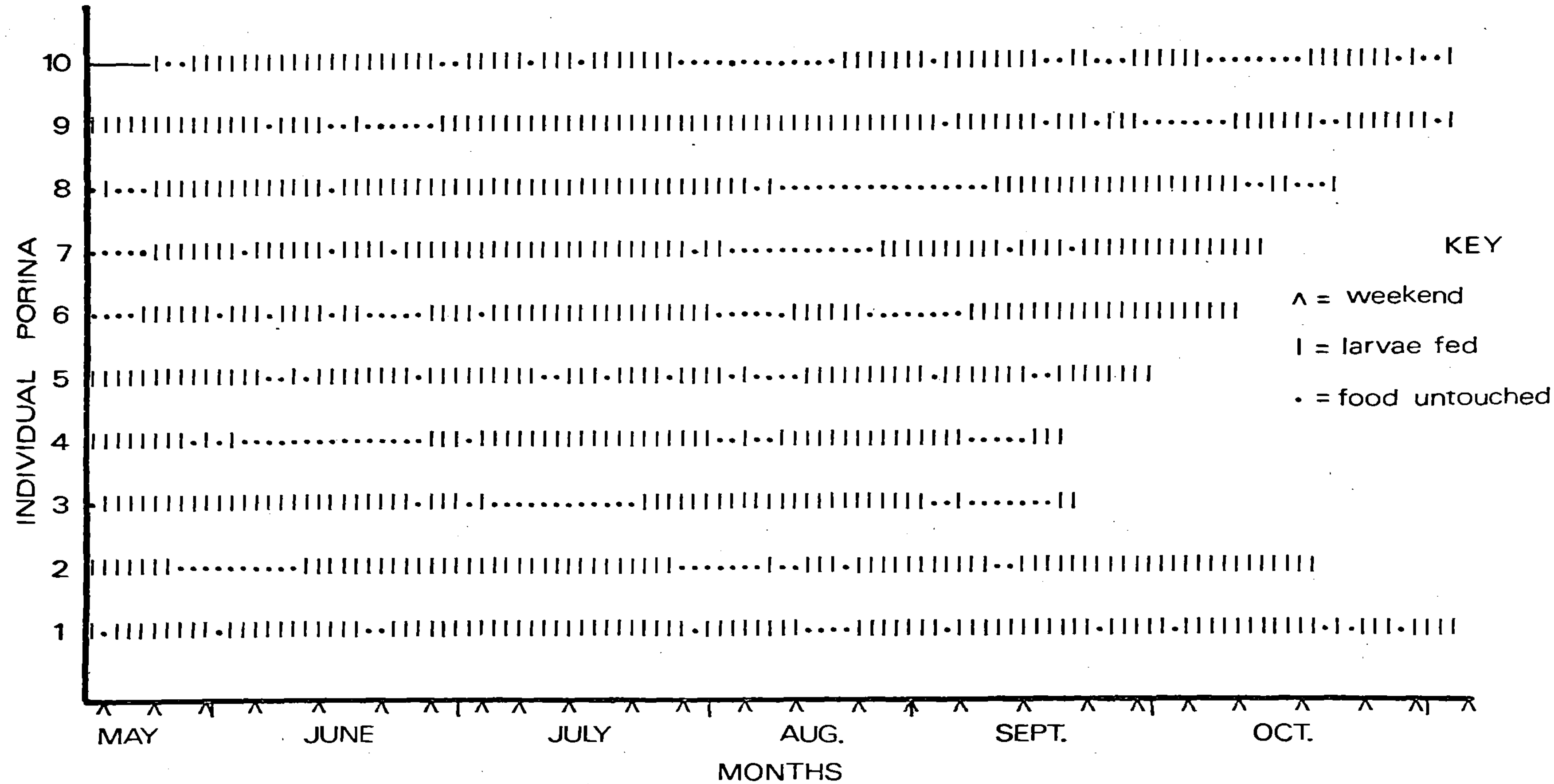


FIG. 57

Feeding behaviour of ten individual porina larvae.

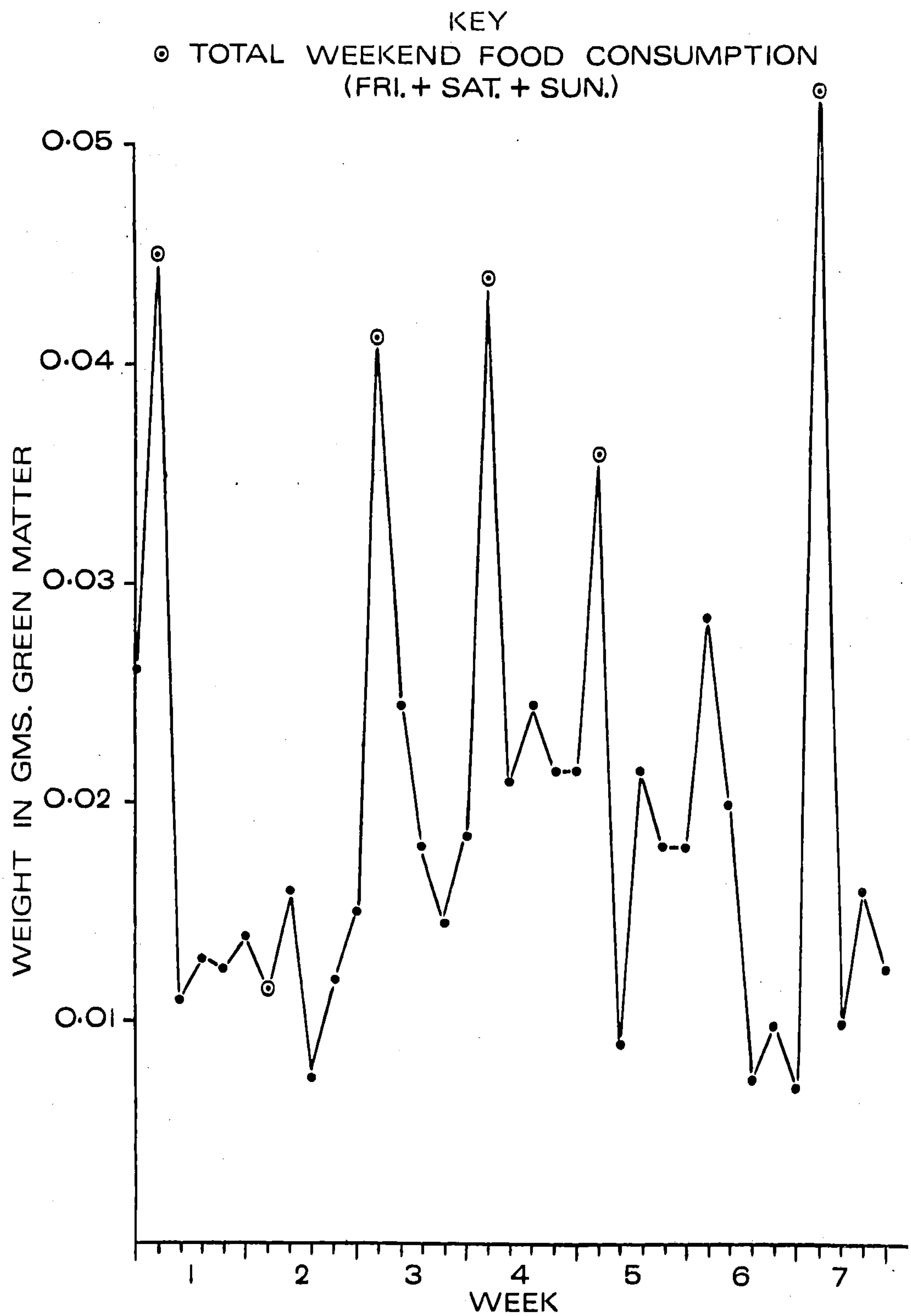


FIG. 58

Mean daily food consumption for a porina larval population showing the wide fluctuations in daily intake.

Table 39 The fate of porina larvae during outdoor feeding experiments at D.S.I.R., Lincoln

	1969 %	1970 %
Healthy larvae		
larvae and prepupae	10	1
pupae	12	7
adults	3	0
mechanically damaged when sampled	3	3
Diseased or Parasitized		
Unknown deformities	3	0
Metarrhizium anisopliae	15	22
Diplocystis oxycani	0	4
Hexamera signata	3	14
Parts of cadavers	3	14
empty tunnels	6	0
cause of death unknown	21	24
Total number of larvae used in experiment	66	67

a T test to compare the "pre-rain" larval food consumption mean
with mean daily "post-rain" larval food consumption

Porina	Pre rain food consumption in g D.M./day					Rain 71.9 mm	Post rain food consumption in g D.M./day			
	9/3/70	10/3/70	11/3/70	12/3/70	mean	15-16/3/70	17/3/70	18/3/70	19/3/70	20/3/70
1	.013	.016	.008	.008	.011		.010	0	.020	.093
2	.010	.014	.003	.016	.011		.004	.009	0	.014
3	.015	.008	0	0	.006		.011	.005	.004	.012
4	.028	.018	0	0	.012		.025	.006	0	0
5	.015	.014	0	0	.007		0	.008	.028	.109
6	.023	.055	.027	.027	.033		.004	0	.029	.197
7	.016	0	.024	.013	.013		.034	.055	.011	0
8	0	.049	0	0	.012		.020	.001	.048	.061
9	.016	.049	.010	0	.019		.032	.003	.047	.135
10	.019	.027	.037	.011	.024		.028	.064	.048	.042
11	.027	.033	.021	.030	.028		.018	.035	.021	.049
							N.S.	N.S.	N.S.	*

between larval food consumption and time, for each year (Figures 54 and 55 for 1969 and 1970, respectively) and in the bulked data (Figure 56), much variation was observed, even though smoothing of the results was carried out.

Some idea of the extent of the variation can be seen in Figure 58. This shows that larval daily food consumption was highly variable and probably influenced by a number of intrinsic and environmental factors such as metabolic rate, feeding rhythms, moulting cycle, food preference, soil temperature and moisture. This is contrary to McLaren and Crump's (1969) opinion that the amount of pasture eaten by larvae depends mainly upon the rate of pasture growth. This is unlikely, as food is seldom limiting in Canterbury and Otago pastures and the rate of larval food consumption would thus be more influenced by behavioural variations, as the information given in Figure 57 would suggest.

The stage of larval development was also important. For example, in August and September a very marked increase in food consumption occurred, i.e. almost twice the normal amount (Figure 56). This would be due to the larvae accumulating sufficient energy reserves to complete metamorphosis during the pupal period.

This late winter increase in larval food consumption has not been previously demonstrated for porina and has important ecological implications. For example, as larval food consumption increases so should pasture damage. The fact that the damage is usually masked is a reflection of both larval mortality and the start of the spring pasture flush of growth. In certain seasons, however, when the spring flush is delayed and larval mortality is low, pasture damage can become more severe. This can mean a serious loss of early lambing feed.

With regard to overall yearly consumption, some variability was also apparent. The slope of the regression for 1969 ($Y = .055 + .00178x$) is steeper than that for 1970 ($Y = .0458 + .000735x$). This indicated a greater feeding rate during 1969. There was, in fact, a statistically significant difference between each year. Although not expected, it is probably biologically true that such yearly variation is a normal occurrence. It could be caused by population or climatic differences. For example, in any one year there could be a greater predominance of smaller larvae, brought about by genetical differences. This could result in an overall reduction in food consumption. Similarly, rainfall, the number of frosts and mean soil temperature could all vary and affect larval food consumption.

The yearly variation was reason enough to bulk the results from each year in order to construct a common regression line that should be applicable (within statistical limits) for most years. Obviously, any estimate of larval food consumption would be more precise if greater replication in time was carried out. Nevertheless, it was considered that the results presented in this chapter are more meaningful than information obtained previously, for the following reasons.

1. The experiments were carried out under almost natural field conditions. The larvae were all established naturally and climatic variations could all exert their influence.

2. Individual larvae were used as the basic sampling unit. Calculations pertaining to population performance were therefore based on the knowledge of individual performance. For example, it was soon noticed when a larva died and thus an underestimate of food consumption was prevented.

3. The study was carried out over most of the larval period and during those stages that caused significant pasture damage. This eliminated overestimates of food consumption which could arise by using results from a shorter period of study and then having to extrapolate these for other larval age intervals.

4. No errors arising from the influence of plant growth were possible. The procedure of feeding known quantities of uniform food, eliminated error based on plant performance measurements. These can be notoriously inaccurate and difficult to carry out, particularly during winter.

The only aspects of the experiments which could cause abnormal variations in food consumption were as follows.

1. The use of plastic lids over tunnel entrances.

2. The placement of the clover leaves directly over tunnel entrances.

Because clover was the only food material available, no feeding preference was possible, nor was there opportunity to search for food. Observations have shown, however, that porina larvae are non-selective feeders. Large, healthy larval populations were frequently found in both clover and grass monocultures while larval gut content examination indicated few, if any, food preferences (Molloy, pers. comm.) Furthermore, food availability within a pasture ecosystem in New Zealand is seldom limiting, except at high larval densities when large areas of pasture can become completely denuded. The time spent by larvae searching for food should, therefore, have little effect on the normal rate of food consumption and for experimental purposes could be discounted.

Nevertheless, the estimate of larval food consumption discussed in the following section may be an overestimation and probably more correctly indicates the potential food consumption of porina caterpillars rather than a mean food consumption.

Calculation of an estimate of larval food consumption and discussion

It was calculated from the information given in Figure 56 that a mean of 4.16 g of green matter or .834 g of dry matter (D.M.) was consumed by one larva during its life of approximately 280 days (November to late August). The figure of 280 days was estimated by extrapolation of the regression line in Figure 56 back to the X asymptote. This indicated that the larvae began feeding (albeit at a very low rate) about late November. It was known that the majority of eggs hatch at this time of the year. It was satisfying to note that the theoretical time of commencement of feeding coincided with the known time of egg hatching.

The estimated food consumption equated to .3 kilogram D.M./hectare/day/10 porina/m^2. In comparison Harris (1969) calculated that over 140 days (April to August) 10 porina/m^2 consumed 3.21 kg D.M./hectare/day. This figure was overestimated for the following reasons.

1. The results were obtained from a glasshouse experiment into which larvae were artificially introduced. As a consequence, diurnal climatic variation was largely reduced.

2. Food consumption calculations were based on the assumption that the larval density recorded at the end of the experiment was established early in the experiment.

Considering the overall decrease in porina numbers from approximately 20 to one per treatment, this was an impracticable assumption. Furthermore, the life table information presented in this thesis shows that, while mortality over the autumn and winter subterranean larval periods is normally low, it can be severe thereafter (over 50 per cent) (see Table 25). Because of this continual mortality which is a natural feature of porina populations, Harris has underestimated the number of larvae involved and therefore overestimated food consumption by basing his final calculations solely on the number of surviving larvae.

Allen (1968) has also quoted a figure for larval food consumption based on information from an eight week insecticide trial, with pasture measurements carried out during the spring. His estimate of 1.04 kg/hectare/day/10 porina/m^2 was considerably lower than Harris's but was still high compared with the results obtained in this study. Allen's technique consisted of measuring spring pasture growth by mowing and comparing the difference between insecticide treated plots with untreated plots. This, however, does not really measure porina consumption "per se". What was really measured was the rate of plant regrowth in spring in relation to the growth depressing effect of porina depredations.

Measurement of spring growth responses is different to the situation in winter, where plant growth is minimal. Furthermore, the results obtained from mowing trials were probably inapplicable to larval food consumption studies, because the measurements were taken above the zone where larvae feed. The best mowers leave about 22 mm of vegetation untouched above the ground, and it is in this zone that porina feeding takes place.

The figures used by McLaren and Crump (1969) were also obtained from insecticide trials from which pasture measurements were taken in spring. Although a very close statistical relationship was obtained between larval number and percentage reduction in pasture growth, it did not indicate actual larval food consumption. Admittedly, it was an index of food consumption, but an index based on measurements in spring would be of doubtful value for assessment of damage in winter because of different pasture growth characteristics.

The biggest disadvantage of all feeding studies, however, and the present one was no exception, is that immediately the food consumption of any organism is measured, its normal feeding behaviour is altered in some way, to a greater or lesser extent. This must always remain a source of error.

Discussion on larval feeding behaviour

An interesting discovery was the obvious irregularity of larval feeding (see Figure 57). The maximum number of larvae which fed on any particular night was about 80 per cent of the population. Esson (1970) who used a photographic technique, observed a similar phenomenon and quoted a figure of 70 per cent.

In 1969 the mean number of larvae feeding in any one night was 68 per cent ± 3.9 per cent, calculated from 30 nights chosen at random out of a total of 139 nights. In 1970 the mean was 57 per cent ± 5.2 per cent, giving a mean of 63 per cent ± 3.5 per cent over the two years.

Most larvae in the population had at least one lengthy period during which they didnot feed. In some cases this period exceeded 10 consecutive nights (Figure 57). Two, or even three such periods were observed for some individuals. It is doubtful, however, whether there was any feeding rhythm as suggested by Esson (1970). In fact, it was impossible to predict when any particular larva would stop, or recommence feeding. There was, however, a well developed diurnal feeding pattern, as the larvae did not feed or emerge during the day unless they were diseased or flooded out by heavy rain. This was demonstrated occasionally, by placing food under the plastic lids early in the morning and leaving it till evening. In every case the food was untouched, yet the same larvae fed normally during the night. Apparently the larvae determine night-time and behave accordingly, even though the opaque plastic lids let in very little light. A possible triggering mechanism for the appropriate larval behaviour could be the marked alteration between day and night soil temperature and surface humidity levels.

It was interesting to note that diseased larvae continued eating until just before death. This occurred when larvae were infected with either muscardine fungus (Metarrhizium anisopliae) or a nucleopolyhedral virus. In some cases the larvae fed normally until they died on the surface two days later with an obvious M. anisopliae infection.

Variations in weather also affected feeding behaviour. For example, the information given in Table 40 shows that larval food consumption increased after rainfall, particularly on the fourth day following rain, when a statistically significant difference was found. This phenomenon occurred after a prolonged dry period and was probably related to increased larval activity due to a change in soil moisture content. Whether a similar result would be observed following rain in already wet soil or in wet seasons, was not determined.

It was occasionally observed that frosts had a depressing effect on feeding activity. It was interesting, however, that larvae still fed actively, albeit at a slightly lower rate, on nights of very low, near freezing, temperatures, i.e. 1°C. Considering the insect's adaptation to mountain conditions, the fact that larvae fed during low temperatures is not surprising. Observations at Tara Hills Research Station, at an altitude of 854 m confirmed this, as signs of feeding were noted even though the soil was "perma-frosted" to a depth of about 76 mm.

Practical implications arising from larval food consumption experiments

Because of the variability of larval feeding, it is impossible to obtain a 100 per cent mortality of a field population using the insecticides currently recommended for porina control. The chemicals recommended are fenitrothion, diazinon and trichlorfon, which should be applied at the rate of 1 kg ai/ha.

Ideally they should be applied during January in Canterbury, (during March in Otago). As a mean of 63 per cent of a larval population can remain inactive for long periods, however, the maximum kill that could be obtained, even under ideal conditions, would be about 80 per cent. In practice a 70 per cent mortality would be more realistic.

Obviously this low efficiency must be considered when studying economic returns from the application of insecticides. They are usually applied in the more costly granular form as the cheaper spray formulation has a relatively short residual life.

If insecticides are applied it should be carried out during, or just after, rain. Application under very dry conditions, i.e. a soil moisture close to wilting point, is not recommended. The larvae appear to enter a type of aestivation under such conditions and feeding activity is markedly reduced (Table 40). Moreover under dry, hot conditions the relatively unstable organophosphate insecticides break down within two or three days.

On the other hand, insecticides should not be applied if a frosty period is expected, because the larvae tend to become inactive under such conditions and therefore would not come in contact with the insecticide before it had broken down.

The economic interpretation of the results from larval food consumption studies

Introduction

Various attempts have been made to determine the amount of porina damage and the profitability of using insecticide to protect pasture from damage.

All these attempts fall short of any meaningful economic assessment of porina damage as the authors failed to consider either one or all of the following factors.

1. The long term effect of porina damage on both national and individual farm production.

2. The distribution pattern of porina larval populations which are not uniformly distributed either within an infested pasture or over a farm.

3. The sporadic nature of infestations which seldom occur every year in a given area.

4. The suitability of pasture sampling techniques, especially by mowing spring pasture and extrapolating these results to winter conditions.

5. The desirability and, at times, the necessity of searching for alternative means of control other than insecticide.

6. The need to subtract the cost of damage to wildlife and soil microfauna from any return obtained from the use of insecticides.

7. Lack of awareness of the flexibility in farm management planning in New Zealand, especially in Canterbury.

Porina damage has always been assumed to be a serious problem by both entomologists and farmers alike. Most farmers believed they had a serious problem because porina damage has been disturbingly obvious at times and consequently has been well publicized by the news media. For example, articles written in the Christchurch Press (July 1 and 22, 1967) indicated that stock numbers in Canterbury would have to be reduced if no "adequate control was forthcoming."

Doubts about the meaningfulness of opinions on the importance of porina damage arose, as the information for this thesis was gathered.

Economic assessment of porina damage at a provincial level

Discussion with many farmers in Canterbury and Otago revealed that all those farmers spoken to had continuously increased their stock carrying capacity from the time they began farming, regardless of porina infestations. No farmer had ever been forced to sell stock because of porina damage. Many admitted that they had occasionally experienced severe porina attacks which did cause some concern and which required some sort of control. It was also stated in many cases that pasture growth during spring and summer covered most porina damage by the following autumn and because of the sporadic nature of infestations, pastures were seldom damaged in two consecutive years.

Some farmers in Canterbury had been able to increase production very successfully without using insecticides, even though they had experienced severe porina attacks (see Christchurch Press October 28, 1967). Furthermore, a study of the Agricultural Year Book on Production Statistics showed that, in most agricultural districts in New Zealand, sheep numbers per hectare have almost doubled since 1948 even though many of the districts were susceptible to porina attack.

Detailed stock number statistics were abstracted for the Ashburton County, as this area had always been notorious for both grassgrub and porina attacks.

It is obvious from the information summarized in Figure 59 that sheep numbers have more than doubled since 1948. Furthermore, this increase took place notwithstanding the fact that Kelsey (1969) maintained that there had been a total of eight widespread and severe porina epidemics in Canterbury between 1930 and 1969 (Figure 59). Admittedly Kelsey's information was only based on a limited number of small plot insecticide trials carried out each year, together with careful observations over a wider area. Nevertheless, it appears that the rate of increase in stock numbers in the Ashburton County has not been affected by either grassgrub or porina damage since 1948.

Although D.D.T. was extensively used from 1951, this author is of the opinion that the increased farm labour force

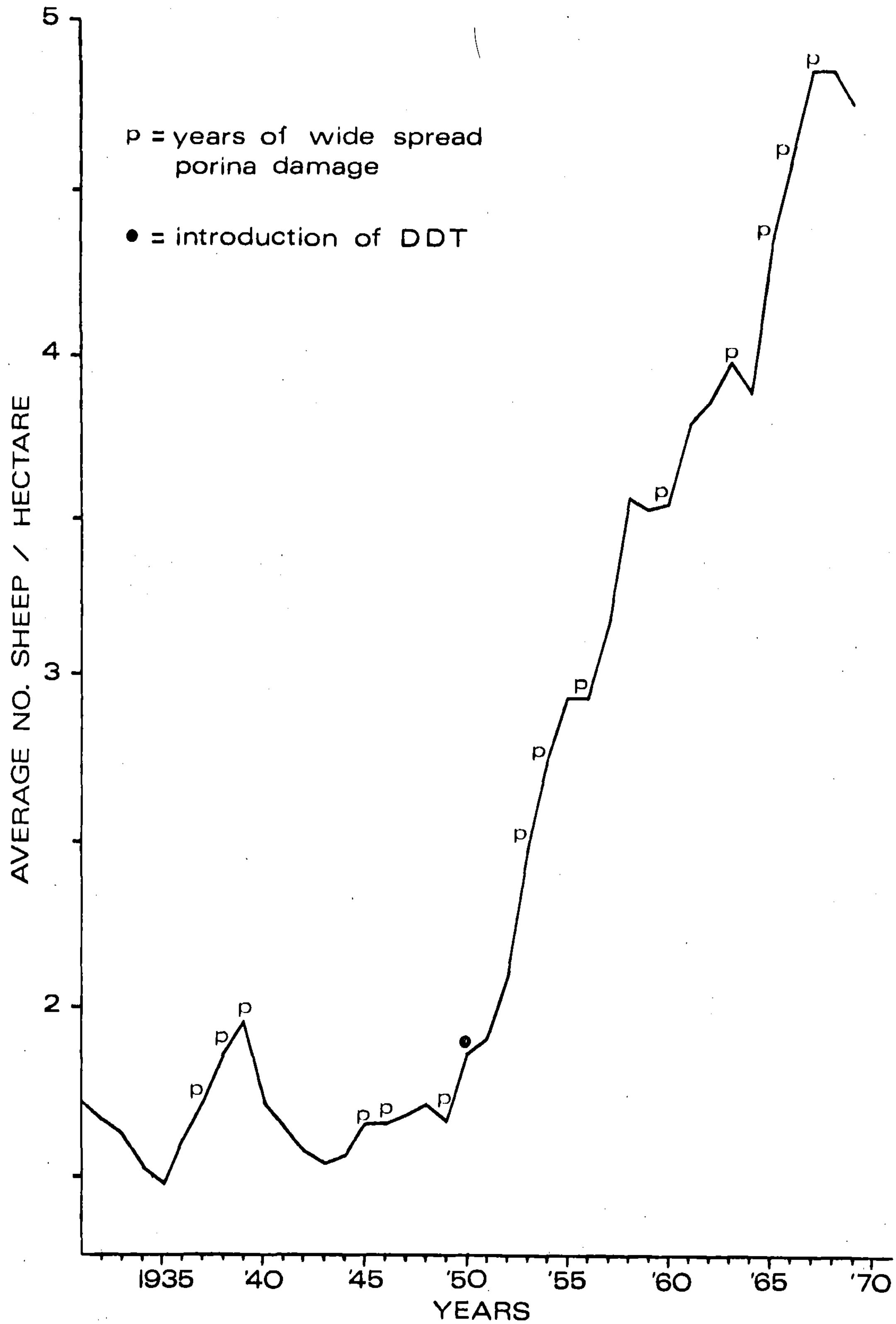


FIG. 59

Annual rate of increase in sheep numbers in the Ashburton county with an indication of years of wide spread porina damage.

resulting from returned servicemen, plus the very high wool price in the post-war period and better pasture utilization, had a far greater effect on increasing stock numbers than the introduction of D.D.T. In other words, lack of labour, low meat and wool prices, and indifferent farm management practices were probably responsible for low pre-war stock numbers than either grassgrub or porina damage.

Economic assessment of porina damage at the farm level

As a result of doubt about the long term effect of porina damage on provincial farm production more detailed quantitative information was obviously required to resolve the situation. The figures obtained from the study of larval food consumption, population distribution patterns and population mortality, provided the basic information for the following economic assessment.

It is stressed that two points be always kept in mind during the following discussion.

1. Porina damage must be assessed in relation to the actual number of sheep to be overwintered and not the potential number which could be carried if porina damage was non-existent. There is no causal relationship between overwintering stock numbers and the current level of porina infestation. This is contrary to a widely held belief that the application of insecticide to reduce porina population levels will increase stock numbers (Rastrick and Upritchard, 1968). Stock number

increases usually occur only over a number of years, except where farmers have a "buying in" policy.

2. A decision always has to be made on whether larval population levels are to be immediately reduced and/or the pasture production status quo restored.

Background information

Figure 60 gives the accumulated dry matter production from February to August in kg/ha, which could be expected from a typical Canterbury pasture consisting of a mixture of Ruanui ryegrass (*Lolium multiflorum*) and white clover (*Trifolium repens*) situated on a Templeton silt loam soil. These figures are based on monthly rate of growth measurements taken on rotationally grazed pastures* (O'Connor and Vartha, 1968). It has been assumed that on the 1st of February this this type of pasture in Canterbury, under average to good early autumn conditions, should contain about 500 kg/D.M./ha (Vartha, *pers. comm.*). The pasture growth as shown in the graph is characterised by an autumn flush of growth, followed by slow or non-existent winter growth and the beginning of the spring flush. Figure 61 shows the effect of applying 250 kg/ha of nitrogen fertilizer to the pasture in the early winter. It has been assumed that up to 30% extra pasture production could be obtained in winter/early spring by applying this amount of nitrogen (Vartha, *pers. comm.*) but there are no quantitative published results to show that this figure is

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*Footnote Rotational grazing is a technique of grazing a large number of stock per hectare for short periods, after which the pasture is spelled for usually a period of four weeks.

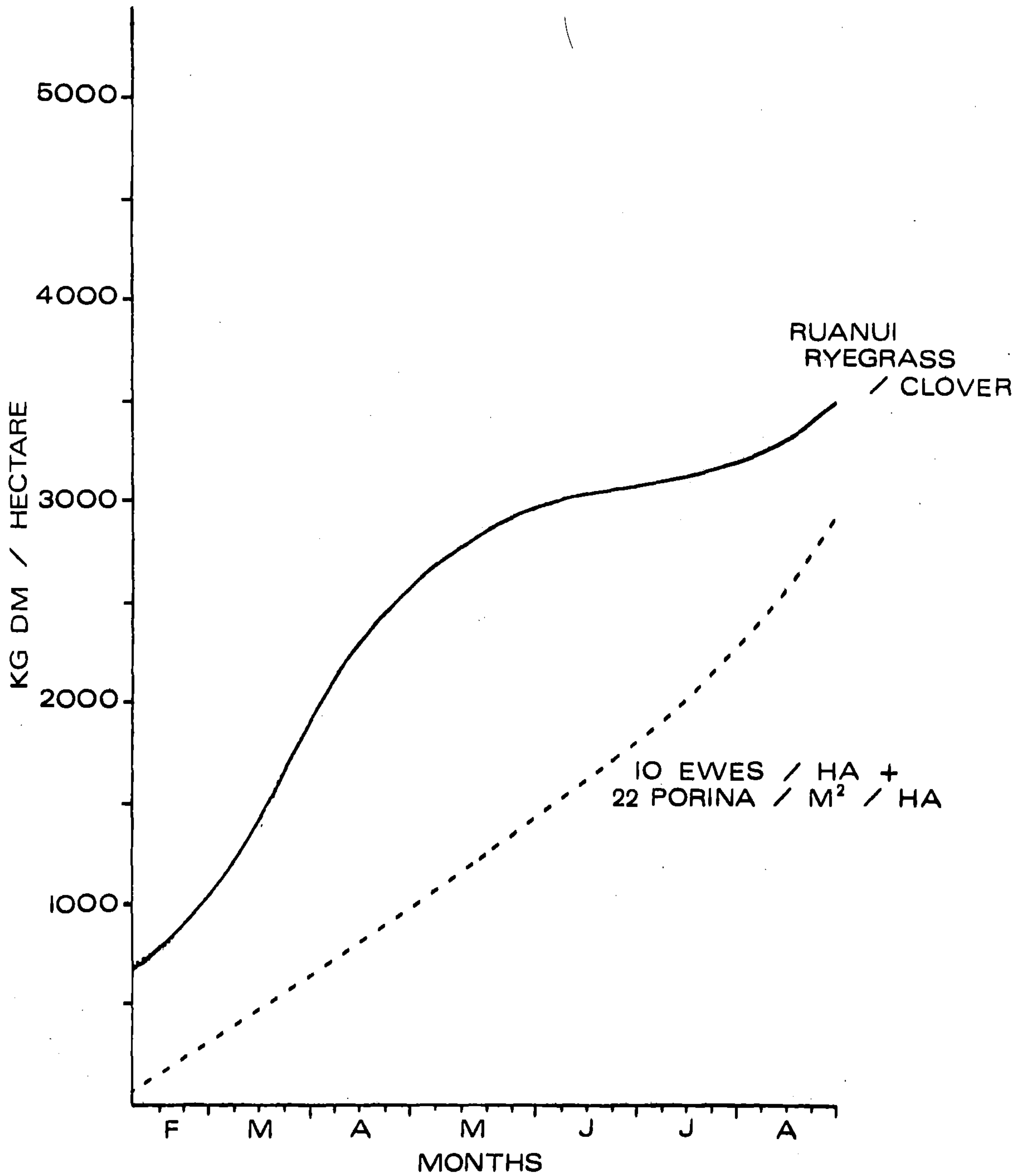

FIG. 60

Expected accumulated pasture production on an average Canterbury farm plotted with accumulated sheep and porina food consumption.

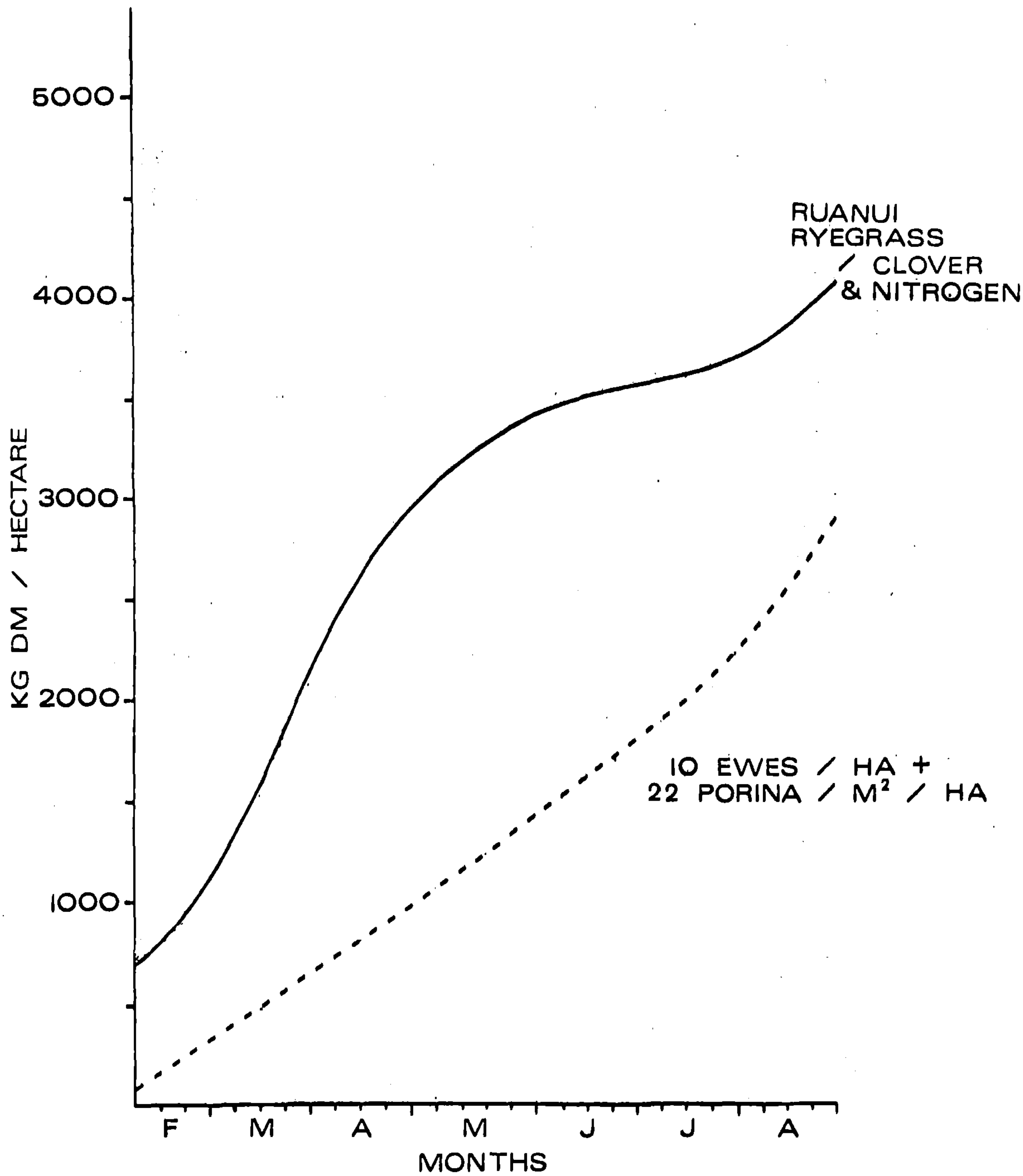

FIG. 61

The effect of nitrogen on the expected accumulated pasture production on an average Canterbury farm plotted with accumulated sheep and porina food consumption.

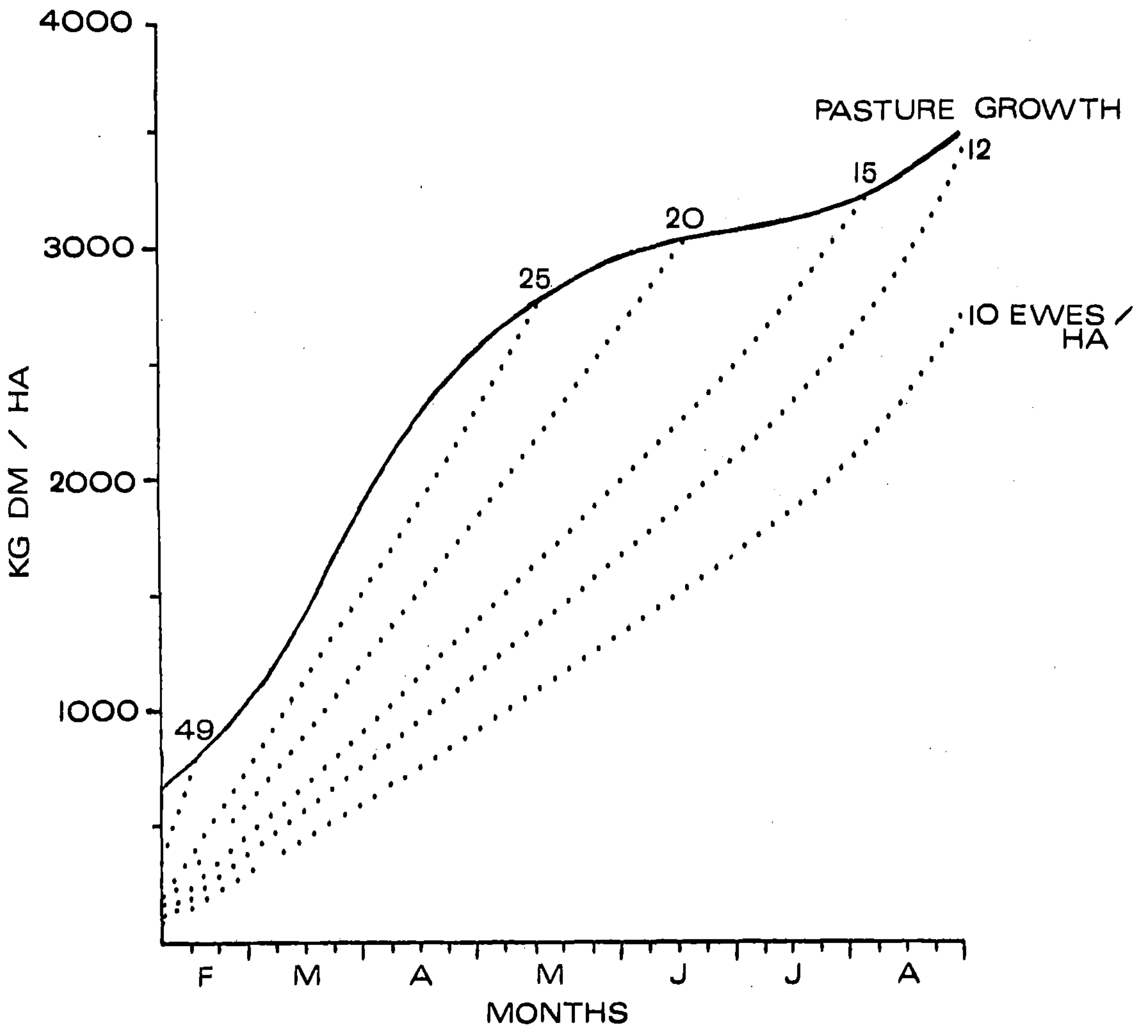

FIG. 62

Expected accumulated pasture production on an average Canterbury farm plotted with accumulated sheep consumption at various stocking densities.

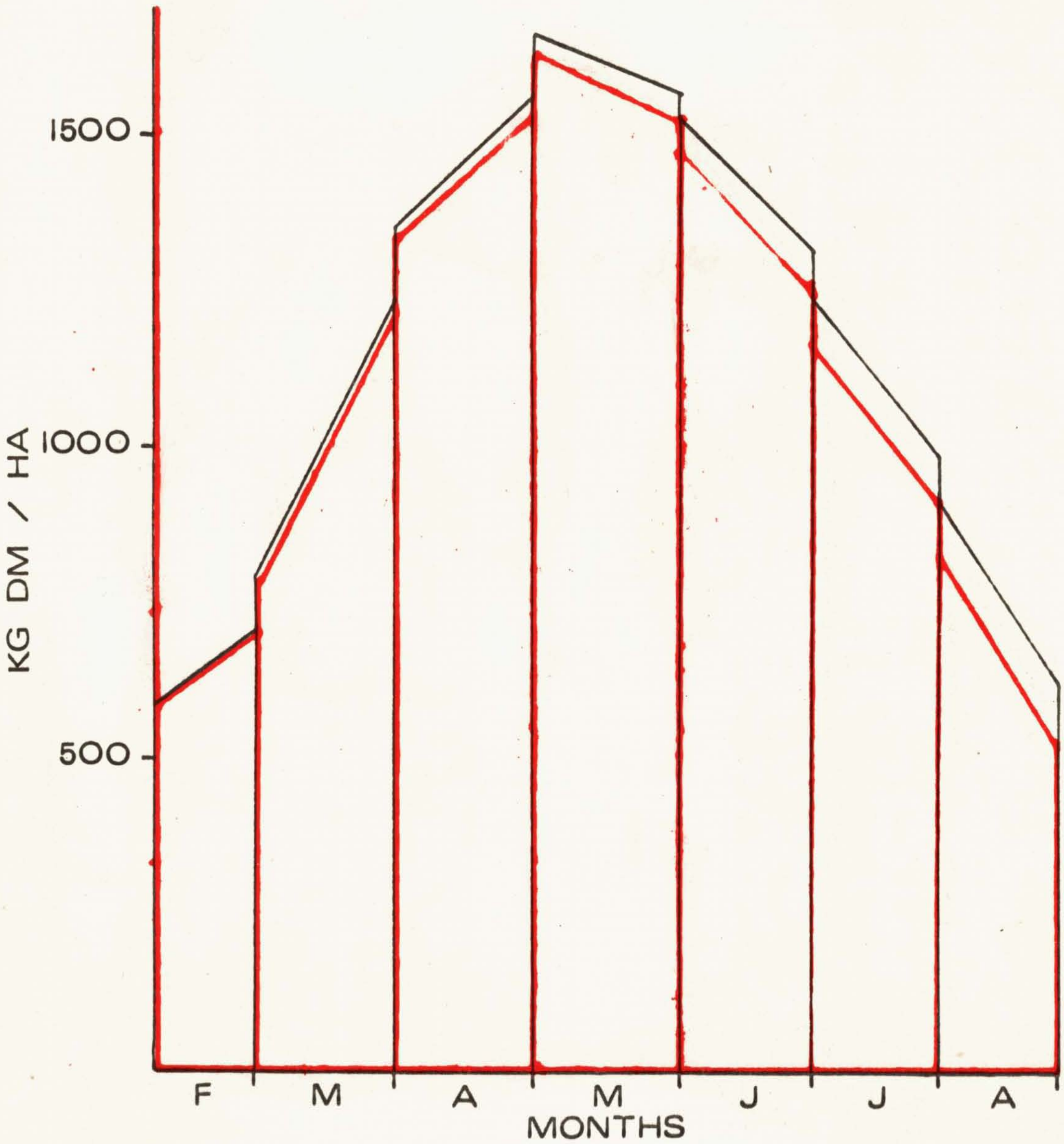

FIG. 63

The effect of 10 ewes per hectare plus 33 and 22 porina larvae/m^2/ha on surplus D.M. production from a Ruanui ryegrass/white clover pasture in Canterbury.
Note: The overlay shows the surplus D.M. at 10 ewes/ha plus 33 porina larvae/m^2/ha.

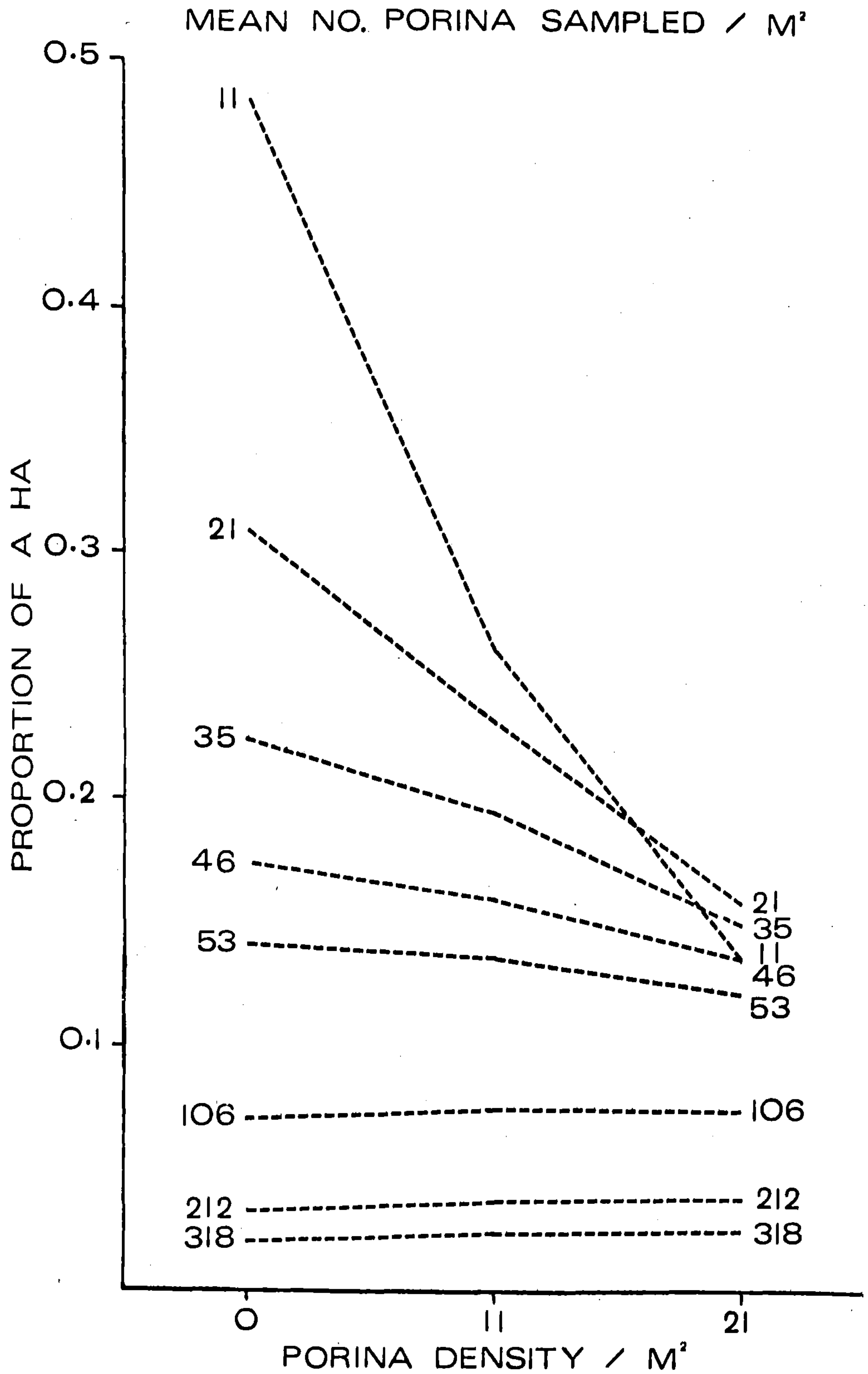

FIG. 64

The proportions of a paddock uninfested and infested with 11 and 21 porina/m^2, at various mean population levels. The proportions are calculated with the aid of the negative binomial distribution model.

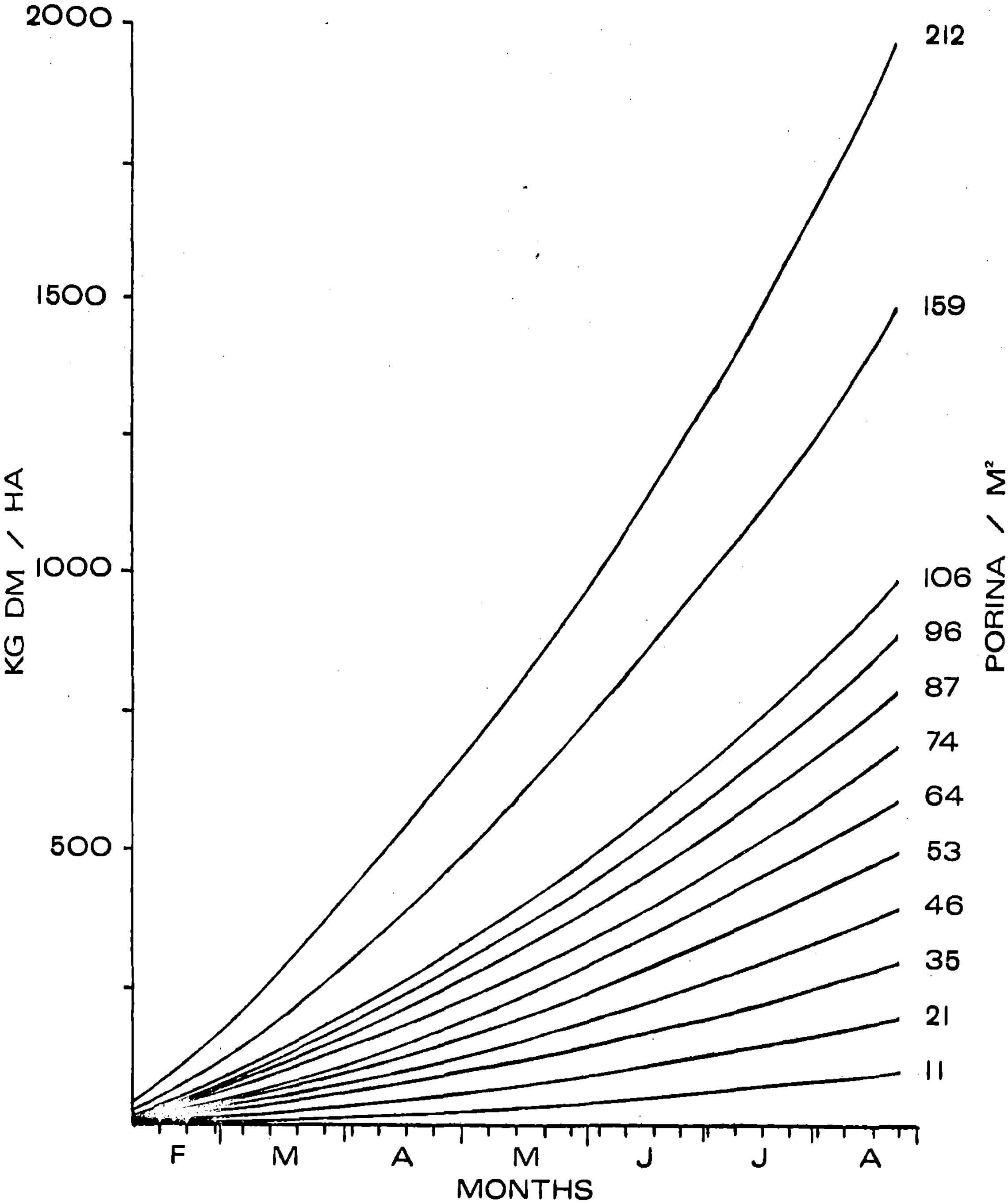

FIG. 65

The accumulated food consumption of different mean larval population densities.

widely applicable.

Figure 62 shows the accumulated amount of dry matter consumed by ewes at various stocking rates. The figures are based on a Romney type ewe weighing about 54 kg (Coop, 1965). Allowance has been made for the extra feed required prior to lambing.

The accumulated food consumption of 10 ewes/ha, plus 22 larvae/m^2/ha is also given in Figure 60. This density of larvae is equal to a population of about 220,000 larvae/ha which consume approximately the same as one ewe feeding for 280 days.

The calculated amount of surplus dry matter during the winter and early spring when 10 ewes/ha are grazed on a Ruanui/white clover pasture infested with porina at a mean density of 22/m^2/ha is given in Figure 63. Note: The measurement of larval density given as numbers per metre square per hectare indicates a fixed population size. For example, 22/m^2/ha is the average density per metre square over a hectare in which there can be found a total of 220,000 larvae. If a conversion to imperial units is required it is incorrect, in this case, to convert directly from metric to imperial units if a fixed population number is involved. Thus 22/m^2/ha as used above, does not equal 2.7/square foot which is a direct conversion, but should be 5.1/square foot/acre, based on a larval population of 220,000. Means given only as m^2 can be converted to square feet if required, by dividing by 10.7

Figure 64 indicates the proportion of each hectare supporting a density of 0, 11 or 21 autumn subterranean larvae per m^2 at various mean infestation levels. This information is based on a negative binomial distribution model with a k_c value of 1.10. For example, at a mean infestation level of 35 larvae per m^2, about 23 per cent of any given hectare would be uninfested, about 19 per cent of the hectare would have 11 larvae per m^2 and 15 per cent would have $21/m^2$. The remainder of the hectare would consist of pockets of infestation ranging from 22 to $300/m^2$. Less than 1 per cent of the hectare would support 300 caterpillars/m^2. These figures, which are proportions, can be multiplied by any number of hectares and hence give an estimate of the area in a paddock infested at the different larval densities.

Interpretation of pasture production data in relation to porina and ewe food consumption

With an infestation of 22 larvae/m^2/ha and rotationally grazing 10 ewes/ha on an average Ruanui/white clover pasture in Canterbury, it should be possible to overwinter both ewes and porina without any need to reduce the porina population or even supply supplementary feed* for the ewes. Moreover at this stocking rate and porina infestation, there is a pasture feed surplus right up till August (Figure 63).

If the pasture was infested with a mean of 33 larvae/m^2/ha this, plus 10 ewes could also be overwintered in the above manner. Pasture reserves, however, would be low by August (Figure 63) and unless supplementary feed was available, this

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*Footnote Supplementary feed is usually fed to stock when pasture growth is insufficient to maintain or increase body weight during either midwinter or midsummer. It can consist of hay, brassica crops, grain or concentrate foods.

situation would be undesirable.

One important point to stress at this stage, is that the above interpretation has been based on the assumption that the porina densities mentioned were not only present in February or March but were maintained at the original densities until August. This is not correct as it is known that larval mortality will occur, particularly in the later stages. Therefore, the information given in Figure 60 showing food consumption at a larval density of $22/m^2$/ha is overestimated. In practice, however, a very precise estimate of porina food consumption may not be necessary as, even at high densities, the proportion of pasture consumed by the porina larvae is very small (Table 41).

Because even high levels of porina consume relatively minor amounts of pasture D.M. compared with the amount consumed by the average sized ewe flock, the real problem for the farmer involves supplying adequate winter and pre-lambing feed for stock regardless of whether porina is present or not.

Up till this stage the discussion has centred around grazing a given number of ewes in a single paddock which is infested with porina. In practice, there are a number of pastures on a farm and the farm manager grazes them in a systematic manner and tries to obtain maximum pasture utilisation.

It is most unusual for all pastures on a Canterbury farm to be infested with porina, therefore uninfested pasture could well compensate for infested. The manager's aim should be to maintain ewe body weight for as long as possible on the cheapest food available, which is pasture, before resorting to more expensive feed such as hay, brassica crops or food concentrates. Therefore, to realistically assess the effect of porina damage on farm production, consideration must be given to determining, firstly, how many paddocks over the whole farm are infested with porina and, secondly, what are the levels of infestation in those paddocks infested.

The whole problem is best expressed and solved by use of a food budget, an example of which is given in Table 41. This technique will be explained later in more detail. It is sufficient to state here that one of the biggest assets a farm manager has, when dealing with porina infestations, is the inherent flexibility in stock and pasture management, plus the fact that porina populations, if present, are not uniformly distributed over the whole farm.

Simplified economic assessments based on the calculation of profitability margins, after porina population densities have been reduced by insecticide, are neither realistic nor meaningful, unless the whole farm approach is used.

Furthermore, the former types of assessment tend to divert thinking away from alternative control measures, by concentrating on one theme, namely insecticide control.

Comment on precision of the agronomic figures

Although the entomological and animal nutrition data used are reasonably sound, there are discrepancies in the agronomic figures which detract from the authoritativeness of the economic assessment presented.

In this thesis no attempt was made to carry out pasture production studies as it was considered outside the limits of what is essentially an entomological study. It was realised, however, that the information on pasture growth rates given herein has not yet been sufficiently replicated in time and space to allow wide interpretation without constraints. Overall, however, this does not detract from the entomological conclusions arrived at by this author based on his interpretation of the agronomic data contained in the thesis.

The most serious constraint is the effect of porina and sheep food consumption on the rate of pasture regrowth. The pasture growth figures presented in Figures 60 and 61 are the production expected from a rotationally grazed and uninfested pasture, with adequate moisture and nutrients. It is incorrect to assume that production from infested pasture is the same. The former is undoubtedly less than the latter. The difference, however, may be negligible with regard to winter pasture production, where growth in an average season is slow or non-existent.

It must also be remembered that porina infestations are uneven and that a proportion of each hectare is either un-infested or only lightly so (Figure 64).

No attempt has been made to assess the effect of porina damage on pasture composition. Destruction of plant growing points becomes increasingly important as the porina population level increases and the number of plants may decline. If plants die or are completely consumed and bare soil results, then low production weeds establish, such as storksbill (Erodium cicutarium), mouse-eared chickweed (Cerastium *holosteoides*), scarlet pimpernel (*Anagallis arvensis*) and catsear (*Hypochaeris radicata*).

Bare patches begin to appear in the pasture at levels of infestation of approximately $44/m^2$. At these higher densities a number of larvae tend to deplete available pasture grasses. Under these circumstances, they will devour both seedling and established winter weeds. Larval mortality will also occur due to the competition, until a balance between available food and larval numbers is reached. The result is that the soil remains bared until the surviving larvae stop feeding in August - September. Thereafter, a more serious problem of spring weed ingress will develop if corrective action is not taken. The suggested technique to overcome this problem is outlined later.

The pasture production figures presented in Figures 60 and 61, obtained by mowing techniques, have a disadvantage in that the amount of pasture below about 20 mm was not measured. Within this height, pasture production can be significant, especially for low profile grasses and clovers. Both sheep and porina "graze" below this 20 mm level. This means that the pasture production figures were underestimated. The under-estimation may be balanced, however, by errors which could have arisen from overestimation of the rates of regrowth of grazed and infested pasture.

The pasture production shown in Figures 60 and 61 is based on the assumption that 500 kg D.M./ha is present on the first of February and that adequate moisture is available thereafter to ensure reasonable growth. These figures were derived from seasonal experiments and should be practicable for any one year, although periods of moisture stress could cause pasture production to fall short of that estimated.

No assessment of the direct costs of repairing pasture damage caused by high uncontrolled porina infestations has been made. If no control measures were carried out at infestation levels of 40 to $50/m^2$ or greater, then about 50 per cent of each hectare will have severe damage and about 20 to 50 per cent will be denuded. Although this damage will have little significant overall effect on the over-wintering of stock, the fact remains that the pasture will be damaged and will require repairing, both to maintain production and prevent weed ingress. Insecticides, if applied too late after the majority of damage is done, only partially protect the remaining pasture.

With infestations lower than $40/m^2$, however, there is usually enough pasture in excess of requirements to prevent irreparable plant damage. Under these circumstances plant regrowth restores the pasture status-quo in spring, especially if extra nutrients in the form of artificial fertilisers are applied. Repeated observation has shown that small, porina-damaged patches in well established pasture recovered in spring when fresh grass tillering and regrowth from clover stolons occurred. Harris (1969) also arrived at a similar conclusion for established clover pastures.

CONCLUSIONS FROM RESULTS OF LARVAL FOOD CONSUMPTION STUDIES

1. The effect of porina damage has been grossly exaggerated both at the provincial and individual farm level.

2. It is possible to overwinter, on pasture alone, 10 ewes/ha rotationally grazed, plus up to 33 larvae/m^2/ha on a standard Ruanui/white clover pasture on a medium soil type in Canterbury.

3. Previous attempts at assessing porina damage have been unrealistic. The authors failed to consider a number of pertinent factors such as flexibility in both stock and pasture management, the unevenness of porina population distributions, and the sporadic nature of infestation. Furthermore, the pasture sampling techniques used were suspect and the data obtained was extrapolated outside its valid limits of use.

4. Porina larvae do, and always will, cause a certain amount of pasture damage on a number of farms in New Zealand each year, regardless of control measures.

CHAPTER 8

MEANS OF PORINA CONTROL ALTERNATIVE TO THE USE OF INSECTICIDE

Introduction

It was shown in the previous chapter that even high levels of porina infestation had little effect on stock number and that it should be possible to increase production without using insecticide. Nevertheless, regardless of control procedures, insecticide or otherwise, porina infestations will always cause some pasture damage and it is desirable that this be kept to a minimum, provided it is economic to do so.

The following discussion is centred around control measures in which insecticides play little or no part. The techniques of control have been developed from quantitative information presented in this thesis and are based on two concepts.

1. The artificial supplement of mortality factors acting on key age intervals.

2. Promoting extra pasture production, over and above that normally expected, to help compensate for porina damage.

In some cases quantitative information has been supplemented by observations of farm management practices. Except for the mob-stocking* technique, the other control measures suggested have been deduced and their real effect is therefore essentially speculative. For convenience of discussion the control procedures are divided into two groups.

1. Measures which minimise the effect of an infestation already established and causing damage.

2. Procedures applied early in the insect's life cycle i.e. egg and juvenile larval stages, before pasture damage becomes significant.

The former is essentially a curative approach while the latter is more preventive.

Minimising the effect of an established infestation

If the farm manager finds through sampling or observation, that a proportion of his pasture is infested with porina then he should determine the following.

1. The area and density of the infestation.

2. The amount of available 'winter feed' for all stock, which includes overwintering and early lambing feed plus dry stock requirements.

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*Footnote Mob-stocking is a stock management technique which involves the grazing of a large mob of sheep at high densities for short periods.

The area and level of infestation can be obtained by using a sequential sampling technique developed by French (1969) for sampling porina populations.

The amount of available feed can best be determined by constructing a food budget as shown in Table 41.

The calculation of D.M. content for the various types of supplementary feed, e.g. brassica or hay, can be determined by studying a farm management reference, e.g. The Lincoln College Farm Budget Manual (1972).

Determination of pasture D.M. is more complicated, especially if allowance is to be made for uneven porina infestations. If the following steps are carried out, however, and the results entered into a feed budget, a reasonable estimate of the feed situation on a farm unit can be obtained.

1. Determine the area of uninfested pasture over the whole farm and calculate the total kg of D.M./ha which can be expected. If the pastures are of a standard Ruanui/white-clover type and adequate moisture and nutrients are available, then the data from Figure 60 could be used. Adjustments will be necessary for local conditions, but the information required should be available from local Farm Advisory Officers.

2. Calculate the proportion of uninfested pasture within an infested paddock with the aid of Figure 64 and the mean number of porina per m^2 sampled for each infested paddock. The D.M. production expected from this area can then be estimated and included in the

Table 41 Example of a feed budget showing the significance of porina damage on a Canterbury light land sheep farm for the period February 1st - August 31st

Credit	kg D.M.	Debit	kg D.M.
134 hectares uninfested pasture	319,272	1800 Romney ewes	481,247
		Cattle	-
		Other Stock	-
*8.5 hectares infested pasture	17,936		481,247
3,000 bales of hay	57,120		
16 hectares turnips	112,411	Porina consumption	
- kg grain	-	12 hectares 43 porina per m^2/ha	4,392
- hectares A.S.P.	-	12 hectares 22 porina per m^2/ha	2,201
		12 hectares 17 porina per m^2/ha	1,701
		12 hectares 9 porina per m^2/ha	900
			9,194
	506,739		490,441
Surplus/Deficit		Surplus at August = 16,298 kg D.M.	

Note: At the level and extent of porina infestation stated, porina damage amounts to only approximately 2% of the total feed intake required by the ewes

* = the pasture production expected from that proportion of the infested area which does not harbour any porina (see Fig. 64 and p. 311)

Assumptions

1. Poor to average values are used to calculate production figures. The credit estimate is, therefore, very conservative. Production should be higher in most other areas in the South Island.

contd.

Table 41 contd.

2. Ewe requirements are calculated from post-tupping (1st February) to pre-lambing (31st August) using data from Coop (1965) p. 17 Table 4-5.

3. Porina numbers remain constant. (No larval mortality has been assumed from 1st February onwards). The infestation level shown is high and atypical of that usually encountered. Furthermore, porina consumption has been over-estimated by only partially allowing for the typical aggregated larval distribution pattern.

4. The amount of supplementary food is that normally stored or grown, regardless of whether pastures are porina infested or not.

5. Pasture utilisation is efficient with intensive rotational grazing practiced. Each pasture is spelled for at least a month between grazings.

6. No other pasture pests are present.

7. The farm in this model is divided approximately into seventeen 12 hectare paddocks.

8. This budget was calculated to show only the overall picture and highlight porina damage. In practice a monthly budget should be prepared.

'credit' side of the food budget (see 'infested pasture' Table 41).

3. Estimate the stock food consumption and porina food consumption, and enter this information on the 'debit' side of the food budget.

Stock food consumption is best calculated using information given by Coop (1965) or Jagusch (1972). Winter food consumption should be estimated up to the commencement of spring growth. For convenience this is assumed to be August 31st.

Porina food consumption can be determined from Figure 65 which gives the accumulated consumption per hectare for a given mean population. This information is not based on a negative binomial distribution, nor has any allowance been made for natural mortality. It is, therefore, an over-estimation of what would actually be consumed in the field. This will have the effect of making the ultimate calculations and conclusions conservative.

Once the data are entered in the budget, it is merely a bookkeeping exercise to determine whether there will be sufficient feed available or not for overwintering stock. In the example given in Table 41 there was a surplus of food. By merely altering each input, however, the final balance could vary considerably. It was significant to note that a theoretical increase in the level of porina infestation (from, say, a mean of $43/m^2$ to $110/m^2$) had little effect, proportionally on the overall balance. On the other hand, a poor brassica crop or low hay yield could make a considerable difference. It was thus deduced that even in rare cases when porina populations denude over 50 per cent of all available pasture and, consequently, cause a potentially serious feed deficit, the following compensatory management techniques can still be used with considerable effect.

1. Nitrogenous fertilisers can be applied in autumn, on uninfested or lightly infested pasture and consequently reduce the feed deficit (see Figure 61).

2. After tupping, the ewe flock can be managed so that they are fed reduced rations early in winter, resulting in a gradual loss of body weight to a predetermined level. Thereafter, the ewes can be maintained at the reduced body weight until about two months prior to lambing. The feed should then be progressively increased as lambing approaches.

3. Mob-stock infested pastures and utilize all the available pasture before porina larvae consume it. The combination of trampling, herbage removal and slurrying of the soil surface places a stress on the porina population. This can cause high larval mortality, part of which would be due to physical damage. Because of the stress there is also an increase in susceptibility to pathogens.

If meadow hay is fed, the seed from it is trampled in and germinates in early spring. This results in an almost new sward if supplemented by oversowing.

Vigorous growth is ensured because of the large return of nutrient by excretion from both porina and stock.

4. Infested pasture can be mob-stocked in March to consume the remaining pasture. The area could then be cultivated with a chisel plough or heavy grubber and subsequently harrowed and rolled. Immediately drill in 30 kg of Tama ryegrass per hectare with 125 kg of superphosphate. When the sward is well established the application of 125 kg of ammonium sulphate per hectare will stimulate extra production. The sward can be lightly grazed in six weeks. As a result of this treatment extra pasture production could be obtained during winter. This not only supplies mid-winter feed but produces abundant late winter and lambing feed at a time when it is most needed and when porina damage is most limiting.

The cost (including cultivation and the extra nitrogenous fertiliser) is approximately $12/ha. In comparison, the application of insecticide costs between $10 and $14/ha without assurance of any increase in pasture production. An advantage of insecticide application, however, would be to lower the density of the source population which could give rise to infestations in subsequent years, although with sound management the farmer can control the subsequent juvenile population and prevent infestation without insecticide and its associated costs.

5. Buy in extra hay or concentrate foods.

The economics of these alternatives would have to be studied in detail for each particular farm, depending on the degree and area of porina damage and the amount of feed available. In practice, however, alternative number (2) is carried out to a greater or lesser extent, regardless of porina infestation. Therefore, the cost involved is negligible. All that is involved is the cost of time and labour to shift a mob of sheep from pasture to pasture.

With regard to comparative costs (Table 42) most of the above alternatives seem to be more economic than the use of insecticide, as the cultural and managerial techniques are aimed at increasing or conserving feed, while insecticides destroy only a proportion of the porina population and hence do not always result in the expected pasture production. If insecticide is applied, however, in late summer or early autumn before significant pasture damage occurs, then most of the expected pasture production will be achieved as shown in Figure 60.

A point often overlooked when using insecticide is the amount of real profitability. It is unrealistic to maintain that the use of insecticide will allow extra stock to be carried as it has already been shown that insecticides only protect remaining pasture, and do not increase pasture production. Furthermore, ewe numbers usually remain static over the winter period and increase only after replacement and additions, in the form of ewe hoggets, are made to the ewe flock in late autumn. In effect, the only real advantage of insecticide use is to partially ease the larger overall problem of producing enough winter feed for all stock, regardless of porina infestations.

Table 42 The cost of applying insecticide to reduce porina population densities, compared with the cost of producing extra pasture D.M. to compensate for porina damage

Method of control or management	Total cost/ha for treatment	Total pasture production kg D.M./ha expected between 1st Feb.- 31st Aug.	Porina food consumption kg D.M./ha 1st Feb. - 31st Aug.	Amount of pasture theoretically available for sheep 1st Feb.- 31 Aug.	Unit cost per kg D.M.
Paddock infested at 33 larvae/m^2/ha " " 100 " /m^2/ha ( )					
Ruanui ryegrass/ clover sward no treatment	-	3000	300 (1000)	2700 (2000)	-
Application of 1 kg ai/ha insecticide granules in Jan.	$10	3000	10 (30)	2990 (2970)	.334c (.336c)
Application of 1 kg ai/ha insecticide granules in March	$10	3000	80 (200)	2920 (2800)	.342c (.357c)
Application of 250 kg/ha ammonium sulphate	$10	3900	300 (1000)	3600 (2900)	.277c (.340c)
Cultivate in March sow 30 kg/ha Tama plus 125 kg/ha superphosphate	$12	5000	100 (300)	2900 (4700)	.245c (.271c)

contd.

Table 42 contd.

Assumptions

1. The pasture production figures are based on a dense well balanced pasture with adequate autumn rain under fertile conditions.

2. With insecticide applied in January, only a small proportion of pasture damage has occurred but a proportion will occur thereafter. With insecticide applied in March a greater proportion of damage has occurred and will occur thereafter.

3. Cultivation and sowing with Tama ryegrass should destroy most of the porina larvae, but some will survive to cause minor damage during the winter.

Finally, it must be stressed that the situation when both high densities and extensive areas of porina are experienced very rarely occurs and usually results from either a wet spring and/or poor spring pasture management. Furthermore, it has been pointed out that porina infestations are characteristically sporadic. This is an obvious advantage, with regard to discontinuity of infestation in one area. Unlike grassgrub infestations, porina infestations seldom occur consecutively in the one area. On the other hand, the sporadic nature can be a disadvantage on lighter land farms which are not stocked to handle increased spring and summer growth, which is the precursor of porina infestation.

With normal infestation levels, however, the use of the techniques outlined above more than compensate for any food deficit, without resort to costly applications of insecticide.

Restoration of pasture damage by oversowing

It is inevitable that porina infestations cause some pasture damage, regardless of control measures. In many cases pasture vigour in spring will compensate for minor winter damage, especially if the pasture is well established and well fertilised. Only at high infestation levels, however, do patches of severe damage occur, allowing weed ingress and consequent long term pasture deterioration.

Under such circumstances, damage can be rectified by oversowing approximately 30 kg/ha of ryegrass with 125 kg/ha of superphosphate. A disc drill can be used, or an ordinary coulter drill with the points just scraping the soil surface. A very light set of chain harrows will help to cover the seed. If time permitted, the use of a Cambridge roller will help seed germinate by compacting the seed bed.

The oversowing should be carried out as soon as possible in early spring, after most of the larval population is either in the pre-pupal or pupal stage. This occurs in early September in Canterbury. In more southern areas of New Zealand, oversowing should be delayed for up to one month, depending upon latitude and altitude.

The results from oversowing porina damaged areas are usually spectacular. Larval feeding seems to condition the top soil by adding faecal material, while their tunnelling brings the mineralized soil to the surface. Evidence for similar benefits from grassgrub infestations was provided by Yāacob (1967).

The result of larval feeding behaviour is a well cultivated, fertile tilth, with little or no plant competition, as occasionally even weeds are destroyed. After oversowing, growth responses of up to 25 mm a week are not uncommon in spring. If carefully grazed, a supply of valuable lambing feed is assured.

Most important, the cost, at \$9.50 - \$11.50/ha, is low when compared with the insecticide treatment, at a cost of \$10.50 - \$14/ha using granules.

The only complications which can arise from the use of the oversowing technique would be caused by the following.

1. The presence of other pasture pests, e.g. grassgrub.
2. Mixed populations of "early" and "late" races of porina.

3. Adverse growing conditions, e.g. low rainfall during spring.

If other pests such as grassgrub are present, then insecticide may have to be used. This can be made more effective, if drilled with the seed.

The problem of mixed larval populations will depend upon the proportions of each race. Furthermore, mixed populations rarely occur. Late larval populations cause less damage than the early populations as spring growth more than compensates for the damaged pasture. Insecticides should be used against late population larvae only if considered profitable.

An alternative to the use of insecticide would be to sow Tama ryegrass in autumn. Mob-stocking and the cultivation required to prepare a seed bed would destroy most of the late larvae, as the majority are still on the soil surface in late February.

PREVENTION OF INFESTATION

There is a need to forecast population levels in enough time to initiate preventive control measures.

Forecasting techniques have been outlined earlier. If damaging infestations are predicted, then one of the following methods can be used.

1. Mob-stock during the surface dwelling larval period.

2. Flood irrigate during the egg or surface dwelling larval period.

Mob-stocking

Introduction

The concept of using stock to reduce porina damage was first obtained from the Hindon life table studies, information from which indicated that the different treatments resulted in significantly different population levels. Further evidence for stocking effects on porina populations was obtained from paddocks, parts of which had had different grazing managements which consequently affected porina densities. Intensive sampling allowed statistically significant differences between the larval populations, under the different management systems, to be revealed. These results are summarized in Table 43.

Method

In the 1969 pilot trial, located at Lincoln, five 20 m x 20 m areas were fenced off (Plate 23) in a pasture containing a high level of infestation of surface dwelling larvae. Two hundred ewe equivalents per hectare were mob-stocked in late January for five days.

In the second trial, conducted in December 1969, and again located at Lincoln, a similar technique was used, except that 70 small cages (Plate 24) positioned randomly (Plate 25) were used as the control areas. A greater stocking rate of 300 ewes/ha was used. Soil surface moisture, soil surface temperature, rainfall, pasture cover and larval numbers were measured before, during and at the end of the trials.

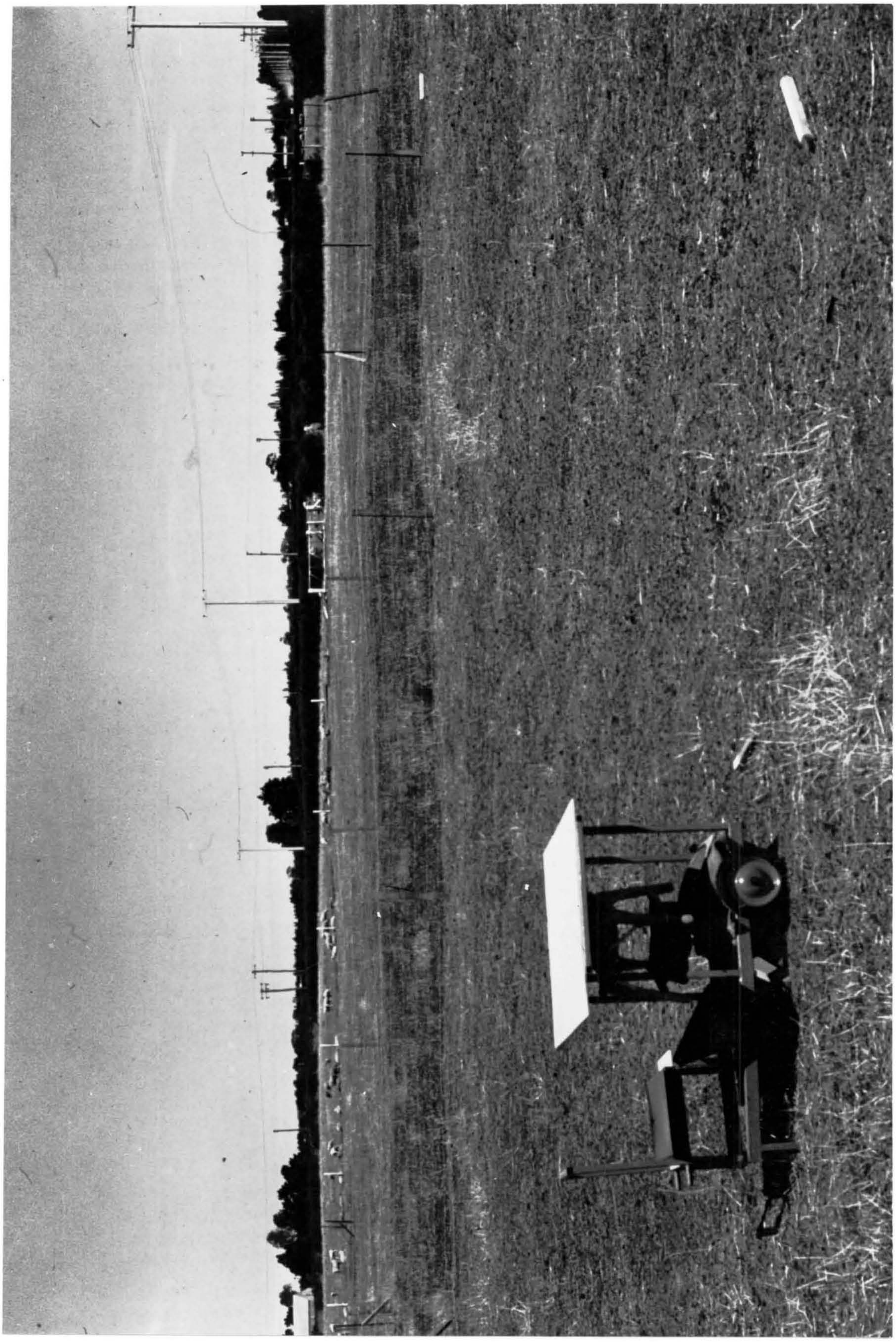

Plate 23 General view of the paddock used for the mob-stocking trial at Lincoln during 1969 showing the state of pasture after mob-stocking. The fenced control plot is in the centre background.

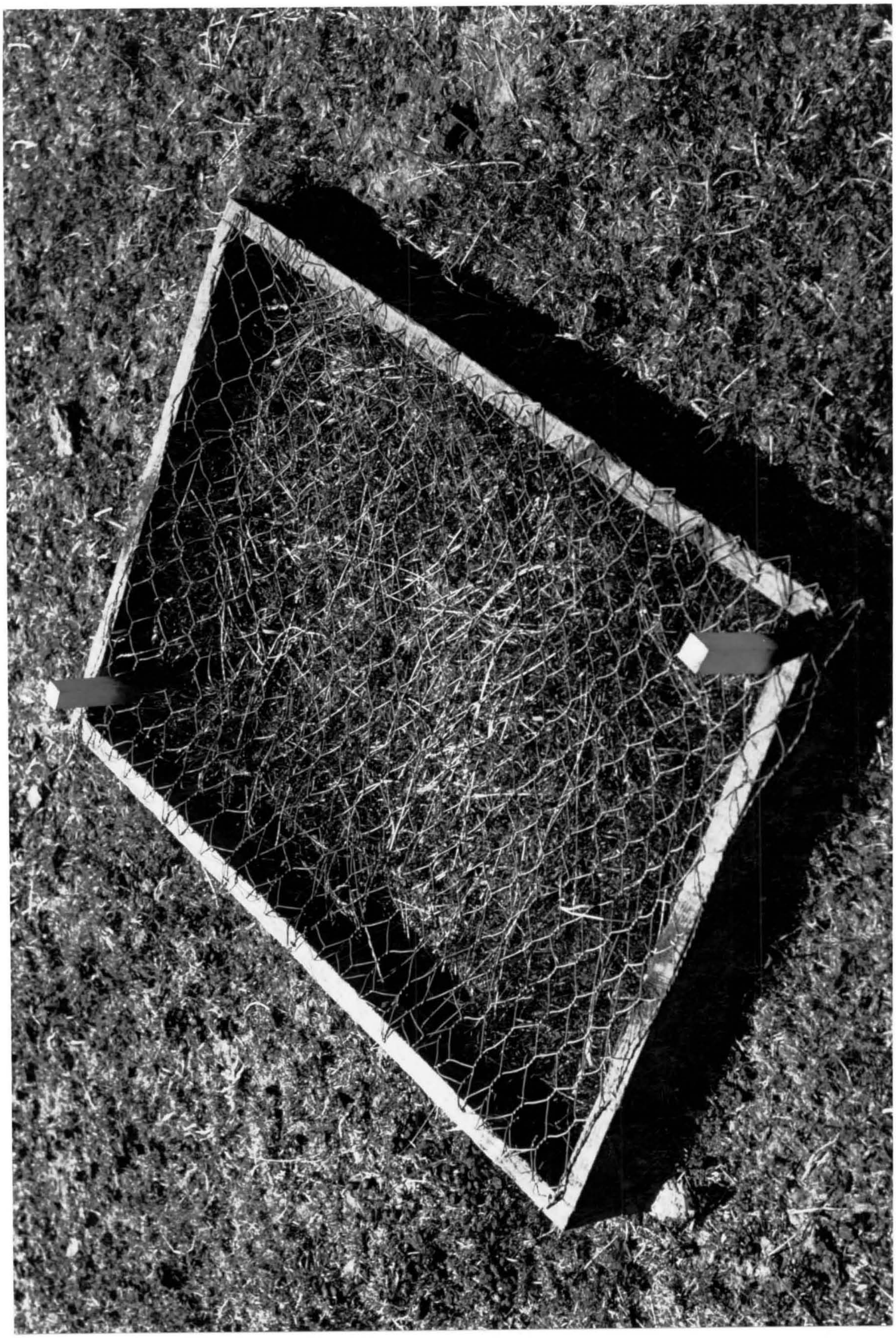

Plate 24 Control cages used for the mob-stocking trial carried out in 1969/70 at Lincoln.

Plate 25 Stock density and positioning of some control cages during the mob-stocking trial at Lincoln during 1969/70.

Table 43 A summary of the effect of differentially grazed areas of the one paddock

Paddock location	Treatment	Number of 15cm x 15cm spade square samples	Total no. of caterpillars	$\bar{x}/m^2$	
1. Methven	Relatively ungrazed during spring	243	183	32	difference 13**
	Grazed during spring	144	64	19	
2. Methven	Relatively ungrazed during spring	144	103	30	difference 9*
	Grazed during spring	144	73	21	
3. Darfield	Relatively ungrazed during spring	176	348	84	difference 27**
	Grazed during spring	168	224	56	

Key

* sig. at $P < .05$

** sig. at $P < .01$

Table 44 Results of mob-stocking trials with sheep carried out against surface dwelling larvae at Lincoln

Grazing Trial 1

Sample date	Sample no.	Sample size	$\bar{x} \pm$ 95% c.l.	$\bar{x}/m^2$
6/1/69	60	7.6 cm dia. core	3.15 ± .95	677
18/1/69	10	"	1.8 ± .52	387
27/1/69 Grazed	50	"	2.02 ± .62	434
27/1/69 Ungrazed	50	"	1.96 ± .58	422
30/1/69 Grazed	20	"	1.1 ± .69	236
30/1/69 Ungrazed	40	"	1.35 ± .63	290
3/2/69 Grazed	10	"	1.1 ± .84	236
3/2/69 Ungrazed	30	"	1.16 ± .42	249

contd.

Table 44 contd.

Grazing Trial 2

Sample date	Sample no.	Sample size	Total egg pop.	Total larval pop.	Total	$\bar{x} \pm$ 95% c.l.	$\bar{x}/m^2$
12/12/69	70	5.1 cm dia. core	136	14	150	2.10 ± 1.47	1019 ± 715
23/12/69 Grazed	59	5.1 cm dia. core	10	4	14	.339 ± .28	164 ± 136
23/12/69 Ungrazed	59	5.1 cm dia. core	26	32	58	1.085 ± .48	517 ± 232
14/5/69 Grazed	140	15 cm x 15 cm spade sq.	-	3	3		.84
14/5/69 Ungrazed	140	15 cm x 15 cm spade sq.	-	1	1		.32

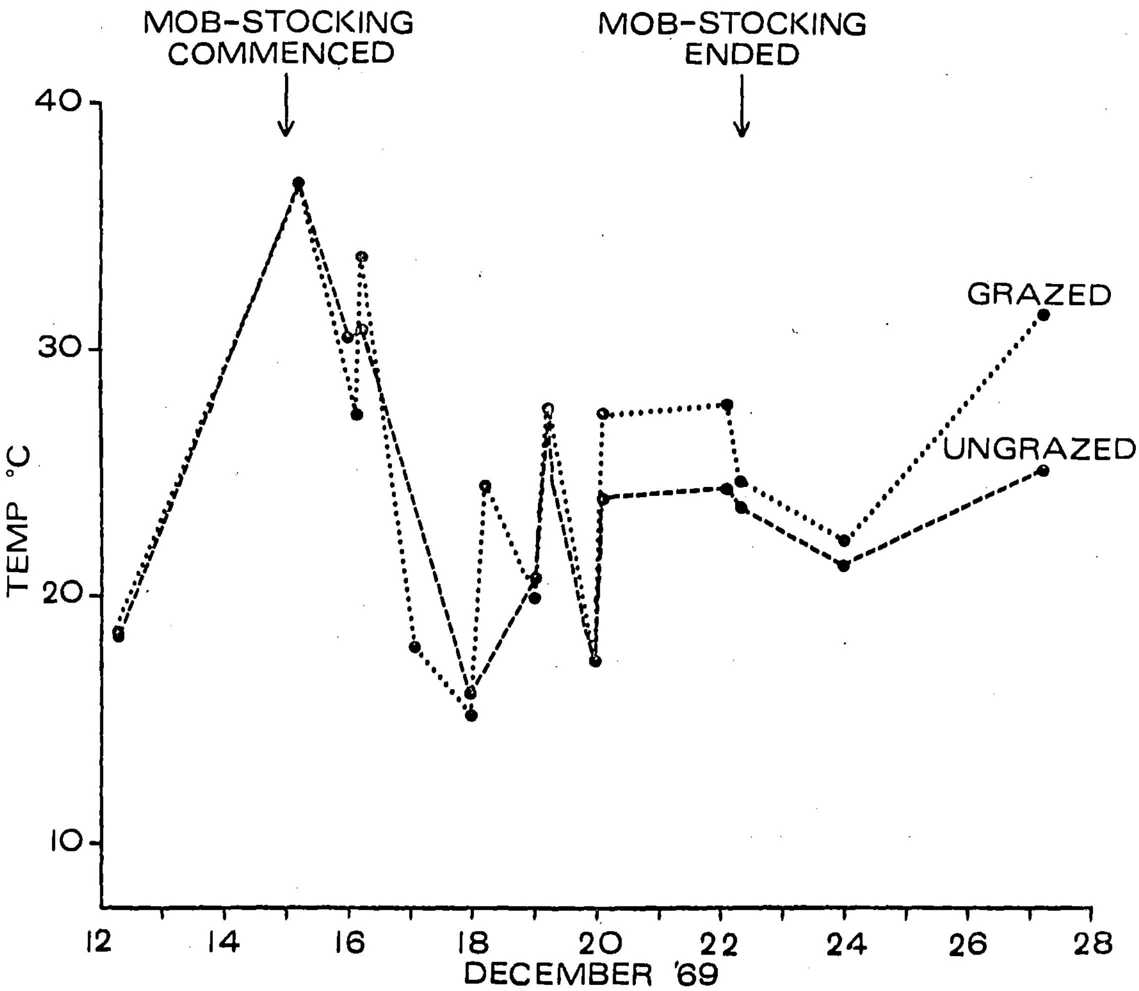

FIG. 66

Mean soil surface temperatures in the ungrazed and grazed plots during the 1969/70 mob-stocking trial at Lincoln.

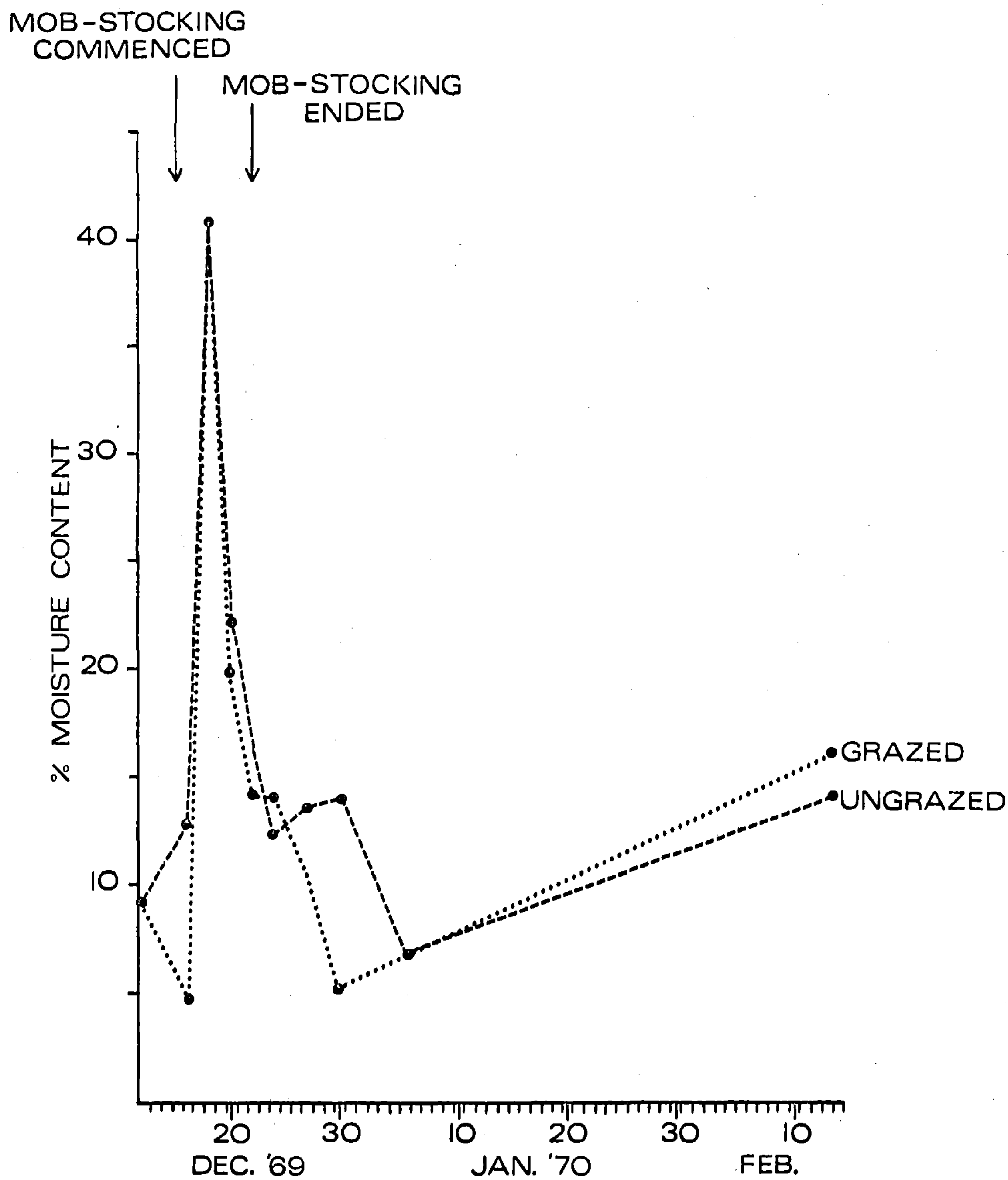

FIG. 67

Mean soil surface moisture in the ungrazed and grazed plots during the 1969/70 mob-stocking trial at Lincoln.

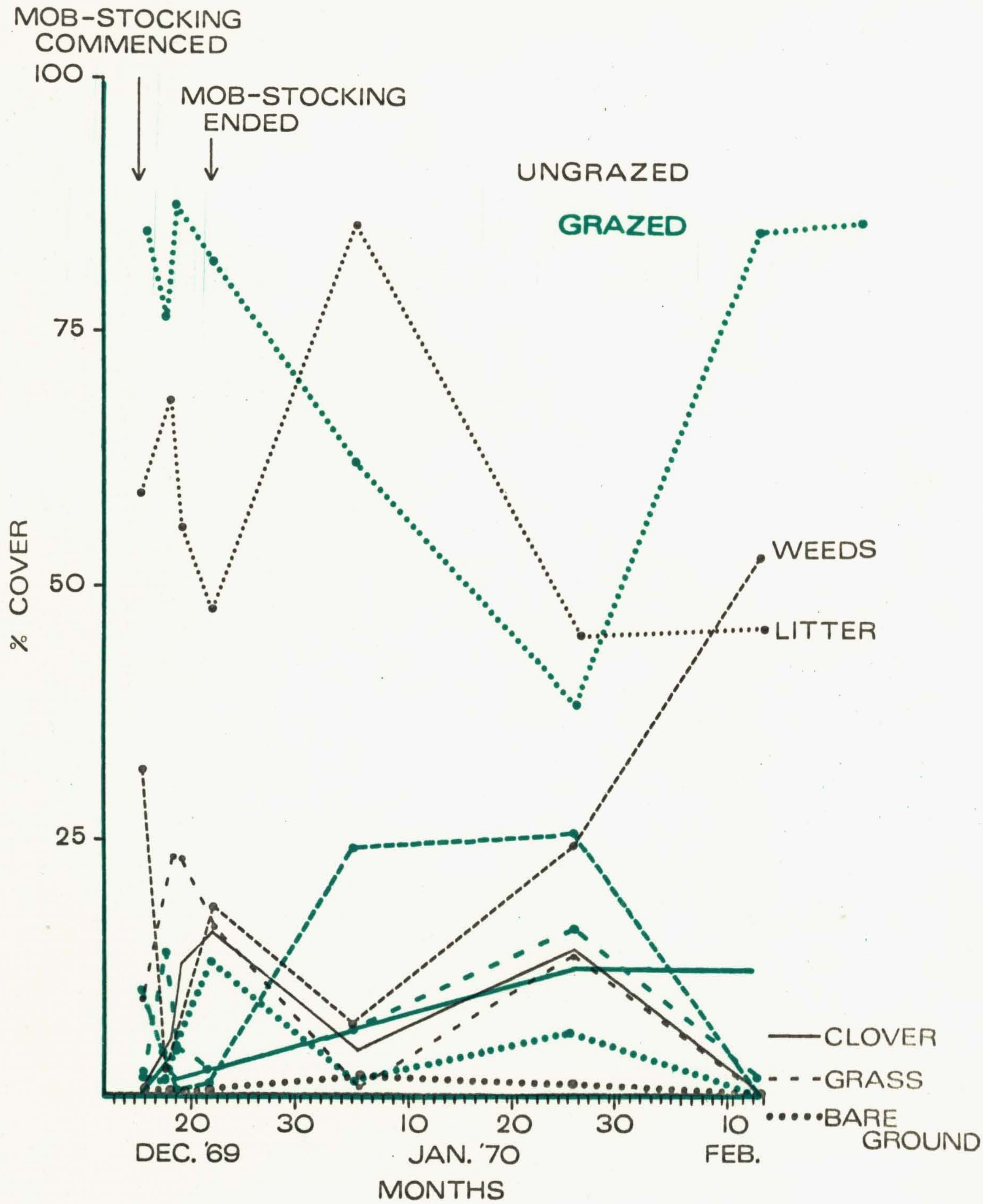

FIG. 68

The effect of mob-stocking on sward composition during the 1969/70 mob-stocking trial at Lincoln. The overlay shows the change in sward composition in the grazed plot.

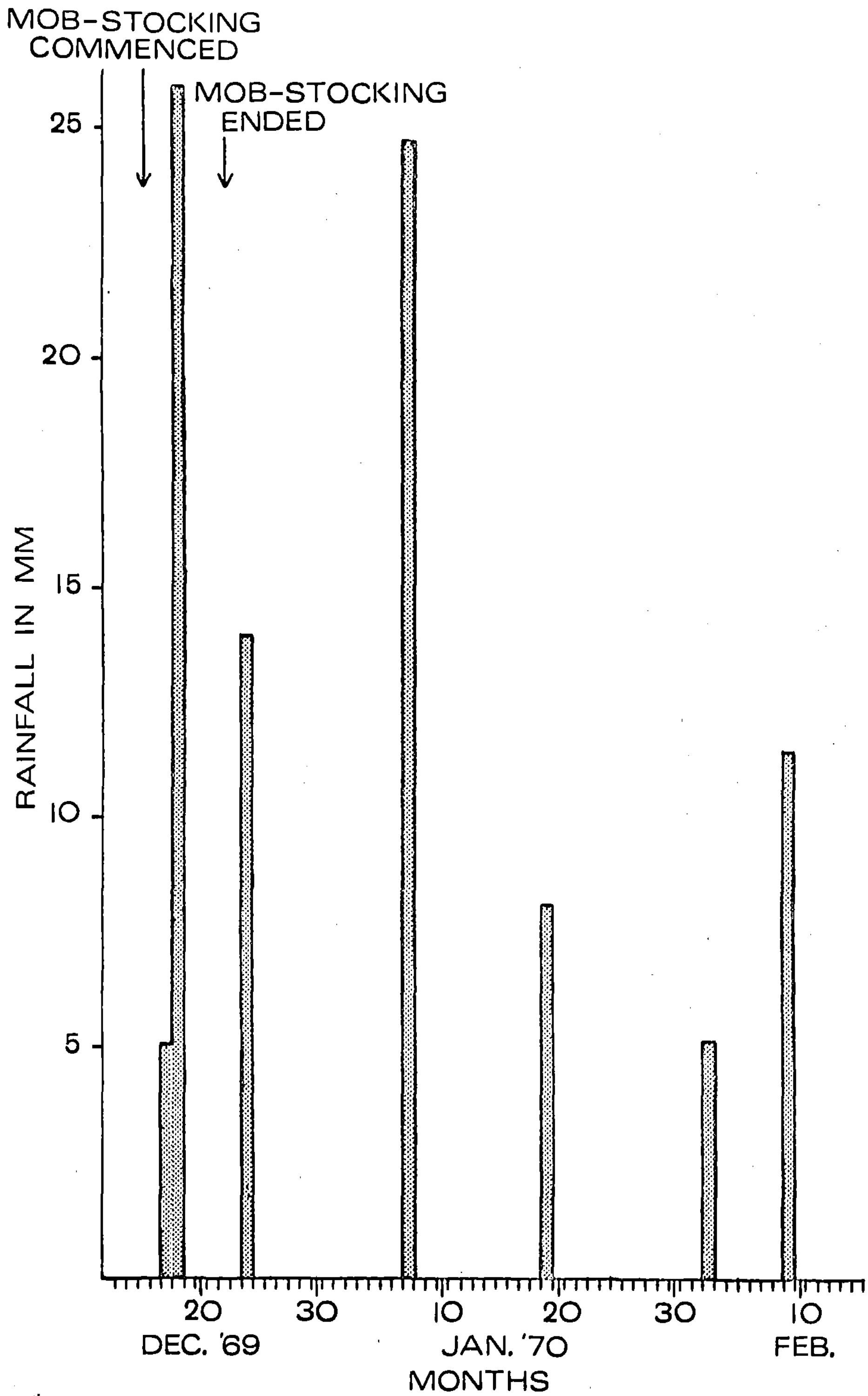

FIG. 69

Rainfall records taken during the mob-stocking trials at Lincoln 1969/70.

Further trials were planned, but drought conditions did not allow suitable sites to be found.

Results

The results of sampling larvae from each trial are given in Table 44. Figures 66 and 67 show the differences in soil surface temperature and soil surface moisture for the 1969-1970 trial only. Figure 68 shows the change in sward composition for both grazed and ungrazed areas in the 1969-1970 trial, while Figure 69 gives the rainfall measured during the trial period.

Discussion

It was obvious from the lack of success in the 1969 trial that mob-stocking was carried out too late (Table 44). It was realised later that most of the larvae would have formed tunnels prior to the stocking.

The second trial in late 1969 was more successful. Stocking began much earlier, i.e. on 15 December 1969. As expected, the pasture cover was rapidly depleted (Figure 68). This resulted in a rise in soil surface temperatures (Figure 66) and a decrease in soil surface moisture (Figure 67). The results were not as spectacular as expected, as rain fell during and after the mob-stocking (Figure 69). This temporarily equalised soil surface conditions in both the grazed and control areas. Nevertheless, differences in soil surface temperature and soil surface moisture were obvious and were of considerable magnitude on the following dates - 16.12.69 and 27.12.69 in Figure 66 and 16.12.69 and 29.12.69

in Figure 67. Overall, the grazed area was hotter and drier than the ungrazed, the differences varying according to rainfall and the type of day, viz. sunny, windy, cloudy or humid. Whether surface dwelling larval mortality was directly due to hot, dry, soil surface conditions or stock trampling could not be ascertained, but nevertheless, considerable larval mortality did occur (Table 44). Approximately 70 per cent surface dwelling larval mortality was achieved by mob-stocking. Dry conditions thereafter increased mortality to almost 100 per cent, as the grazed and ungrazed plots were sampled in May and produced only four larvae out of a total of 280 samples. This was from an original population of $1019/m^2$.

Information summarised in Table 43 and the results obtained from the mob-stocking trials showed conclusively that stock grazing management can reduce larval population levels.

Recommendations when using the mob-stocking technique

It was found not sufficient to merely keep pasture short during the whole of the porina juvenile stage using low numbers of ewes grazing on the pasture for long periods. Although this will cause some extra mortality, the larvae could compensate for slow changes in the microclimate by moving to more sheltered positions. Significant mortalities can only be achieved by a sudden change in a previously acceptable pasture microclimate. This places a sudden stress on the larvae, which appear unable to cope with it. Besides the immediate dessicating effect of a sudden microclimatic change, subsequent mortality can occur. Observations have indicated that after stress has occurred in a larval population, there is increased susceptibility to pathogens.

Mob-stocking should not be extended to the detriment of the pasture. This can only be judged by individual farmers, and will vary from pasture to pasture.

If drought conditions prevail after the treatment, some change in sward composition must be expected. Recent unpublished research has shown that high stocking rates normally used on pastures during summer reduces autumn and winter pasture yields. It would seem that heavy stocking is detrimental to pasture. However, good pasture recovery can be anticipated, given reasonable moisture, as the heavy application of urine and dung from mob-stocking helps to stimulate pasture growth.

When carrying out mob-stocking, large numbers of stock per hectare are essential. At least 250 ewe equivalents per hectare are required. It is not known whether heavy stocking with cattle would have a similar effect, although some larval mortality should occur.

The time to mob-stock is most important and will vary throughout New Zealand. The information given in Table 2 provides a guide. The earlier the treatment is carried out after the majority of larvae hatch, the better. Where mixed populations of late and early races co-exist, mob-stocking may be necessary twice. If "late" populations are present, mob-stocking would be more effective if delayed till autumn.

It is not known whether the technique would destroy porina eggs. Theoretically it should, considering the high soil surface temperature which can be achieved in summer after mob-stocking. If the results given in Figure 66 are compared with the data given in Figure 6, it will be seen that a lethal temperature could be reached. If eggs are susceptible to the mob-stocking treatment, more time would be available in which mob-stocking could be effectively carried out.

Flood irrigation

It had been observed that where flood irrigation was carried out during the summer porina caused negligible pasture damage (Lobb, 1970). The life table work at Winchmore indicated that in flood irrigated pasture, low surface dwelling larval counts were obtained, even after high egg counts. Fenemore *et al.* (1969) has supplied some quantitative evidence to show that *excess* moisture during the surface dwelling larval period can cause high mortality. Therefore, as an unproven recommendation, flood irrigation could be substituted for, or used with, mob-stocking. Observations suggest that spray irrigation does not adversely affect porina.

Control of porina in hay, grass seed and clover crops

Generally, these crops, because of their growth habit, provide a favourable environment for the egg and surface dwelling larval stages. If hay crops were shut up early, harvested before the end of December, and, if infested, mob-stocked immediately the hay was harvested, good control could be obtained. On the other hand, grass seed and clover crops are not harvested until January or February and larvae have often established themselves in tunnels by this time. If grass seed or clover crops are found to be infested insecticide should be applied immediately after harvest, if economic to do so. If a spray formulation is to be used it is important to remove as much pasture cover and litter as possible by grazing before the insecticide is applied. In Canterbury this is the only time that the use of insecticide is economic, provided conditions are moist enough to stimulate larval feeding, and larvae obtained maximum exposure to the insecticide.

If conditions are very dry, it is doubtful whether any insecticide will be effective. As an alternative to insecticide, mob-stocking can be carried out immediately after harvest, regardless of the time of year. Observations have shown that when there was plenty of cover, the surface dwelling larvae delayed tunnelling. Therefore, if mob-stocking was carried out immediately after harvesting, even late in January, good control could be achieved.

Finally, it is never certain that a damaging infestation will occur in hay and grass or clover seed crops. In very dry seasons even these crops fail to provide adequate shelter for the juvenile stages. If there was no infestation in the previous year, there is little chance of a severe infestation following unless seasonal flight conditions allow immigration.

Discussion on possible long term preventive control

There would be a possibility for long term control if a better understanding of the population dynamics of porina was obtained than this study allowed. Additional information on the long term national economic outlook would also be required to assess the economics of long term porina control. For example, the fact that wool and meat prices paid to the New Zealand farmer have doubled in 1972, means that the economic status of porina must have changed and no doubt will change in the future.

Essentially, long term control is aimed at manipulating a key mortality stage, where, if extra mortality occurs, a significant reduction in population density will result in the subsequent generations. For example, this study has indicated that the egg and surface dwelling larval instars are stages in which a key mortality or mortalities, operate. It has been shown how mob-stocking during this key age interval will reduce the risk of current damage. Furthermore, the analysis of life table results in Chapter 5 suggested that the use of the mob-stocking technique can also regulate the size of the population in at least the next generation. The life table results also suggested that additional pre-pupal, pupal or adult mortality could also affect future population densities. These age intervals, however, are not so easy to manipulate and the methods hypothesized and discussed below require demonstration and fuller understanding.

Manipulation of adult mortality

For long term population control the manipulation of adult mortality means either significantly decreasing fertility and/or fecundity, or preventing migration. Wind can significantly affect both fertility (by preventing mating) and moth migration (by preventing flying) but cannot be manipulated. Although prevention of moth migration appears impracticable, there is some observational evidence (page 82) to suggest that gorse hedges or shelter belts reduce the extent of moth dispersion from infested areas. This is probably due to the low-flying characteristics of female moths, particularly under windy conditions.

Biological control

Biological control has not been successful for porina, as pasture damage generally seemed to occur before natural enemies exerted an influence. Eyles (1965) on the other hand, has indicated that porina populations may be maintained at low densities provided there is a suitable environment to maintain a high density of biological control agents. He showed that low levels of porina existed in pasture close to scrub areas which harboured *Occisor versutus*, *Plagiomyia* sp and *Pterocormus lotatorius*. If a suitable environment for these biological control agents was developed in pasture monocultures, porina population densities may be kept within tolerable limits.

Other promising work is being carried out by Moore (1972) on nucleopolyhedral viruses. If these agents can be manipulated, long term porina control could result. Such hopes, however, were held for *Bacillus thuringensis* (Helson *et al.*, 1954) but were not upheld.

Winter irrigation

Observations have shown that when soil moisture levels in winter become greater than field capacity, larvae evacuated their tunnels. They were then exposed to bird predation. If bird numbers were high enough porina populations could be significantly reduced. This happened, for example, in the winter of 1967 when heavy winter rains flooded many infested paddocks.

Increasing soil moistures to above field capacity in winter can be done artificially on irrigated farms. Flooding in winter would also undoubtedly place a stress on surviving larvae, which probably helps to trigger epidemics of pathogens (see page 217). Latch (1965) has also indicated that a humid environment is required for an attack against porina by *M. anisopliae*.

Application of insecticide

Insecticidal control of porina may be justified if it could be used for long term protection and population control as a preventive measure. To achieve this objective, the insecticide would need to initially increase generation mortality past the population constant mortality. Such an effect by insecticidal use has not been proven. Predictive models which simulate the population dynamics of porina would be required before this type of control could be attempted.

Table 45 Summary of alternative methods for porina control

1. Take no action and rely on management and pasture vigour in spring to repair damage.

2. Reduce stock rations to cause a pre-determined weight loss and consequently conserve pasture for feeding out later.

3. Use infested pasture as an early "run-off" paddock. Mob-stock for a period and, if required, feed minimal amounts of hay. Oversow in spring if necessary.

4. Cultivate infested pasture and sow Tama ryegrass in March. Apply nitrogenous fertiliser after seedlings appear.

5. Oversow Tama ryegrass into the sward in March after a period of heavy mob-stocking. Later apply nitrogenous fertiliser.

6. Restore pasture after damage by oversowing 30 kg/ha of ryegrass plus 125 kg/ha of superphosphate in spring.

7.

   a. Mob-stock approximately 250 ewes/ha for a short period during the surface dwelling larval stage.

   b. Flood irrigate during the surface dwelling larval stage.

   c. If excess spring growth occurs harvest hay or silage early and then mob-stock.

8. For control of porina in hay, grass seed and clover crops

   a. Take no action if drought conditions occur prior to or after harvesting.

   b. Mob-stock as soon as crop is removed. Early harvesting would make this treatment more effective.

contd.

Table 45 contd.

c. Apply insecticide only if required, immediately after harvest and larval sampling, but only under favourable conditions.

To date, realistic predictive models have not been demonstrated for any pest although Hughes (1968) has developed a population model for *Brevicoryne brassicae* which indicates that realistic models can be developed in time.

CONCLUSIONS

1. As porina damage has little, if any, real effect on farm production the use of insecticides in most cases is uneconomic.

2. To reduce the effects of porina damage, it is more economic to use one or more of the alternatives summarised in Table 45. An important advantage is that most of the alternative control measures result in *extra* pasture production, whereas insecticides only protect existing pasture and do not produce extra growth.

3. Mob-stocking of infested pasture in spring or early summer is the most practical and effective of the preventive control measures.

4. Long term control measures may be successful when more information is accumulated, to fully understand the causal relationships influencing porina population fluctuations.

FINAL CONCLUSIONS

Research philosophy

1. With few exceptions, previous studies in New Zealand on pasture insect pest ecology have been inadequate. No study has been based on an understanding of population dynamics, and control strategies have relied upon the curative or preventive use of insecticides.

2. Pasture insect pest problems in New Zealand will not be solved by entomologists alone, because of the interaction of pest control procedures with other agricultural disciplines such as agronomy, soil fertility biometry, economics and farm management. Economic entomologists must view pasture insect pests as just one of many disruptive factors in the farm agroecosystem. This concept necessitates a broad entomological outlook in order to find an agriculturally meaningful solution to the pests concerned. This thesis was designed around this concept.

3. As a broad and practical, yet quantitative, approach to pasture pest problems, the study of insect population dynamics and the development of modified life tables

should be mandatory. This approach helps focus attention on the environmental parameters affecting insect populations.

4. Regardless of the lack of practical application, future research on the prediction of porina damage and development of more sophisticated controls, lies in the development of predictive mathematical and simulation models.

5. This preliminary study has shown that the rapid development of practical control procedures based on the understanding of an insect pest's population dynamics is possible with limited manpower and research funds.

<u>Ecological</u>

1. Natural populations of porina characteristically experience high levels of mortality within a generation. Wide fluctuations in population density also occur between generations.

2. Within a generation, high mortality normally occurs in the early surface dwelling larval stage. This, plus added mortality, will periodically depress future generation levels. Relatively high mortality during the later age intervals, especially adult, may have the same effect.

3. Egg population density in a subsequent generation can increase markedly by up to several thousandfold, due to the high fecundity of porina and the influence of wind on dispersal. On the other hand, randomly occurring unfavourable weather during the flight period and the juvenile stages, can catastrophically decrease the population levels of subsequent age intervals.

4. With such wide fluctuations between generations, it is possible within two generations for an economic damaging population to build up from a previous, very low unmeasurable one.

5. It was concluded that a 10 per cent standard error of the mean was impracticable and unnecessary for a preliminary study of porina population dynamics. A standard error of the mean between 15 and 20 per cent was found acceptable.

6. A statistical relationship was found between an index consisting of potential evaporation (measured at the soil surface) minus rainfall, and autumn subterranean larval population densities. This index, used in conjunction with light trap and soil type information, and a knowledge of age interval population mortality as revealed by life tables, will give some idea of when pasture damage is likely to appear. In addition an approximate estimate of the density of the population responsible for the damage can be calculated.

7. The distribution pattern of autumn subterranean larval populations can be adequately described by a negative binomial model. A simplified sampling system was developed from these results, which will assist the large scale assessment of porina damaged areas. This has been published by French (1969).

8. Food consumption of larval populations was found to be less than was originally estimated. It was estimated to be .3 g D.M./day/hectare/10 porina/m^2.

9. The rate of larval food consumption varies considerably each night. There may also be a significant variation in food consumption between larval generations.

10. A significant proportion of the larval population normally do not feed for periods ranging from two to fourteen days. It is therefore impossible to achieve more than 70-80 per cent mortality with insecticide, even when used under ideal conditions.

11. Environmental factors such as rainfall, can significantly affect the amount of food consumed by subterranean larvae.

Economic

1. The damage attributed to the depredations of porina larvae has been overrated. In most cases pasture damage caused by porina has little, if any, direct effect on stock carrying capacity.

2. Porina damage must be thought of as merely another farming cost, among others, all of which must be minimized to achieve maximum production.

3. Porina will never be eradicated in New Zealand, and regardless of current control measures, will always cause some damage to pastures.

4. To minimize the effects of porina damage, it is generally more economic to use compensatory techniques, aimed at increasing pasture production, particularly short term winter production, rather than rely on inefficient protection of existing pasture, with insecticide.

5. It is preferable to prevent porina infestations, or have an early preventive approach to control, than be forced to later compensate for damage. A preventive technique developed in this study is to use heavy mob-stocking with sheep in a rotational grazing system. Prevention of damage can also be achieved by generally controlling pasture growth, in particular, spring growth.

6. It was concluded that the higher the stocking rate, the less chance there is of porina infestations causing damage. This belies the belief that at higher overall stocking rates porina damage will have a more adverse effect on farm profitability.

SUMMARY

Prior to a critical review of literature of the research previously carried out on porina ecology, the approach and tactics used for this thesis were outlined.

The approach adopted was a broadly based quantitative ecological study of porina population dynamics.

The tactics involved firstly, quantifying some behavioural aspects of the insect, especially those thought at the time to be of some importance for later life table studies. These included flight behaviour, oviposition, fecundity and the physical ecology of the egg and surface dwelling larval stages.

This was followed by the development of sampling techniques for the main age intervals of the life cycle. The distribution patterns of autumn subterranean larval populations were also studied. The negative binomial model was found to adequately describe the distribution pattern for this age interval.

Life table experiments were set up in three geographically different areas and after sampling up to four generations, the results were analysed, using Varley and Gradwell's, and Watt's methods. Both analyses highlighted the significance of surface dwelling larval and adult mortality.

The factors thought responsible for surface dwelling larval mortality were studied in detail, with the aim of developing predictive models and ascertaining the possible use of the mortality factors as an economic means of control.

A mortality factor index consisting of potential evaporation minus rainfall was developed which, when used with other information such as soil type, assisted in the prediction of porina damage. There was insufficient data to allow confident prediction of population densities, although this could be calculated approximately using the results from previous life table work. The usefulness of predictive models was then questioned in the light of inadequate meteorological forecasting.

Following a detailed study of the larval food consumption and feeding behaviour of the subterranean larval stages, an economic assessment of porina damage was carried out. The importance attached to the damage caused by this insect was critically discussed. It was concluded that porina damage had no real effect on the successful over-wintering of stock.

Finally, alternative means of control to insecticide use were discussed. These were aimed at minimizing the effects of porina damage by maximizing pasture production elsewhere on the farm, or preventing porina infestation and damage from actually occurring. A preventive technique was developed. It consisted of causing high mortality in surface dwelling larval populations by heavy mob-stocking of sheep in a rotational system.

It was concluded that porina damage was a much overrated problem and that the solving of pasture pest problems in New Zealand is not possible by economic entomologists alone. Pasture pest problems require the application of information from other scientific disciplines, such as agronomy, soil fertility biometry, economics and farm management, all aimed at increasing pasture production and stock carrying capacity, at minimal cost.

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