THE BIOLOGY, DISTRIBUTION AND CONTROL OF ANTS IN HAWAIIAN PINEAPPLE FIELDS

By

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Summary

The dominant ant in the Hawaiian Islands is *Pheidole megacephala*: it is gradually driving the other species out of all except the driest areas. The fire ant, *Solenopsis geminata* race *rufa* is the second most important species in pineapple plantations on Oahu but it does not occur in those of the other islands. The workers of both ants have a life cycle of about two months. There are three other ants of minor importance, the sugar ant *Plagiolepis mactavishi* and the crazy ants *Prenolepis longicornis* and *P. bourbonica* var. *hawaiiensis*. *Tapinoma melanocephalum* is the only other ant consistently fostering mealy bugs in pineapple fields, but it is not often found there. Other minor species occur but are of no economic importance.

The distribution of ants in these islands depends upon rainfall and to a lesser extent upon temperature; elevation is a very minor factor. In most of the pineapple growing areas, *Pheidole* is the dominant ant; in very dry areas, a number of other species are found.

Ants are beneficial in that they form a very effective check on noxious insects; their control of house flies is proved by experiment. On the other hand, they also destroy many useful insects and do a considerable amount of damage to plants; this damage is partly direct but mainly indirect. By far the worst way in which ants harm vegetation

is by their habit of fostering plant-sucking insects.

The control of ants in pineapple fields is exercised in a number of ways. The species are controlled in their distribution by factors of temperature and humidity; experiments are given showing the different requirements of the two chief species in this respect. Heavy winter rains are the chief checks on ants in Hawaii and take a heavy toll.

Biological control is exercised interspecifically, but ants have no other animal enemies of any significance in these islands.

In the pineapple fields, attempts are made to control ants by various methods. Poison baits and soil fumigation are the most effective ways of dealing with Solenopsis, while ploughing and ant fences are used with moderate success in the fight against Pheidole. The use of poisons and repellent, odoriferous substances against the latter species have not proved effective.

Edge infestation and the advance into fields by ants, as well as their relations with mealy bugs, are discussed.

The paper contains an extensive bibliography and a new key to the species of ants in Hawaii.

CLASSIFICATION:

Representatives of five of the seven sub-families into which the ants are classified by Wheeler (437)--which classification is the one accepted by Brues and Melander in their recent Classification of Insects (438)--are found in these islands.

The distribution is as follows:

Sub-family	DORYLINAE	....	Unrepresented
"	CERAPACHYINAE	....	1 genus; 1 species
"	PONERINAE	....	2 genera; 4 species
"	PSEUDOMYRMINAE	....	Unrepresented
"	MYRMICINAE	....	7 genera; 16 species
"	DOLICHODERINAE	....	2 genera; 2 species
"	FORMICINAE (CAMPONOTINAE)	....	3 genera; 5 species

Of these, only the Ponera species may be considered as doubtfully endemic; the rest are all immigrant cosmopolitan ants.

Some twenty years ago, Miss Gulick (204) compiled a key to local species. Since then, seven more species have been found and two included in her key have never become established. Some of the key distinctions are misleading owing to later additions; for instance, to separate Cardiocondyla from Tetramorium, a size distinction was made which would lead one to identify two species of the latter genus, discovered here after the key was made, as Cardiocondyla, whereas, the hairiness or otherwise of the abdomen is a far safer means of separating the two genera. For these reasons, it was decided to compile a new key and to present it in a form more in accordance with modern practice.

KEY:

Key to Species of Ants in the Hawaiian Islands

1 A marked constriction between the first and second segments of the gaster ... Sub-family PONERINAE 2
(including CERAPACHYINAE)

No such constriction 6

2 (1) Workers about 7 to 8 mm. long .... Leptogenys falcigera Roger var. insularis Smith
Workers about 2 to 3 mm. long 3

3 (2) Antennae nine-jointed; eyes absent ... Cerapachys sylvestrii Wheeler
Antennae twelve-jointed; eyes present 4

4 (3) Light testaceous yellow ... Ponera gleadowii Forel race decipiens Forel
Dark brown or reddish 5

5 (4) Head shiny .... Ponera kalakaua Forel
Head dull .... Ponera perkinsi Forel

6 (1) Pedicel 2-segmented ... Sub-family MYRMICINAE 7
Pedicel 1-segmented 21

7 (6) Antennae 4-jointed ..... Epitritus wheeleri Donisthorpe
Antennae 6-jointed ..... Strumigenys lewisi Cameron
Antennae 10 or 12-jointed 8

8 (7) Antennae 10-jointed; workers sting ...Solenopsis geminata Fabr. race rufa Jerdon
Antennae 12-jointed; workers do not sting 9

9 (8) Metanotum without spines 10
Metanotum with conspicuous spines 16

10 (9) Head and thorax dull and minutely roughened; insect pale yellow, posterior of gaster somewhat darker .... Monomorium pharaonis (L.)
Head and thorax shiny 11

11 (10) Entire insect very dark brown ... Monomorium minutum Mayr var. liliuokalani Forel
Not as above 12

12 (11) With deep meso-metanotal hollow, sloping steeply, constricting the thorax; metanotum subcubical, rectangular at base .... Monomorium gracillimum Smith
Not as above 13

13 (12) Nodes of pedicel much broader than they are long ...... Monomorium latinode Mayr
Nodes of pedicel narrower than they are long 14

14 (13) Entire insect dingy yellow or light brown; metanotum denticulated and with a median groove ... Monomorium fossulatum Emery var. seychellense Emery
Not as above 15

15 (14) Posterior of gaster dark brown; remainder of body yellowish brown ... Monomorium destructor Jerdon
Head, gaster and antennal clubs dark brown; thorax and petiole light brown ... Monomorium floricola Jerdon

16 (9) Neuter forms dimorphic; occiput smooth ... Pheidole megacephala (Fabr.)
Neuter forms monomorphic; occiput rugulose 17

17 (16) Abdomen smooth 18
Abdomen hairy 19

18 (17) Dark brown ..... Cardiocondyla nuda Mayr var. minutior Forel
Light brown ... Caridocondyla wroughtoni Forel var. hawaiiensis Forel

19 (17) Workers more than 3 mm. long; head reticulated .... Tetramorium guineense (Fabr.)
Workers less than 3 mm. long; head striated 20

20 (19) Thorax striated; gaster dark ... Tetramorium simillimum (Smith)
Thorax reticulated; whole insect light brown .... Tetramorium tonganum Mayr

21 (6) Anal orifice slit-shaped, unciliated ... Sub-family DOLICHODERINAE 22
Anal orifice terminal, circular, surrounded by a fringe of hairs ... Sub-family FORMICINAE 23

22 (21) Head black; body light coloured;
anal orifice apical ... _Tapinoma melanocephalum_ Fabr.
Body black; tarsi whitish;
anal orifice inferior ... _Technomyrmex albipes_ (Smith)

23 (21) Workers 7 mm. long or more ... _Camponotus maculatus_ (Fabr.)
race _mitis_ Sm. var. _hawaiiensis_ Forel
Workers under 5 mm. 24

24 (23) Yellow; workers less than 2 mm. long ....
Plagiolepis mactavishi Wheeler
Brown or black; workers at least 2 mm. long 25

25 (24) Scape more than half antennal length ....
Prenolepis longicornis Latr.
Scape less than half antennal length 26

26 (25) Entire body very dark brown .. _Prenolepis bourbonica_ Forel
var. _hawaiiensis_ Forel
Head and thorax light brown .. _Prenolepis sharpii_ Forel

The following notes on species were written solely with regard to their bearing on the pineapple industry in the Hawaiian Islands.

On this account Pheidole, by far the most important ant, is discussed at greater length than the others; Solenopsis, second in importance, is dealt with rather less fully, while Prenolepis and Plagiolepis, both very minor economic factors, occupy proportionately less attention. The other species, which as far as we know are insignificant economically, receive only cursory consideration.

All these ants are well-known, cosmopolitan species. They have been figured and described, some of them several times, by a number of writers. For instance, a description with illustrations of Pheidole megacephala, with some account of its habits and life history in Madeira, was published by Heer as far back as 1852 under the name Oecophthera pusilla, and it was reported on, under various names, as early as the eighteenth century. Similarly, Solenopsis geminata is recorded under the name Atta geminata by Fabricius in 1804; it has been described a number of times since. Accordingly, it seems unnecessary to describe these species here and I have therefore confined myself to such details of their life history as may be considered to be affected by the environment, such as the duration of the different stages in the life-cycles of these species, their local habits and similar matters.

The exceptionally equable climate, which implies an active and almost uniform development throughout the year, the remarkable absence of ant predators and the abundant food supply at all seasons, together with the somewhat specialized conditions under which pineapples are grown--all these factors combine to modify the life and habits of so adaptable and plastic an insect as the ant and to make the problems of its control in Hawaii somewhat different from similar problems in other countries.

The chief method used for the study of life histories was to enclose a small colony in an artificial nest. Such a precedure may seem simple but actually it required a vast expenditure of time and trouble before the matter was satisfactorily adjusted.

Ingenious, home-made appliances of plaster of Paris and other substances, as suggested by Janet, Forel and Wheeler, proved quite useless as a prison for Pheidole, though doubtless serviceable for the study of many other species; in fact, later experiments showed that some of the other ants, occurring locally, could be confined with comparative ease.

Barriers of liquid or of repellent substances were crossed by Pheidole without serious difficulty. Newell and Barber (285) experienced similar difficulties in their investigations on the life history of the Argentine ant; they finally succeeded by establishing a barrier of running water; reasons of economy and lack of space precluded the use of some similar device here. Finally an artificial nest was purchased from a firm specializing in such apparatus and after certain alterations were made in order to provide further ventilation and moisture, it was found to meet the purpose. A local carpenter made a number of copies of this nest but they were found to be useless for Pheidole though adequate for other ants. It is essential to have close fitting glass plates and timber that will not warp and has no cracks; otherwise Pheidole will escape with ease.

Later it was found that a glass jar, floored with sand and provided with food and tubes containing water, made a quite satisfactory nest for Pheidole. These jars were secured at the top with muslin, cheesecloth or bolting silk fastened with a rubber band; in the case of Solenopsis, this proved to be inadequate, as the ants were able to bite through the strongest cloth; so a wire mesh had to be used.

PHEIDOLE MEGACEPHALA (FABR.)

Just as men of many different nations have flocked in their thousands to these islands, letting loose economic and political forces, which have forced the original inhabitants to relinquish all but a small fraction of their original patrimony, even so have the cosmopolitan ants invaded Hawaii and driven the unfortunate, indigenous species before them to live as best they may in odd nooks and crannies.

And of all these invaders, the undisputed master is *Pheidole megacephala*. In countless hordes, it wages incessant warfare on all the other insects and has exercised a profound influence on the local flora and fauna. Only in the driest coastal districts and in the more mountainous, afforested areas is its influence unfelt.

In the inhabited settlements, it is rather more beneficial than otherwise, acting as a scavenger and destroyer of household pests, especially of flies. On the other hand, it may be somewhat of a nuisance in the larder, but these depredations can be easily checked by counter-measures. It is only in the sphere of agricultural operations, the chief business concern of these islands, that its activities become a matter of serious consequence.

Like all other ants, *Pheidole* is a social insect of great adaptability and lives in well organized colonies, containing specialized individuals belonging to a number of castes.

The Castes:

Many years ago, Heer (278) described the different castes of this species in great detail taxonomically, so that it would be unnecessary to do so here. I append some particulars of the role of these castes as they affect nest-life in these islands.

(a). The Queens:

There are usually several queens in an average sized nest; in one, considerably larger than the average, I found between thirty and forty; doubtless, there were even more, for they show strong negative phototropism and scuttle under cover as quickly as possible; they are found in the moister parts of the nest and, under mulching paper and litter, this is often at or near the top, where moisture has condensed. There is a greater disparity in size between the queens and other castes of this species than there is in any other found here. A young queen has a shiny appearance and a firm abdomen, whereas an old one looks duller and the abdomen is somewhat shrunken.

Mating flights have been seen and, in some cases recorded, by a number of observers--Gifford (216), Ehrhorn (219), Fullaway (221) Illingworth, Swezey, Craddock and Solander among others. These observations had a number of points in common; the observers are agreed that the flights occurred early in the morning, usually between 5:15 and 7:00 A.M. and that they were almost invariably made after a heavy rain; the seasons reported varied from September to March, about Christmas to New Year appearing to be the most frequent time. Perhaps details of the swarms observed might be of interest:

Observer	Time		Locality
Illingworth	Early morning, Nov. 15th.		Kaimuki
Swezey	" "	?	Manoa Valley
Solander	5:15 A.M.	Jan. 4th.	Fort Ruger, Kaimuki
Gifford	6:30 A.M.	October	Keeaumoku St., Honolulu
Ehrhorn	-	Winter	Honolulu
Fullaway		About Xmas	Kohala, Hawaii
Craddock	ca, 7:00 A.M.	Jan. 3rd.	Waipio
Craddock	-	Mid-Sept.	Waipio
Nichol		? October	Wahiawa area

The swarm reported by Gifford (216) was recorded as about four feet wide and forty or fifty feet long. Swezey stated that the swarm he had observed in Manoa Valley were attended by mynah birds, which fed on them; Craddock has seen dragonflies hawking a similar flight. Ehrhorn (219) makes an interesting observation stating that the winged ants were immediately captured on alighting by workers and soldiers. This is an important point; from the results of experiments detailed later, it seems exceedingly unlikely that a Pheidole queen can start a colony on her own and were a part of such a swarm to alight in a locality devoid of worker ants--such as an ant-fenced pineapple field--there seems every reason to believe that they could not survive, so that there is no danger of nests being established within protected fields in this manner.

Although these swarms are known to occur at times, this is not the normal way Pheidole establishes a new nest. Usually, when a nest grows large, a part of the colony moves out as a complete entity--queens, soldiers, workers and immature stages--and establishes another nest nearby; thus, there is a constantly ramifying network of small or moderate-sized Pheidole nests and this is well shown under the mulching paper in pineapple fields, where nests are often found under every other plant or perhaps every three or four plants. This means that Pheidole is rapidly dispersed over an area in small, closely-connected concentrations. That nests are formed in this way is proved firstly by examining a pineapple field every few months and watching the growth of nests under the mulching paper, secondly because the new nest may be observed occasionally on the march moving to its new home and thirdly and perhaps most convincingly by the fact that small nests, complete with all immature as well as mature forms can sometimes be found in month-old fields. As the field has always been ploughed up just prior to planting and as the pupae must be more than a month old, it follows that they must have been moved in as eggs, larvae or pupae from an old nest and that it could not have been a case of a female alighting after a mating flight and founding a new nest with a number of workers.

Virgin queens are found in nests in larger numbers than the fertilized females; like the latter, they are negatively phototropic and positively thigomotropic.

(b). The Males:

The males are also usually found at the top of a nest, often clustering together; they seem to be singularly useless and helpless; occasionally a feeble specimen is found in the open, some distance from his nest, The only function of this caste appears to be to fertilize the female. In many countries, the winged forms---especially the males--- are only found at a certain season; but here, they seem to occur all the year round.

The immature forms of males and females are not found in small nests; only when a nest is strong and well-established are these forms found.

(c). The Soldiers:

The large-headed soldiers, which give Pheidole its specific name, form perhaps the most noticeable feature of a colony. That they are not strictly necessary to its existence is shown by the fact that they do not occur in some of the smaller nests and, in fact, I have been able to establish small, artificial colonies of a hundred individuals or less equally well with as without this caste. Like most specialists, they are a convenience to a large community but can be dispensed with in a small one. Wheeler (354) observes that the workers of a related species, Pheidole militicidae regularly kill and eat all the large-headed soldiers in the winter, when the food supply is limited. In some of my small colonies, I have known workers to kill the soldiers but not to eat them.

The term 'soldier' is rather a misnomer. It is true that their powerful mandibles are extremely useful in severing the joints of an opponent, but in fights they are more inclined to wait till the workers have grappled with the enemy and seized its limbs and then to come along and cut them off than to close with the foe on their own account, though on occasion they will do so. Wheeler, indeed, goes so far as to call the Pheidole soldiers cowardly and not inclined to fight (443) and states that they prepare food so that it may be carried home. Buckingham (303) considers that their function is for defense and for carving up food; this author, however, while admitting that the workers do more than the soldiers, has observed the latter digging and carrying earth as well as larvae. This is so here; the ant castes do not seem to have 'trade union rules'; soldiers are often seen pottering about, moving along a line of workers in a loafing or supervisory capacity, often waving their mandibles menacingly; if the nest is disturbed by a manhandled trowel, they will actually swarm over one's hand and nip the tender skin between the fingers, but they may also be seen cutting up dead insects and they will pick up and carry eggs, larvae and pupae when the nest is wrecked or menaced.

(d). The Workers:

These are the smallest forms in the nest but comprise the most of its population. They vary slightly in size inter se as do indeed the soldiers, but not very greatly and far less so than those of Solenopsis.

A peculiar characteristic is the variation in color shown by different colonies. Of course, newly-hatched forms are always lighter and there are differences in lustre probably due to whether the ant has been recently cleaned or not, but the color variation mentioned above is a different matter--some colonies containing ants almost jet black, other dark brown while, in certain cases, the inhabitants of a nest have a pronounced greenish tinge.

The functions of the worker are all embracing; it performs all the work of the nest and has even been known to oviposit on occasion. It attacks and carries home prey, constructs covered runways and excavates galleries and cleans, feeds and moves all the other castes and immature forms. Like the soldier, it is always apterous. Whether certain individuals habitually perform specified duties, even in the larger colonies, is very doubtful. Apart from the fact that the callows specialize in the care of the young, particular workers probably participate in all kinds of work; they certainly do so in small nests. In connection with this, it may be mentioned that Wheeler (273), Lubbock (445) and Viehmeyer (446) have found adult workers of certain species performing a single duty in the colony for long periods of time, if not indefinitely.

The workers, too, are responsible for nest construction and will make use of any environment that may suit them. I have found their nests under stones, mulching paper, litter, manure piles decayed stumps and rotting vegetation, in holes in trees, behind the leaf-bases of coconuts, in dead stems of sugar cane and horseweed, behind woodwork in houses and even in an electric light wall-socket.

Their attitude to other ants has been described elsewhere in this paper; towards ants of other colonies belonging to their species, it seems to vary greatly from deadly antipathy through indifference to acquiescent tolerance and adoption; this holds true for their treatment of queens as well.

The Immature Stages:

(a). The Egg:

The new-laid egg is an ovoid, pearly white object, about .20 mm. long by .14 mm. wide; its surface is covered with an adhesive, mucilaginous coat. For this reason, eggs adhere together in masses and are so handled by the ants; they will stick to any surface. The eggs as well as the larvae and pupae are constantly being moved, probably to secure the optimum conditions of temperature and humidity. As it ages, the egg becomes more opaque.

(b). The Larva:

The larva is a white, legless grub, slightly curved and with the head curved forwards; it is helpless and almost incapable of motion except for its mandibles, which are armed with two denticulate teeth. The alimentary system is closed and there is a meconium, which is voided at the end of the larval life. The body is covered with fine, bifid hairs, slightly recurved at the tip and also with what appear to be globules of a waxy secretion. The hairs are of two kinds--firstly fine, short, curved ones, arising in pairs from a common pit and these are found all over the body; secondly another thicker and more flexible kind, about three times as long, ending distally in a bifid hook, the recurved points of which branch in opposite directions and are armed with minute bristles. These latter hairs are relatively few in number and are placed dorsally: they look just like cables with anchors attached and presumably have some such function, whereas the smaller hairs probably act as springs, protecting the body when it is being moved about, as is constantly the case. These peculiar anchor hairs seem a Pheidole characteristic. Wheeler (273) figures one in an illustration of Pheidole instabilis; they are not found on the larvae of Solenopsis.

(c). The Pupa:

Like the other stages, the pupa is at first a delicate pearly white, becoming opaque and rather yellowish with advancing age. In the early part of its life, a very thin, transparent membrane may be noticed, enclosing it. The hairs are few and minute. As it ages, the body assumes a light brown coloration, the edges of the mandibles, the petiole, the thorax and the proximal portions of the legs being darker than the rest. In the case of queen pupae, the wing cases (which are about half as long as the wings inside them) assume a purplish-grey tinge, an optical effect due to the number of layers of folded wing tissue, for when they are freed from their covering, both wing and case are seen to be transparent.

When a newly-hatched adult or 'callow' emerges from the pupal covering, it is at first almost colorless; only after a day or two does it darken to the normal hue. Callows are seldom found outside their nest; their first duties appear to be connected with tending the young, for they may often be seen grooming and moving the immature stages.

Feeding:

Wheeler & Bailey have shown (430) that the larvae of ants are fed on various substances such as pieces of insects in the case of the more primitive species, on pieces of seeds in many granivorous Myrmicinae, with contents from the infra-buccal pocket in certain formicine ants and with liquids regurgitated by the workers, probably the most common method. They claim that the larval organ, known as the trophorhinum, is a stridulating organ and that it may emit at least three different sounds, corresponding to particular needs. With a microphone, I have attempted to pick up sounds, which might be made either by the larvae or by the adults of our common species, so far without success, though Pemberton (206) has described a stridulating organ in the adult form of Pheidole.

Wheeler (354) has shown that the feeding of the larval forms by the workers is not due to a purely altruistic impulse. There is trophallaxis, in which the larva gives as well as takes. In the Ponerinae, where the nurse feeds the larva on pieces of insects, the latter covers the offered portion with a digestive secretion, which is eagerly lapped up by the nurse: Myrmicine larvae have large, salivary glands full of a clear liquid, which Wheeler believes to be too copious for digestive purposes alone and to be used for satisfying their attendants. Some larvae have special thoracic and abdominal appendages, such as tubercles, which act as exudatory organs and contain a sweetish liquid which the nurses lick and so clean the larvae. It was noticed that the larvae of *Pheidole* were covered with opaque, white flakes; it seemed possible that it was this substance which appealed to the nurses and caused them to clean the larvae. To see whether this was the case, a dozen larvae were washed with a little warm water and the resultant liquid was tested by the Schaffer and Hartman method (444) to see if it contained sugars. The result was negative.

Life Cycle:

The following records show particulars of the life-cycle of *Pheidole* ants during the different seasons of the year. Each colony consisted of one or two queens with from 25 to 100 workers and soldiers; exceptional cases are considered separately. The colonies were fed and watered at weekly intervals and inspected twice a week, sometimes oftener.

Colony	Period	Egg Stage	Larval Stage	Pupal Stage
1	Sept./Oct.	9-12 days	18-21 days	17-23 days
2	Sept.	10-13	died	-
3	Sept./Oct.	8-12	19-22	died
4	Sept./Oct.	10-12	19-22	17-23
5	Sept./Oct.	9-12	18-21	died
6	Sept.	10-13	died	-
7	Oct./Nov.	11-13	18-21	17-20
8	Oct./Nov.	11-14	20-25	18-21
9	Oct./Nov.	12-14	18-21	17-20
10	Oct.	11-13	died	-
11	Oct./Nov.	12-15	18-21	17-20
12	Oct./Nov.	15-20	20	18
13	Nov./Jan.	15-20	24-28	20-21
14	Nov./Jan.	15-18	20-25	18-20
15	Dec./Feb.	15-20	24-30	17-20
16	Nov./Jan.	15-18	20-25	23
17	Dec./Feb.	15-20	24-28	18-21
18	Dec./Feb.	15-20	24-30	17-20
19	Dec./Feb.	15-18	20-25	18-20
20	Jan./Mar.	18-20	28-42	21-24
21	Jan./Mar.	18-20	24-30	21-24
22	Jan./Mar.	18-20	24-28	21-24

If these records are grouped into three classes, representing the warm, moderate and cool months of the year, the effect of temperature on rate of development becomes apparent.

The average monthly temperatures were as follows. Relative humidities do not affect these experiments as the nests were kept as humid as possible with tubes of water.

Month	Average Monthly Temp.	Month	Average Monthly Temp.
January	75 degrees F.	July	81 degrees F.
February	73	August	$81\frac{1}{2}$
March	76	September	81
April	77	October	80
May	79	November	$78\frac{1}{2}$
June	80	December	76

Greatest average monthly difference (Aug.-Feb.)...$8\frac{1}{2}$ deg.

Average for the twelve months .... 78 deg. F.

In the following table, Class A represents months with an average temperature of 80 degrees and over, Class B months with an average temperature between 80 and 76 degrees, while Class C contains those with an average temperature of 76 degrees and less.

The stages are placed from the preceding table into the class in which they occur; where there is overlapping into two classes, the class in which the greater part of the stage occurred is taken.

LIFE CYCLES ARRANGED IN SEASONAL CLASSES:

Colony	Egg Stage			Larval Stage			Pupal Stage			Total Life-cycle			
	A	B	C	A	B	C	A	B	C	A	B	C	All
1	9-12			18-21			17-23						
2	10-13			-			-						
3	8-12			19-22			-						
4	10-12			19-22			17-23						
5	9-12			18-21			-						
6	10-13			-			-						
7	11-13			18-21				17-20					
8	11-14			20-25				18-21					
9	12-14			18-21				17-20					
10	11-13			-				-					
11	12-15			18-21				17-20					
12	15-20			20				18					
13		15-20			24-28				20-21				
14		15-18			20-25				18-20				
15			15-20			24-30			17-20				
16		15-18			20-25				23				
17			15-20			24-28			18-21				
18			15-20			24-30			17-20				
19			15-18			20-25			18-20				
20			18-20			28-42			21-24				
21			18-20			24-30			21-24				
22			18-20			24-28			21-24				
Average	12	17	18	20	23½	27	20	19	20½	52	59½	65½	59

These data show that the life cycle of a worker ant of this species averages about two months, roughly a week less in the summer and a week more in the winter. These are indoor conditions and it is true that outdoor temperatures would be somewhat warmer in summer and somewhat cooler in winter than laboratory ones.

In view of the fact that Pheidole was shown to be unable to withstand a constant temperature of 86 degrees (see p. 153), it is improbable that its life cycle would be accelerated by higher temperatures than indoor summer ones and it is fairly safe to assume that the shortest period in which this ant can develop from egg to worker adult is about seven weeks. Indeed, it seems rather strange that summer field temperatures are not fatal to Pheidole; that they are not fatal is, I think, due to the fact that the brood is constantly being moved, so that the slowly moving shade above ground is utilized as a protection and also because the warmer temperatures last only for a few hours daily. In the temperature cabinet, on the other hand, there is no possibility of shade and the heat is constant.

In the case of outdoor winter temperatures, the indoor records offer no true criterion; soil minima at Wahiawa were about five degrees lower than indoor minima at the Honolulu Experiment Station. There can be no doubt that the foraging activities of the workers are greatly restricted and this as well as their slower metabolism at lower temperatures must retard the development of the immature stages.

Moreover, wet weather is frequent, necessitating constant changing of quarters and construction of new turrets and runways with their demands on the workers' time. Experiments outlined in this paper show that the larval stage is lengthened when the food supply is reduced and this factor must often operate during the winter, not that there is a lack of food, but that there is less time and labor available for feeding the immature stages.

How long the life cycle is under winter field conditions, it is not possible to say and it would be exceedingly difficult to find out, for when a colony is disturbed, it nearly always moves elsewhere, so that periodical inspections of 'wild' nests are impracticable; it is almost certain, however, that the life cycle is longer than the 65½ days average winter cycle in the laboratory. Field observations seem to indicate that the proportion of larvae to pupae is somewhat greater in the cold than in the warm season, which would suggest that the larval stage suffers the greatest protraction. I must add that this is only an impression and not based on experimental evidence.

Wheeler (273) quotes Miss Fields as stating that 'Other factors being equal, the development of the eggs within the ovaries, the feeding and growth of the larvae, the pupation and hatching, all appear to be determined by temperature', and again, 'Among the ant-young observed by me, none has developed at a temperature below 70 deg. F., while long exposure to a degree of heat above 90 deg. F. manifestly causes injury'.

The length of the life cycle of Aphaenogaster fulva was determined by Fielde and that of Myrmica rubra by Janet. They were as follows:

Species	Egg Stage	Larval Stage	Pupal Stage	Total
A. fulva	17-22 days	24-27 days	13-22 days	54-141 days
M. rubra	23-24 days	30-71 days	18-22 days	71-117 days

It may also be of interest to compare these results with those obtained by Miss Fielde with a number of groups of ants of various species (426). In these experiments, she found that the immature stages do not develop at temperatures below 70 deg. and that they are injured if exposed to temperatures above 90 deg. F. This does not accord with my experiments in Solenopsis (p.). That all stages, including adults, are killed at 122 deg. F. and that different species had rather different temperature optima for development but that all fell between 76 and 82 deg. F.

Her periods for the development of Camponotus sylvanicus at 'artificial room temperatures' were twenty days for the egg stage, thirty for the larval and twenty for the pupal stages, making a total of seventy days.

The fact that the immature stages do not develop at temperatures below 70 deg. F.--if Miss Fielde's statement can be taken as true for ant species as a whole--taken in conjunction with the results of other of her experiments (440), in which she found that adult ants become sluggish at temperatures below 60 deg. F., must seriously limit the development of ant colonies in temperate regions throughout the greater part of the year; in Hawaii, on the other hand, it means that ant development must continue throughout the year in all the pineapple growing areas. And this is, in fact, the case; larval development is retarded in the winter months but not arrested. It is this unceasing growth which is one of the chief factors of the ant's successful dominance in these islands.

Lengthening of the Life cycle under special conditions:

An artificial nest colony had been placed in the 77 deg. F. temperature cabinet. Through inadvertance, the ants had not been fed for three weeks and the result was that the larvae were not full-grown at the end of thirty-eight days. Fresh food was supplied and the larvae matured and pupated at the end of another eight days.

The experiment was then repeated, food being withheld for periods of two, three and four weeks and then resumed. Results varied; the larval stage was lengthened but in the last two cases, the workers died and when they were replaced by new workers, the latter killed and ate the larvae; the first case, however, was successful and the larval period was lengthened to 32-36 days; the pupal period appeared to be of normal length.

Another case of lengthened larval stage occurred when a nest was reduced to a queen and three workers; they continued feeding the larvae for 33 days; one then died (presumably of overwork) and the others appearing sluggish, thirty new workers were introduced. These killed the original workers and the immature stages but spared the queen, who recommenced ovipositing; the resultant brood developed normally.

<u>Numbers necessary to Start a Colony</u>:

A number of tests were made to see the minimum number necessary for the foundation of a colony. In one case, a small colony was kept going for three months with 1 queen, 1 soldier and 12 workers, but this was exceptional. Even double the number seldom proved sufficient and fresh batches of workers had to be introduced, usually a disastrous proceeding as they generally killed the original workers and often the immature stages, too.

In general, it was found that at least 50 workers and soldiers were necessary to start a nest, even though food was provided and foraging was therefore unnecessary. On many occasions, solitary queens were placed in artificial nests, but they never survived for more than a few days. Furthermore, queens were placed with eggs and larvae in nests to see whether they would rear them; but they never did so. It therefore seems highly improbable that a fertilized queen of this species can start a nest on her own under field conditions; and so, the danger of queens flying inside an ant fence after a mating flight and establishing there need not be considered.

As to the proportion of soldiers necessary to a nest, no evidence was forthcoming. Nests were started with various proportions of soldiers to workers, but it seemed to make no difference to the life of these small nests, which went on equally well without any soldiers at all. It is probable that the role of the soldier is necessary in a large nest but not in a small one; the fact that the immature stages produced in the artificial nests (the population of which did not exceed 100 individuals) were invariably workers tends to support this view.

Adoption of the Immature Stages of Queens:

When the immature stages of queens are introduced into a strange nest, which has a queen already, they are adopted and fostered. Furthermore, if a number of workers and soldiers are introduced into a nest with immature workers, there is no cohesion and they will abandon them. When only the queen of an existing nest dies, a similar thing happens; the colony becomes listless and disorganized and dies. But if a queen or even the immature stage of a queen be placed in such a nest, the colony becomes a unit and all immature stages are again fostered.

Test 1. Dec. 2, 1932

Two queen pupae and three queen larvae were placed in a nest containing a queen, fifty workers and some worker eggs and larvae. The immature queen stages were adopted by the colony. By Dec. 24th the queen larvae had pupated and the pupae had reached the adult stage. The nest was then used for other purposes.

Test 2. Dec. 3, 1932

Workers and soldiers were placed in a nest with worker eggs and larvae; after a day or two the workers did not attend the immature forms; they became listless and died. This experiment was repeated six times; on no occasion were the eggs and larvae systematically tended and though some of the workers survived, there was also a very high mortality, suggesting that a queen is not only indispensable for the renewal of the colony but is also a sort of necessary psychical nucleus.

Test 3. Dec. 2, 1932

One queen pupa and four queen larvae were placed in a nest with about fifty workers and soldiers and some worker eggs and larvae. The queen pupa and larvae were immediately adopted by the colony. On Dec. 13th the queen pupa became a virgin and one of the larvae pupated. On Dec. 31st, this pupa also became a virgin, having spent eighteen days in the pupal stage--about the same time as a worker does--. The other queen larvae died. On Feb. 8th they had laid 3 eggs; by March 1st, there were about two dozen eggs and both virgins were completely dealated. At the end of April these unfertilized eggs were still being laid but none had hatched, though some were now three months old.

<u>The Eggs of Virgin Queens:</u>

If a <u>Pheidole</u> virgin queen be introduced into a queenless colony of workers and soldiers, she will usually be adopted by the colony and treated in a similar manner to a fertilized queen.

A fertilized queen may start ovipositing at once, but apparently a virgin queen cannot or does not do so; however, after a number of days, a virgin will often commence to oviposit.

These eggs are cared for by the workers in the normal manner, but I have never succeeded in getting them to hatch. It may well be that if a very large number of tests had been made and the resultant eggs kept for three or four months, some of them might possibly have hatched, as was the case with certain other species, reported on by previous ant students.

The experiments of Miss Fielde (425), (426) with <u>Camponotus herculeanus</u> and <u>Formica argentata</u> gave quite different results. In general, she found that unmated queens did not oviposit nor did they lose their wings even when kept for ten or twelve months; one of these virgin queens, however, did oviposit and all the eggs developed into males. In experiments with workers, segregated from the nest as callows to prevent any possibility of impregnation, these began to lay when about ten months old (in July) and the eggs, which took about the normal time to hatch and pass through the other stages, all developed into males. This oviposition of what appeared to be worker forms took place under the influence of rises of temperature, in the case of C. herculeanus to 75 deg. F., in that of F. argentata to 82-85 deg. F.

The development of males from unfertilized eggs is admittedly a common occurrence among the Social Hymenoptera (454). Both Wheeler (427) and Wasmann have also found egg-laying ant workers and these have always begotten males. Fabre (272) however, quotes Reichenbach (428) to the effect that Lasius workers sometimes lay eggs which develop into workers.

Experiments with Virgin Queens:

Test 1. Sept. 22, 1932

Two virgin queens were placed in a nest with about fifty workers and a few soldiers. For nearly a month, no eggs were seen, but on Oct. 20th, six were observed. On Nov. 10th, the virgins were noticed to have lost their wings. By Nov. 14th, there were about 20 eggs visible but none had hatched, though six were nearly a month old--twice the normal egg stage period. The original workers had nearly all died, so a new batch were introduced; unfortunately, they killed the virgins and the remainder of the old workers and did not attend to the eggs.

Test 2. Sept. 22, 1932

A similar experiment was conducted with three virgins. These also gradually lost their wings. No eggs were noticed until Oct. 13th when about a dozen were observed. On Nov. 3rd there were about 20 and on Nov. 10th at least 50 were seen. By Nov. 20th, only a dozen workers were left and by Nov. 28th only one. Fresh workers and soldiers were added, but on Dec. 1st., the virgins were found drowned in a water tube and the eggs abandoned. The eggs in this case had remained tended but unhatched for five to six weeks.

Test 3. Sept. 29th, 1932

One virgin was placed with one soldier and ten workers in a nest jar. The virgin was dealated on Oct. 13th but died on the 17th without ovipositing.

Test 4. Sept. 29, 1932

This was a duplicate of Test 3. On this occasion the virgin survived until Oct. 25th but did not oviposit.

Test 5. Dec. 15, 1932

One virgin and about thirty workers and soldiers were placed in a nest. They were kept uneventfully until Jan 25th, 1933 but no eggs were laid; on this date, the virgin was found drowned in a water tube and the experiment was abandoned.

Test 6. Dec. 21, 1932

Two virgins were placed in a nest jar without workers. By Dec. 25th, about 20 eggs had been laid but these were not tended by the virgins. By Feb. 1st, both were dead.

Test 7. Dec. 25, 1932

Half-a-dozen virgins were placed singly in nest boxes, a dozen were placed in pairs in six similar boxes and another dozen were placed, three in a box, in four similar boxes. A few of the virgins oviposited, but most of them did not do so; all were dead within eight days. The experiment was repeated with similar results.

Test 8. Dec. 23, 1932

(a). Two solitary virgins were placed in a tube containing eggs.

(b). Two other solitary virgins were placed in a tube containing larvae.

The object of the experiment was to see whether they would rear the immature forms; they did not do so and all were dead within seven days.

Test 9. Nov. 22, 1932

Virgin queens and males were placed in a nest with about fifty workers. Fertile eggs were not produced, so apparently mating did not occur.

<u>Test 10</u>. Nov. 28, 1932

This was a replica of Test 9. The result was the same, for the eggs oviposited did not hatch.

<u>Earthworks</u>:

Though far less elaborate than the nests of fire ants, those constructed by <u>Pheidole</u> will usually contain a number of interconnected runways; these are also made between nests; these later communicating channels are usually superficial, just deep enough to shelter the foragers from exposure to the sun; they are in fact, trenches with earth flung up on either side, but they are usually interrupted throughout parts of their length by deeper portions where the ants have mined completely under the surface.

A remarkable and characteristic feature of <u>Pheidole</u> workings and one which is mainly in evidence after rain is a peculiar, turret-like structure (pp.302/3); it invariably has a crater-like top with a central hole. It is possible that these turrets assist in aeration and in drying of the nest after a rain.

Aphidicolous Habits:

Mention has been made in a number of places in this paper as to the attending of the pineapple mealy bug by *Pheidole*; it also attends *Pseudococcus longispinus*, another mealy bug attacking pineapples, but far less common than *P. brevipes*, as well as the sugar cane mealy bugs. On the roots of weeds at the edges of fields, it is found in considerable numbers attending *Antonema indicus*, a scale insect very like a mealy bug, and various aphids; these insects, though they do not attack pineapples are nevertheless indirectly harmful as they cause a great increase in ant populations. The scale mentioned above is often found on the same weed roots as the pineapple mealy bug, constituting a sort of mixed herd kept by *Pheidole*. A great variety of scales as well as other kinds of hemiptera are also attended by this ant.

SOLENOPSIS GEMINATA FABR. RACE RUFA JERDON:

Distribution:

Apart from the Mahukona district in the northwest of the Island of Hawaii, where it was observed by Mr. Swezey of the Hawaiian Sugar Planters' Association in 1931, the fire ant (or red ant) is only found here on Oahu.

That it has not succeeded in reaching the other islands of the group is remarkable when one considers firstly that the other ants common on Oahu, namely *Pheidole*, *Prenolepis* and *Plagiolepis*, in addition to a number of less common species, have all done so, secondly, that the fire ant is quite common in Honolulu itself and on the quarantine island at the mouth of the harbor and thirdly that inter-island traffic is of daily occurrence.

On the other hand are a number of factors, which may work against the migration by ship of this species--the tendency to form large colonies remaining in one place in contradistinction to the ramifying small nests of *Pheidole*, the great depth at which queens are found, the fact that a mating flight of this species has never been reported here, the antipathy between the fire ant and *Pheidole*, which would result in the destruction of a small migrating colony of the former if it landed in a territory dominated by the latter. This last factor would not operate if *Solenopsis* landed on the Island of Molokai or at Lahaina in Maui or possibly on Lanai.

The fact that it has recently migrated to a dry district on Hawaii and established itself there shows the immunity of the other islands to be a happy accident. To trust to luck in this matter seems rather a hazardous proceeding. Precautionary measures should be taken to see that this ant does not establish itself on Molokai, where its presence would very materially increase the difficulties of pineapple culture. The possibility of its establishing on the other islands, though highly undesirable, would not be such a serious matter.

This species has a very extensive distribution. Wheeler (273) states that it is 'coextensive with the tropical and sub-tropical portions of America and also occurs in the tropics of the Old World.' It is found in India, Malaya, Borneo and New Guinea; among the Pacific Islands housing it are the Philippines, Formosa (351) the Society Isles, the Tuamotus and Samoa (305), (349).

Nesting Sites:

It occurs as a house ant in British Guiana (3), and the Southern United States (7) and used to do so in Honolulu, till it was driven out by Pheidole. In Porto Rico (45) and California, it forms nests at the base of citrus trees; in Texas (273), it has been found nesting under cow dung and in Guiana in hollow trees. In the

Hawaiian islands, it is usually found either under boulders or in the ground, where it forms deep, subterranean nests but does not build mounds, although small heaps of loose earth are often found on top of the nest. This ant prefers exposed localities, devoid of sheltering vegetation, and so in the pineapple fields its nests are far commoner on the paths and on the edges of rows than among the plants themselves, a habit which greatly facilitates control.

Food:

As to its food, Forel (272) perhaps sums it up best, when he remarks that 'It rears aphids, eats fruit, kills and devours many insects and makes fine granaries containing tidily arranged seeds of tithymal and plantain.' Clark (283) states that its food consists of portions of various plants, including the leaves, bark and tender twigs, larvae of many insects, honeydew from aphids and scale insects and various kinds of seeds. Wheeler (273) writes it is difficult to say whether this ant is more granivorous than entomophagous, for it attacks and eats almost everything that comes in its way.' In Hawaii, though it has been found killing and cutting up insects--presumably for food--the greater part of its diet seems to consist of mealy bug excretions and seeds. Even in pineapple fields, where there is an unlimited supply of mealy bugs for it to foster, it forms granaries. This storage habit, surviving in a country where there seems to be no necessity for it--for food of all kinds, including weed seeds, is available in abundance throughout the year--is a matter of great interest. Possibly, it is connected with the fire ant's crowded manner of living, which involves the building and maintenance of enormous nests, containing probably hundreds of thousands of individuals. It may well be that the feeding of such vast numbers necessitates a centralized commissariat.

I have found seeds of the following plants in the upper parts of its nests on Oahu:

Grasses:

Wiregrass (*Eleusine indica*)

Yellow Foxtail (*Setaria lutescene*)

Bristly Foxtail (*Setaria verticillata*)

Perennial Foxtail (*Setaria geniculata*)

Crab grass (*Digitaria sanguinalis*)

Kukaipuaa (*Digitaria pruriens*)

Kukaipuaa pua poni (*Digitaria violascens*)

Family PORTULACACEAE

Purslane (*Portulaca oleracea*)

Family COMPOSITAE

Sow Thistle (*Sonchus oleraceus*)

Family LEGUMINOSAE

Fuzzy Rattlepod (Crotolaria saltiana)

Family EUPHORBIACEAE

Graceful Spurge (Euphorbia bifida)

Garden Spurge (Euphorbia hirta)

Family OXALIDACEAE

Sticky Sorrel (Oxalis cornicula)

Family SOLANACEAE

Popolo (Solanum nodiflorum)

Family AMARANTHACEAE

Spleen Amaranth (Amaranthus hybridus)

Slender Amaranth (Amaranthus gracilis)

Wheeler (273) reports that 'shallow nest chambers contain quantities of carefully husked seeds, which usually belong to species of Euphorbia, Croton, Plantago and other herbaceous plants. It seems to be less fond of grass seeds.' Here, on the contrary, with the exception of purslane, grass seeds seem more favored than those of other plants. These ants have been observed, in other countries, bringing seeds out of their nests after rain and exposing them to the sun to dry. It has been stated that/they bite off the radicles to prevent the seeds germinating: this is not the case here, for on many occasions I have planted seeds from ant granaries and they have developed normally.

On account of this habit of collecting and storing weed seeds, this ant is probably responsible for a considerableamount of weed dissemination; and when it is considered that the chief seed harvested, and therefore probably the one most widely spread by it, is purslane, a plant which has been shown by the Pathology Department of this Station to be suffering from the attacks of two widespread, virulent pathogenic organisms (a *Rhizoctonia* and an undescribed species of the Fungi imperfecti), it may be the indirect spreader of other diseases besides pineapple wilt: purslane, moveover, is a harmful factor in dry areas--where it is perhaps the commonest weed---in that it robs the soil of badly needed moisture.

Economic Aspects:

This appetite for seeds makes *Solenopsis* a pest in many places. In Java (56), Mauritius (177) and elsewhere, it robs the tobacco seed beds. It not only chews the young branches of citrus trees in Porto Rico (45) but also bites off the bark from young shoots and stems of avocado in Trinidad and Tobago (60); in California, it damages passion vines (67); strawberries and other fruit are attacked by this ant (276). But apart from these examples of direct injury to plants and the pain and annoyance caused by its stings--for it is one of the most aggressive of ants--the chief source of damage is due to its habit of fostering mealy bugs and other coccids on sugar cane, pineapple and various tropical and sub-tropical crops. Were it not for *Pheidole*, the plantations on these islands would be overrun by this pugnacious ant.

It is true that Pheidole is just as harmful as a mealy bug fosterer and therefore as an indirect spreader of pineapple wilt; but the latter ant can be ploughed out of fields at the end of each cycle, so that there is at least a possibility of starting a new cycle with an ant-free field. Moreover, Pheidole does not sting and its mandibles are not powerful enough to pierce a man's skin. A few hours investigation of fire ant nests suffices to convey some indication of what work on the plantations would be like if it and not Pheidole were the dominant ant.

But it must not be imagined that this species is wholly harmful; on the contrary, it has much good work to its credit. In India (170)(181), it feeds on the larvae of predacious moths attacking the lac insect. It is said to destroy up to 50 per cent of the larvae of the injurious boll weevil, a pest of cotton in the southern United States, besides pupae and adults (259); it also destroys the larvae of the cotton leaf roller (276). It is said to attack the soy bean caterpillar in Louisiana (302). In India (380) and elsewhere it attacks termites and is used by the natives of Madras to destroy them in warehouses. Even in houses, where it can hardly be an unmixed blessing, it destroys other insects. Fullaway (208) reports finding it eating eggs of the melon fly in Manila and it is also said to feed on the eggs of the corn leafhopper in the same district.

The Castes:

Like Pheidole, colonies of Solenopsis contain queens and virgin queens, males, soldiers and workers. Among the last two castes, however, there is a very much more pronounced polymorphism; soldiers and workers are easily distinguished from each other by differences in size and in the shape of the head but each caste has very considerable gradations in size. The largest soldier is as big as a queen, while the smallest worker is about half the size of a large one.

The fact that the dwarf workers or micrergates are most numerous in small colonies suggests that they may be undernourished forms, the first brood of a colony founded by a solitary queen. On the other hand, these forms are also found in large nests, though in far lesser proportions and also in small artificial colonies where food is provided. Furthermore, we have at present no evidence that Solenopsis queens are able to establish colonies on their own, I have attempted to induce them to do so in artificial nests, but though they can apparently exist by themselves for far longer periods than can Pheidole queens and will lay eggs, they have always died before these eggs hatched. However, on account of the extreme difficulty and expense of getting these queens--for it takes a couple of men the greater part of the day to excavate a nest as far down as the queens are found--I have not been able to make many experiments on these lines. We do not even know whether Solenopsis queens have mating flights or not, for though both sexes are winged, there is no real record of such a flight having been witnessed, in spite of the number of keen entomologists in the territory.

The Colony:

As to how new colonies are founded, this cannot be stated with any certainty, though I have noticed what are apparently migrations on a few occasions. In these cases, the ants moved in a line partly overland but mainly in a characteristically entrenched, straight ditch--not with earth thrown up on each side as in Pheidole trenches, but similarly interrupted in places by mined sections. The migrations, as might be expected, seemed to be for longer distances than those of the little brown ant.

From the vast sizes of many fire ant nests, from the fact that swarms have not been witnessed and also because this species has not spread to the other islands (except Hawaii) or even to the dry but isolated area in the Mokapu peninsula, it seems likely that Solenopsis is the least migratory species of our common ants.

These large concentrations, which necessitate deep nests, may be disadvantageous to the ant in certain circumstances. Thus, on Feb. 14th, 1933, after two weeks of intermittent heavy rain, a large nest was dug up to a depth of about three feet. The first six inches contained most of the living inhabitants of the nest including the immature forms, a number of males and a very few virgin queens. The galleries below were crowded with drowned ants and there were a few living ones, and those mostly very feeble. A feature of the dead was the great number of drowned virgins, probably trapped once their long wings became wet. It was not possible to find out the actual percentage destroyed but it appeared to approximate to 90 per cent. Queens were not found either at the top of the nest or drowned lower down: they must have been below the three feet excavated, but whether drowned or not, we had not time to find out. In addition to this destruction must be taken into account the arrested development of the immature stages during the disorganization, which takes several days to put in order.

Life Cycle:

The actual time taken by the various stages to develop do not seem to differ greatly from those of *Pheidole*. The following data are from autumn and winter records of artificial nests:

Colony	Period	Egg Stage	Larval Stage	Pupal Stage
1	Nov./Jan.	18-22 days	16-19 days	13-18 days
2	Nov./Jan.	12-16 "	18-23 "	15-20 "
3	Dec./Feb.	16-22 "	25-31 "	18-24 "
4	Nov./Jan.	11-16 "	20-28 "	17-23 "
5	Dec./Feb.	17-23 "	26-38 "	20-25 "
Average		17.4 "	24.4 "	19.0 "

Average life cycle (late autumn and winter) ....60.8 days

We have noticed that many of the colonies found in dry, rocky areas are usually small; they have comparatively shallow nests and the individuals are undersized and little aggressive, sometimes not stinging at all when handled; whereas the large colonies in pineapple fields have very deep nests, are composed of individuals of many sizes but with a small percentage of micrergates; they swarm to the attack at the least sign of provocation.

Pricer (450), in an interesting paper on a species of Camponotus, found that the workers produced by a queen in the first season were all of the smallest size and as the colony increased in size, larger and larger workers were produced. It seems not unlikely that the same thing is true with this species.

Nest Parasites:

Even this fierce species is not without nest parasites. Wasman is stated (273) to have found the larvae of Neoblissus parasitaster living in their nests in Brazil. Here, a minute, reputedly endemic cricket, Myrmecophila quadrispina, is found in their nests as well as in those of Pheidole; in addition, a small, pale silverfish is a guest in their nests and, further, a much larger silverfish, black with a white, transverse band on each segment, is found associated with their nests in very dry regions.

PLAGIOLEPIS MACTAVISHI WHEELER:

The sugar ant, a minute, yellow Formicinid, is about one and a half millimetres long in the worker caste; the queens are about twice the length of the workers; there are no soldiers. As Illingworth (254) states, it can be easily recognized by using a hand lens, for the yellowish color of the body is so transparent that the stomach contents show through the body wall as a dark spot.

This ant is another cosmopolitan species, common in the warmer parts of the world, and is well distributed throughout the Pacific, being recorded from the Marquesas (307), the Society Islands (307) (349), Formosa (305) and Easter Island (305).

In Hawaii, it is a comparatively recent arrival, not being listed in the Fauna Hawaiiensis (published in 1913); it was first recorded by Ehrhorn (380) in 1912. Reported variously as P. exigua and P. mactavishi, it was finally re-identified by Wheeler (424) as P. mactavishi. By 1926, it had increased so greatly as to be placed seventh by Illingworth (254) in a list of thirteen species occurring in Hawaiian pineapple fields, species which he listed in the order of their abundance. Since then it has become even more widespread and, if all the islands be considered, I think it is now second only to Pheidole in distribution and probably in numbers too, though not, of course, in point of economic importance.

An increase so remarkable warrants attention and perhaps investigation; if this species has made such headway in only twenty years, what will be the position in another twenty? Williams (251) indeed states that it has been known, for a time at least, to replace Pheidole. As stated elsewhere ,.. Crawford (215) and Gifford have observed this to happen in the Manoa Valley.

There are, I think, three reasons which favor its rapid increase. Firstly, it has wide tolerance limits of temperature and humidity, for though found mostly in drier areas--and no area seems too dry for this ant--it is also met with in the moister regions. Secondly, it is not attacked by any of the other common species; I have found its nests under the same stones as those of crazy ants and fire ants and I have even seen a sugar ant and a Pheidole ant attending the same mealy bug; individuals placed in Pheidole nests are ignored, whereas those of most species would be instantly destroyed. Thirdly, it has a shorter life-history than the other species, averaging about 6 weeks. Illingworth (254) states that he has never been able to observe it attending mealy bugs but that it feeds extensively at times upon the honeydew given off by these coccids; however, I think it can be said that sugar ants do attend mealy bugs, for they certainly solicit honeydew by tapping them with their antennae.

Williams (251) records it as common in houses, on plants about Honolulu, on sugar plantations and under trash. It is also found in many pineapple plantations on all the islands, usually nesting just under the mulching paper and also in old pineapple stumps in ratoon fields; in some districts, e.g. near Waihee on Maui, it seems to be the dominant ant, but on account of its minute size it is often over-looked. Common nesting sites are in algaroba hollows and under stones. The nests are usually small, comprising a few hundred individuals; the workers are monomorphic; there are several queens to a nest.

As regards mating flights, I have neither seen nor heard of any; at 10:00 A.M. on June 15th. 1932, I found swarms of winged forms under a boulder in the dry area between Koko Head and Makapuu Point. On examination, they proved to be all females; some of these were taken back to the laboratory for observation, but they did not oviposit and died in two or three days.

Some of the workers appear to act as 'repletes', for in artificial nest, certain individuals may be found with greatly distended abdomens; it is probably that they act as a social stomach for the colony.

PRENOLEPIS SPECIES:

There are three species of this genus on Hawaii. They are known as 'crazy ants' on account of the rapid and erratic way they run about when disturbed. All of these are cosmopolitan species, widely distributed in the tropics and sub-tropics and more especially in the Neotropical a nd Indo-Malayan regions.

They are *P. longicornis* Latr., *P. bourbonica* Forel. var. *hawaiiensis* Forel and *P. sharpii* Forel. All the species are notably hairy. The first two are black or very dark brown and shiny. The last-named has a light brown head and thorax and it is somewhat smaller; it is rarely seen in pineapple fields, though flights of winged forms are fairly common in the autumn and early winter, when they throng round electric lights.

The two other species can be differentiated by the fact that the antennal scape of *P. longicornis* is much longer than that of *P. bourbonica*. The former has been recorded from Moorea (349) and Fiji (345), while the latter is represented in Fiji by another variety *bengaliensis* (345).

In Hawaii, the former is the commoner insect in pineapple fields; it favors dry districts and can live in more barren and dessicated land than the fire ant. Though most frequently found in littoral localities, it also occurs in localized areas in the drier parts of the Wahiawa plateau. P. bourbonica may also be found in the Wahiawa district and occurs generally at higher elevations than P. longicornis and also, I think, in damper places. I have even found this ant at the top of the Pali, a damp and windswept place as well as near the summit of Mt. Tantalus.

Crazy ants are of little economic importance to the pineapple industry on Oahu, for there are no very dry areas on that island now under cultivation. But on the other pineapple raising islands of the Hawaiian group, where there are considerable tracts under cultivation in the drier zones and where Solenopsis does not occur--for it is only found on Oahu and Hawaii--crazy ants are of considerably greater importance. This applies more especially to Kauai and Maui, where crazy ants occur in such numbers in certain areas as to merit attention and control.

Illingworth (254) considers that *P. longicornis* finds ideal cover under the mulching paper, which 'increases the warmth of the soil and conserves the moisture, both factors so necessary for the maintenance of the ant brood.' As a matter of fact, moisture is less necessary to the brood of this species than to any other here and they are often found in particularly dry places; he also states that *P. bourbonica* is a strong digger and that its nests extend right down into the subsoil: that has not been my experience as I have always found it either in very shallow nests, in tree hollows or in the lower parts of pineapple plants. *P. longicornis* also often has its nests in the hollows of algaroba trees and, in the pineapple fields they are frequently found inside the plant itself.

But perhaps his most surprising statement is that he has not seen this ant attending mealy bugs. It is, in fact, an inveterate fosterer not only of mealy bugs but also of scales, aphids and other types of Hemiptera and can be seen attending them wherever it occurs. Williams (251) states that it attends aphis on sugar cane and in addition to having observed them myself attending mealy bugs on pineapple on all the islands--and particularly in the southern plantations of Kauai, I have also noticed them fostering scales and aphids on a great number of different plants in the drier districts of Oahu. They have also the pernicious habit of heaping earth round the fruits and leaf-bases of pineapples to protect the mealy bugs.

I am also inclined to doubt the correctness of another remark in this paper, namely that these two species show no predacious habits, as I have seen these ants kill individuals of both Solenopsis and Camponotus.

P. longicornis has two curious guests in its nests, firstly a minute black cricket, Myrmecophila americana Saussure, itself looking rather like a crazy ant; this insect is extremely agile and is said to live partly on the secretions and salival droppings of the ants and doubtless also on the nest debris; secondly, a small shining, brown, lathridiid beetle, Coluocera maderae Woll.

Crazy ants are more easily drowned and poisoned than either Pheidole or Solenopsis. I found it was useless to supply my experimental nests with tubes filled with water, as I did with the other species, for I almost invariably found them drowned inside the tubes. To transfer my field captures to artificial nests, I often used ether, chloroform or carbon tetrachloride to immobilize them and prevent their escape; with Prenolepis, the merest whiff of gas usually had an immediate effect and too long a dose would kill them, while the same amount would hardly make Solenopsis dopey. The poisons employed on Pheidole and Solenopsis were also used on Prenolepis and found to be much quicker and more severe in their effects.

THE MINOR SPECIES

Of the remaining twenty-four species of ants found in these islands, a few are occasionally met with in pineapple plantations. In almost all cases, they are stray wanderers and have no economic significance for the industry. *Ponera kalakaua* is of this class.

Some of them are aphidicolous and have been reported to attend mealy bugs, in some instances on pineapples. There is always a possibility of such insects spreading under a combination of favoring circumstances and becoming of local importance, perhaps in the drier areas. *Tetramorium simillimum*, an ant which has multiplied rapidly in west and southwest Oahu of late years, and which I have observed attending mealy bugs on the roots of nut grass (*Cyperus rotundus*), is a possibility in this direction.

Other species, such as *Tapinoma melanocephalum*, are actually found attending mealy bugs on plants sporadically in small sectors. One or two species, however, notably *Cardioconoyla nuda*, are consistent inhabitants of plantations; they have not been observed fostering coccids and are usually only seen in very small numbers.

As most of these insects are encountered at some time or other in the pineapple fields, it has been considered advisable to accord a few notes to each of them in this paper.

CAMPONOTUS MACULATUS (FABR.) RACE MITIS SM. VAR. HAWAIIENSIS FOREL:

The large carpenter ant or wood ant can hardly be overlooked as it is a veritable giant of its kind, the queens measuring about half an inch; the males and workers are about two-thirds as large. The workers are polymorphic, but there is no soldier caste.

This ant is rufus-luteous with a transversely dark-brown striped abdomen. It is quite common in the dry parts of Oahu, Maui and Molokai but, like the other dry land species, it has been driven out of the moister regions by Pheidole, for in spite of its vastly greater size and formidable looking mandibles, it is no fighter and succumbs quickly to the latter ant; in fact, my first artificial nest of Camponotus, which had an ill-fitting glass lid, was destroyed in a few hours by Pheidole coming through the cracks. Williams (398) has noticed that it falls a victim to the hour-glass spider Latrodectus mactans.

Nevertheless, a few nests are found in houses in Honolulu, even in the comparatively wet Manoa Valley; how these escape being massacred by Pheidole is a remarkable thing, possibly by flight, for they move with much greater rapidity and seldom seem to have any organized material in the shape of a nest. Besides breeding within the woodwork of houses—and in Perkins' day, it was said to be an intolerable nuisance as a house ant in Honolulu (251), swarming all over the house on dark nights, for its habits are nocturnal--it also occupies hollow logs, tunnelling in unsound wood; its most frequent habitat is under boulders in the dry areas, though it is occasionally found in tree hollows. Kuhns (377) found this ant tunnelling galleries in a tree in Maui. It is curious that although it is common in the west and southwest of Oahu, it is so rarely found in the other dry district of the island, namely the Koko Head - Makapuu Point area. Specimens were taken on Sand Island, the quarantine station at the entrance to Honolulu harbor by Mr. Masao Hayashi.

In this species, both the sexes are winged. Swarming is said to take place on dark, still nights; I have never seen a swarm but I have caught winged individuals of both sexes outside the library of the University of Hawaii in Honolulu and in the town of Lahaina on the island of Maui, in August and September, 1932, respectively. A male and female were caught in flight separately by Mr. Masaru Yoshioka, a university student, at Moiliili, Honolulu, at the end of November in the same year, while in December a male was found in the departmental greenhouse.

Camponotus attends aphids and mealy bugs and is said by Williams (251) to patronize honey-dewed plants. Illingworth (254) has found colonies living in old pineapple stumps and also attending mealy bugs on the fruits and roots; he also noticed them attending mealy bugs on purslane. The plantation where the observations were presumably made--namely that of the Pearl City Fruit Company, near Waianae--has been abandoned; the ants, however, are still there. I have never actually seen *Camponotus* attending mealy bugs on pineapples, though I have often found them at the edges of fields and, very occasionally, inside fields. However, Mr. Omura, a trainee of this department, has observed a case of this in the very dry area in central Maui and I have received reports of two other, but more doubtful cases. Another race of this ant, viz., *pallidus* tends coccids in Fiji (345).

This ant produces a white, waxy substance in its nest, said by Illingworth (254) to be used in rearing its brood; however, this substance is produced by the ants whether there is a brood or not.

Though a swift mover when necessary, individuals have an extraordinary habit of remaining perfectly still for minutes at a time; the rigidity of this attitude gives them a petrified and not a restful appearance.

Camponotus forms small colonies of probably less than a hundred individuals; there is usually a considerable amount of dried vegetable litter about the nest, but no tunnels or galleries.

The life history is considerably longer than that of _Pheidole_ or of _Solenopsis_ and takes about ten weeks to complete. The eggs are oblong with rounded ends: the queens appear to lay two or three of them a day during a favorable oviposition period.

TAPINOMA MELANOCEPHALUM FABR.

This is a well-distributed tropicopolitan ant. It occurs in most of the Pacific Island groups from the Galapagos (305) to the Philippines and Formosa (351); it is found in the Society Islands (349) and Fiji (345), while a variety australe inhabits the Marquesas. In Hawaiian pineapple growing islands, it has been recorded from Lanai, Kauai, Molokai and Oahu.

The species occurs most commonly in the dry areas, living under boulders, in the hollows of algaroba trees, in dried pineapple stems and dead sugar cane; a consignment of pineapples from fields in the Anahole area, Kauai, sent to the Experiment Station in January 1933, contained a number of nests in the hollows of fruit beneath the crowns and sometimes under the eye bracts. They did not appear to be harming the fruit directly, as their nests seemed to be superficial. Illingworth, however, has noticed (254) a sawdust-like material scattered on the leaves near nests in old pineapple stems, indicating a certain amount of excavation. This species has been observed fostering mealy bugs on pineapples but less consistently than the commoner ants: it attends sugar cane mealy bugs in Cuba (165) and is the commonest ant in British Guiana, where it infests houses, attacking food of all kinds, and dead insects.

Tapinoma has nests of moderate size, containing perhaps a few hundred individuals. It is a plump ant with a black head and conspicuously whitish thorax and abdomen. An extremely fast mover, when startled its motions are often too rapid for the eye to follow. Like the crazy ant, it will then rush round in an apparently aimless fashion, so that it appears crazier than the crazy ant.

This species is small, about two-thirds the length of *Pheidole*, the males being similar in size to the workers. The larger queens are very hardy: I have kept specimens for six weeks; they laid a few eggs but did not seem to look after them.

Tapinoma prefers a hot and dry climate and is seldom found in moist areas, though a single nest was once found on a pineapple fruit at Waipio, a medium moist locality; it is not uncommon on or near the seashore. Only on Kauai has this ant been found in any numbers in pineapple plantations; here it is fairly common at low elevations near the sea. Though rarely found in *Pheidole* areas, on account of the different humidity requirements of the two ants, I have not noticed that the latter ant attacks it; possibly Tapinoma is too small, for *Pheidole* usually ignores the smaller species. Or it may be that it moves too fast for *Pheidole* to catch it or possibly the *Tapinoma* odor, a defensive measure secreted by an anal gland, suffices to protect it.

CARDIOCONDYLA SPECIES:

The two species of this genus found here are slender ants, about two millimetres long in the worker caste, with a well-marked pair of thoracic spines, placed posteriorly; the petiole appears larger proportionately than that of *Pheidole* and the second node thereof is longer and rounder than the first. The abdomen of both species is very dark brown and shiny; in *C. nuda* var. *minutior*, the head and thorax are colored a burnt umber tint; in *C. wroughtoni* var. *hawaiiensis*, they are testaceous and occasionally the abdomen is similarly colored. The latter species is said to be an upland, the former a lowland ant. Actually there is considerable gradation both in the coloring of the head and thorax and in the altitudinal range, so it is often difficult to say which species is present. As their habits appear to be similar, they may well be taken together.

Though present in most fields in small numbers, *Cardiocondyla* appears to be harmless and of no economic importance to the pineapple industry. It is found on all the islands, singly or a few individuals at a time; *C. nuda* occurs in Fiji (345), the Marquesas (306), Samoa and Tonga (348). The nests are small; one found in grassland contained only twenty or thirty individuals; Williams (251) has found its nests in compost heaps. The male of most species of this genus is said to be wingless and to resemble the worker.

LEPTOGENYS FALCIGERA ROGER VAR. INSULARIS SMITH:

Quite different in appearance from the other species found here, this is a large, black ant of slender build, seven or eight millimetres in length. Like all Ponerine ants, Leptogenys has a marked constriction between the first and second segments of the gaster.

According to Illingworth (254), 'the queen phase has entirely disappeared and has been replaced by fertile workers, each one apparently taking the place of a queen.' They are wingless. Wheeler (435), however, in describing a related species, L. elongata, states that there is only one female per nest, never winged, which looks just like a worker, except for a shorter and more rounded petiole node and a more voluminous gaster. The males are winged. Illingworth (254) writes of these as 'tiny': actually they are about 5 mm. long, or 2/3 as long as the workers, quite a large size for an ant. The pupae form black cocoons. The immature stages are carried not as in other ants, held in front between the mandibles, but longitudinally beneath the body and between the legs: the males are carried in a similar manner when the nest is disturbed.

The nest comprises a few individuals only; it is usually found behind or under stones, at the bases of trees or in dry soil. Williams (251) reports nests in hollows of algaroba and other trees and behind banana leaf bases. Illingworth (254) found these ants, at times, tremendously abundant around pineapples, eating the fertilizer.

This ant lives on small land crustaceans--sow bugs and pill bugs, the remains of which may be found near the nest entrances and so often betray their location. This diet seems a peculiarity of the genus, for _L. elongata_ also feeds on these isopods (435); _Leptogenys_ ants have long, slender, wicked-looking mandibles, probably particularly effective in piercing the joints of crustacean armour. Forel (272) and Wheeler (273) also state that they attack and kill termites.

This species occurs on all the islands, rarely in districts dominated by _Pheidole_ and not very commonly even in other areas. Though more frequent in the dry areas, nests are occasionally found in moist districts, egen in the wet highlands of the Forest Reserves. That they can exist in small numbers in _Pheidole_ territory is shown by the fact that three nests were found in one of the Experiment Station greenhouses.

On northwest Maui, a specimen tube containing a few of these ants and some mealy bugs was handed to me with the statement that they were found together. That this ant fosters mealy bugs is most improbable; it is far more likely to feed on them.

PONERA SPECIES:

Believed to be the only endemic representative of ants in Hawaii, this genus is represented by three species. They are *P. perkinsi* Forel, *P. kalakaua* Forel and *P. gleadowii* Forel race *decipiens* Forel.

The last-named species has not been reported in or on the edges of pineapple plantations. The other two are somewhat doubtfully distinguishable from each other by differences in the lustre of the head. They are both dark brown or black insects, superficially resembling *Pheidole*, but somewhat larger; they are, however, different in build and have shorter antennae. The easiest way to distinguish them from *Pheidole* is by the constriction between the first and second segments of the gaster, which is peculiar to ponerine ants.

P. perkinsi is more generally found in forest areas, nesting under stones, bark, moss and debris, sometimes in rotton cane. *P. kalakaua* is occasionally found in pineapple fields, usually singly. It occurs on all the islands, living in very small communities. A winged female was found at the top of the Pali on Oahu in December 1932, a damp, high and windy locality; the males are said to be wingless and to resemble the worker (273), so mating probably occurs inside the nest.

As far as pineapple cultivation is concerned, this species is harmless as it is not aphidicolous and is also very sparsely represented.

TETRAMORIUM SPECIES:

There are three species of this genus found in the islands, namely *T. guineense* (Fabr.), *T. simillimum* (Smith), and *T. tonganum* Mayr. The last-named species is uniformly light brown; it has not been recorded in or near pineapple fields. The other two have the gaster very dark brown and shiny. *T. guineense* is over three millimetres in length and has a reticulated head and thorax, while those of *T. simillimum* are striated and the whole ant is only about two millimetres long. Both are known to be aphidicolous.

T. guineense is a species well-known all over the tropics as the 'Guinea ant'; most of the Pacific Island groups including the Societies, the Marquesas, Fiji and Samoa (305), (306) support it. It has been reported from Kauai and Oahu pineapple fields and Williams (251) mentions it as found attending aphis and mealy bugs on sugar cane in the Hilo district of the Island of Hawaii. It acts similarly in British Guiana (3) and Georgia (136). Illingworth (254) found a colony near the sea coast in Mr. Horner's fields on Kauai and both Dr. Carter and myself have found these ants in this area in the Hanalei district, the former on fruit. It is occasionally met with under boulders in the dry Waianae and Ewa sectors on Oahu, but it is by no means confined to dry districts; on the contrary, I have found a nest in the dead hollow stem of a horseweed (*Erigeron albidus*) in a marshy area east of Wahiawa, at an elevation of about 1500 feet, a district with a rainfall of ca. 100 inches. On another occasion, I found a nest near the top of Mount Tantalus, an equally wet and elevated location. Both of these places were out of the region dominated by Pheidole; but on his return from a seven months trip, Dr. Carter found a nest of this ant in an office drawer at the Experiment Station, the buildings of which are overrun by Pheidole. A nest also arrived here in a mail package.

To see whether the latter ant would attack T. guineense, I placed an individual of this species in an artificial nest of Pheidole: it was at once surrounded by a group of the smaller ants, which tugged at its legs and antennae, trying to pull the invader apart. The Tetramorium kept as motionless as possible and submitted to this harsh treatment unprotestingly and appeared to feign death. After a time most of the Pheidole left it, but two suspicious or persistent individuals kept pulling away at its antennae in opposite directions for over half an hour. At length they too desisted; the Tetramorium remained motionless for some minutes and then cautiously crawled into a corner, apparently little the worse for its ordeal.

In addition to its habit of attending aphids and mealy bugs, *T. guineense* is said by Wheeler (348) to eat ripe and broken fruit of the papaw (papaya) in Culebra, an island of the West Indies. This fruit grows abundantly in Hawaii, but there is no record of its being attacked here by this ant.

T. simillimum, which is also found in Fiji (345), the Marquesas (306) and the Philippines (351) seems to have spread rapidly in the dry Waianae and Ewa districts of Oahu in recent years.

I have found it attending mealy bugs on the roots of nut grass (*Cyperus rotundus*). To see whether it would attend coccids on pineapples, a nest of these ants was established in the greenhouse in a pot containing a mealy bug-infested, pineapple plant. The ants were not observed to foster mealy bugs on the leaves but they appeared to be tending those established on the roots.

In the dry areas, this species nests under boulders or loose pieces of earth; the nests are shallow and in the case of the largest ones, contain some hundreds of individuals. Wheeler (348) has found this ant nesting under stones and logs on the beach and under stones in creek bottoms.

MONOMORIUM MINUTUM MAYR VAR. LILIUOKALANI FOREL:

There are believed to be seven species of Monomorium in these islands, but M. minutum is the only one recorded in pineapple fields, though other species occur commonly in the sugar cane plantations.

It is a minute, dark brown, shiny, slender ant, less than two millimetres long. It constructs small nests under stones and boulders in the drier areas, often sharing a boulder with other species, which seem indifferent to it. In the pineapple fields in the dry Kupehau area of Oahu, it is occasionally found and has been recorded by Illingworth (254) and others near the sea shore in the northern pineapple area of Kauai. It doubtless occurs in many other places, for such a tiny, inconspicuous, unobtrusive insect is very easily overlooked.

Species of this genus are common as house ants in all the warmer parts of the world; they are often found in detritus. M. minutum does not appear to be of any economic significance to the pineapple industry here.

DISTRIBUTION

The General Situation:

The distribution of ants in the Hawaiian Islands is determined by the climatic factors of temperature and rainfall, (pp. 304 - 306) so that a knowledge and appreciation of these factors is essential as a basis to the study of this insect problem.

Allen (308) remarks of these islands--'There are few more equable climates anywhere'. True in essence, this statement masks a local variation in temperature and, more particularly, in rainfall, which is most remarkable in the case of such small land masses.

The prevailing winds are the moisture-laden northeast trade winds, which blow with great regularity throughout most of the year. All the larger islands are mountainous in the interior and, as a general rule, these mountains rise abruptly from near the coast leaving a narrow strip of flat littoral. The result is that the islands are usually moist in the north and east, very wet in the hilly centre and dry in the south and west districts. The Island of Kauai (p. 306) perhaps shows this best.

In Maui (p. 305) and Oahu (p. 304), where the situation is complicated by there being a lower central area between two mountain ranges, the main climatic features are nevertheless similar, except that the central lower area has less rainfall than the higher areas both to the east and to the west of it. The main pineapple center of Oahu, namely Wahiawa, lies in such an area. Voorhees (259) has shown that the distance from the crest is a far more important factor in determining the quantity of rainfall than is the elevation of the point on which the rain falls; he found, too, that the altitude of the crest of the range in line with the wind was another important factor. These points complicate the situation in such an area and mean that the isohyets follow rather an intricate course and not one determined by the topographic contours. In the Wahiawa plateau, which is about one thousand feet above sea level, the mountains on either side are only about a dozen miles apart and their crests are, on an average, not more than two thousand feet above the central area. In consequence, the plateau is a moist area without great extremes in precipitation, that is between about thirty and sixty inches anually. In Maui, on the other hand, the eastern and western ridges are about twice as far apart as on Oahu, the central area is lower and the ranges are very considerably higher, reaching ten thousand feet on East Maui and nearly six thousand feet on West Maui. As a result, the central area has far sharper precipitation variations. For instance, a field in the Kailua district of Central Maui is so arid that it is actually irrigated, a practice which is abnormal in the pineapple industry. A few miles to the east in the Piiholo district--also in Central Maui--there are pineapple fields with a rainfall of a hundred inches.

But these variations in area between the ranges are insignificant compared to differences of precipitation between western and inland regions. In Kauai, Waimea on the southwest coast has a rainfall of nineteen inches, whereas on the summit of Waialeale, some thirteen miles inland, an average of four-hundred and seventy six inches is said (431) to fall annually. Still more remarkable is the contrast between Lahaina on the west coast of Maui and the mountain crest of West Maui; here a distance of only six miles produces a variation in rainfall from thirteen to four-hundred and twenty inches!

The dry areas are appreciably hotter than the moist ones and this factor of high temperature is also a factor in limiting ant distribution. It may be asked, would not dry areas also be cooler in the night time, more especially in winter? Might not then the low temperatures in these areas also affect distribution? But, as a matter of fact, the dry areas are all found at low elevations and consequently the temperature is never low enough to influence the distribution of any of the species--at least as far as the pineapple growing area is concerned.

The practical effect of these climatic variations is to limit the habitat of the dominant species, Pheidole megacephala. In regions where conditions are favorable to it, this ant may be said to be dominant; on the borders of these regions, it contests the ground with Solenopsis geminata and may suffer the intrusion of other species; finally, in unfavorable regions, it is either not found at all or is represented by a few nests, introduced by some accidental agency and surviving because of some local favoring circumstance.

This ant, in spite of its supremacy in average Hawaiian climatic conditions, is far more sensitive to high temperatures and low humidities than are its competitors and so it is unable to spread freely into the arid areas. Thus, the only parts of Oahu free from Pheidole are the areas on the west and southwest coasts round Waianae and Ewa respectively and, in addition, the Koko Head - Makapuu Point area. The last-named district is also a wind-swept locality and unfavorable to most insects.

A remarkably fine example of how Pheidole is replaced by other species may be found by descending the western slope of the Waianae Mountains from Kole-kole Pass. At the top of the pass, some fifteen hundred feet above sea-level, Pheidole nests are found in great numbers beneath the surface vegetation. The way downwards leads first through a zone of koa scrub, lantana and grass; a little lower and the koa gives way to plantings of eucalyptus and there is also some Norfolk Island pine. Throughout this area, Pheidole is found in abundance and the other ants (except tolerated species) are not found. There is a considerable amount of Mimosa pudica among the grass and there are thickets of Leucaena glauca or Koa haole.

Descending, the district becomes appreciably and progressively drier and a little cactus makes its appearance with some algaroba until the Forest Reserve gate is reached. On the other side of the gate, there is a marked change; the ground becomes very rocky and the vegetation consists entirely of algaroba, cactus, a little grass and a few of the more xerophytic herbs. A quarter of a mile west of the gate and almost at the foot of the hills, the nests of Pheidole cease entirely and are replaced by those of Solenopsis. There are a few evidences of fighting in the shape of masses of dead ants outside a nest, usually remains of fire ants, showing slight advances made by one side or the other. Behind the Solenopsis outposts, colonies of other species--*Prenolepis*, *Camponotus*, *Plagiolepis* and *Tapinoma*--may be found. To the west of this line, the country becomes drier and *Pheidole* is rarely met with except in the neighborhood of houses or ditches, where it has been brought in on timber or some other carrier by human agency and become established in a small pocket, more protected from heat and drought than the surrounding area. Pockets of this nature may be found at Waianae, Nanakuli and Ewa Beach, where there are human settlements in the middle of arid areas.

This ant boundary line on the western slopes of the Waianaes is like nothing so much as the line of opposing trenches in France and Belgium during the Great War. Both have their salients and re-entrants, their sallies and repulses, their temporary advances and occupation of some enemy sector of the line and both remain, on the whole, anchored to their positions and unable to make a general advance, *Pheidolo* because of the climatic conditions and the unfavorable terrain, its adversaries because of the superior mobility, co-ordination and tactics of *Pheidole*.

More intensive human settlement, involving irrigation, the provision of shelter, the breaking up of the land and the destruction of weeds--all factors favoring Pheidole and the latter two working against Solenopsis--would probably upset the balance and the little brown ant would extend its boundaries still further. This has already happened in the drier parts of Honolulu. Its influence can be seen round Ewa and Honouliuli where Pheidole has advanced deeply into the drier regions and the dry land ants have been driven back; but in the dry waste lands, Pheidole has been unable to make headway. From Keeau in the north to a point south of Ewa in the south, along a strip of varying width, perhaps five miles wide at its greatest depth, amidst some of the driest, stoniest and least densely settled land on Oahu, the dry land ants stand firm, maintaining a last foothold against the conquering Pheidole.

The ant boundary line on the western slopes of the Waianaes is exceptionally clear-cut and is due to the steepness of the precipitation gradient, a condition which is maintained through a wide area, so that there are no dry pickets on the wetter side of the line nor wet pockets on the drier side. The rainfall map (p.304) does not show this; it is admittedly based on data from too small a number of stations in this area to do so. From the appearance of the vegetation, it would seem highly probable that the forty-inch isohyet should be moved much nearer to the sixty-inch one; further, the twenty-inch isohyet is not shown at all, though the three stations in this area at Lualualei Camp, Waianae and Makaha kai have an average rainfall of twenty inches. It is probable that a great part of the Waianae plain has a precipitation barely if any greater than this. In a good many places, however, the boundary is by no means so clear-cut, so that there are extensive districts with patches of Pheidole or of the other ants interpolated like isolated outposts in the outer regions of enemy territory and the distribution might strike the casual observer as haphazard. But it is not haphazard, for closer examination would reveal the irregularity of the conditions of temperature and moisture caused by an infinite complexity of factors of wind and terrain, particularly noticeable in the winding gulches of the western part of the Wahiawa plateau--a region with a border line precipitation--and in places round the coast with a similar rainfall and irregular local climatic patches.

The borderline precipitation referred to is that between the twenty-inch and forty-inch isohyets. The rainfall in Oahu varies from below 20 inches to above 240 inches; according to Voorhees (259), the average for the whole island is 68.4 inches. In the map on page 304 , the rainfall data are taken from Voorhees' rainfall map of Oahu, which shows isohyets at 20-inch intervals; the number of meteorological stations is insufficient to guarantee anything but an approximation of the true positions of these lines and no doubt further data would alter these positions somewhat in a number of places; nevertheless, they indicate roughly the relative wetness of different parts of the island.

In the areas shown as having a rainfall of under 20 inches, *Pheidole megacephala* is absent. In those with a rainfall greater than 40 inches, this ant is predominant--except in waterlogged areas and perhaps the most exposed, windswept heights--and other ants are only found in small numbers. In the areas with a rainfall of between 20 and 40 inches, either *Pheidole* or *Solenopsis* may be dominant, depending upon a number of factors, but chiefly, I think, configuration of the local terrain; a hot, level stretch or one with a slight slope exposed to the sun favors *Solenopsis*, while areas with a colder aspect or rough ground will probably harbor *Pheidole*.

The factor of temperature is therefore less important than that of rainfall in determining the distribution of ants in Oahu and, in fact, in the Hawaiian Islands generally, because temperatures are far more equable than in most countries and precipitation far more extreme.

In the areas which are too wet, too cold or too windswept for Pheidole, very few ants are found and only those which nest in very small colonies. Species of Ponera, unobtrusive ants which may be of native origin, occur on the wet slopes of the Koolau range, most commonly in forested regions, 1500 to 2000 feet above sea-level. Small nests of Tetramorium guineense have been found in the dead stems of horseweed (Erigeron albidus) in a water-logged field at Helemano (ca. 1200 ft. elevation), which has arainfall of about 100 inches, though curiously enough, this ant is also found in dry areas and at low elevations such as in the sugar-cane fields around Waianae. Prenolepis bourbonica was found at the top of the Pali (1150 ft.), an extremely windswept area with a rainfall of 115 inches; this ant also occurs at the top of Mt. Tantalus. At Olinda, Maui a specimen of Technomyrmex albipes was taken at an altitude of 4000 ft. In all these localities, Pheidole appeared to be absent.

The gradation from a moist to a drier area is often marked by the increasing abundance of Plagiolepis mactavishi. This minute, yellow ant seems to be tolerated by all the other species including Pheidole, so that its occurrence can be viewed from the climatic standpoint, uncomplicated by biotic factors. It is considered to be a fairly recent immigrant, having been first recorded by Ehrhorn in 1912. In 1926, Illingworth (254) placed it seventh in order of abundance among the ants of Hawaiian pineapple fields. Today, it is probably second only to Pheidole. Though found in moist regions such as the Manoa Valley, it has undoubtedly a drier optimum than has Pheidole, and is a true dry-land species. The borderline precipitation areas on the Wahiawa plateau and on the coastal strips as well as the dry areas have an abundant sugar-ant population. It is especially abundant in cane-fields and its tolerance of low humidities is at least as great as that of Solenopsis and only exceeded by Prenolepis longicornis. The last-named species (the crazy ant) is found in the very driest parts of the island. Though occasionally found in the drier parts of the Wahiawa plateau and the bush-covered areas in the Mokapu peninsula, its favorite haunts are the dry, sandy areas with sparse vegetation: here it is more common than either Solenopsis or Plagiolepis. Experiments show that it drowns more easily than any of the other ants, which is probably one reason why it is rare in moist areas.

As stated above, Solenopsis nests are found in border line precipitation areas and also, though to a lesser extent, in moister regions in the pineapple areas of Oahu.

Their distribution is irregular and there is no definite line dividing Pheidole and Solenopsis as in the west and southwest of the island.

I believe the reason for this apparently haphazard allocation to be as follows: all observations in the past have been to the effect that Pheidole is replacing Solenopsis in many parts of the island and it seems fair to assume from this that the latter became established here before Pheidole arrived and spread over large areas, probably including much of the Wahiawa area where Pheidole is now dominant.

The little brown ant then began to appear in this locality and at first spread very slowly; but with the planting of agricultural crops on a large scale, the spread was rather more rapid. With the adoption of the practice of laying mulching paper (p.309) conditions became ideal for Pheidole and its dominance must have been markedly and rapidly increased. However, when fields are 'knocked down' and ploughed as they are every few years, the entire Pheidole population of shallow nests is destroyed or dispersed and it is impossible for them to become established in such fields, owing not only to the scarcity of food but also to temperature conditions.

Per contra, the deep nests of _Solenopsis_ experience only superficial destruction and the temperature conditions do not harm them: there are always plenty of weed seeds left, which form their staple diet. Thus pockets of fire ant nest-nuclei are left inside these fields and alowly build up a population which is not apparent for some time.

Pheidole cannot establish again until a new crop has been planted up and has grown a little, but the dispersed ants have in the meanwhile infested other crops and unplanted areas adjacent to the knocked-down field.

The result of these plantation practices is that _Pheidole_ is all the time extending its hold on these areas and gradually wiping out the fire ant colonies, but that nevertheless, owing to periodical field ploughings, isolated pockets are scattered everywhere within its territory, forming 'internal', as distinct from 'edge' populations.

Admittedly this explanation contains more inference than evidence, but it is based on observations of what has actually happened in certain localities.

Thus, a field at Waipio containing both species of ants was knocked down and ploughed; at first, the area appeared to be clear of ants but, within a month, nests of Solenopsis appeared and with the coming of weeds--for the field was left unplanted--there were soon many nests of both species. The weeds spread rapidly all over the field and on re-examining the field three months later, I was surprised to find that Solenopsis had driven back Pheidole in this area in several places. This was no doubt due to the great quantity of weed seeds, a food supply which favored the fire ant. On the other side of the road, barely a quarter of a mile away, the situation was just the opposite: here, in a plant crop, Pheidole was making slight gains at the expense of Solenopsis.

Again in C.P.C.Field 71, near Schofield Barracks, was a crop in first ratoon. In the spring, definite areas of fire ants were found in the southern part of this field, which was otherwise occupied by Pheidole. During the summer, the crop fruited; some of it was left to rot but most of the fruit was picked and the crowns cut off and left lying in heaps between the rows; the result of this practice was that the earth between the rows was kept damp and cool, forming an ideal breeding ground for Pheidole ants, of which they took full advantage. By autumn, they had increased enormously and had driven back the fire ants, so that when the field was re-examined in October, most of the Solenopsis nests were full of dead fire ants and their conquerors were found making their characteristic tunnels in the subjugated territory. A few weeks later, this field was knocked down and this will probably save Solenopsis from complete extermination in the area.

DISTRIBUTION ON INDIVIDUAL ISLANDS:

By far the greater part of the time employed in the preparation of this paper was spent on the Island of Oahu; and, as only a few days were passed on each of the Islands of Molokai, Maui, Kauai and Lanai, the information obtained about the situation there was necessarily very limited.

Each of these islands possesses one or more features, deserving of special study. Thus, on Molokai, the ant fences which exist under peculiarly favorable conditions are perhaps the most notable item; on Kauai, there are facilities for comparison of areas with and without mulching paper and speciation in the fields is more diversified than elsewhere; on Maui, remarkable extremes of precipitation may be found, while Lanai is the sole instance here of an island almost entirely devoted to pineapple culture and under one management.

Of the other Hawaiian Islands, Hawaii, by far the largest of the group, has no longer any pineapple plantations and the Islets of Niihau, Molokini and Kahoolawe are also not engaged in pineapple culture.

CONDITIONS ON OAHU:

The general distribution of ants on Oahu has already been discussed under the previous heading. To sum up: In the hilly, afforested regions, with a rainfall of over one-hundred inches, the terrain which constitutes the backbone of the Koolau Range in the eastern part of the island and which is wholly under the control of the Forestry Department, ants are comparatively scarce and such species as occur are fugitives, living as best they can in a region which Pheidole cannot dominate.

Ponera perkinsi, Prenolepis bourbonica, Technomyrmex albipes and Cardiocondyla wroughtoni are the ants most commonly found in these rather uncongenial surroundings, but Pheidole itself is also present as well as occasional colonies of Plagiolepis mactavishi, Monomorium latinode, Tetramorium guineense, Leptogenys falcigera and Strumigenys lewisi.

In the areas with an annual precipitation of between forty and one-hundred inches, Pheidole is everywhere dominant and, with the exception of Plagiolepis mactavishi and the two species of Cardiocondyla, other ants are rarely found; Ponera kalakaua occurs occasionally.

The parts of the island with a rainfall lower than forty inches may be considered under two headings:

(a). Twenty inches and under

(b). Twenty to forty inches

Taking (a) first, the rainfall map reproduced herewith (p. 307), only shows one area of this kind; this is in the extreme southwest of the island. There can be no doubt that this picture is erroneous, even if the scant data furnished by the few stations we have are alone taken into consideration. Firstly, there is, in addition, a small portion, in the southeast of the island, about a mile wide, running from Koko Head to Makapuu Point parallel with Kaiwi Channel. Then there is a very considerable area in the Waianae district, occupying probably the greater part of the Waianae Plain; the forty-inch isohyet here, as I have mentioned previously, almost certainly runs considerably further to the east than is shown on the map: the extent of this district has been outlined in the previous general description. Finally, it is possible and even likely that the eastern portion of the Mokapu Peninsula (southeast of Kaneohe Bay) should be included in this precipitation division. Fire ants have not been found in this area--due, I believe, to its isolated position with regard to the other dry areas--but the lowland species of the crazy ant, common in arid localities, abounds and the vegetation is typical of these zones.

Throughout the areas of this division--with the exception just mentioned--the dominant ant is Solenopsis geminata: Prenolepis longicornis and Plagiolepis mactavishi are almost as abundant, while Camponotus maculatus, Tapinoma melanocephalum and Caridocondyla nuda are common, though the former is not often found in the southeastern localities. In addition, Tetramorium simillimum, Tetramorium guineense, Monomorium minutum and other Monomorium spp., Leptogenys falcigera and Ponera kalakaua are not uncommon.

The areas with a rainfall between twenty and forty inches, localities with the border-line precipitation mentioned under the previous heading, include the greater part of the coastal zone and a central belt consisting of the Wahiawa Plateau in the middle with extensions coastwards to north and south. The coastal zones usually have Pheidole on the inland side and the dryland species on the seaward; however, in the northern districts, a cool part of the island, Pheidole extends throughout the area, sharing it with the sugar ant, Plagiolepis and occasional Cardiocondyla, and the dryland species do not seem to occur. This holds true for the entire northern coast, for the north part of the western coast as far south as one mile north of the 21°30' parallel of latitude, where Pheidole nests cease and those of the dryland species commence: on the eastern coast, there are small localities between Punaluu and Kahuku (the northern twelve miles of this coast), where small colonies of crazy ants may be found, but not fire ants. The area from Koko Head right around to Pearl Harbor, originally predominantly a dryland species region, is now mainly occupied by *Pheidole*, a situation due to intensive human settlement. The Wahiawa Plateau and its extension north and south constitute the main pineapple areas: in the north and east, *Pheidole* is dominant, but in the west and south, the fire ant is a very big factor. In the Kupehau district and in a considerable part of Kunia, the latter species is dominant and extends northwards as far as Brodie: in the Robinson and Waipio districts, it is found in considerable patches, sharing the area with *Pheidole*.

CONDITIONS ON MOLOKAI:

Than Molokai there can be few less attractive places. Hot, dry, dusty, windswept and desolate, its existence had been tactfully ignored by the Hawaii Tourist Bureau. Yet, despite its barren inhospitality, this island produces some of the finest pineapples grown.

The eastern half of the island is a mass of rugged, mountainous terrain, inaccessible and sparsely inhabited; it is the western half that contains the pineapple growing areas, (p.308).

The Mauna Loa Sector:

The extreme western sector, based on a central hill named Mauna Loa, consists of very large fields of about five-hundred acres or over, bounded by ant fences. It is a dry district, the annual rainfall averaging twenty-two inches. Some of the area is stony, but the boulders have been or are being gradually cleared from the fields. Persistent anti-ant measures have been going on for a number of years. These are of the nature of oil-spraying collections of boulders and destroying ant nests and keeping ants out of fields by ant fences ~~and the~~ on account of these measures and of the windswept nature of the area, of the low rainfall and of the sparse vegetation, the ant situation is well in hand, probably better than in any other pineapple growing area in the islands.

It is true that in some of the older ratoon fields, which have been let go, there are some very badly infested places; it is also correct that the stony sectors on the edges of some fields have a large *Pheidole* population. But these areas form an insignificant portion of the whole estate and, moreover, they are easily held in check and are not a source of potential danger to the rest of the fields, provided that the same sound policy is followed in the future as in the past.

This sector exemplifies the success of the ant fence, described elsewhere (p. 245), in an almost spectacular manner. That it is so successful is due partly to climatic conditions and partly to the nature of the terrain, which is undulating but not precipitous, nor is it cut up by numerous gulches as on the other islands; because of this and because of the low ratio of perimeter to area in these large fields, ant fence costs are comparatively low on this estate.

In addition to *Pheidole*, the only other ants found here were *Cardiocondyla* and *Plagiolepis*; they are nowhere very numerous.

Although the ant fence is the most successful defence so far discovered against *Pheidole*, it is by no means perfect even on Molokai. Throughout the life of the plant crop, ants are seldom found among the pineapples; but when the field comes into first or second ratoon, they will sometimes make their appearance. Small wilted patches in ratoon fields, a sign that ant-fostered mealy bugs have been at work, are occasionally noted. These patches are often in the middle of the field, indicating that the mealy bugs were probably brought in on planting material or blown in as crawlers by the strong prevailing winds and not carried in by ants from outside the field, a procedure which is marked by edge wilt.

As to the ants, how did they get into the field? Did they slip through some breach in the defences? Did they burrow under the fence? The fact that they are usually only in evidence after the field is two or three years old makes this appear unlikely in most cases. Are they the result of winged females alighting within the field after a mating flight and establishing nests? Studies outlined elsewhere in this paper tend to refute this theory. Is it possible that the ploughing of the field beforehand had not destroyed all the nests? On Oahu, such a hypothesis would not be tenable but here, as stated later, the nesting habits of Pheidole have been modified to withstand conditions which are normally fatal to this species, nests having been found at a depth of four feet. Perhaps, then, small nest-nuclei have been left undestroyed by cultivation and in the course of so many months have gradually built up their populations so that they have become large enough to tend the few mealy bugs on the planting material and help them to establish and multiply sufficiently to cause wilt.

The Homesteads:

The central portion of the pineapple growing district consists of an area of good land in the Holehua locality, divided into forty-acre plots, each occupied by a homesteader who must be of Hawaiian or half-Hawaiian blood. The homesteader may use his land for a number of purposes so that the blocks occupied by pineapples may be quite small, usually five or ten acres; they may be surrounded by other pineapple crops of various ages or by land used for other purposes or by unutilized land.

The greater part of these blocks are very badly infested with ants and mealy bugs, especially those around the periphery of the area, the makai (or seaward) sections being particularly bad. In the central parts of the area, there are still many plots at present untouched but doomed in the future to be infected. In other cases, a newly-planted area may be surrounded by (say) old ratoon plots on two sides, a year-old infected plot on the third and an unplanted, weedy area on the remaining side. Such a crop will have no chance of avoiding infection.

Ant-fencing around each of these plots is impracticable on the ground of expense; a certain amount of cultivation around the edges has been done in most cases but it seems ineffective as a field protection. It is now proposed to combine a number of the holdings into new fields of more suitable economic size and thus make it worthwhile to fence them and to adopt other measures of management necessary for successful pineapple husbandry.

Although innumerable ants were present, nests were not found immediately under the mulching paper. It was stated that in these dry areas, nests had been found up to a depth of four feet, where the soil would be moister. The nests become more superficial, however, during the wetter periods, which occur on Molokai during the late winter and early spring. Soil, precipitation and other conditions appear to be fairly similar to those at Mauna Loa, so that the great contrast in ant and mealy bug populations at the two places must be due to the difference between effective and ineffective anti-pest measures. Every critic of the value of ant fences should see these two areas.

The results of the homestead regime are visible in the area of wilted plants. I was informed that at first it was easy to raise a number of ratoon crops in this area; under present conditions, this will be out of the question and even a plant crop will sometimes be problematical.

The burrowing habits of Pheidole (mentioned above) in the dry areas of Molokai is a matter of great interest and importance. It does not seem to occur on the other islands (except in parts of Maui). On Oahu, the presence of the fire ant in dry areas, which are its natural habitat, prevent the encroachment of Pheidole and the nests of the latter species are almost invariably superficial. This ant, so sensitive to high temperatures and low humidities, could not exist on most parts of Molokai, had it not adapted itself to meet these conditions by abnormal nesting habits.

The results are not without danger to the pineapple crop as the nests are invariably found under and among pineapple roots, probably causing too rapid drainage and certainly causing damage to the root system by abrasions and the destruction of root hairs; possibly, the unusual number of mealy bugs on pineapple roots on this island is not unconnected with the aberrant local nesting habits of Pheidole.

The Kualapuu Sector:

The eastern sector, based on Kaulapuu is managed by another company. It, too, consists mainly of large fields but the terrain, climatic conditions and methods employed in pest control are entirely different from those in the Mauna Loa sector. In addition to having areas with a rainfall of about twenty inches or less, there are also wetter areas with about four times as great a precipitation as in the driest ones. The wet areas are mainly at an elevation of about 1000 feet and over and, in some of them, there is an additional factor of very violent winds, which actually shred the leaves of the pineapple plants.

In dry areas, ant runs often follow the line of the root system, where moisture is most abundant; nests and societies of workers are found mainly among and under roots and not under the mulching paper. Root hairs are frequently nibbled away and the ends of roots are sometimes rotten and coated with a beetroot colored fungus layer. Nematodes are reported to be absent.

The method of protecting the plants from ants and mealy bugs here is the guard row system; this has only been in practice for two or three years, so some of the fields with older crops are still unprotected. Up to ten guard rows are planted in the newer fields. The rows are sprayed against mealy bugs with 'Johnsontine'--a variant of Petrotine--. In addition, there is cultivation in strips at the edges of fields.

New fields are planted up with 'slips' as they are found to be less liable to contamination and surer than 'crowns'; they are also larger. 'Suckers' are said to be unreliable for planting material and give a varied size and kind of fruit; their fruiting season too, is spread through a longer period of time.

Before taking 'slips', the crop is inspected and graded. Blue 'pins', signifying absolutely clean stock are placed in the clean areas. 'Ordinary' planting slips are taken from areas somewhat clean. The rest are destroyed. In this way, a gradually improved material is being built up for planting year by year. This process has been accelerated of late. During the 'boom' period, when the demand for pineapple was greater than the supply, planting material was taken from where it could be best obtained; now, that the slump has come, companies can afford to be very 'choosy' about their planting material and discard all but the very cleanest and best material.

Strong winds are a factor unfavorable to the increase of mealy bugs. In windswept areas, the outside vegetation is kept down and there are few mealy bugs and ants in the adjoining fields; whereas in sheltered areas, the edge vegetation is rank and the fields adjoining it are liable to extremely heavy infestation.

The effects of the guard rows (p.310) which are simply a number of rows of pineapples at the edges of fields, planted parallel to the edges and separated from the remainder of the field by a plantation road, is to delay the advance of mealy bugs; for, it has been found that these insects will travel along a row far more quickly than across from row to row. The field proper, on the other side of the plantation row separating it from the guard rows, is usually planted so that the rows run at right angles to the road and therefore to the guard rows. There can be no question that this system does hold up mealy bug advance and when these insects are noticed in the guard rows, they are sprayed and thus advance into the field proper is prevented. The spraying of this peripheral part of the field is not necessary more than once a month and usually not so often. Regular patrols ensure the efficient working of this practice.

There are, however, weak points in this system. Firstly, the guard rows like the rest of the field are intersected at intervals by ditches, running to the edges of the field. These are necessary for drainage purposes; they are usually of packed earth and are ideal for the percolation of ants and mealy bugs into the field. Inspection of these holes in the defence shows that they are utilized by these insects. Another weak point, peculiar to Molokai and probably to dry areas on Maui, is that in addition to infesting leaves and fruits, the mealy bugs here are found in appreciable quantities on pineapple roots and in considerable numbers at the collar at the base of the plants; spraying does not seem to touch these insects, for an inspection made immediately after spraying showed that numbers of insects in these positions were entirely unaffected.

The southern part of this estate consists of large fields situated in very dry localities with average annual precipitations of under twenty inches.

The gulches and waste lands at the edges of these fields have scanty vegetation consisting mainly of algaroba (Prosopis julifora), ilima (Sida fallax), sand bur grass (Cenchus echinatus) and various other grasses but no redtop (Tricholaena rosea); they are usually rocky and contain boulders irregularly distributed.

Only in the northern parts of these areas does Pheidole occur and it is rarely found in any considerable numbers. The pineapple mealy bug (Pseudococcus brevipes) is replaced by another species, P. virgatus, which is not a pest of pineapples but is found on the roots of ilima, the commonest weed in this area.

In the southern regions, Pheidole disappears and instead are found small colonies of Camponotus maculatus, the large carpenter ant; it occurs mostly under boulders. This ant, though it does sometimes attend mealy bugs, is rarely found in pineapple plantations. Pheidole will not tolerate it, so that its presence in a district is usually a sign that the region is too dry for the former ant.

THE ANT FENCE EXPERIMENT:

An interesting experiment on the relative efficiency of ant fences and sprayed and unsprayed border plantings in preventing edge infestation of mealy bugs was tried out in this area.

The experimental area consists of a number of blocks on the edge of a field, arranged as in diagram and treated as follows:

<u>A</u> Blocks sprayed once a month.

<u>B</u> Blocks surrounded on three sides (but not the interior side) with an ant fence, which is sprayed three times a week.

<u>C</u> Check area blocks; these are left unsprayed or fenced, except the rear five lines, which are sprayed to protect the interior of the field.

Outside the area, there is a steep gulch, covered with various weeds, including redtop and elephant grass, lantana, guava and vervain. The edge has a mulched border between it and the gulch. Inside the ant fences, there are also mulched strips. The rainfall is said to average forty to forty-five inches. There is a strong prevailing wind, blowing down the valley; its direction is indicated in the diagram.

In the gulch itself, Pheidole is plentiful and Pseudococcus brevipes common, mostly on redtop grass in localized patches; these insects are commoner at the western than at the eastern parts of the field edge. The area is very stony. In addition to Pheidole, Cardiocondyla and Plagiolepis occur in small numbers.

The experiment was initiated in September 1931. Relatively clean slips were used as planting material; estimates based on samples taken from similar material showed it to have between one and two bugs on ten per cent of the plants.

When visited in January 1932, the ant fence plots appeared to be quite clean; the sprayed plots (which had been sprayed the day before my visit) showed no mealy bugs, but there were quite a number of ants under the mulching paper. In the unsprayed (control) plots, ants and mealy bugs had penetrated up to the third lines.

Three months later, this area was inspected by Dr. Chapman: he found that mealy bugs had by then reached as far as the seventh line, in general making the greatest progress where there were drainage ditches. He found no mealy bugs in the guard rows spray-area or in the ant fence area.

In September 1932, one year after planting, Dr. Chapman again inspected this area and found that in the unsprayed, control areas, mealy bugs had extended in as far as twelve beds and that ants and mealy bugs were abundant in the first four beds. The other checks had some mealy bugs extending in from five to no rows. No mealy bugs were present in either the sprayed or fenced areas but ants were found in the former. One mealy bug, however, had been found previously inside the ant fence.

In March 1933, when small fruits had just formed and were beginning to develop, I revisited the area. In the A (sprayed) plots, there were Pheidole ants but no mealy bugs on the pineapple leaves, but there were bugs on red-top grass weed roots inside these plots. As the areas had just been sprayed, the freedom of the pineapple leaves from bugs was to be expected. In the B (ant fence) areas, there were no Pheidole ants and very few mealy bugs. In the C (control, unsprayed) areas, there were far more ants than in A and mealy bugs were abundant on the fruits and leaves (especially on the former) and had invaded the plots as far as the sprayed barrier (fifteen rows), as far as block C 1 was concerned.

The control areas (C 1 and C 2) showed remarkable differences. In C 1, the leeward or western side was badly infested, up to the sprayed rows, nearly every fruit being affected; in the windward part of the block, which was somewhat protected from the wind by the adjacent ant fence block, especially at the rear, infestation was less noticeable. In C 2, the mealy bugs had not advanced nearly so far. The windward side, which was entirely protected by an adjacent and protecting, sprayed, guard row section, was free of mealy bugs; in the center of the block was a ditch and here the mealy bugs had advanced to the fifth row; at the leeward edge, there were a few bugs as far back as the ninth row but only the first three rows were at all heavily infested. The whole layout seemed to demonstrate the effectiveness of wind as a mealy bug carrier.

The Species on Molokai:

Although the ant fauna of the pineapple areas seems comparatively poor, there are a number of other species found elsewhere on the island. Swezey and Bryan (231) (393) list the following ants as occurring in the forest areas of east Molokai:

Ponera perkinsi, Tetramorium guineense, Cardiocondyla wroughtoni var. hawaiiensis, Cardiocondyla nuda var. minutior, Prenolepis bourbonica var. hawaiiensis, Technomyrmex albipes, Pheidole megacephala, Plagiolepis mactavishi, Leptogenys falcigera var. insularis. In the Fauna Hawaiiensis, three other species are recorded: Monomorium floricola, Tapinoma melanocephalum, Prenolepis longicornis and Illingworth (254) also found Ponera kalakaua to be present.

These, in addition to Camponotus maculatus race mitis var. hawaiiensis, found south of Kualapuu and in the Mauna Loa area, and Cerapachys silvestrii, found by Dr. Williams in 1931, makes a total of fifteen species for the island.

It is noticeable that the fire ant is not found here; this is very fortunate as the locale is ideal for that species. If it were introduced, the value of the ant fences in the Mauna Loa area would be very greatly reduced. It would seem prudent to take the strictest precautions against accidental introduction from Oahu by the pineapple barge.

ECONOMIC ACTIVITIES OF ANTS:

The question as to whether ants are beneficial or injurious to man depends largely on the point of view. In general, those who have studied their habits consider their helpful activities outweigh their harmful ones. Both Forel and Wheeler, eminent authorities, who have devoted many years to the study of ants, incline strongly to this view.

In Hawaii, where tropical agriculture is the paramount industry, the aphidicolous propensities of the chief species and the way houses are overrun with these creatures as well as the difficulties they create to the establishment of beneficial insect parasites are all too obvious while the good they do is not so easily apparent. Williams (251) believes that the harm done by the dominant species here (Pheidole megacephala) overbalances the good. Illingworth (254), on the other hand, goes so far the other way as to say that he is 'more and more convinced that ants do more good than harm in our pineapple fields'. Whatever way the balance may incline in the pineapple and sugar cane industries, there can be no doubt that we owe a great deal to ants in that they keep in check a great number of pests, only too prevalent in less fortunate countries. In particular, the house fly, a menace and an annoyance in many parts of the world, is kept down to negligible numbers here owing to the incessant aggression of Pheidole.

ANTS AS BENEFACTORS:

General Remarks:

Ants are the chief check on injurious insects. In British Guiana (3), they attack pest of cacao; in Java (23) they kill the larvae and adults of beetles infesting Tephrosia pods and protect cacao trees against Helopeltis (27) and also against the cacao moth, Acrocercops crameralla. Pierce (35) relates how species of Solenopsis Pheidole, Monomorium and Iridomyrmex, though they encourage aphids, whiteflies and scales, make ample amends by their efficiency in destroying the cotton boll weevil.

Pheidole megacephala and other species are reported (304) to have killed pupae of the red bollworm (Diporopsis castanea) after they had been ploughed up by cultural operations. Pheidole also destroys the eggs of the leaf-eating ladybird, Epilachna vigintiocto-punctata, in Queensland (147). In Mexico and Central America, the vegetation is protected from attacks by man, cattle and leaf-eating insects by the formidable genus Pseudomyrma (36), though the latter does not succeed in warding off wood-borers.

Friederiche (69) reports the use of weaver ants (by Government Ordinance!) against palm leaf beetles in New Guinea and that the same ant, as well as others protects the vegetation in China and Cambodia against many insect pests. He suggests their introduction into the South Sea Islands for similar purposes. At least as early as the Middle Ages, ant colonies were established artificially in orchards in China, Japan and Java to defend the trees from attack by other insects. Groff and Howard (109) state that this is still the case in the citrus orchards of China and in regions where it is too cold for ants to survive the winter, fresh ones are imported yearly in the spring from warmer districts and placed in the crutches of trees; candle wax is smeared on the branches to prevent their escape and their passage from tree to tree is aided by specially placed bamboo bridges. The weaver ant usually associated with this practice is Oecophylla smaragdina; however, both Wheeler (273) and Forel (272) quote McGowan as saying that there are two varieties of ants concerned, a red and a yellow one. Simmonds (115) speaks well of Oecophylla as a destroyer of insect pests in various islands of the Southern Pacific. In Trinidad (105), Urich mentions a number of species as being of value as destroyers of noxious insects.

In 1918, Stitz (61) discussed the economic importance of ants in their relation to man and showed that besides killing pests, they improved the soil and distributed seeds.

Plodia and Ephestia, two widely-spread moths of catholic tastes, which attack a variety of stored products, are said by Myers to be attacked by ants in Australia (167). Solenopsis destroys the pupae of an Indian Noctuid moth, the larvae of which prey on the lac insect (181).

Many examples might be quoted of ants as friends of the forester. Caterpillars of the Teak moth, another Noctuid and a defoliator, are attacked by ants in the East Indies (166). Eidmann (112) says that in Germany forest ants actually prevent the occurrence of pest epidemics. In a later paper (132), he quotes instances of entire stands being saved from defoliation by caterpillars by the red forest ant, Formica rufa. Laws were enacted to protect this species and the allied F. sanguinea some fifty years ago in Germany and this paper (133) also describes a method of favoring their increase. Eidmann (138) has tried to figure out the actual importance of the role played by ants in forest protection. He finds that the average annual food requirement of a large colony of Formica rufa amounts to several million insects, most of which are injurious species of Lepidoptera and Diptera; the hunting area of such a colony may cover up to 17 acres and most insects brought into the nest are overpowered when healthy and uninjured;

he found that no significant forest damage was done by this ant. Forel (272) also stresses the usefulness of this species as the natural protector which saves the forests from destruction by Bostrichid beetles.

Other examples of the good done by ants are the destruction of the soy bean caterpillar in Louisiana (302) and the control of thrips in the Belgian Congo and elsewhere (189) (85). In India, tins of surface sand filled with nests of fire ants (Solenopsis geminata) are placed around trees infested with termites (197). Ants, indeed are notable enemies of termites, destroying them wherever they may find them. Forel (272) devotes about fifty pages of his work on The Social World of the Ants to an account by Bugnion of 'The War between the Ants and the Termites'. He asserts, indeed, that the very mode of life in termites has been determined by the necessity of protection from ants and that the ingenious weapons and methods of defence have been evolved by reason of this ceaseless warfare. Solenopsis geminata is mentioned as one of their most inveterate enemies; it is said to be introduced into warehouses in India to check their activities (336) (337).

I can find no reference to it tackling termites in Hawaii. Pheidole, on the other hand, does control these pests to a considerable extent. Fullaway (266), writing of termites, states, 'They are an easy prey to the black ant when their excavations or galleries are broken into or exposed' and Muir and Swezey (237), in a short survey of termites in sugar cane fields, mention that, '--the presence of our little common ant, Pheidole megacephala in numbers in our cane fields is a good protection against the starting of such colonies' and again '--it plays a very important part in checking the spread of termites--- Innumerable small colonies must be destroyed by them'. They record that Pheidole had already been found attacking small termite colonies in railway ties and clearing them out. Williams (251) also writes of it as an important enemy of termites.

To give even a list of the insects controlled by this ant here would be a lengthy business. Muir (262) states that it preys upon all insect life. Illingworth (288) considers these ants highly beneficial and has found them killing Dermestid larvae infesting fish, flies and even such large insects as mole crickets and June beetles. He is of the opinion that by removing aphid excretions, they check the spread of leaf fungi. In a further paper (254), he particularizes this last statement more closely by stating that the development of black smut on pineapples from Coccid excretions is prevented by the ants' fondness for the saccharine product. He also states that they have been observed eating the mealy bugs. But these last two statements rather lose their weight when it is realized that if it were not for the ants' attentions, there would be an infinitely smaller mealy bug population to eat and to spread black smut. The case for ants is strong enough without urging dubious benefits of this kind, Illingworth has found them destroying nematodes in all stages and states that they will open galls to get at them. On the other hand, Bailey (99) (276) shows that the infrabuccal cavity of certain ants contain numerous nematodes, which are, of course, voided and Janet (404) found that certain nematodes pass their larval stages in the pharyngeal glands of ants, the sexed individuals occurring in the detritus of ant colonies. Thus, though ants destroy a great number of these pests, they are also responsible to some extent for their distribution.

Largae and adults of Carpophilus beetles, larvae of bud moths, root maggots and root grubs such as Adoretus sinicus, Gonecephalum seriatum, Pantomorus godmani, Monocrepidis exul and their adult stages and various root infesting organisms as well as fruit maggots, all these bad pests are destroyed by Pheidole.

Illingworth also found that the tunnels made by ants near pineapple roots greatly assisted drainage, so that rain quickly reached even the deepest parts of the root system. This may be so in certain sectors, but in the drier areas which are the very places where Pheidole is most frequently found among the root systems, it is possible that this rapid drainage is more deleterious than otherwise; in the wet sectors, where it would be advantageous, this ant is rarely found tunnelling among the roots but nests as close to the surface as possible.

Nevertheless, Illingworth's remarks on the way in which Pheidole controls noxious insects cannot be over-emphasized. On June 28, 1932, after a heavy rain, while out with Dr. Chapman, a freshly-ploughed area at the Wahiawa Experiment Station was seen to be covered with the tenebrionid larvae of Gonecephalum seriatum; they were nearly all being attacked by parties of Pheidole, each party usually having a number of workers with their mandibles pulling at the membranous parts at the sides of the larva and a soldier with his mandible sunk into the posterior end. Adoretus grubs were also being attacked. This is a common sight after rain.

At most times, wet or dry, Pheidole workers can be seen in the field carrying pieces of injurious insects--mainly dipterous or coleopterous larvae--back to their nests.

Williams (251) reports that this ant invades the tunnels of Xylocopa varipuncta, the carpenter bee which damages woodwork in Hawaii, and destroys the contents.

Fullaway (261) considers Pheidole to be the most active predacious enemy of the delphacid, Peregrinis maidis, the injurious leafhopper held responsible for the 'yellow stripe' disease of maize.

Pemberton and Willard (53) give an interesting account of some experiments they made to find out how far this ant acted as a control on fruit flies. Tests with kamani fruit showed that 1.2 fruit fly puparia per fruit survived when they were protected from ants. When loquats were used, the protected fruits produced over five times as many puparia. In the case of black myrobalan, only one and a half times as many evolved to the pupal stage under protection as without it. The experimenters concluded that one-third to four-fifths of fruit fly larvae never mature owing to the activities of Pheidole.

As a general scavenger, it is impossible to exaggerate the help given by this species. Every dead or injured animal is immediately set upon a nd consumed and one cannot take a walk without evidence of this; in this respect, Pheidole probably does a vast amount of beneficial, unseen work in our houses. It has been reported as destroying the eggs of cabbage butterflies, fruitflies and house flies and as pulling the fruit fly larvae out of imported coffee (209). Illingworth (205) saw Pheidole taking the larvae of house flies out of manure piles and seizing them as they came out of the manure to enter the ground to pupate; he also saw them seizing the eggs as they were laid. It has been believed for some time that the scarcity of house flies here is due to the control exercised by Pheidole but hitherto no one has attempted to secure any exact data on the matter. Illingworth does state (253) that he estimates 75% of house flies are destroyed by Pheidole, but I can find no record of actual experiments on which this statement is based. In addition, he has observed them attacking and dismembering adult flies.

It was decided to set up an experiment to see whether the scarcity of house flies here is actually due to the activities of Pheidole and, if so, just how effective such control is.

Intentionally blank

Fly Control Experiments:

Accordingly, on October 8, 1932, two 3-foot square, timber enclosures of six-inch boarding were set up in the Experiment Station grounds. The boards were placed so that half their depth (3") was below the surface of the ground. The earth in the experimental area had been dug up to a depth of about one foot, cleared of stones and vegetation and treated with carbon-disulphide to destroy any ants which might happen to be there.

One square was sprayed with a mixture of Avon weed killer and threading compound in equal proportions to prevent the ingress of ants and spraying was repeated at three-day intervals; the other square was left unsprayed as a control (p.311).

Bait in the form of overripe papayas and peaches was placed in boxes inside each square; later sugar cane mud-press was tried. The bait was kept damp and shaded to attract flies to oviposit. The control was soon full of ants, whereas the treated square remained clear of them.

Unfortunately, only fruit flies were attracted, but these laid many eggs and a large number of flies were bred out within the treated square; the material in the control did not breed out any flies owing to ant activities.

On October 18th, horse manure was obtained; this did not prove a successful breeding medium for house flies, possibly because it was not fresh enough.

On October 25th, fish refuse from Alaa market was used in the boxes. Both blowflies and house flies were attracted and oviposited. On November 2nd, numbers of Pheidole were seen pulling out maggots from the fish remains in the control square and apparently none were left alive. Most of the fish remains in the treated square had been stolen by a nocturnal marauder, but sufficient remained to breed out a few blowflies and house flies; ants had not succeeded in getting inside this square.

A fly-rearing medium (wheat bran, alfalfa, yeast and diamalt), taken from an issue of 'Science' (340), was used in rearing the maggots to make sure of the nature of their adult stages, as of course they flew out of the squares as soon as they became imagines, so that samples had to be reared separately for identification purposes. The fly-rearing medium, however, did not appear to attract ovipositing flies (except fruitflies) as the extract from 'Science' had stated.

The experiment was repeated with fish remains as bait; wire mesh was placed over the squares to protect the fish from marauding mammals.

Test 1

Nov. 12th. Fish remains placed in both boxes

Nov. 16th. Protected box - Between two and three hundred larvae visible.

Control box - None visible

On the following day, however, ants were seen dragging out larvae from the offal in the control box; the house flies were either killed or eaten or dragged away whole; blowflies were usually cut up and dragged away in pieces.

Nov. 19th. Protected box - 28 blowfly pupae
ca. 250 house fly pupae
ca. 150 150 assorted larvae

Control box - 87 blowfly pupae
27 house fly pupae
18 assorted larvae

The results seemed to indicate that control was less effective than had been anticipated and the reason for this was believed to be as follows. There were heavy rains on the 17th and 18th., flooding Pheidole nests, drowning many of the inhabitants and compelling the rest to repair the damage caused; the boxes were also flooded for a brief period. This suspended or at least greatly diminished ant activity for two or three days and allowed some of the larvae to pupate unchecked.

Ants did not or could not attack blowfly pupae but were seen attacking the larvae and taking them away in pieces. To see whether they would attack the pupae of either house flies or blowflies, if not provided with supplies of larvae, ten of each species were placed in the control box; they were found uninjured after three days. The ants swarmed all over them but did not attack them either because they were too tough or because they were motionless objects.

It had previously been suggested that aliquot parts of protected and control box contents be counted to determine the percentage of control by ants; but the fact that pupae were not touched suggested that a better criterion would be <u>the number that succeeded in pupating after a definite internal</u>; ten days was found to be a suitable experimental period.

<u>Test 2</u>

<u>Nov. 24th.</u> Fish offal placed in two boxes.

<u>Dec. 3rd.</u> <u>Protected box</u> - 47 blowfly pupae
96 house fly pupae

<u>Control box</u> - 25 blowfly pupae
4 house fly pupae

<u>Test 3</u>

<u>Dec. 3rd.</u> Fish offal placed in the two boxes.

<u>Dec. 13th.</u> <u>Protected box</u> - 59 blowfly pupae
187 house fly pupae

<u>Control box</u> - 22 blowfly pupae
2 house fly pupae

Test 4

Dec. 13th. Fish offal placed in the two boxes

Dec. 23rd.	Protected box -	42 blowfly pupae 131 house fly pupae
	Control box -	18 blowfly pupae 0 house fly pupae

Test 5

Dec. 23rd. Fish offal placed in the two boxes

Jan. 2nd.	Protected box -	53 blowfly pupae 142 house fly pupae
	Control box -	16 blowfly pupae 0 house fly pupae

Assuming that conditions were identical in the two boxes, the results of tests 2, 3, 4 and 5 show that the ants controlled on an average 60% of the blowflies and 99% of the house flies.

Of course, the fly breeding grounds were placed in such a way that ant access was as easy as possible, a factor which might not occur under average conditions, though Pheidole ants show a remarkable facility for getting food from the most inaccessible places.

To sum up, the experiments show very plainly how tremendously effective Pheidole is in controlling the house flies here. They show also that blowflies are controlled to a considerable extent but not nearly so effectively.

It should be noted, however, that towards the end of the tests, Pheidole had built up very large nest populations in the vicinity of the boxes, owing to the attraction furnished by continual supplies of easy food; this must be taken into account in considering the extraordinary and increasingly effective control shown in the later experiments.

Per contra, however, it must be realized that similar conditions of huge nest populations would come into existence whenever refuse--and therefore a house fly breeding ground--accumulated for some time in a circumscribed area, and so equally effective control would result. The only case when this would not occur would be in an area where Pheidole could not penetrate such as waterlogged ground. Illingworth furnished an instance of this, when he noted an outbreak of house flies in cannery waste on waterlogged ground.

THE HARM DONE BY ANTS:

On the debit side of the account is a formidable list.

Transmitting Diseases:

Ants have been accused of spreading disease. Eastman (4) considers insects as one of the most important agencies in the spreading of plant diseases, both fungal and bacterial. The charge against ants seems to be mostly an indirect one, due to their fostering of aphids, coccids and other hemiptera which transmit a number of seriously pathogenic organisms. Thus, Gossard (10) considers that the habit of ants visiting colonies of woolly aphids living in blight cankers and then of visiting aphids on expanding buds, which in turn are visited by bees and flies in quest of honey-dew, may be a means of spreading fire-blight. This is a very intricate and indirect charge and here the ants act only as one link--and by no means an essential one--in a chain of causes. Stitz considers that ants may transmit pathogenic organisms (61). Bailey (99) believes that the infrabuccal chamber contains an ideal culture medium for pathogens and says that it has been demonstrated that hyphae and spores in the voided pellets of Attine queens have given growth to luxuriant hyphae. He investigated the relations between ants and fungi in thirty-eight species belonging to all the five sub-families and including examples of diverse feeding habits and habitats. This meant examining the contents of 736 pellets from infrabuccal cavities.

Bailey found fungal spores and hyphae present in nearly every case but the amount varied greatly. It is of interest to note that harvesting ants were found to have abundant fungal matter in these cavities and he specifies the fire-ant (of which he examined six specimens from the Philippine Islands) as having numerous spores or fragments of hyphae in their infrabuccal cavities. He concluded, however, that apart from the Attini, ants were not fungivorous and that the fungus was not gathered for consumption but was the incidental result of cleaning operations or of collecting other food; a good deal of the fragments were viable and consequently pathogenic organisms would be mechanically transported from place to place. Sharples (369) has shown how certain pathogenic fungi are disseminated in rubber plantations through the agency of ants.

Wheeler (339) points out that, in addition to this way, ants might also spread disease by such methods as carrying the germs attached to their hairy bodies and walking over food or some suitable medium or through the deposition of their germ-laden faeces. Ermakov (21) suspects ants of a sinister connection in the spread of <u>Phylloxera</u> in orchards. Gravatt and Marshall (368) have indicated ants as carriers of <u>Cromartium</u> <u>rubicola</u> in greenhouses.

As regards the present problem, the immense indirect importance of ants (in particular _Pheidole megacephala_) in the matter of pineapple wilt is perhaps one of the main reasons for their control as far as the industry is concerned.

Illingworth (229) has indicated that wilt is transmitted by mealy bugs, that it is usually a disease which creeps in from the edges of fields, that the mealy bugs also come in mainly from the edges and that they are brought in by ants and when there, fostered and protected from their natural enemies by them.

In the Philippines, Barber (341) recovered cholera vibrios from the bodies of _Monomorium latinode_--an ant which is also present in Hawaii--some nine hours after they had fed on faeces from cholera patients. Cornwall (370) believes that _Leishmania_ may be transmitted by ants and Chalmers (371) writes of Oedema of the eyelids caused by them.

Carter (258) and elsewhere, in later and more detailed studies (441) (442), has established the connection between edge wilt and mealy bug infestations, particularly on young plants. Without the protection and stimulation afforded by ants, mealy bugs are usually unable to establish themselves.

Bites and Stings:

A minor harmful factor is the injury and annoyance caused by biting and stinging species.

Van Zwaluwenburg (34) reports that the little yellow ant in Porto Rican coffee fields is so vicious that pickers refuse to enter areas where it is established. In tropical countries, there are species which will attack and kill the largest animals. An army of these must indeed be as terrifying and as ruthless as a forest fire.

Though there is nothing of this nature in Hawaii, the fire ants can sting fiercely and not only can but will do so on the slightest provocation. They pour out of their nests at the first sign of an intruder, curling up their abdomens menacingly, and swarm over his clothing seeking a vulnerable spot. An interesting feature of the sting is the different effect it may have on the individual stung. In some cases, the affected part develops large and painful swellings, which may last for three or four days; in others, it is a mere momentary inconvenience. In infested fields, these ants are a considerable annoyance to laborers and for this reason alone quite apart from their habit of fostering mealy bugs, the trouble and expense of controlling them is worth while.

Fortunately, the far more widespread _Pheidole megacephala_ does not sting. The soldier caste of this species will bite but its mandibles are not powerful enough to penetrate the skin: if, however, they succeed in reaching tender, thin-skinned parts, such as the lips or between the fingers, they can inflict painful nips.

Species of the _Formicinae_, which have poison glands and a reservoir but no sting, are said to spray poison from the tip of the abdomen into wounds made by their mandibles.

Killing Beneficial Insects:

A far more serious count is that of the killing of useful insects. Ants do not discriminate in our favor when dealing with other insects and though they kill more harmful than beneficial ones, this is because the former are more vulnerable to their attacks. The beneficial parasites among the hymenoptera and diptera, for instance, are a far less easy prey than, say, the larvae of injurious lepidoptera and coleoptera. Nevertheless, ants do attack quite a number of beneficial parasites. In Turkestan (6) they have been observed gnawing through parasitized living individuals of the aphid, _Lachnus persicae_, in order to extract the larva of the parasite, though they did not harm unparasitized aphids of this species. In Mysore (38) _Coccus colemani_, a pest of coffee, is protected from a number of parasites and predators by ants; in the absence of ants, the coccid is said to be moderately well controlled. Ants are similarly said to protect mealy bugs from their enemies in Florida (71). In Western Australia, Clark (95) found the Argentine ant destroying large numbers of beneficial insects. Jarvis (142) notes that the chief insect enemy of a Tachnid parasite of the weevil borer of sugar cane is Pheidole megacephala and this ant gave considerable trouble when the breeding of this parasite in cages was attempted in Trinidad. There are said to be over forty species of predators and parasites of the common coffee mealy bug, Pseudococcus lilacinus, in Kenya, but their activities are seriously proscribed by ants, notably Pheidole punctata (145) (175) and the breeding and distribution of the ladybird Crytoplaemus montrouzieri had to be discontinued, as it was found that it was destroyed by ants three or four days after being liberated (144). In California (158), Formica cinerea was reported as disturbing the work of beneficial insects. Solenopsis geminata and other species are said to prey on the lac insect in India (185).

In Hawaii, a large number of beneficial insects have been introduced owing to the favorable conditions for their work here and to the success of one or two early efforts in this direction. In many cases, the establishment of these insects has been hindered or entirely prevented by the aggressive *Pheidole*. *Scolia manilia*, a very beneficial parasitic wasp, introduced by Muir to deal with the *Anomala* beetle, and which also parasitizes the larvae of *Adoretus sinicus*, is often attacked by *Pheidole* after heavy rain. I have seen a pack of *Pheidole* workers hanging on to this wasp, heaping earth over its wings to prevent it rising and then cutting them off; after which, it is only a matter of time before it is dismembered and carried away. Similar instances have been noticed previously by others. Williams (251) has observed *Pheidole* attacking the pupa of the ladybeetle, *Caelophora inaequilis*, the most important enemy of the sugar cane aphis. Illingworth (254) mentions that *Crabronids* and wasps of the genus *Odynerus* are also attacked, all useful insects.

Plant Damage:

In addition to the transmission of disease, ants have been accused of injuring plants in a number of ways. Firstly, there is the simple, clear-cut case of seed removal, practiced mainly by that large group known as the Harvester Ants. The fire ant, *Solenopsis geminata*, is a good local example of this group and a number of seeds, mainly weeds are found in its nests. In North America, it is said to do injury to the soft parts of seeds and also to strawberries (334). In Java (56), it carries off tobacco seeds as does the ant, Plagiolepis longipes. Another variety of the fire ant (var. xyloni) damages milo maize seed in Arizona (77).

Pheidole megacephala also is a thief of tobacco seeds, collecting them from seed-beds in Nyasaland (164). Two species of ants have been reported from the Barbados as destroying onion seeds (1). In India, Troup (12) noticed some small red ants at Dehra Dun feeding on the seeds of Pinus longifolia; the attacks were especially severe in bare areas and those with a layer of pine needles: he suggested that ants may be a cause of failure in forest regeneration.

Atta octospina has a propensity for removing the skin of cacao pods in Trinidad (13). In Kansas, Solenopsis molesta destroys the seeds of sorghum, maize and sugar (16). Atta sexdens is a pest of wheat in the Argentine (79) and maize in Brazil (151). The seeds of cotton as well as the young shoots are attacked by a large reddish-black ant (unnamed) in Queensland (84).

It is a matter of great interest that the fire ant should retain this seed-storing habit here where it is not necessary. There is abundant food--seeds, flesh or honey-dew--all the year around in these islands; yet, even the large nests in pineapple fields, in places where the fire ant is fostering Pseudococcus brevipes and has also over-ripe pineapples to gorge on will contain these granaries: they seem, however, to be perhaps less abundant in the spring and early summer than at other seasons.

By this practice, seeds are transported everywhere; it is true that they would be so carried by the wind, by mynah birds and by other agencies, but close-growing rows of pineapple plants might offer something of a barrier to seed dispersal by the two last-named methods, whereas foraging ants wander in and out among the rows and must drop a considerable quantity of seeds among them during transport to the nest.

It has been said by Emery (335) and others that the stored seeds are prevented from germinating because the ants bite off the radicle. This is by no means the case here; I have grown a number of weeds from seeds taken from ant nests, including popolo, purslane, foxtail, wire-grass, sow-thistle and a species of spurge.

Ants must play an important part in the dispersal of weeds. Serander is said (276) to have found that a single colony of Formica rufa transports about 37,000 seeds and fruits during one season. The figures here must be very much higher, owing to the large nests of the fire ants, the fact that activities extend throughout the year and the far greater numbers of seeds available.

Perhaps the most serious damage to plants by ants, especially in tropical countries, is that caused by leaf injury. The genus *Atta* is the chief offender in this respect. The leaves are cut and carried into the nest galleries where they serve as a medium for the growth of an agaric fungus, *Rhozites gongylophora* on which the ants feed. Trees may be completely defoliated as a consequence of attack. These leaf-cutting or parasol ants (Attinae) are found in tropical regions of America and are the only ants known to be strictly vegetarian. In Trinidad (13), they are a serious pest in gardens and cacao estates. In Cuba (14), they are said to injure citrus trees. Attinae are found defoliating coffee and cacao plantations in Ecuador (46), Colombia (272), the Argentine (272), Brazil (117, 120, 151, 172) and other Central and South American countries. In Brazil, they also destroy cabbage seedlings, turnips, radishes, roses, peach and orange trees.

A species of *Acromyrmex*, known locally as the 'Quem-quem ant' is also said to cut cacao leaves for fungus breeding in Brazil; besides this, it cuts the flowers and bark (103).

Fruit as well as leaves are injured. Strawberries and blackberries are attacked by Solenopsis molesta in the eastern parts of the United States (16). Strawberries are also subject to attack here, as I have noticed Pheidole sampling them at a grower's farm at Wahiawa. In the pineapple fields, ripe fruit will nearly always have ants on them, though the actual sucking of the fruit is usually but not always accomplished via the mealy bug. Whether Pheidole can itself pierce the tough exterior of an uninjured pineapple is open to doubt, but the smallest opening leaves the fruit vulnerable to attack. On the edges of fields, guava fruits are commonly found full of ants. In this case, I believe that the initial damage is done by grasshoppers and that ants swarm in through the holes these insects have made.

Other parts of the plant are also liable to damage by ants. In British Guiana (32) Atta octospina destroys the cambium layer of recently-tapped rubber trees, Monomorium floricola, a cosmopolitan species also found here, infests coconut palms and Solenopsis pylades is said to burrow in the stems of rice.

The coffee tree is attacked by an ant in Porto Rico (34) which eats out longitudinal tunnels for its brood. Both *Prenolepis imparis* and *Iridomyrmex humilis*, the Argentine ant, have been observed injuring citrus blossoms in California orchards (59, 158) and biting off leaves, twigs and bark of citrus plants in Western Australia (95). The fire ant bites the shoots and stems of avocados in Trinidad (60) and injures passion vines by girdling them in California, (67).

An ant of the species *Myrmelachista* is said to infest coffee trees so heavily in Porto Rico that they break (104). To slightly offset the good done by ants in forest, *Camponotus herculeanus* has been observed in Germany cutting the May shoots of oaks so that they bend and wither. Only oaks appear to be attacked (111). Another species of this genus, *C. fastigans* destroys coffee bushes in Brazil by stripping the roots of their bark (153). In the Philippines (83) a species of *Pheidolegaster* is reported to injure the seedless Siamese pomelo, attacking the roots, twigs and leaves.

Ermakov (9, 21) seems to consider that ant-infested trees are more liable to frost attack, as when they are present they cause a lack of uniformity in the movement of sap. He found that after getting rid of ants in his orchard, frost-bitten trees disappeared.

Tetramorium cespitum has been accused by Headlee (30) of New Jersey of causing extensive damage to lawns; *Acromyrmex landolti* is said to have injured pastures in Brazil (107). The Argentine ant has wrought havoc in vegetable gardens in the south of France (122) and necessitated an anti-ant campaign there.

Sugar cane is another crop that suffers from the direct as well as the indirect attacks of ants. In Queensland (124) (141), they build mounds round the shoots and prevent them stooling besides injuring the young roots; this also causes a severe stunting of the stools. *Pheidole proxima* has also been found in that country, tunnelling the stems and eating the softer, central portions; it undermines the rind at the nodes from which the roots spring and prevents them developing normally (143).

Nevertheless, in these islands, where sugar cane is the main industry, ants are not considered to be *directly* injurious to the plants.

Direct Damage to Pineapple Plants:

Ants do a certain amount of direct damage to pineapple plants, though it is usually not of a serious nature. Illingworth (254) has made a careful study of the matter both in the field and in the laboratory and has concluded that ants do not harm the plants and that injury attributed to them should in reality be placed to the debit of soil-inhabiting organisms on which the ants live.

Nevertheless, in the dry regions of Molokai, where *Pheidole* has modified its nesting habits and lives among the root-systems of the plants, there is evidence of injury. The roots are abraded and thus made more liable to the attack of pathogenic organisms and in many cases, the root hairs have been worn away. So far from being beneficial in carrying water immediately to the deepest parts of the root system, as Illingworth contends, it seems more likely that the drainage becomes too rapid in such places.

Further there is the unpleasant habit of ants in heaping up soil around leaves and fruits to protect coccids. *Pheidole*, *Solenopsis* and *Prenolepis* are all culpable in this respect.

Ant Relations with Hemiptera:

By far the greatest cause of damage ants do to man is by their activity in tending various plant-sucking hemiptera. In the vast majority of cases, the injury done to vegetation by these insects, if unprotected by ants, would be negligible; but tended by Formicidae, they not only multiply unchecked by their natural enemies but are stimulated in such a way as to greatly increase their normal demands on the plant tissues. In most countries, this is a major agricultural problem.

The attacks of these insects are not confined to a special part of the plant but leaves, stems, young shoots, fruits and roots are all attacked. Aphids and coccids are the hemipterons most chiefly concerned but species of Membracids, Jassids and Delphacids do considerable harm to some of our most important plant crops and have similar symbiotic relations with ants. Thus, in Queensland, sugar cane is weakened by subterranean Delaphacids, Jassids and an Aphid attacking the roots; these insects are associated with the ant Aphaenogaster longipes (141). Sugar cane is attacked by a great many ant-tended sap-suckers; in Hawaii, where it is the chief crop, very considerable success has been achieved against these harmful insects by the introduction of parasites, but in a number of cases, ants have nullified or partially nullified the efforts to introduce such parasites. In Louisiana (360), the cane is attacked by a mealy bug, comparatively harmless in itself but a serious pest when tended by the Argentine ant: this instance is a typical case. In addition to sugar cane, the ant-hemipteron biocoenose constitutes a menace to coffee, cacao, pineapples, bananas, vanilla, hops, figs, maize, avocados, cotton, coconuts, hemp, guavas, mangos, citrus fruits and vegetables as well as grasses and forest trees: in fact, it would be difficult to find any kind of vegetation which does not pay tribute to this parasitic alliance.

Ants transport mealy bugs from one plant to another, thus facilitating, hastening and extending their distribution; they protect them from their enemies by driving away predators and parasites and from the weather by building earthern shelters around them and moving them to protected places: they clean them of self-produced excretions, thus guarding them from attack by pathogenic fungi. The stimulation produced by the ant demand for their sweet excrement greatly hastens the physiological development of the mealy bugs, accelerating the tempo of their life-cycle and thus automatically making for an increase in their numbers. In Java, Van der Goot (23) found that in the case of *Coccus viridis*, the green scale of coffee which is fostered by the ant *Plagiolepis longipes*, the death rate of the scale on ant-infested bushes was considerably lower, they developed more rapidly, their parasitism by Ichneumonids was reduced and their progeny was twenty times more numerous. In Mysore (28), experiments have been made to show the influence of the ant *Cremastogaster* on the scale *Coccus colemani*. In an area infested with this scale, all ant nests were removed from one block, whereas another was left untouched. Seven months later the former block showed only 8 trees with scale on them, while the control had 132 infested trees. Another experiment to determine the effect of ants on scale parasitism showed that plants with ant nests had only unparasitized scales, whereas when nests had been destroyed many scales were found parasitized by hymenoptera.

Not only does the presence of ants greatly increase the fostered hemipteron population, but the converse is also true and a large hemipteron population leads to a speeding-up of ant augmentation, because copious supplies of an easily digestible food are available. Thus a vicious circle is formed. The control of one partner in the association automatically limits the increase of the other, though it must be pointed out that ants have many other sources of food open to them and are far less dependent on the hemiptera than the latter are on them. Nevertheless, the limiting factor is there as instanced in Seychelles (52), where a reduction in the numbers of scale insects by the agency of the fungus, *Cephalosporium lecanii* appeared to have led to a decrease in the numbers of the ant *Technomyrmex albipes*.

That hemipterons are actually transported by ants to the food plants has been questioned by some, butapart from having myself seen both *Solenopsis* and *Pheidole* moving pineapple mealy bugs on many occasions, the habit has been observed in many countries. Thomas (24) states that the cotton root louse aphid (*Aphis maidiradicis*) is dependent upon ants for traveling from plant to plant. In the Philippines (168), Manila hemp is affected by a disease called 'bunchy-top', transmitted by the aphid *Pentalonia nigronervosa* and this insect is spread through the fields by two species of ants.

Virus and toxin diseases transmitted by the secretions of sap-sucking insects exemplify some of the worst dangers with which agriculture must contend; in a great many cases, the insects concerned are fostered by ants, which thus facilitate the extention of the disease and the rapidity with which it spreads. Fire Blight (367), cucurbit wilt (362), the mosaic disease of sugar cane (363), Pear Blight (364, 365, 366) and pineapple wilt (256) (258) are examples of such diseases.

Aphids and mealy bugs are sometimes found in ant nests, for instance a species of Pheidole in Rhodesia harbors Aphis pheidolei (5). In adverse weather, nests of the ant Cremastogaster were found crowded with the coffee scale, Coccus colemani, which were hardly found at all on the coffee bushes where they usually occur (38). Pussard (194) states that the winter eggs of Aphis forbesi, which give rise to stem mothers in the spring, and are found on the petioles and leaf hairs of strawberries, are protected by two species of ants, which build earthern shelters around them. Aphid eggs are also found in ant nests as was noticed by Lubbock (361) and many others.

Another cause of injury to vegetation due to ants fostering hemiptera, is the uncovering of roots in order to secure nourishment for aphids (47); in Uganda (108), they are even said to strip the outer bark of the stem bases of coffee bushes below soil level to produce areas where the first attack by mealy bugs occurs.

The Relations of Local Ant Species with Certain Hemiptera:

Of the ants found here, Pheidole, Solenopsis, Prenolepis and Plagiolepis are inveterate mealy bug fosterers and are the species chiefly responsible for damage in pineapple fields. Though the role of the last-named may not be so comprehensive, the other species, protect, move and 'milk' the mealy bugs, even building earthern shelters (p.323) for them, an objectionable habit which induces rot in the pineapple plant around which the shelter is built. The crazy ant, Prenolepis, is particularly culpable in this respect, though the other two species often offend similarly.

Carter (441) has noticed that the incidence of wilt is low when these ants, notably Pheidole and Solenopsis, are absent. He has shown that a mealy bug colony of Pseudococcus brevipes is abnormal when it is unattended by ants. Such a colony is unlikely to increase and usually disappears.

Of the other ants in the Hawaiian Islands, the species of Tetramorium, Camponotus and Tapinoma are known to be aphidicolous, while those of the sub-family Ponerinae are believed not to foster hemiptera of any kind.

Only in the case of Tetramorium simillimum have I found mealy bugs actually inside an ant nest; in this case, the nest was constructed around the roots of nut grass. In the case of Pheidole, I have dug up nests and found roots covered with both mealy bugs and the scale Antonema indicus on grass roots among the galleries but never in the galleries themselves.

Not only are mealy bugs carried into fields from the edges by ants, but should the former be introduced into a field by some other agency such as the wind or by its own movements, it is quickly discovered by foraging ants, which look after it. Carter (441) remarked that when he has 'planted' mealy bugs in sample plots for experimental purposes, ants promptly appeared in attendance.

That ants transport mealy bugs is a well-known fact. Workers of Pheidole have been observed on many occasions with these coccids in their mandibles and the fact that they are thus introduced into the guard (or outer) rows of pineapple fields from the roots of wilt hosts on the edges is indisputable. The progress of such an invasion was watched for a period of eleven months in the Helemano area and a definite relation between the line of ant advance and that of the mealy bugs seemed to be pretty well established. In general, it may be taken that the foraging ants are found some distance in advance of the mealy bug colonies they have introduced. Once the mealy bugs are established in a field, it is quite likely that the crawlers themselves may ~~not~~ move from one plant to another. It is rather remarkable that when moving or being moved along a row, mealy bugs will often miss the weak plants and establish on the nearest healthy one. The movement is far more rapid along a row than across the rows; in this way, the guard rows, which run parallel to the field edges usually at right angles to the rows of the field proper, are a very great help in delaying the advance of both ants and mealy bugs and keeping the field clean. Ditches and banked roads, when constructed at right angles to the line of advance, more especially when they contain small, loose particles of earth and are sharply graded, retard the advance of these insects to a very considerable degree.

PART II

ANT CONTROL

CONTROL

General:

Basically, control of ants in pineapple areas may be exercised in two ways - by attempting to keep them out of the fields or by attacking them when they are there. The former would seem by far the sounder method but reasons of economy may dictate the employment of the latter.

Keeping ants out of the fields is effected by means of chemical or mechanical barriers as instanced by sodium fluosilicate barrier lines, 'ant fences' and 'dry mulching'. When already in the fields, ants are destroyed by ploughing, by dusting or spraying with various chemicals, by injecting lethal gases or volatile liquids into their nests and sometimes by igniting such gases and by poison baits.

Indirectly, ants are controlled by destroying mealy bugs--chiefly by the petrotine spray method--or by delaying the movement of mealy bugs into a field by cultural practices such as the 'guard row system'.

Climatic control of ants is an important, if irregular feature; heavy rains flood the nests, especially those with holes near an irrigation channel, and drown many of the inhabitants.

Biological control of ants is negligible in Hawaii except inter-species. There are no important ant predators and no instances of parasites have been recorded locally. Ants are singularly immune from epidemic diseases, owing to their cleanly habits, and no such cases have been noticed here.

CLIMATIC CONTROL:

General Remarks:

As has been shown in an earlier part of this paper, the distribution of ant species in Hawaii, according to observations in the field, seemed to be dependent on the rainfall. Was this actually the case or had I mistaken a number of coincidences for cause and effect?

If laboratory experiments confirmed the theory based on field observations, it was fair to assume that precipitation really was the determining factor.

Already it had become evident in my studies of life histories, that moisture was essential to life as far as *Pheidole* was concerned, for on a few occasions the water supply in artificial nest colonies had dried up unnoticed with fatal results to the colony, whereas when the same thing had occurred with *Solenopsis*, there had been no ill effects. In fact, *Solenopsis* ants were often found drowned in the water tubes provided, whereas this was rare in the case of *Pheidole*.

Moreover, in the field, Pheidole nests were always found in damp places--under mulch paper, rubbish, decaying vegetation and boulders, in short everywhere where the moisture lingered longest. On the other hand, Solenopsis seemed to prefer the open, sun-baked places for its nests; it too was found under boulders but only in dry, dusty areas where the soil was powdery; in moister areas, if found at all, its nests were always in the open and well aerated with numerous small holes.

Furthermore, as regards temperature, the ants would frequent the hottest places and the foragers were active during the warmest part of the day. Pheidole, on the other hand, was most active in the early mornings, the evenings and at night; it seems to avoid hot places as far as possible. These things seemed to suggest that temperature as well as humidity affected the two species differentially.

TEMPERATURE AND HUMIDITY EXPERIMENTS

The Effects of Low Temperatures:

Experiment 1 - January 9, 1932

Ten worker ants and five soldiers were placed in a conical flask, the air temperature being 78 degrees F. This was then transferred to a refrigerator and left for half-an-hour. When re-examined, the thermometer fitted through the cork of the flask showed a temperature of 32 degrees F. All the ants were dead except one soldier which was very feeble. Replaced in the warm air they did not recover.

This test simply showed that ants exposed suddenly to very low temperatures, as when accidentally introduced with food into an ice-box, would be killed.

Experiment 2 - January 9, 1932

A similar number of ants were again placed in the refrigerator but this time the drop in temperature was made more gradual by leaving the refrigerator door open and the minimum temperature reached was not so low. The results were as follows:

Temperature	Time	Remarks
82 deg. F.	1:56 P.M.	Ants normal
68	2:02	" rather sluggish
68	2:08	" less sluggish
66	2:14	" " "
62	2:22	" more sluggish
50	2:28	" unconscious mostly

At first the drop in temperature had made the ants sluggish but as the rate of decrease was retarded , the ants adjusted themselves to it and made a partial recovery; then as the temperature became still lower and reached 50 degrees F. they collapsed. So low a temperature does not occur in the soil of Hawaiian pineapple fields, though air temperatures below 60 degrees have occasionally been recorded at the Wahiawa Experiment Station on nights in January and February. The corresponding temperature recorded two inches below the soil in pineapple plantings is 62 degrees F. at which the ants are sluggish and nest life slows down. The effect of low winter temperatures is to suspend ant field activities at night, whereas in other seasons ants may be found tending mealy bugs during all hours.

<u>Experiment 3</u> - January 9, 1932

In the previous experiment, the ants were in contact with the glass of the flask, whereas the thermometer inserted in the cork registered the temperature of the air inside the flask. To offset any differences that might have been due to this fact, filter paper was placed inside the flask, the thermometer pushed down until the bulb came into contact with the paper and the experiment was repeated.

Temperature	Time	Remarks
88 deg. F.	3:02 P.M.	Ants normal
83	3:07	" "
71	3:13	" "
66	3:20	Slightly sluggish
61	3:26	Rather sluggish
61	3:33	Still sluggish
58	3:40	A few unconscious
53	3:47	About half the ants collapsed
50	3:53	No change
47	4:00	Further collapse
48	4:06	No change
46	4:15	All but 2 unconscious or comatose
60	4:20	Signs of general recovery
82	4:32	All recovered except 2, dead.

This experiment confirmed the results of the previous ones and also showed that ants which had been exposed to comparatively low temperatures for short periods, though temporarily rendered insensible, usually recovered.

The Effects of High Temperatures:

Temperatures in pineapple fields show considerable variations. During 1931, records were made by Dr. Carter at the Wahiawa Experiment Station of air temperatures and of temperatures taken two inches below the surface of the soil, under planted material, with three different systems of planting; the latter did not differ very considerably *inter se*.

In the winter months, the air temperatures varied between a minimum of 59 degrees F. and a maximum of 84 degrees F. The corresponding soil temperatures were 62 and 85 degrees F.

In the summer months, the air temperatures varied between 63 and 88 degrees F. whereas those of the soil fluctuated between limits of 73 and 92 degrees F.

All these temperatures were extremes and lasted only for short periods. The records were made on a thermograph installed at the Experiment Station.

The Station itself is fairly representative of the pineapple areas as a whole; it is situated at rather less than a thousand feet above sea level and has a somewhat moist climate (about 50" annual rainfall). The drier areas would certainly experience higher temperatures.

Soil under planted material has much lower temperature maxima than the soil of unplanted fields. Hagan (421) took temperatures of uncovered soil at Wahiawa Experiment Station during the summer months of 1931. He found that uncovered soil at 1/4" depth frequently rose above 104 degrees F. (40 degrees C.) for two hours or more, except from December to April. In July and October, the soil at a depth of three inches occasionally has temperatures between 100 and 104 degrees F. for two hours or more.

Soil covered with mulching paper, but unplanted, averaged 12½ degrees F. higher in temperature than uncovered soil at 1/4" depth and 11½ degrees F. at 3" depth.

The nests of *Pheidole* in pineapple fields are almost invariably found under mulching paper shaded by plants; those of *Solenopsis* usually occur in uncovered soil not shaded by plants.

It may be objected that the shadows of plants move with the sun and so it would be fatal for a nest to be located at any given spot. This is quite true, but the ants counteract the shifting shade by moving their immature stages and themselves from one part of the nest to another. The high temperatures underneath unshaded mulching paper is the reason that a young field only contains small *Pheidole* populations of scattered, little nests. As the plants grow and provide more shade, these nests increase in size and ramify under the mulching paper; movement to other rows is less necessary and so the rate of invasion into the interior of the field is often retarded.

Pheidole is the dominant ant at Wahiawa, though small colonies of *Solenopsis* are sometimes found.

To test the effect of high temperatures on the two species, artificial nests of each were placed in constant temperature cabinets at 77 deg. F. (25. deg. C.), 85 deg. F. (30 deg. C.) and 95 deg. F. (35 deg. C.). The first fairly represents average yearly temperatures on or just below the soil, under planted material, at places such as Wahiawa; the second represents existing conditions on the surface of unplanted soil and 1/2" below it, during the warmest part of the day in the winter months and at a depth of 3" during the summer; whilst the third is somewhat below surface soil temperatures and those just below the surface, during the warmest hours of the day in summer.

For each experiment, nests consisting of glass jars closed with bolting silk and containing one queen and about fifty workers and soldiers on a floor of quartz sand together with food and water were placed in the temperature cabinets. The experiments lasted from October 31 to December 1, 1932.

Results with the 77 degree F. Cabinet:

Solenopsis: The colony was kept successfully for a month; the ants seemed somewhat sluggish and less aggressive than usual but otherwise behave normally.

Pheidole: The colony was kept successfully for a month and appeared to be behaving normally.

Results with the 86 degree F. Cabinet:

Solenopsis: The colony lived normally throughout the month.

Pheidole:	Oct.31st.	Colony placed in cabinet
	Nov. 1st.	Appearance normal
	Nov. 3rd.	Some workers dead
	Nov. 5th.	Queen dead; most workers and soldiers dead. Experiment repeated in larger jar with fresh colony.
	Nov. 7th.	A few workers dead
	Nov. 16th.	Entire colony dead
	Nov. 17th.	Experiment restarted.
	Nov. 21st.	Queen dead; only one worker and one soldier alive. Experiment abandoned.

The experiment showed that a continuous temperature of 86 degrees F. is too high for Pheidole, though perfectly suited to Solenopsis.

Results with the 95 degree F. Cabinet:

Solenopsis: The colony was kept successfully for a month though a few died; the ants were abnormally aggressive and swarmed to the attack whenever the jar was touched.

Pheidole:	Oct. 31st.	Colony placed in cabinet
	Nov. 1st.	All soldiers and workers dead; queen very feeble. Experiment repeated in larger jar with fresh colony.
	Nov. 2nd.	All workers and soldiers dead.
	Nov. 3rd.	Queen dead. Experiment repeated with fresh colony.
	Nov. 5th.	Entire colony found dead. The experiment was repeated using moist earth as a floor instead of quartz sand; this time the ants lasted a little longer but all were dead in three days; the experiment was repeated with the same results.

The experiment shows that while Solenopsis is quite able to live at this temperature, it is soon fatal to Pheidole.

It was now clear why Pheidole nests were always found in sheltered places, whereas Solenopsis chose unprotected soil: but this did not explain the local geographical distribution of these species.

Humidity Experiments:

It was decided to try and find out whether relative humidity was the determining factor in this respect and as Pheidole queens seemed always to choose moist locations for their habitats, experiments were made to determine their humidity optima.

Accordingly, an apparatus was prepared as follows: Four zinc cylinders, 6" high and $3\frac{1}{2}$" in diameter, were made, each with the top flattened so that a greased, ground-glass plate could be placed on it and make an air-tight joint. The bottom of each cylinder fitted into a cylindrical tin containing a solution designed to keep the humidity of the air within the cylinder constant (422), when the glass top was in place. Two-thirds of the way down, a metal gauze platform, secured with a wire ring, fitted tightly inside the cylinder. The platform was to support the queen ants and to prevent them from falling into the solution below. Just above the platform was a hole in the side of the cylinder into which a short metal tube was brazed, leading outwards. The distal end of each of these cylinder tubes was connected with rubber tubing to the metal tubes of the central chamber. This chamber was the same width as the cylinders but only 1/2" high and closed at the bottom but having no top, being fitted with a glass plate similar to those of the cylinders. The central chamber had four small tubes, at right angles to each other, leading outwards; they were connected with rubber tubing to the tubes of the four cylinders. Page 3/2 shows the apparatus set up.

Queens were placed in the central chamber and allowed to move through the tubes into whichever cylinder contained the most suitable atmosphere. The temperature was about 80 degrees F. throughout the experimental period. The atmospheres in the cylinders were kept at constant humidities by keeping the following super-saturated solutions in the tins.

Relative humidity of Cylinder Atmospheres:	Super-sat. Salt Solution:
(i) 10% Rel. Hum.	Zinc chloride
(ii) 33% " "	Magnesium chloride
(iii) 63% " "	Ammonium nitrate
(iv) 93% " "	Potassium nitrate

During the course of the experiment, solution (iii) was found to corrode the container and was replaced by:

(iii)a 60% Rel. Hum.	Sodium bromide

The relative humidity of the room during these experiments varied from a minimum of between 50 to 60% in the middle of the day to a maximum of 80 to 90% at midnight. Experiments were conducted in a dark room, so that light was not a factor; the cylinders were switched around to different tins after each test to obviate any hidden factors which might be attributable to them.

Test 1. Oct. 18th

Nine queens (Pheidole) were placed in the central chamber.

Sixteen hours later 8 queens were found in the 93% cylinder
1 queen was found in the tube leading to it

Test 2. Oct. 19th

The same queens were used again.

Twenty-four hours later 5 queens were found in the 93% cylinder
1 queen was found in the tube leading to it
2 queens were found dead in the central chamber

As most of the specimens now appeared weakly, they were discarded and ten fresh queens were obtained.

Test 3. Oct. 20th.

Ten queens placed in central cylinder.

Twenty-four hours later 9 queens were found in the 93% cylinder
1 queen was found dead in the 10% cylinder

Test 4. Oct. 22nd

Eight queens placed in the central chamber

Twenty-four hours later 5 queens were found in the 93% cylinder.
3 remained in the central chamber

Test 5. Oct. 23rd. 1932

The experiment was repeated using the same queens.

Twenty-four hours later 4 queens were found in the 93% cylinder
1 (very weak) in the central chamber
1 in the 63% cylinder
2 (dead) in the 10% cylinder

Test 6. Oct. 26th

Ten fresh *Pheidole* queens were placed in the central chamber.

Twenty hours later 8 queens were found in the 93% cylinder
1 queen was found in the 63% cylinder
1 queen was found in a connecting tube.
This last one was in a weak condition and was discarded

Test 7. Oct. 26th

Nine of the ten queens used in the previous experiment were once more placed in the central chamber.

Twenty-four hours later 6 queens were found in the 93% cylinder
2 were found dead in the central chamber
1 was found in a connecting tube (to the 93% cylinder).

Test 8. Oct. 27th

Eight fresh queens were placed in the central chamber.

Twenty-four hours later all 8 were found in the 93% cylinder.

Test 9. Oct. 28th.

The same queens were placed again in the central chamber.

Twenty-four hours later 5 queens were found in the 93% cylinder
2 in the 33% cylinder (very feeble)
1 in the 10% cylinder (dead)

Test 10. Oct. 29th

Six queens (2 fresh, 4 old) were placed in the central chamber.

Twenty-four hours later 3 queens were found in the 93% cylinder
1 in the connecting tube to it
2 in the central chamber (rather feeble)

Summarizing this experiment, out of a total of 86 queens, used in 10 tests, 72% of them went into the 93% cylinder (Relative Humidity); but during the course of the tests, it was found that owing to death and rapid feebleness supervening if queens were used more than once, their reactions were unreliable and so could not be compared with their natural behavior in the field. A fairer summary of results would include only those tests made with fresh queens and, if only such be taken into consideration, out of 39 fresh queens, 89% of them went into the 93% cylinder. As regards the driest (10%) cylinder, the only four queens which found their way in during the ten tests were found dead.

The results of these tests show that Pheidole queens prefer an atmosphere of very high relative humidity and cannnt exist in one of low relative humidity.

This experiment was repeated with Solenopsis queens but no results of any significance were found to be obtainable; the queens simply huddled together and might be found in any of the compartments: the only conclusion which might be drawn--and that very questionably--was that these queens were indifferent to the relative humidity of the atmosphere.

Habitat Experiment:

A sample area with dry powdery soil at Gilbert (Ewa) in the Solenopsis area was selected. Two large enamel trays were sunk with the rims nearly flush with the ground.

A nest each of Solenopsis and Pheidole were placed in the respective trays with plenty of the powdery earth from this area and a large flat stone for shelter. The rims of the dishes were liberally greased with a mixture of axel grease and pine tar to prevent the ants escaping or being attacked from outside by other ants. A low canvas screen was erected to prevent dust being blown over the grease.

The trays were left exposed to the sun in a similar manner to nests of the fire ant in this district. Two days later, the locality was revisited. Pheidole were all dead; Solenopsis still alive.

The experiment was repeated twice with the same results.

This test showed that the habitat, which suited Solenopsis is too hot or too dry (or both) for Pheidole to inhabit. As the experiment was made during the cooler part of the year, (end of November 1932) dessication and not temperature was probably the determining factor.

Warmth and Moisture Traps:

A practical application of these tropisms is a trap, moister than the surroundings in dry districts or warmer than its surroundings in cold seasons.

In Louisiana (37), these were made of wooden boxes, filled in winter with damp stable manure and dry seeds and straw, the manure acting as a heat producer and attracting the ants to the nest in the box.

In fairly dry areas, Pheidole, when present at all, may always be found in places where moisture is most conserved, e.g. under mulching paper, boulders, etc. By placing similar objects in suitable places, these ants may be induced to nest under control and destroyed at intervals.

At my request, Mr. Y. Omuro conducted a preliminary experiment on these lines in the very dry Pulehu district of central Maui (Jan. 1933). Empty cans were filled with a quantity of soil and one of the following materials--wasted, decaying mulching paper, dried weeds, decaying empty sacks, dried weeds with sliced pineapple, sections of pineapple root and green weeds. The cans were soaked in water and then buried under the mulching paper. After 10 days the cans were removed and examined: three out of fifteen cans contained ant nests and seven out of the remaining twelve contained ants. Waste mulching and sections of pineapple root gave the best results.

BIOLOGICAL CONTROL

Predators:

Arthropods:

Forel is said (276) to have stated that 'the most dangerous enemies of ants are other ants, just as the worst enemies of man are other men'. This statement, true in general, might be made more emphatic in its application to Hawaii. Here, one might go so far as to say the only dangerous enemies of ants--apart from man--are other ants, for we lack even those few predators which take their toll in other countries.

(a) Arachnida:

Colonies of ants kept at the Experiment Station under artificial conditions sometimes became weakly and the nests were found to be infested by mites. In December 1931, Mr. Ito of this Station found that *Pheidole* ants, which he was keeping in root cages, attending mealy bugs, were covered with mites in such numbers that the ants could not cope with them. Mites are said by Van der Goot (23) to be the worst enemy of *Plagiolepis longipes* in Java. Australian ants (31) are reported to be associated with a large number of *myrmecophilous* mites, but these are not all harmful, some acting as nest scavengers. Newell (252) found two kinds of such inquilines in the nests of the Argentine ant, a species singularly immune from 'guests'.

Spiders harm ants to some extent. The winged stages are often caught in their webs and workers are both snared and hunted by certain spiders, some of which actually enter formicaries and seize and carry off feeble individuals; certain spiders even spin their webs near or inside ant hills. In Hawaii, Williams (234) observed an attid spider rob Prenolepis bourbonica workers of their larvae and pupae, while they were moving their nest; he also found a local hunting spider, Heterapoda regia, would seize and eat Prenolepis queens. The same observer states that the nocturnal Camponotus maculatus falls victim to the hour glass spider, (398) Latrodectus mactans. Nevertheless, the ant population is so vast that the amount of control exercised by spiders must be insignificant. Howard (29) describes a Solpugid spider, Eremobates magnus, which when taken to an ant hill destroyed hundreds of the ants in a few minutes: possibly the introduction of such a species might act as an appreciable control.

(b) Insecta;

Among insects, Cicindellidae have been observed catching ants by a number of entomologists. Among the Neuroptera, the antlion is a well-known formiciphage: some dipterous larvae of the family Leptidae behave in a similar manner, as described by Reaumur and De Geer and quoted by Bequaert (296). Some muscids attack ants moving their nests and snatch the immature stages in the same way as did the spider recorded by Williams: Asilidae have been seen attacking winged ants. A bug, Ptilocerus ochraceus, attacks ants in Java (27).

A few wasps of the super-family Sphegoidea are described by Bequaert (276) as ant hunters and provision their nests with them, some with the queens--which is understandable--but some take worker ants, surely a meagre form of nutriment for the wasp larvae. Trachloides quiniquenotatus is said to store forty or fifty paralyzed workers of Tapinoma erraticum in each cell. I have noticed nothing like this here, though the opposite case is often in evidence, especially after heavy rain, when Pheidole workers may be seen attacking and killing such parasitic wasps as Scolia in considerable numbers: in dry weather, such attacks are seldom made.

But the only real insect checks on ants are other species of ants and sometimes ants of the same species. Forel (272) has recorded numerous instances of wars between the same species and different species of ants, which may be of long duration and may occur for almost as many reasons as they do among men. Besides the ants which occupy definite territory and only fight to defend it or to extend it or to appropriate some desirable property of their neighbors, such as a colony of aphids, there are others, the driver or legionary ants, which are analagous to the nomadic tribes of desert Arabs and whose existence is just one campaign after another.

Many species, through the possession of some characteristic of success, such as superior adaptability, cooperation or persistence or through the possession of an invincible weapon or tactic have managed to dominate other species and, in some cases, almost to exterminate them. Human progress, in the shape of increasingly swift and extensive transport facilities has greatly enlarged the dominion of such species.

Wheeler (273, 348) has recorded how Pheidole megacephala was at first the dominant ant on Madeira--almost certainly having been introduced from elsewhere to the detriment of earlier inhabitants--and how it in its turn has been supplanted by the Argentine ant, Iridomyrmex humilis. He mentions two islands in the West Indies, Culebrita and Culebra, separated by a narrow channel, the former over run by Pheidole megacephala (which he suggests was introduced from St. Thomas), no other species being present, the latter by Solenopsis geminata. He suggests that the absence of Pheidole on Culebra is due to the presence of the fire ant there; judging from experience in Hawaii, it is far more likely that the opposite is the case and that, if introduced into Culebra, Pheidole might replace Solenopsis. These examples of ant wars, invasions and supplantings could be multiplied a hundredfold. The above cases are instanced because these species are the very ones with which we are concerned in these islands.

There is no record of when these and other species were first introduced here. The only ants believed to be indigenous to Hawaii are species of _Ponera_; formerly, they may have lorded it here; now, they are not often seen and persist as comparatively rare insects, hidden away in odd corners not yet occupied by the aggressive aliens. Very occasionally, one or two specimens are found in the pineapple fields. It would be interesting to know in what order the various cosmopolitan species found here became established and to follow the gradual assertion of supremacy by one species over another. At present, the issue of the struggle seems clear enough--_Pheidole_ is slowly driving the other species out of all the territory habitable to itself. Why this is so, I have tried to show elsewhere in this paper.

There is evidence that this struggle has been taking place for some time. As early as 1880 (308) _Pheidole_ was said to be one of the commonest ants on Oahu. Already in 1913 (252), Perkins had noticed the spread of this ant and how it had displaced other insects in regions favorable to it. In 1916 (207), Illingworth noted that it had supplanted _Prenolepis longicornis_ and _Solenopsis geminata_ in certain districts here.

On the other hand in 1922 (215), Crawford makes mention of a temporary scarcity of Pheidole in Manoa Valley and states that it was being replaced by Plagiolepis; Gifford had also noticed the prevalence of one or other of these species at various times. It should be noted, however, that they are not antagonistic to each other but will occupy the same territory, so that this is not a case of the balance of combat but of some other factor, possibly climatic fluctuation.

Perkins (252a) stated that the large, striped ant, Camponotus maculatus, was an intolerable nuisance in Honolulu houses, breeding in incredible numbers in the walls. This is certainly not the case now, though it is not uncommon in certain parts of the city and Williams (251) considers that Pheidole is responsible for this decrease. Illingworth concurs with this (254). I have kept this ant and other species (Solenopsis, Prenolepis, etc.) in artificial nests in the laboratory: before I had realized the necessity of safeguarding them by placing them on ant-proof tables, I invariably found that they were killed by Pheidole within twenty-four hours. These intolerant invaders probably lived within the woodwork of the Experiment Station buildings and unerringly discovered the presence of alien species; assembling an army, they invaded the artificial nests through minute crevices and made short work of the strangers.

In 1926 (223) (254), Illingworth re-emphasized his observations of ten years previously, namely that Pheidole was driving out the other species and described the way in which it attacks Solenopsis.

On many occasions I have tested the fighting capabilities of these two species. The following is an example of what happens:

Ant Fight - Monday, January 11, 1932

A contest between the two ant species, Pheidole megacephala and Solenopsis geminata was staged in a zinc tray, 3 ft. wide by 4 ft. long by 6 inches deep, filled with earth.

Colonies of approximately equal size were dumped into the middle of the tray, about a foot away from each other.

A fierce contest ensued. It was soon apparent that, singly, Pheidole was no match for the fire ant. The latter's modus operandi was to crush the head of a Pheidole worker in its jaws; as it could not crush the soldiers' heads, it crushed their abdomens or severed the petiole. Pheidole workers, on the other hand, fought by hanging on to the appendages of an opponent and pulling or biting them off; these tactics proved relatively inefficient, unless their superiority in numbers was very great. (In the field, this is usually the case and organized gangs of Pheidole workers may be seen, mobbing a larger opponent, all hanging on to a leg or antenna and pulling different ways for hours if necessary, until their luckless opponent is pulled to pieces). The soldiers use their mandibles to sever the limbs or abdomen of an opponent.

In this contest, the *Solenopsis* colony seemed the better organized, some acting as aggressors, others removing larvae and pupae to a place of safety; whereas the *Pheidole* ants ran hither and thither with their larvae and pupae and seemed to have no organized plan.

As the contest seemed too uneven, another colony of *Pheidole* was added as reinforcements, more than doubling their numbers but the fire ants continued to kill them and to drive them away. After an hour or so, fighting died down; the fire ants established two nests in diagonally placed corners of the tray, where pineapple plants had been planted and a small *Pheidole* nest was formed near one of them; others of the smaller ant retreated under the beading of the tank. The latter was isolated from the table on which it stood by oil-filled cans. On more than one occasion, a *Pheidole* queen was attacked by fire ants but escaped uninjured. Three or four hours later, pugilistic activities appeared to be in abeyance and when the fire ants encountered the remnants of their adversaries, there was no aggression. A week later, there were a few of each species still in the tray, but most of them had escaped.

On the 29th. of January, a [illegible] nest of fire-ants was added and also some *Pheidole* ants; this time, they were placed further apart--two feet. Nevertheless, foraging fire ants immediately attacked the Pheidole stronghold, but being few in comparison with the Pheidole they were eventually killed. The fire ants, however, established one nest near the Pheidole nest and another party of them advanced to the other end of the tray, where they found a small fire ant nest established by the earlier inhabitants of eighteen days ago. There was a fierce struggle for some hours, which resulted in many casualties. Eventually, however, hostilities died down and they appeared to tolerate each other.

These two species then not only attack each other but will also fight other nests of their own species--though this is not always so. Toleration, after an interval, seems the rule in each case.

A further instance of this was noticed when an individual Tetramorium guineense (which is larger than Pheidole but not aggressive) was placed in a small Pheidole (artificial) nest. It remained absolutely still--its forelegs placed defensively over its head--while several Pheidole workers investigated the stranger and some threatened it. The The Tetramorium moved slightly and one very suspicious Pheidole noticed this and began nipping its legs and abdomen. This brought more Pheidole workers along and two of them secured its antennae and began to pull them from opposite directions very vigorously. After half-an-hour of this, they left it alone and it began to move again very cautiously.

Fire ants and Pheidole will usually fight when they meet, grappling like lightning and seldom letting go until one is dead, however long the fight may last; but they do not do so invariably. When one species is in greatly inferior numbers or on enemy territory, it will avoid combat when possible. When these two species have settled down in adjoining territory, they may remain without intercourse, hostile or otherwise, indefinitely. Then some predisposing cause, probably climatic or biotic, will precipitate an advance by one side or the other--usually by Pheidole--and there follows war, massacre and an adjustment of boundaries.

Pheidole will tolerate very small ants such as the sugar ant, Plagiolepis mactavishi, and the Cardiocondyla species, which live in very small colonies; I have seen Pheidole and Plagiolepis attending the same mealy bug and colonies are often found under the same stone; very occasionally, Pheidole allows Tapinoma melanocephalum, an ant intermediate in size between the ants mentioned above and itself to nest in its territory; however, this ant is far too fast for Pheidole to catch anyhow.

Although Solenopsis is stronger and far more menacing when its nest is attacked than Pheidole, outside the nest the former ant is far the less pugilistic. When I placed Camponotus and Solenopsis colonies together, the latter quickly destroyed the former, for Camponotus, in spite of its great size, is quite incapable of defending itself; but, in the field, all the species will nest in the same territory as Solenopsis undisturbed and under the protection it offers against Pheidole.

Plagiolepis mactavishi and the Cardiocondyla spp. enjoy the same immunity from the fire ant as they do from Pheidole and will nest under the same stone. I have also found Tapinoma and Monomorium similarly placed and apparently quite at ease.

A very surprising find was a number of dead fire ants in the nest of a crazy ant colony (Prenolepis longicornis). Was it possible for these weak creatures to tackle and kill the terrible Solenopsis? My question was soon asnwered for in the same nest, I soon came across a large Solenopsis soldier, which was being mobbed and killed by crazy ants. The latter were too quick to allow the fire ant to bring his formidable weapons into play.

Warren (237) has studied the food habits of two species of Hawaiian dragon flies, both of which take ants to some extent. He does not say whether they were winged or otherwise. The Odonata seem to feed mainly while flying and it is unlikely that they take a heavy toll of ants except during a mating flight. Mr. Swezey of the H.S.P.A. tells me that he has observed dragon flies hawk the winged stages of ants. Hadden (236) in his analysis of the food of Mantids in Hawaii does not record any ants.

Amphibia:

Amphibia are an important check on ants in other countries, taking up to two-thirds of their food in the form of ants. Pheidole megacephala has been found in the stomachs of both frogs and toads in the Belgian Congo (276), where five out of eleven species took ants as about fifty per cent of their food.

Reptilia:

Reptiles are, if anything, more partial to ants than are amphibians. The Australian moloch, for instance, is reported to feed exclusively on them. Lizards, chameleons and skinks, all are insatiable devourers of ants. In the southwestern United States, horned toads eat large numbers of Formicidae and will attack their nests.

In Bermuda, an Anolis sp. of lizard fed largely on Pheidole megacephala (128). Stejniger (265), lists four geckos and three skinks as occurring in the Hawaiian Islands, none of them indigenous. Neither he nor McGregor (263) nor Snyder (264) make any reference to their food habits except a general statement of Snyder's that 'they may be regarded as beneficial in that they destroy a large number of insects. They are not inhabitants of pineapple fields: Dr. Carter of this Experiment Station has noticed a lizard to be common in Caribbean pineapple fields; it is a mealy bug eater.

Aves:

But the most widespread predators are birds. In the temperate zones, blackbirds, thrushes, finches, flycatchers, wrynecks, meadowlarks and woodpeckers--especially the last-named--are prime ant feeders. Beal (313) found that ants form the largest item (28.4%) of the food of the sixteen species of North American Picidae. Brachypternus aurantius is a great destroyer of ants in India and Ceylon (68). Wasmann (314) has seen the green woodpecker not only attack the nests of wood-boring ants but also those of terrestial ones. The mynah is said to prey on ants in Australia; mynahs in Hawaii are so numerous as to be a pest, yet I have never seen them eating ants and Mr. Hosaka of the Bishop Museum, Honolulu, has examined the alimentary tracts of mynahs as well as those of pheasants, turtle doves, quail, plovers and linnets without finding any. Mr.Swezey of the H.S.P.A., Honolulu, however, believes that he has seen ants in mynah's stomach contents.

In the tropics, there are many birds whose diet is entirely or almost entirely restricted to ants, such as the Formicariidae or ant-thrushes of Central and South America, and it is unfortunate that a few such species have not reached these islands and become established.

The stomachs of three plovers, two quail a nd three doves freshly shot in an abandoned pineapple field in the Helemano district were examined in February 1953; no ants were found.

Mammalia:

In addition to these animals, there are many mammals, which habitually or occasionally prey on ants, such as moles, mice, rats, hedgehogs, shrews, bears and monkeys. Jarvis (116) states that rats in Queensland destroy a considerable number of the larvae and pupae of *Pheidole megacephala*. An African mongoose, *Bdiogale nigripes*, does so but the introduced mongoose in these islands has not been noticed to have similar feeding habits. Chimpanzees devour colonies of *Camponotus* and *Megaponera* spp. in Central Africa (276). Even man has included forms of Formicidae in his diet either as an actual food or as a condiment and the habit is so widespread as to include peoples in Asia, Africa, America and Australia. In tropical Africa (317), queen ants are eaten by the natives, while in India, Burma, Siam and Borneo, a paste of the green weaver ant is eaten with curry as a condiment (318, 319). All forms of another species are eaten pickled in Siam (358). North Queensland has another recipe, for here (320) ants are mashed up in water to provide a drink with a kick. Mexican and Indians of the southwest United States are said by McCook (290) to eat repletes of the honey ant. Riley (316) records a number of instances of ant consumption in rural districts of America. The great variety of races in Hawaii, though their diet contains an incredibly weird assortment, seems lacking in this respect.

Then there are a number of animals specially adapted to deal with ants such as the armadillos of South America, the spiny ant-eaters of Australia and the African pangolins, animals which also occur in southern and eastern Asia; most of these creatures attack ant nests. The idea of a mobile band of trained pangolins, attached to the headquarters of a pineapple company for use in ant-ridden quarters, is not without its attractions: armadillos in Brazil are said to prefer the fire ant to other species (276): they could have an epicurean feast in some of the drier fields on Oahu.

PARASITES:

Insects:

Ants are far more immune from parasitic attack than are other insects; the adults are active, aggressive, hard-bodied and cleanly, all of which makes them difficult to attack, and the immature stages are inaccessible and constantly guarded. Nevertheless, ants have parasites; a large number of these live within the nest and have been described in considerable detail by Forel (272), Wheeler (273, 275), Wasmann and other authorities.

But in addition, there are other parasites, which attack adult ants outside the nest. Smith (148, 149) has observed two species of Phoridae, _Plastophora crawfordi_ and _P. spatula_ attacking worker fire ants in Mississippi and presumably ovipositing in them. Thinking they might be of use in controlling fire ants here, I wrote to him about them; he answered that any control they might exercise was too insignificant to notice. Pierce and Crawford had previously noticed that the fire ant was attacked by these Phorids, as reported by Coquillet (324). According to Forel (272), Coquillet states that in Brazil _Plastophora crawfordi_, whose female is wingless, lives with the ants, laying its eggs on the head of _Solenopsis geminata_. Another Phorid, _Apocephalus_ pergandei, attacks a species of Camponotus and A. schmitzi parasitizes a Crematogaster sp. In Java, there is a Tachnid, which attacks the ant Dolichoderus bituberculatus, a pest of cacao plantations.

Pergande (325) was the first to describe flies attacking ants in this way.

Fungi and Bacteria:

In spite of living under such crowded and intimate conditions, ants seem comparatively immune from fungul and bacterial diseases; this is probably due to their extreme cleanliness. Bequaert (58) records the case of a species of Formica, attacked by a fungus near Boston. He further mentions a number of fungous parasites on species of Formica, Lasius, Camponotus, Paltothyreus and Pseudomyrma. He states, however, that such cases are extremely unusual and considers it due to the very cleanly habits of this insect. Three species of the family Laboulbeniaceae are mentioned and these do not appear to injure their hosts. On the other hand, ten species of Cordyceps, a genus whose members attack many insects, have been recorded on ants and are extremely deadly. The paper contains an annotated bibliography at the end. In a later work (276), he gives further examples.

In Brazil (121), Argollo Ferrao has imported cultures of Botrytis bassiana and Isaria densa in an attempt to control the leaf-cutting ant, Atta sexdens. Donisthorpe (327) found an alga infesting a species of Lasius in the south of England.

Ants do not appear to suffer from bacterial diseases. Glaser (in a letter dated January 4, 1932) writes 'I know of no epidemic diseases attacking ant colonies' and that ...'ants are usually regarded as immune to infectious diseases'. However, ants like other insects do possess unicellular organisms within certain of their body cells. These organisms live in symbiosis with their host and are transmitted to the next generation at oviposition. Blochmann (328) (329) was the first to observe and describe these symbionts. Buchner (330) gives the best and latest general account of them. They are found in all castes and their functions, though probably connected with the digestion of the ants' nutriment, are not yet thoroughly understood. Their presence has been noted and studied in species of Formica and Camponotus.

CHEMICAL CONTROL

A considerable number of chemicals has been employed in the destruction of ants with varying results. These substances are either applied directly in dust, spray or gaseous form or mixed with some attractive substance used as bait. The direct method is quicker but usually only kills the insects coming into contact with the poison, though doubtless it has minor secondary effects in that ants clean each other and thus other ants may lick up poison from infected ones and the latter may also leave poison about the nest. In the case of poison baits, however, the secondary action is far more widespread, owing to the fact that workers regurgitate their food and feed the nest inhabitants, thus poisoning nest workers, soldiers, males, females and even the immature stages. So slowly but surely, poison is spread through the entire nest with devastating results.

DIRECT POISON APPLICATIONS:

Dusts and Sprays:

The substances most generally favored are cyanides. Sodium or potassium cyanide has been used successfully by Van der Goot (23) in Java against *Plagiolepis longipes*, the gramang ant, which fosters green scale in coffee and cacao plantations, by Girola (41) in the Argentine in protecting wheat, in the control of the fire ant in Trinidad and Tobago (60), where it is a pest of avocados and against the same ant in California (67) where it injures passion vines. In Florida (71) and Panama (72), successful results have been obtained against various ants by this method. The substance is used generally in the form of a solution, 1 or 2 ozs. of the potassium salt, 2 or 4 ozs. of the sodium salt to a gallon of water, though a solution as weak as 0.3 per cent of sodium cyanide has been used effectively in Italy (160) against Tapinoma erraticum and Iridomyrmex humilis.

Calcium cyanide has been employed in powder form either by blowing dust down the nest holes or by scattering it around them. In tropical and sub-tropical America, including the West Indies, it is used to control the leaf-cutting Atta species (114, 127) and to attack a Camponotus sp. in Ceylon (126). Wildermuth and Davies (288) recommend it against the red harvester ant, Pogonomyrmex barbatus, though only claiming that it suspends ant activities for a week or so. It has been used in Mauritius against the fire ant (177). As mentioned later, experiments in controlling this ant by this substance were made during the course of the present studies but though very effective, it was found to be too expensive for extensive use. In Kenya coffee plantations, it has also been tried and found too expensive.

Hydrogen cyanide (prussic acid) has been used against the Argentine ant (48) in liquid form and as a gas for destroying ants in houses in Denmark (74).

Cyanide compounds are very dangerous to use as they are lethal to man as well as to insects; this factor, in addition to that of expense, greatly limits the employment of this highly efficient group of insecticides.

The application of poison dusts gives rather uncertain results and is usually effective only against a small proportion of the population attacked. They are more useful in houses than in the field. Gibson (17) suggests sodium fluoride should be blown into cracks or openings in the woodwork of houses with a dust gun. Illingworth (207) remarks that if this dust is laid in places frequented by ants, it causes them to disappear. Marcovitch (125) recommends the use of sodium fluosilicate against ants. Both ~~these~~ substances were tried in the course of these studies, the latter proving slightly more efficacious in laboratory experiments; however, in the field, it met with only partial success. The dust was apt to cake in the presence of moisture and was also liable to be blown away by the wind in the preliminary experiments when used as a barrier outside the guard rows and for dusting ant runs. Calcium fluosilicate proved less effective than the sodium salt.

Mercury bichloride (corrosive sublimate) has been widely used against ants. Though chiefly recommended as a repellent in the form of ant tape, etc., it is also used as a contact poison. Woodworth (344) found it ineffective against the Argentine ant, though he obtained good results with it against a Tapinoma sp. From experiments outlined later, it seems to be of limited use against Pheidole. Horton (18) suggests mixing it with tree-sticky in the proportion of one to six parts and states that tree bands smeared with this mixture remain effective for three months; he also gives a recipe using 20 gms. of the mercury salt dissolved in 60 cc. of ethyl alcohol and added to 31 gms. of shellac. This dope painted on wood is, he states, effective for more than a year. As shown later, both these recipes were tried on ant fences but were ineffective in keeping Pheidole out for more than two or three weeks. Nevertheless, though not of much use out-of-doors in Hawaii, mercury bichloride appears to be an effective control when applied on house furniture both here (207) and in South Dakota (76). It has been used in Ecuador (72) and Brazil (173) against the leaf-cutting ants and for protecting beehives in South Africa (110). Dissolved in methylated spirits and mixed with resin in a solution of castor oil, it is applied on tree-bands for protecting coffee in Kenya. The mercury bichloride, alcohol, shellac mixture is also used as a banding solution in Mexico (80); it must not be allowed to come into contact with metal.

Lead is another toxic metal which has been used against ants and it has been found that if onion seeds are shaken up in red lead powder before sowing, they are effectively protected against ant attack (65).

Other contact dusts include pyrethrum powder, which has been tried in Germany (75) and quicklime poured on ant hills in Colombia (19). Arsenic and sulphur have been used against Atta species in Brazil (151, 159), by burning these substances and letting the resultant gases penetrate the nests; this is sometimes modified by the addition of wood charcoal--all three substances in equal parts--(137). In the United States, arsenical compounds such as sodium arsenite, London purple and Paris green have given good results when sprinkled in rings around nests (288, 303). In Cuba (14) and Ecuador (72), fumigation with sulphur dioxide gas has been used against leaf-eating ants, whereas in the Argentine (28), liquid sulphurous anhydride was used against the same pests: sulphur fumes were also employed against them in Brazil (78, 173).

Paradichlorbenzene mixed with carbon bisulphide has been tried in Queensland (124), it is used by itself to control both aphids and ants in Ohio peach orchards (135) and dissolved in cottonseed oil proved effective against the lesser peach borer (195). This chemical seems harmless to plants and mammals, is moderately cheap and has a cleanish odor. As shown later, it proved fatal to ants in laboratory experiments. When used alone, it is too volatile to be effective for long periods, though excellent for household use, where it can be renewed at intervals. In the field attempts were made to prolong its effect by dissolving it in liquids of slight volatility: they were moderately successful. What has been said of paradichlorbenzene applies with equal force to naphthalene and camphor: Zacher (75) considers that they have only a slight repellent effect. A disadvantage in household use, pointed out by Marlatt (7), is that these substances cannot be placed near food as they taint it. I have kept boxes of chocolates in drawers with paradichlorbenzene and in a few hours, the vapor has permeated the cardboard, paper and lead foil wrappings and made the contents most unpalateable. A prescription from Bogota (19) recommends a solution of 10 gms. of naphthalene in 50 gms. of benzene sprinkled over furniture: probably the benzene, despite its volubility, is more effective than the naphthalene as wood soaked in benzene tested at this Experiment Station, was fatal to ants when enclosed in a flask with them some three weeks after the liquid had been applied. A naphthalene and lime mixture proved unsatisfactory in Kenya (129), when placed at the base of coffee trees.

Spraying is an easy and therefore an attractive method of control. Formalin has been tried in Java (23) but did not prove very satisfactory. A solution of derris root has been used in Malaya (64). Kerosene and turpentine mixture has been used to protect seeds against attack in the United States (16). A mixture of alcohol and benzene sprayed on colonies of the Argentine ant is reported to have given good results in Spain (87). Vaporite (1) sprinkled on seed beds in St. Vincent (Barbados) gave a temporary deterrent action; a rather unusual remedy from Russia is a weak decoction of cow-dung (21); this was also said to destroy mole-crickets.

Petroleum products such as crude petroleum, kerosene and gasoline enjoy a certain vogue and are cheap and effective. Marlatt (7) suggests injecting kerosene or gasoline into cracks in woodwork against house ants. In Grenada (40), crude petroleum is applied to nests in cacao trees and to any weak parts of the tree liable to attack; it is also poured into ant nests in Rio (42) and in Brazil (103) and then set alight; a similar method is employed against <u>Atta</u> spp. in Brazil (78), though said to be successful only against nests near the surface. Against the fire ant in Cuban pineapple plantations (82), a spray solution is made of water, kerosene, carbolic acid and caustic potash; it should not be applied when the fruit is forming: a similar mixture is used against the same ant in Porto Rican plantations (97). In both cases, it is claimed that both ant and mealy bug are destroyed, but experience with sprays here shows that they only deal with a small proportion of the worker ants, a loss to the nest which is soon made good. A kerosene emulsion has been used against Atta in Brazil (159), by pouring it into the nest. Mixed with water, kerosene has been used against ants and termites in the Philippines (192). Spraying the woodwork of buildings with kerosene or gasolene is a common practice. In Java (23) gasolene and aerogene have been poured into ant nests but were found less effective than carbon bisulphide; however, a mixture of gasolene with carbon bisulphide poured into ant nests in the cacao plantations of Ecuador and then ignited was found to be a very effective method.

Coal tar derivatives have also been employed against ants. In France (51), an emulsion of coal oil, coal tar or creosote is used to destroy the nests. Morrill (77) reports that milo maize seed is soaked in coal oil for half an hour to protect it against the fire ant. In Kenya (145, 179, 180, 190), the most effective method of dealing with ants is by using a high boiling point tar oil called 'kresotow'; it is used for banding on greaseproof paper over cotton wool and its effect is said to last for ten weeks after the first application, while two applications are sufficient for one year. Woodworth (344) recommends a weak solution of cresol in water as an ant barrier.

Nicotine compounds, though employed mainly against Hemiptera are said to be effective against ants too. In Russia (11) tobacco extract was successfully used and in Trinidad (16) seeds have been protected against Solenopsis molesta by immersing them in a solution of Blackleaf 40 and crude carbolic acid; this is said not to hinder germination of the seeds. A solution of Blackleaf 40 has been sprayed with good results on fire ant nests in California (67).

Besides the use of carbolic acid with Blackleaf 40 mentioned in the previous paragraph, the former substance, mixed with caustic potash or fish-oil soap--with or without kerosene-- has also been used as a spray against the fire ant in Porto Rico (45) and Cuba (82). A soap and carbolic acid emulsion has been tried in Mexico (80) against ant nests and is recommended. Solutions of lysol are being tested in Spain (87) and a 2 per cent solution of this liquid as well as a 10 per cent solution of cresyl is a standard method of destroying the nests in France (122).

Gas Injections:

A legacy from the Great War has been the greatly increased utilization of lethal gases against insects. The method of attack against ants is to inject them either in the gaseous form or as volatile liquids into the nest, so that the deadly vapor spreads throughout the galleries. In actual practice in the pineapple fields here, the scheme does not work well against colonies in deep nests, so I have found it best to use this method only after heavy rain, when the nest population, flooded out of the lower levels, is concentrated near the surface: it is then very effective. Acetylene gas has been tried in the Barbados (1) but gave very uncertain results. Carbon tetrachloride is recommended from Germany (75). A mixture of hydrogen sulphide and carbon monoxide gave very promising results against leaf-cutting ants in Brazil (159).

Neifert and Garrison (66) tested a number of gases against various insects, including a number of species of ants. These included phosgene, arsine, carbon monoxide, cyanogen chloride and chloropicrine; they found that only the last two gave satisfactory results and that they could only be used for stored products. Chloropicrine has been tried out here but it is extremely unpleasant to use and no more effective than carbon bisulphide, though it has been found to have an abnormally rapid power of penetrating the tracheae of insects (312).

The last-mentioned gas is the one most commonly used for injection. Marlatt (7) recommends it against house ants, as does Britton (89). In Trinidad, this is the method suggested for dealing with the nests of fire ants (60) and with Atta spp. though Houser (14) seems to doubt its efficiency when dealing with leaf-cutting ants, in that the liquid is quickly absorbed by the soil and the fumes are liberated too slowly to be efficient. Van der Goot (23) recommends its use in the cacao plantations of Java. Horton (37) has employed it against the Argentine ant in Louisiana. In the Argentine, Brazil (42), Ecuador (72), Florida (71), S. Dakota (76), West Australia (95), Queensland (124) (141), Germany (75) and Italy, it is one of the commonest and most successful methods used in fighting all species of ants. Woodworth, however, points out that this poison, though effective against the fire ants infesting passion vines, is injurious to the plants (67), and Britton (176) does not recommend it for cleaning ants out of lawns for the same reason. We have found that this ant usually makes its nests here in bare ground and seldom actually among the vegetation, so that the question of plant injury is a minor one. Hawley (113) suggests an emulsion of carbon bisulphide and water. In Brazil (120), the carbon bisulphide is lighted after injection into the nest; this is also the method in British Guiana (171). This method is considered by Headlee and Dean (343) to be both useless and dangerous against Pogonomyrmex occidentalis and presumably against any ant with deep nests. During the dry season in Trinidad (127), carbon bisulphide was found to be ineffective owing to cracks in the ground; calcium cyanide was then successfully used in its stead. Wille (159) found that the gas was not effective at any distance against leaf-cutting ants in Brazil. Wildermuth and Davis (288) consider injecting carbon bisulphide the best of various measures discussed. They remove a six inch layer of topsoil the day before injection and paur the liquid into the tunnels; spring and autumn are found to be the best seasons of the year for treatment and midday is stated to be the worst time for its application, for then many of the worker ants will be out foraging. In mid-summer, it is considered that the liquid volatilizes too quickly; a moist condition of the soil is recommended as this aids diffusion of the gas downwards.

Experiments with Fluosilicates:

Of recent years, attempts have been made to find an effective substitute for arsenic as a poison for mandibulate insects, a substance equally toxic to insects but less toxic to mammals and less injurious to plant life.

The compounds of fluorine, particularly the fluosilicates would seem to offer considerable advantages in these respects and have been used with effectiveness against such pests as the potato beetle (Leptinotarsa decemlineata), the Mexican bean beetle (Epilachna corrupta), the cucumber beetle (Diabrotica vittata), the sugar cane borer (Diatrea saccharalis) cutworms, lice and grasshoppers.

Marcovitch (125, 284, 415, 416) is perhaps the leading propnnent of the use of this group of chemicals against insects. He found (284) that many insects when they come into contact with powdered fluorides, clean themselves by drawing their feet and antennae through the mouth and thus consume a fatal dose. As ants are continually cleaning themselves, each other and all the immature and helpless stages and castes within the nest, it seemed that the fluosilicates and fluorides might offer a good method of control.

Sodium fluoride has already been used against ants by Gibson (17) and Illingworth (207) as mentioned above, but as Marcovitch had found fluosilicates to be more satisfactory than fluorides as insecticides, it was decided to test the effect of calcium fluosilicate on the ant Pheidole megacephala.

Experiment 1 - Nov. 20, 1931

a. Six ants were placed in a large glass tube containing a small amount of calcium fluosilicate.

b. Six ants were placed as a control in a similar, empty tube.

After twenty-four hours, the former were all dead, the latter all still alive. The experiment was repeated with the same results.

Experiment 2 - Nov. 22, 1931

Six ants were placed in a tube with a little calcium fluosilicate and then transferred to another tube containing six clean ants. The poisoned ants were seen cleaning themselves and being cleaned by the uncontaminated ones. All were dead within eighteen hours. The experiment was repeated with identical results except that one ant survived for twenty hours and then died.

Experiment 3 - Nov. 24, 1931

As a control had not been used in Experiment 2, the experiment was repeated. This time twelve ants were placed in a flask, plugged with cotton wool as a control. Twelve more were placed in another flask; six of these had been stained with methylene blue and had then walked on a surface covered with calcium fluosilicate. After twenty hours, the control ants were all alive, the others all dead.

Experiment 4 - Nov. 20, 1931

To test the effect of calcium fluosilicate as a poison barrier.

A large galvanized iron tank was placed on a table, insulated from the floor by standing its legs in oil. Within the tank was placed an enamel dish, containing an ant nest in earth; from the side of the dish a quarter-inch board, thinly covered with earth, acted as a ramp between the dish and a piece of inch-thick boarding, placed also within the tank. The boarding was covered with earth and on the top of this was a thin circle of calcium fluosilicate and sifted earth, mixed in equal parts; within this circle were placed cookies covered with honey.

During the day, foraging ants were seen to cross the fluosilicate barrier and feed on the cookies.

The next day, a number of dead ants were noticed scattered about the iron tank and some live ants were observed dragging dead ones away from the nest. No more ants were seen crossing the barrier. The ants had moved their nest to another part of the enamel tray, probably becaused poisoned ants had at first returned to the nest and had perhaps been cleaned by others, thus passing on the poison and alarming the nest.

The poison barrier now acted as a barrier and not as a poison, the cookies being left untouched.

Some poison was placed in the way of a moving line of ants; they avoided it, making a detour.

Next some poison was placed on a few ants in the nest; the following day, the nest had been moved again.

Later, poison was placed on about half the nest population including larvae and pupae; on the next day, the entire population of the nest was dead.

This experiment showed firstly that foraging ants walking through poisonous substances would carry them back to their nest and disseminate the poison to the other inhabitants; but it also showed that this species quickly learnt to avoid a poison a nd to move their nests when death was unduly busy within.

These conclusions have been amply borne out by later experiments and are the reasons why attempts to poison this ant have never met with any considerable degree of success. At the same time, the fact that Pheidole is so quick to recognize and avoid a poison seems to indicate the possibility of using such a substance as a barrier in the field.

The next step was to find out what percentage of fluosilicate mixed with a suitable carrier would prove toxic to ants, for to use the salt unmixed with a carrier would almost certainly prove too expensive.

The carrier chosen was sifted earth; calcium fluosilicate was used as a poison as in the previous experiments and a period of twenty-four hours was fixed to determine the effects of the poison.

<u>Experiment 5</u> - Nov. 30, 1931

Mixtures of calcium fluosilicate and sifted earth in the proportions outlined below were placed in litre size, conical flasks, fitted with rubber bungs. The amount of the mixture used was just sufficient to cover the bottom of the flask. Ten ants were placed in each flask.

No. of flask	Percentage calcium fluosilicate	Ants alive after 24 hours
1	None (Control)	All
2	25	6
3	20	5
4	15	7
5	10	All
6	$7\frac{1}{2}$	All
7	5	All

The results of this experiment indicated that the mixtures chosen were too weak to be effective, so it was decided to increase somewhat the proportion of poison to carrier and then to test the comparative toxicity of a number of fluosilicate compounds and then to employ the most effective of these on a larger scale.

<u>Experiment 6</u> - Dec. 1, 1931

To determine the relative toxicity of various fluosilicates

Ten ants each were placed in a number of litre conical flasks, fitted with rubber bungs and containing a layer of a mixture of 33 per cent poison and 68 per cent sifted earth.

No. of flask	Control	Ants alive after 16 hrs.	Ants alive after 24 hrs.
1	Control	All	All
2	Calcium fluosilicate	9	7
3	Sodium fluosilicate	0	0
4	Levesol, light (80-85% sodium fluosilicate)	3	2
5	Levesol, extra light (70-75% sodium fluosilicate)	2	2
6	Cryolite	10	6
	(Alum. & sodium fluosilicate)	10	8
7	Tutox (patent preparation, composition unknown)	10	8

This experiment seemed to indicate that sodium fluosilicate was the most toxic of the salts to ants.

In a test to determine whether the fluoride salt would give better results, it was found that the latter killed all ants in twelve hours, while only six out of ten were killed in that time by the fluosilicate; at the end of eighteen hours, the remaining four had died. In view of this and of the greater toxicity to mammals of the fluoride salt, it was decided to use the fluosilicate.

Accordingly a trial shipment of half a ton was ordered from New York and arrived in about two months. As sifted earth was not altogether satisfactory as a carrier, it was decided to use gypsum.

Experiment 7 - March 4-April 11, 1932

Field experiment with sodium fluosilicate

Six plots and checks were chosen in the Kunia district for this experiment. The field had been newly planted and had few ant nests inside it at the commencement of the experiment; its shape was that of a peninsula, surrounded by a gulch which was thickly populated with ants (*Pheidole megacephala*). The general outlay is shown in the accompanying diagram (page 313). The field was protected by a six-row, guard-row system.

Dust barriers (page 314) of the sodium fluosilicate-gypsum mixture, approximately 110 yards long, were laid down outside the guard rows of plots 1, 2 and 3, turning back at right angles at each end of the plot and culminating 15 yards inside it. Adjacent check plots without barriers were located and marked out. The barriers were to be renewed when necessary, which proved to be about weekly. Ant runs were to be staked and counted weekly in plots and checks.

In plots 4, 5 and 6, 100-yard lengths of guard-row were taken as the plots and similar, adjacent lengths as checks. In the plots, ant runs were to be staked and sprinkled with the poison dust three times a week, as they occurred; in the checks, there were to be staked but not sprinkled. Comparison of plots and checks would show whether dusting the ant runs was effective or not.

The color of the stakes was changed every week to facilitate checking the age and frequency of the ant runs. Runs were divided into new, i.e., those occurring since the last count, active and non-active runs of previous counts.

Labor: A man was supplied by the pineapple company, owning the field. Unfortunately, there were frequent changes in personnel during the experiment and, in many cases, the instructions were misunderstood and either incorrectly carried out or not carried out at all. Finally it was found impossible to arrange for a man who could be trusted to do the work correctly and the experiment was abandoned.

Cost of material: Two 170 lb. bags of gypsum and sodium fluosilicate mixed including freight, carriage and cost of mixing at $6.60 per bag--$13.20.

Results of Experiment:

a. Ant Barriers

The details given below show that the sodium fluosilicate barrier was partially effective in keeping out ants. Although at the beginning of the experiment, there were more ant runs in the plots than in the checks, at the end of the period, the reverse was the case.

Apart from labor troubles, the following disadvantages were found in practice:

(i) The barrier was too rapidly dispersed by wind.

(ii) Ants sometimes burrowed underneath the barrier.

(iii) As the pineapples of the first line guard-row grew, some of the leaves bent over the barrier, thus forming a bridge for the ants; weeds showed similar tendencies.

b. Ant-run Control

Dusting ant-runs with sodium fluosilicate is only partially effective as the accompanying figures reveal. Though the checks and plots, about equally infested at the start, showed considerable differences later, control could not be considered more than 50 per cent effective. The main reason for this was that the greater part of the ant-runs occurred underneath the mulching paper (page 309) and could not be dusted. It was hoped that ants from dusted runs would carry the poison to their protected nest-mates and infect them, as was the case in laboratory experiments. In the field, however, this did not seem to happen with any great effectiveness.

To sum up, this method, though partially successful, does not seem to warrant the trouble and expense involved.

RECORD OF FLUOSILICATE EXPERIMENT, KUNIA
Number of ant-runs

Date	Ant-barrier - Plot 1			Check 1			Ant-barrier - Plot 2			Check 2		
1932	New	Active	Non-active	New	Active	Non-active	New	Active	Non-active	New	Active	Non-active
March 4	6			1			22			14		
March 11	3	3	3	0	1	0	0	12	10	9	8	6
March 18	4	7	1	7	1	0	5	17	5	3	12	8
March 28	1	7	5	2	7	1	6	17	9	8	16	7
April 4	1	7	6	3	7	3	0	23	8	4	25	6
April 11	1	7	7	3	9	4	2	22	7	5	28	7
	Ant-barrier - Plot 3			Check 3			Ant-run contr.Plot 4			Check 4		
March 4	0			0			7			8		
March 11	0			0			0	3	4	0	8	0
March 18	0			0			6	5	2	4	8	0
March 28	0			0			0	12	1	3	10	2
April 4	0			0			0	6	8	3	14	5
April 11	0			0			2	8	6	3	15	7
	Ant-run contr.Plot 5			Check 5			Ant-run contr.Plot 6			Check 6		
March 4	14			15			57			49		
March 11	9	9	5	3	9	6	3	29	28	7	40	9
March 18	7	9	14	18	12	6	10	34	25	7	45	11
March 28	8	10	20	5	31	5	5	38	30	8	51	11
April 4	0	18	20	1	35	6	2	38	35	6	49	16
April 11	1	12	28	6	28	14	1	34	41	4	51	20

Experiment 8 - March 11, 1932

Effect of sodium fluosilicate on *Pheidole* ant workings

At Moanalua, tunnels and workings in the territory of eight *Pheidole* nests were ringed with sodium fluosilicate. Examination a week later showed that only in two cases were there movements of the tunnels; a few dead ants were seen.

On the other hand, a very large *Pheidole* nest under a big boulder was strewn with this chemical; when revisited two days later, the nest was bare of ants. Very few dead ants were noticed, indicating either that the effect had not been fatal and the ants had simply moved away or that the dead had been removed. However, in a month's time a new nest was established under the boulder.

In order to get at the nests of *Pheidole* in pineapple fields, it is generally necessary either to remove the mulching paper or to pull up plants. The nests are usually small and well-distributed; to dust them would involve disturbing or destroying a considerable part of the crop. This is the reason that the workings and tunnels were dusted in this experiment and not the nests.

The results showed that the control effected in this way was negligible.

POISON BAITS:

General Remarks:

The attractiveness of the direct method is that results are swift and easily visible. On the other hand, when poison baits are used, the effect may not be apparent for some time and consequently a hasty conclusion may be reached that they are no good.

This judgment would be a mistaken one; in general, they are surer and more widespread in their effects than are contact methods and are usually considered cheaper in the long run; moreover, where ants are in places where they cannot be reached or only with difficulty, such as in the middle of a weed-infested, ratoon pineapple crop, this method is the only practicable one: in buildings, too, poison syrup in suitable containers is a far easier and less expensive way of dealing with the pests.

Poisons used with the various baits include tartar emetic, recommended by Headlee (30) against _Tetramorium caespitum_ in houses and Wallace (81), one part of the poison to ten parts of sugar and one-hundred of water, placed in shallow dishes containing a sponge. Sodium fluoride, mixed with sugar and maize starch has been tried in Utah (113).

In Porto Rico (104), one ounce of sodium or potassium cyanide is mixed with half a pound of ground-up meat. A chloral hydrate--sugar-honey-water syrup has been tested by Horton (37) against the Argentine ant. This preparation was used in the experiments described later but was found less successful than other poisons, notably thallium sulphate, which is very deadly and comparatively rapid in its action. Against the latter may be mentioned the fact that it is very expensive and also extremely poisonous to human beings; nevertheless, it has been used in pill-boxes against Monomorium pharaonis in houses (174) and found very effective; it also met with success against Prenolepis imparis in Californian orchards (184). I have even found it capable of clearing Pheidole megacephala out of houses; in pineapple fields, however, this ant can only be kept on the move by poisoned bait, but extermination is impossible as it will soon learn to leave the syrup alone. Solenopsis geminata does not seem to be so wise and can fairly easily be killed by this method.

The commonest poisons used in baits are arsenic compounds. These, though slow poisons, are very cheap and in the long run extremely efficient. Fink (310) has shown the physiological effect of arsenical compounds on the respiratory system of insects: he proved that it depresses the respiratory metabolism by lowering the oxygen consumption and the carbon dioxide production. Young insects were found to be more susceptible than older ones and sodium arsenite proved 59% more toxic than the arsenate salt. Campbell (311), who studied the relative effects of arsenites and arsenates on tent caterpillars, also found that arsenites were the more deadly compounds; he considered that 0.02 mg. of arsenic per gram of insect was the minimum lethal dose.

Syrups of lead arsenate and sodium arsenite have been used against house ants in the United States (7). The latter salt is the more popular and forms the basis of what is known as the Barber formula (309), which is as follows:

Granulated sugar .... 9 lbs.
Water .... 9 pints
Tartaric acid (cryst.) .... 6 grams
Benzoate of soda .... 8.4 "
Boil slowly for 30 minutes. Allow to cool
Dissolve sodium arsenite (C.P.)...15 grams
in hot water .... ½ pint
Cool. Add poison solution to syrup and stir well.
Add to the poisoned syrup 1¼ lbs. of honey.
Mix thoroughly

This formula has been used primarily and very successfully against the Argentine ant but also against other species in a number of places--California (26, 150, 158, 163), South Dakota (76), Mississippi (191), Mexico (80), Dutch Guiana (96), Porto Rico (97), Cuba (165), and France (122). Woglum (59), however, found that this syrup was too concentrated and had a tendency to crystallize in a dry atmosphere; he therefore modified the formula slightly. A similar recipe is recommended by Swain (63), who boils it for half-an-hour to prevent souring of the syrup and crystallization of the honey; costs were said to be very low.

The arsenate salt of sodium has been employed in Connecticut (44) against house ants and in coffee plantations in Guatemala (90). Horton (37) too, recommends arsenical solutions, as also does Urich (40) of Trinidad.

On the other hand, there is evidence that this type of poison has not been found universally satisfactory. In Queensland, Cottrell-Dormer (124) states that they failed to control ant pests and recommends soil fumigation methods instead. In Kenya (134), they are said to have been ineffectual against Pheidole punctulata; in a further bulletin (145), the Kenya entomologist goes further and reports that poisons were in no case effective and that he had tried over a hundred methods of control (including poisons). The Barber formula, when tried out in Brazilian sugar-cane fields is also said to have given unsatisfactory results (146); in the cane-fields of Georgia, a similar ineffectiveness was noted.

There would appear to be at least two reasons for non-success in using bait; firstly, where equally attractive saccharine material is present in abundance, the bait is no longer a temptation; secondly, there are a number of species--Pheidole megacephala is an excellent example--which quickly learn that the bait is dangerous and thereafter do not touch it.

As shown later, it may be three or four weeks before decisive results are apparent from arsenic poison baits; a mixture of bran, arsenic, honey and sugar was used in this case and besides being extremely cheap, it was also durable and the traps did not need constant refilling as they do with a syrup. Syrups, too, have the disadvantage that they glaze over or dry up after a time. White arsenic was the poison used in these experiments. It should be noted that too great a proportion of arsenic defeats its own ends and acts as a repellent. Zacher (75) considers 1/4 - 1/8 per cent of arsenic to be the best proportion, but this is putting it rather low and there is no doubt that higher proportions give better results over here.

FIELD EXPERIMENTS

Experiment 1 - March 11, 1932

Use of bran, honey and arsenic bait

A dozen fire-ant nests were surrounded each with a ring of bait. Twelve days later, four of the nests were apparently not at all or little affected, five were mainly or entirely destroyed or evacuated and the remaining three were considerably reduced. Very few dead ants were seen, but owing to the red color of the soil and the action of the wind, they were extremely difficult to detect.

Similar experiments with Pheidole ants at Moanalua showed less success. Out of eleven nests, six showed practically no differences; in three cases, there were piles of dead Pheidole ants and in the other two cases, there were a few dead Pheidole and lateral movement of runs.

It was felt that ringing the nests was a wasteful procedure as the bait was soon covered with dust or dispersed by the wind. Consequently half-pint, cylindrical ice-cream cartons were used as receptacles. They are cheap, handy and waterproof and can be used a number of times. Occasionally, they were blown over by the wind or knocked over by laborers; on the whole, however, they proved very suitable for the work.

In the case of fire-ants, whose nests are usually in exposed places between rows, the cartons were placed on the nest (p.315), which was then disturbed and caused the inhabitants to swarm all over the box. In the case of Pheidole, cartons were placed as near to the nest as possible.

Several kinds of poison bait were used. When these were liquid, they were poured into the carton to a depth of about half an inch and a sponge was placed therein to facilitate feeding; with the solids, such as bran, a similar amount was used but no sponge. The carton was covered with a lid, but a hole was cut in the side to allow ingress and egress of the ants. This form of bait box was used by Clark (283) recently in the control of fire ants in the lower Rio Grande Valley.

The poison he used was thallium sulphate. As he had obtained exceedingly good results with it against one of the two ants, which we were trying to control here, it was decided to try this poison in local experiments.

The cost of molasses here is almost negligible, so in some of the experiments, it was used instead of honey. This substitute proved comparatively unsatisfactory and was later abandoned.

Colored stakes were used to mark the positions of nests and bait boxes; different colors were used for different poisons, the boxes and stakes being of the same color in each case.

As the idea of using poisoned baits against ants is not to kill the foragers at once but fairly slowly, so that they could carry the poison back to their nest and regurgitate it throughout the colony, both to mature and immature stages, it was realized that a suitable poison might be one that would take some time for its effects to be apparent.

Experiment 2 - April 1932

Pheidole and fire ant control with poisoned baits

Locality - Waipio for Solenopsis
Moanalua for Pheidole

General Scheme - Half-pint ice-cream boxes, filled with sponges in cases (c) and (d), and containing mixtures as under, were placed on ant nests. The nests were examined after ten days and the results noted.

Mixtures		Color of stakes and boxes Moanalua	Waipio
(a)	1 lb. white arsenic 1/2 lb. honey 30 lbs. bran water	Red	Red
(b)	1 lb. white arsenic 1 lb. molasses 30 lbs. bran water	Green	Blue
(c)	2 ozs. thallium sulphate 1/2 lb. honey 5 lbs. sugar made up to a gallon with water	Yellow	White
(d)	2 ozs. thallium sulphate 1/2 lb. honey 5 lbs. sugar made up to a gallon with water	White	Yellow

Twenty boxes of each mixture were set on nests at Moanalua and Waipio on April 8th and 13th respectively. When examined ten days later, results were as follows:

	Moanalua (Pheidole)			Waipio (Solenopsis)		
	Effective	Partially	Not effective	Effective	Partially	Not effective
(a)	10	7	3	5	10	5
(b)	7	5	8	4	6	10
(c)	16	4	0	13	3	4
(d)	2	6	12	6	3	11

Effective meant complete evacuation of nest; in many cases, few dead were found; so, in the case of *Pheidole*, the inhabitants had moved and what percentage remained alive was not known.

The experiment showed that promising results might be expected from the use of poison baits, but it was soon found that whereas *Solenopsis* nest populations had been reduced because of poisoning--as revealed by digging up the nest--the lack of inhabitants in *Pheidole* nests was due to their having moved as soon as the poison began to take effect; the migrants could not be induced to take the poison again, whereas fire ants would do so repeatedly.

Consequently, no further poison experiments were made at Moanalua but tests were continued against *Solenopsis* at Waipio. Molasses having proved less effective than honey as a bait was not included in the new mixtures.

Nests, which had been baited with bran-arsenic in the previous experiment with a 'partially-effective' result were later found to be completely reduced, showing that the arsenical action is accumulative and much slower than that of the thallium salt.

For this reason, the next experiment, which was made with the two more effective of the four baits previously tested, was spread over a longer period, so that more fairly comparable results could be obtained.

Experiment 3 - May 4, 1932

Bait traps were set up at Waipio as follows and the results checked up on June 6th.

Bait	No. of traps	Effective	Partially	Not effective
Thallium (mix c, Exp.2)	56	35	21	0
Bran-arsenic (mix a, Exp. 2)	27	15	11	1

Effective means ant nest population completely reduced or with only a few dying survivors.

Partially effective means a noticeable diminution in the population of nest, but survivors still apparently vigorous.

The experiment showed that both these poisons were very effective against *Solenopsis*, this ant taking the bait even though it had been in use for some weeks.

Thallium, though quicker than arsenic in its effect, is much more expensive even though a far smaller quantity is necessary for fatal effects; moreover, this liquid bait has a tendency to glaze over and requires renewal about every two weeks, whereas the arsenic-bran mixture lasts at least twice as long; if too much water is used in mixing the latter, it has a tendency to turn mouldy.

During the month of June, a number of patent preparations were tried out; they proved to be of little use.

During July and August, experiments were suspended owing to the presence of fruit pickers and the consequent danger of their being accidentally poisoned.

The result was a recrudescence of red ant activity in the area, further accentuated as much of the fruit had been left unpicked and there was consequently an abnormally large food supply and therefore a greatly increased insect population.

Moreover, there were also signs that nests which had been considered 'effectively' poisoned made some surprising resurrections. This was due to the fact, not realized at first, that the nests of fire ants extend downwards to a considerable depth--five feet or more--and therefore nests which appeared to be wiped out probably had a nucleus of survivors including queens in some of the lower galleries.

For the next experiment, it was proposed to compare the effectiveness of poison baits with that of fumigants.

A compact area at Waipio was chosen, containing a number of parallel paths and the nests, on and adjacent to the pahts, were treated with a poison bait or fumigant. The outlay was as shown in the figures (pp. 316 & 317). Red ants place their nests preferentially in open places, seldom in among the plants, so that they were easily located on or near the paths. The treated nests were inspected at intervals and redoped when necessary. The duration of the experiment was six months, from September to March.

Situation at the beginning of September:

At the outset of the experiment, six lines only were employed but two months later more poisons were tested and the whole of the area was brought under control; a check was not used, because if one of the lines had been so used, ants might have spread from it to the next and so nullified observations. It was not practicable to take part of an adjoining area as check, for the block taken was partly isolated by a deep and wide ditch and partly by a wide space and conditions in adjoining areas were not strictly comparable. The conditions at the outset of the experiment were regarded as the best form of check. The lines were as follows:

Line No.	No. of Nests	Poison Used
1	27	Thallium sulphate
2	31	do
3	35	Bran-arsenic
4	32	do
5	25	Carbon disulphide
6	27	Chloropicrine

Chloropicrine having been found unsatisfactory, a poison syrup containing chloral hydrate was substituted for it at the end of the two-months period. At the same time, the other lines in this area were treated with calcium cyanide dust and a mixture of paraffin oil and paradichlorbenzene sprayed on the nests. Owing to the comparative scarcity of nests in line 8, the half-line 9 was treated with the same poison.

The chloral hydrate mixture was made up as follows:

8 lbs. granulated sugar
4½ ozs. chloral hydrate
½ lb. honey
made up to 1 gallon with water

This mixture is recommended by Horton (37). The paradichlorbenzene spray was compounded thus: Nineteen ounces of paradichlorbenzene were dissolved in half a gallon of gasoline and the resultant solution thoroughly mixed with half a gallon of Oronite Crystal Oil. The nests were then sprayed with this mixture by means of a small pressure sprayer.

The lines at the beginning of the experiments, which were started on Nov. 3rd with these additional poisons were as follows:

Line No.	No. of Red Ant Nests	Poison Used
6	22	Chloral hydrate syrup
7	15	Calcium cyanide dust
8	9	Paradichlorbenzene mixture
9	6	do

An unexpected factor, which complicated this experiment considerably was the fact that _Pheidole_ nests bounded the area on the northern and western sides; the result was that when a nest was seriously depleted by poison, the _Pheidole_ ants raided it and wiped out the survivors: this was particularly noticeable in the first four lines. The poisons were then turned on _Pheidole_ but proved to be comparatively ineffective.

Renewed applications of the poisons were made weekly or when necessary. This series of experiments was stopped at the end of a six-month period to see whether the colonies would recover. A comparison of the appearance of the area at bi-monthly intervals is appended. The data are illustrated in the accompanying diagrams (pp. 316-317). It should be borne in mind that a dot represents a nest but does not show whether the colony strength has been reduced or not. Another rather unfortunate feature is that nests were sometimes apparent after rain, which gave no sign of their existence when it was dry. The diagrams show rather clearly the effective assistance given by _Pheidole_ in the northern and western areas in wiping out weakened nests.

Line No.	No. of Red Ant Nests				Poison Used
	Sept.	Nov.	Jan.	March	
1	27	12	1	1	Thallium
2	31	8	2	2	do
3	35	14	3	3	Arsenic
4	32	11	5	3	do
5	25	12	3	2	CS_2
6	27	22	17	14	Chloropicrine (2 months) Chloral hydrate (rest)
7	-	15	4	3	Paradichlorbenzene
8	-	9	6	3	do
9	-	6	4	2	

Effects of the poisons used:

Thallium sulphate - This compound has given excellent results and is quick in action, one week being usually sufficient for its distribution throughout a nest with fatal results. It has the disadvantage of being very expensive and unsafe to use where children and uneducated labor have access to fields. Used as a solution, it may dry up or glaze over and should therefore be inspected weekly and renewed where necessary.

Bran Arsenic - Arsenic is a slowly acting poison; consequently, it may be a month before decisive results are noticed and it is sometimes assumed to be ineffective because sufficient time has not elapsed for its action to have become apparent. It should be placed in containers, having an aperture to admit the ants and should not be strewn over the nests, otherwise it will be dispersed by the wind. This mixture is cheap, keeps well--if not moistened too much, when it becomes mouldy--does not require frequent renewal and is not dangerout to field workers.

Chloral hydrate - The action of this substance appears to be similar to that of bran arsenic; it is perhaps slightly quicker though less sure. It is more expensive than the latter and has the disadvantage of drying up, as it must be used in solution like thallium sulphate. However, it is not as dangerous to use as the latter material.

Honey, sugar and water are mixed with these baits. Molasses has been tried instead of honey but has not proved so effective. Poisoned ants may be recognized by their 'dopey' appearance, slow gait and unaggressive behavior, all of which are in sharp contrast to the characteristics of healthy ants.

Soil fumigants:

Carbon bisulphide - This liquid was injected directly into the nests. Its effect is lethal and immediate but very local and nests which may appear to be destroyed will often show a hearty recrudescence after rain when the inhabitants of the lower strata come to the surface. The soil injector usually used for this does not seem to be an efficient apparatus against ant nests; better results are obtained by digging up part of the nest with a trowel, pouring some of the liquid into it and then covering up with soil. A number of applications at intervals of three or four days are required. CS_2 seems quicker, less sure and more troublesome than the poison bait method.

Mr. Craddock of Libby, McNeill & Libby, has found that if, after injecting carbon bisulphide, the nest is covered with a waterproof tarpaulin with the windward corner slightly lifted, the entire nest population is destroyed in two hours.

Chloropicrine - This chemical was used against a number of nests and applied with an injector. Its effect is similar to that of carbon disulphide but as it is more expensive and extremely unpleasant to handle, its use cannot be recommended. Nichol (245) used this chemical under inverted funnels placed over the nest and then corked: he found it to be 79 per cent effective at air temperatures of 80 degrees C. and over, but ineffective at lower temperatures. The method proved to be too costly.

Neither of the above-mentioned fluids can be injected near pineapple plants as they are injurious to the roots. When used, they are most effective when applied after heavy rains, for the ant population is then concentrated near the surface. Moreover, a moist condition of the soil aids diffusion of the gas downwards; and, per contra, in dry soil, there are too many cracks through which the gas can escape upwards, before it has become effective.

Calcium cyanide - This dust is exceedingly deadly and appears to be very effective against all ants in its vicinity. The drawback to its use, apart from the danger of its employment in untrained hands, is that HCN, the gas emitted, is much lighter than air; consequently, if the dust does not drop to the bottom of the galleries, the ants in the deeper parts of the nest remain unaffected. It is also rather expensive to use.

Paradichlorbenzene mixture - This is comparatively inexpensive. All the ingredients are lethal to ants and the effect of the crystal oil seems to be to retain the paradichlorbenzene unvolatilized for a longer period than it would otherwise remain so. First results are seldom effective and at least half-a-dozen treatments every few days are necessary for good results.

In addition to the above poisons, others were also tried for short periods but abandoned for various reasons.

Waste oil from automobiles - Effective but spoils the soil.

Gasoline, Benzene, Xylene, Toluene - All very lethal but too volatile.

Nitrobenzene - Very effective but too expensive.

ATTRACTANTS AND REPELLENTS:

Introductory Remarks:

Many early writers were inclined to view all insect activities in human terms. Today, the pendulum has swung so much the other way that most entomologists inveigh against the sin of anthropomorphism, particularly in dealing with the social insects.

There can be no doubt that human and insect phychology differ widely, largely owing to the different states of development of the various senses in each and also to differing physiological structure; nevertheless, the fundamentals underlying the continued existence of an animal organism are the same, so that though anthropomorphism may lead us astray in detail, in principle it is not without value, being in many instances the only yardstick we have for use.

Another modern tendency which may have been carried too far is to regard the nest of social insects as a unit and the individual ant as without an entity of its own. It is true that the ant as part of the nest functions in some ways differently from the solitary ant, owing partly to environmental factors, partly to what is perhaps a mass psychology--as instanced by the aggressive behavior of members of a large assembly of Solenopsis, compared with the inoffensive behavior of members of small communities or solitary specimens: but this is true of most, if not all, social organisms.

In addition to nest life, ants play a solitary part in such activities as foraging, which necessitate individualistic responses, and for this reason it is sounder to regard them not merely as a nest faction, meaningless except as a component of that nest, but rather as an independent entity with an added acquired social consciousness.

A considerable amount of work has been done in experimenting with various substances which attract or repel certain insects and there is no doubt that such experiments may lead to valuable results in economic control.

As far as ants are concerned, Forel (272) believes them to have a topochemical sense, the organs of which are located in the terminal joints of their antennae. He quotes an instance (loc.cit.I, p.[illegible]) of ants attacking and knocking down a plaster arena to get at the honey inside and concludes that they have the faculty of perceiving odors at a distance. Wheeler (273) states--'ants are able to perceive odors diffused in the air as well as those dissolved in liquids; for even the blind species often stop and wave their funiculi about in a peculiar manner when within a short distance of an odorous body'. It is admittedly remarkable how quickly ants will congregate on food left lying about; I have often left fruit and chocolate on a chair or table and returned in perhaps half an hour to find them being consumed by ants. Numerous observers have noticed this and assumed that the insects' sense of smell is so keen that they will be attracted from considerable distances to attack exposed food.

Such observations as I have made have inclined me to think that this assumption is, in the main, a false one--at least as far as our common ant is concerned--and to conclude that the sense of smell is, like the sense of sight, a very short-range in ants. On many occasions, I have placed sugar, honey, biscuits, fruit, etc. close to an ant nest or to a number of ants confined in a small space; there were never any signs of recognition until one of the foraging ants actually came in contact with the food; when this happened, after tasting it, the forager would return to the nest and soon there would be a number of ants attacking the food. Undoubtedly, their presence was due to some communication between them and the original forager either by direct antennal contact or by the waving of antennae conveying a message, or, as Wheeler (273) suggests, by stridulation. Pemberton (206) described a stridulating organ in Pheidole megacephala, an oval striated area situated dorsally on the third abdominal segment, but though I have used a microphone in attempts to hear these ants stridulate I have never succeeded in doing so.

I have placed a vessel containing honey inside an artificial nest and made it inaccessible to ants both with gauze and muslin. If ants were really attracted by the smell of honey, one would expect to see them swarm all over the gauze and attempt to penetrate it; on the contrary, they appeared completely indifferent.

Below are some of the results made with various substances to test the olfactory responses of ants; these results were never clear cut, often contradictory and it was impossible to draw any reliable conclusions as to the olfactory attractiveness or otherwise of any of the substances tried.

The fact that ants are social insects, mere fractions of a community rather than independent organisms, their whole existence bound up in contactual intimacy with the other fractions, seems to me to lie at the root of this matter. Is it not probable that this has led to the development of a vast network of short-range communication of great delicacy and intricacy and on the other hand has resulted in the abortion of faculties, which have become of little consequence, such as long-range sight and smell?

The practical application of the principle of olfactory attractants and repellents has been utilized in many control measures but it is difficult to say how effective such attractants and repellents really are, because they are usually employed in conjunction with some other idea.

Thus the success of attractants in poison bait is more likely to be due to a pleasant taste than to a seductive odor.

In the case of repellent agencies, they are either lethal in themselves like paradichlorbenzene, sulphur, mercury bichloride, etc., or they are mixed with some poisonous or sticky material and the reason they repel is not that they are olfactorily repugnant--experiments described below show that ants will approach these substances indifferently until overcome by their effects--but rather that experience shows them to have a fatal effect on their companions and they avoid the 'repellent' substance in the same way as they avoid poison after a time.

Britton (176) suggested as ant repellents the following substances--borax, camphor, cedar oil, tobacco, sulphur, powdered cloves, mustard and pyrethrum powder. Gobbato (101) reports that the natives in Brazil grow castor-oil plants in their gardens to protect the other plants from ants and he also recommends burning the seeds as an ant fumigant. The castor-oil plant is abundant here and often has a liberal supply of the ant, <u>Pheidole megacephala</u>, on the stem, leaves and young shoots.

Effects of Certain Substances:

Aromatic substances have been used extensively to attract and, in certain cases, to repel insects. Van Leeuwen & Metzer (419) found that geraniol and eugenol, mixed in definite proportions, was irristibly attractive to the Japanese beetle (Popillia japonica) and succeeded in taking about nine million beetles in five-hundred traps during a six-week period.

In further work against this insect, Metzger (280) tested 306 different substances and discovered that a number of them, in particular O-cresol, decreased the attraction of the geraniol-eugenol combination; he found volatile materials mainly unsatisfactory as repellents but certain resinous substances proved of distinct value.

In a later paper on repellents, Metzger & Grant (418) tested extracts of plants immune to attack by the Japanese beetle. Utilizing material from 390 plants, they found that only 56 of them gave any indication of repellency and of these, few were of real value and these injured the foliage of other plants and were too expensive to be of practical value.

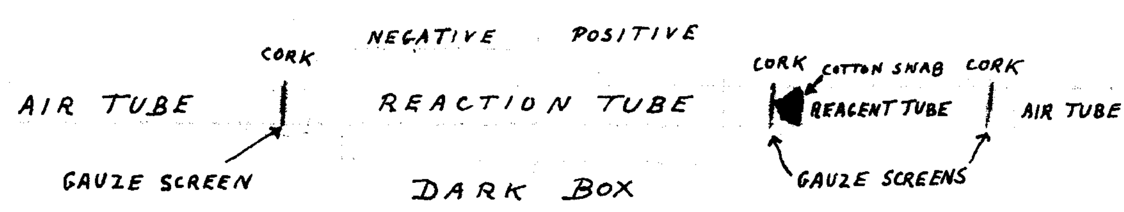
Parman, Bishopp and others (281) tested the repellent action of a very large number of substances against the screw-worm fly, Cochliomyia enacellaria, one of the worst stock pests of the south-western United States. They grouped these chemically as far as possible. Both repellents and attractants were found in most of the groups, including the essential oils. The chlorine substituted ketones appeared to be the most effective class tested, but good results were obtained with pine products, furfural mixtures and coal-tar creosotes.

McIndoo (286) reviewed certain experiments on the effects of attractants and repellents; he considered that the latter are usually unreliable remedies. Morgan & Crumb (287) discussed the chemotropic responses of insects belonging to a number of orders; both attractant and repellent substances were discovered for the various insects tested.

Experiments with Essential Oils:

A number of essential oils were tested to see whether they would either attract or repel Pheidole megacephala.

The apparatus used was similar to the Chemotropometer described by Folsom (279), but air boxes were not provided at each end as experiments were conducted in a dark room to eliminate phototropism. The apparatus was arranged thus:



Fifty ants were used in each experiment and results were noted at the end of half-hour periods. Two and a half per cent solutions of the various oils and other substances were made in 95 per cent ethyl alcohol and ten drops of each solution poured on to a cotton wool swab. The swab was placed in the inside of the reagent tube, adjacent to the wire gauze at one end of it. Alcohol of the strength used as a solvent for the oils was tested and found to have neither attractant nor repellent effects.

At the end of the period, if the number of ants in the negative half of the reaction tube exceed that in the positive half, the oil was recorded as repellent; if the reverse was the case, it was recorded as attractant; an equal or nearly equal result was recorded as neutral. Experiments were repeated twice and the mean of the three results was taken.

The results are given below merely as a matter of record. I do not consider them to be of any real significance, partly because results differed considerably each time but mainly because I do not believe that ants are affected consistently either one way or the other except at very close range; even then, they will cross over substances, which are dry but still very odorous and which they will not cross when wet. Moreover, they were often observed to approach volatile, lethal substances such as benzene and toluene until overpowered and killed by the fumes.

Substance	Action	Remarks
Oil of Cubebs	Mainly repellent	
" " Jasmine	do	
" " Pimento	do	
" " Coriander	do	
" " Petitgrain	do	
" " Cypress	Neutral	
" " Mustard	Mainly repellent	
" " Mase	do	
" " Mullein	do	
" " Sage	do	
" " Rue	do	
" " Citronella	do	
" " Bergamot	do	
" " Birch	Neutral	Killed ants in 20 minutes, when enclosed in a flask with them.
" " Pine tar	Mainly repellent	
Oleoresin capsicum	do	
Amyl acetate	do	Killed ants in 30 minutes when a 1½ per cent solution was placed on cotton wool and enclosed in a flask with them. Jones (357) found that this percentage attracted the ant _Solenopsis molesta_.

Repellent Effect of Certain Plant Extracts:

Not only is the pineapple mealy bug attended by a number of ant species--as shown in other parts of this paper--but the ants are equally catholic in their tastes, having been seen attending a great variety of coccids and aphids. There is thus no specificity in either direction, as was assumed by some early workers in this field. This applies particularly to *Pheidole megacephala*; scales, aphids and mealy bugs of different kinds may be found on most of the abundant vegetation of Hawaii and few of these are unattended by our common ant.

In a recent paper by Jones (357), it was found that ants would not eat certain insects feeding on plants with an acid, poisonous sap, such as members of the families Asclepiadaceae and Apocynaceae. It might therefore, be possible that sap-suckers feeding on local members of these families would not have ants attending them, though of course, the hemipterons might tap these plants without imbibing any of the contents of the poisonous cells. I have examined a number of plants, species of the above families found locally, with the following results:

Plant	Type of Predator	Species of Attendant Ant
Apocynaceae		
Plumeria acutifolia	aphid	Pheidole
	scales (2 spp.)	Plagiolepis
Nerium oleander	P. longispinus	Prenolepis
	scales (2 spp.)	
Allamanda hendersoni	scales-a few only	No ants observed
Allamanda carthartica	scale	Plagiolepis
	P. longispinus	
Alyxia olivaeformis*	scale	No ants observed
Asclepiadaceae		
Calotropis gigantea*	Microlepidopteron	Ants not observed.
Stephanotis floribunda	Pseudococcus sp.	No record (Reported (401) not observed personally)
Gomphocarpus physocarpus*	Microlepidopteron	Ants not observed
Solanaceae		
Datura stramonium	Microlepidopteron	Ants not observed
Datura arborea*	None observed	do
Solanum sodomeum*	do	do
Euphorbiaceae		
Ricinus communis	aphid	Pheidole
	leafhopper	Plagiolepis
		Prenolepis
Euphorbia pulcherrima*	None observed	Ants not observed
Euphorbia geniculata*	do	do
Euphorbia hirta*	do	do

*Only examined once.

The fact that most of these reputedly poisonous-leaved plants nourish phytophagous insects, the excretions of which in turn are consumed by ants seems to show that either insects are immune to these vegetable poisons or else that the plant feeders obtain their nourishment from specialized, non-poisonous parts of the plant. In case latter reason was the correct one and as ants and other insects are known to be effected by a number of vegetable poisons, it was decided to see whether extracts of these plants were deterrent to ants and more particularly to _Pheidole megacephala_.

Accordingly parts of the following plants (stem, seeds and leaves) were stewed in a 10 per cent ethyl alcohol solution; the infusions were then drained and the resulting liquids mixed with a bait of biscuit and chocolate. The cakes were then placed in definite and equal areas together with a control of biscuit and chocolate only and a similar cake, mixed with a few drops of nitrobenzene.

The baits used in the areas, which were so placed as to be all equally exposed to ant attack, were as follows:

(i) *Datura stramonium*
(ii) *Allamanda hendersoni*
(iii) *Nerium oleander*
(iv) *Thevetia nereifolia*
(v) *Calotropis gigantia*
(vi) *Plumeria acutifolia*
(vii) *Ricinus communis*
(viii) *Euphorbia hirta*
(ix) Control
(x) Nitrobenzene

Baits (i), (iii), (vi), (vii) and (viii) were eaten as readily as the control and were entirely consumed in two days; (iii) was also attacked but rather less readily and lasted four days; (iv) and (v) did seem to have a somewhat deterrent effect and were not entirely eaten until about a week after the start of the experiment. But none of these home-made plant extracts were comparable in effectiveness with nitrobenzene which remained effective fully three weeks and was then only dissipated by the combined effects of rain and wind.

However, the test showed that there did appear to be a deterrent principle in at least two of the plants tested and possibly with adequate methods of extraction and concentration, effective ant-repellent plant extracts could be made.

In the paper by Jones (357) mentioned above, ants were successfully repelled by mixing the juices of certain ant-repellent insects with ordinarily attractive food; the ants then refused it and Jones concluded that the repellent insects derived their noxious principle from their host plants, which were members of the families Asclepidiaceae and Apocynaceae.

MECHANICAL CONTROL

General:

Mechanical control is used either by itself or in combination with chemical control. In the latter case, either may be the primary factor. Thus, the grease band used by itself is a purely mechanical control; when mixed with corrosive sublimate, the chemical side is probably the more important factor, especially after some time. In the ant fence, the mechanical effect is the principle deterrent above ground, the chemical one being dominant below.

Under this heading, cultural methods of control will also be discussed.

The method most in favor outside Hawaii appears to be some form of grease banding; this is applied in areas where the agricultural crop is produced on trees. Orchards, coffee and cacao plantations are examples. The band must be weather proof, fastened so as to prevent ants crawling underneath and yet not so tight as to injure the tree. The preparation consists of some sticky substance which prevents ants passing it or some poisonous substances which kills them should they attempt to do so or a mixture of both; other pests, as well as ants, are disposed of by the bands.

Horton (18) recommendsorchard protection by adhesive bands four to six inches wide and a quarter of an inch thick, containing a mixture of one part of corrosive sublimate to six parts of tree-sticky; it was effective for three months. Finding that the mercury salt was injurious to the bark, he replaced it with flowers of sulphur. He also tried a purely mechanical band of one part of black axle grease to two or three parts of tree-sticky and found it lasted for two months. Woglum (59), however, found banding unsatisfactory against the Argentine ant in citrus orchards and prefers poison bait. Urich (60) has used tanglefoot bands against Solenopsis geminata in the West Indies and both it and the corrosive sublimate formula have been used with success in Mexico (80). In Colombia (19), the bases of trees are girdled round with a two foot wide band of liquid pitch covered with charcoal powder. Other sticky band formulae include a mixture of Burgundy pitch, ordinary oil, linseed oil and molasses used in Brazil (86), resin and castor oil or resin and fish oil with some sticky substance--both Spanish remedies (87)--and a simple molasses band which has been used to protect the lac insect against fire ants in India (107).

As shown below, many of these remedies have been tried here on ant fences; they have all given unsatisfactory results, mainly because the circumstances in which they must function are all against their success.

Used on trees, they are protected to a large extent from sun and dust, but here these dessicating agencies have full play and rapidly render the protective banding dry, dust covered and useless. Over most surfaces, the thinnest film of dust is sufficient to allow ants to cross in safety and this is soon produced on the fence in the windy, dust-laden atmosphere of Hawaiian pineapple fields.

Somewhat allied to the grease band idea is the grease trap. Britton (176) suggests a method whereby plates greased with lard are prepared; the ants are attracted thereto in considerable numbers and find escape difficult; they are then killed with hot water.

Another type of repellent banding is fine fibrous material which ants cannot cross or only with difficulty. Cheeseman (304) noticed that in Tahiti, those caterpillars which had spun a silken net across their burrows were safe against ant attack. A cotton wool plug will keep ants captive inside a specimen tube. With this in mind, I experimented with cotton wool and silk floss to see whether ants could be kept inside a large glass vessel by glueing these substances round the edge, but though they found it exceedingly difficult to escape, they always did so eventually. In Colombia (19) a band of woven hair round the base of the tree is said to keep away ants. In Java, mosquito netting is stretched over seed beds to protect them against Solenopsis geminata and old netting with holes in it is said to be quite effective. As I have found this ant will not only gnaw its way through muslin but also through extremely tough bolting silk; the complete success of this method appears questionable.

A further type of mechanical barrier is the water channel; it is used in Brazil (159) against leaf-cutting ants and in the form of drainage ditches against the Argentine ant in the United States (37). Care must be taken to keep these ditches clear of weeds. This is one of those ideas more excellent in theory than in practice, for it is not practicable to keep a ditch of any appreciable length clear of debris and places where ants can cross will usually be found sooner or later. Moreover in any place where the water is still, dust and scum collect on the surface and afford a foothold for ants. I have tried to keep ants inside an artificial nest by means of a small water barrier; invariably a dust covering, not apparent to the eye, soon collects and the ants escape over it.

Direct destruction of the nests by cutting them out of trees (40) or digging them out of the ground and burning them (14) are methods advocated and it is also suggested that where they infest seed beds they can be destroyed by spreading a layer of dry grass over the beds and setting fire to this (1). Urich (60) recommends destroying the nests with boiling water. Suffocating the ants by burying them in trenches at least eighteen inches deep was tried in Java (23) but was only moderately successful; it can only be practiced effectively during the rainy season.

Cultural methods are often cheap and simple, yet effective. Early planting of crops was found by McCullogh (16) to lessen the damage done by Solenopsis molesta, an enemy of seeds and young plants. In Brazil (146), the planting of sugar cane shoots instead of slips was found to prevent ant attack. Rotation of crops is recommended by Forbes (20) and Thomas (24) as one of the principal measures against both ants and aphids.

Ploughing is another cultural method which has given excellent results against ants. It destroys the nests of all soil-inhabiting species except those which nest deep down and it also breaks up runways and hinders foraging ants, for loose, friable soil with alternate ups and downs is a great deterrent to ant travel. Against Solenopsis molesta, McCullogh (16) recommends autumn ploughing, whereby not only are the nests broken up but seed germination is hastened. Early and deep ploughing has been found an effective measure in the maize fields of Illinois (20). A system of shallow cultivation prevents the ants establishing themselves in the cotton fields of South Carolina (24). Ploughing up the ground is practiced in Brazil (107) to destroy the nests of an ant, Acromyrmex landolti, which damages coffee plantations; and such general cultural measures as planting only clean seed and destroying trash are recommended in the cane fields of Georgia (136).

Ploughing before planting is practiced in Hawaii and undoubtedly it is very effective in clearing the fields of Pheidole megacephala, which usually nests just below the surface, but it does not destroy the formicaries of the fire ant, Solenopsis geminata, which may extend to a considerable distance below ground level.

The practice of cultivating strips or 'dry-mulching' around the edges of fields is used both in conjunction with the guard row system (p.310) and with the ant fence (p.318). It prevents the establishment of ant nests close to the edges of fields and greatly hinders access to them, as the alternate rises and dips, combined with the loose soil make progress difficult and discouraging for the ant. The weak point is that these mulches become firm after rain and this is just the time when ant activities are at their maximum. Ants will cross moist mulches with ease. Another disadvantage of their use outside ant fences, especially in dry areas, is that the fine, dry dust is blown on to the ant fence and dries it up, leaving a coat on it, over which ants may and do cross.

Experimental Evidence:

Experiments to Test the Obstructive Effect of Finely Divided Particles on Ant Advance:

If one observes the progress of ants over various surface, one cannot fail to be struck with the difficulty these insects seem to have in their passage over finely divided earth. The finer the particles, the slower the advance of the ant, which loses its footing constantly and seems to have great difficulty in making any progress. When in addition, the surface is graded, the difficulty is greatly increased; the steeper the gradient, the more hazardous the crossing. The banks which border each side of the path, which runs between the guard rows and the rest of the field is a good example of this. These banks are fairly precipitous and are made of loose earth. The effect is to deter the ants from crossing from the guard rows to the rest of the field. But during rain, the loose earth becomes consolidated and afterwards ants can and do cross such places with ease; and as it is always after rain that ant activities are at their maximum, the effectiveness of these banks are not so great as might be supposed.

Nevertheless, the principle of loose, fine earth as an ant barrier is a good one and seems to suggest possibilities of control, if only the effects of showers could be avoided. The dry mulch or cultivated strip run around the edges of fields, mentioned earlier, is another example of this idea.

To test the effect of different sized particles on ant advance some finely sifted earth from a pineapple field was run through sieves of various meshes and then ridged in concentric circles. Several Pheidole ants were placed in the center and their progress watched.

Results:

In earth,	passing	through	8 meshes	per inch gauze,	ants walk easily.
"	"	"	20	"	" "
"	"	"	40	"	ants walk uphill with slight difficulty.
"	"	"	60	"	ants walk uphill with considerable difficulty.
"	"	"	80	"	Ants walk uphill with very great difficulty.
In plaster	"	"	100	"	ants were unable to ascend an acclivity of about 60 degrees.

Plaster of paris was used instead of soil for the 100 mesh to the inch test, as it was difficult to get sufficient earth fine enough to be used. This experiment was tried in November 1931. In March 1932, it was decided to try further experiments on these lines.

In a large tray were placed two heaps of finely divided material, one consisting of coral sand, the other--much finer--of flowers of sulphur. Each had concentric circles of three ridges and depressions and in the middle a Syracuse watch glass filled with honey. A similar watch glass was placed on the tray itself and another on a block of wood placed on the tray.

In the middle of the tray was placed a nest of ants with a little earth, a colony taken from under a boulder nearby.

After 24 hours, no ants had succeeded in reaching the honey dishes in the middle of either heap. There were a number of dead ants, lying scattered throughout the sand heap and rather fewer just within the periphery of the sulphur heap.

Ants were observed to travel in the sand with some difficulty which increased as the sand dried and became more crumbly; they found difficulty in orienting themselves. Red ants were able to travel over sand more easily than <u>Pheidole</u> and crazy ants moved without apparent difficulty.

As far as the sulphur was concerned, only one ant succeeded in surmounting the first ridge; the rest slipped continually and soon became exhausted--or possibly their spiracles became clogged with fine sulphur particles.

The honey dish on the tray was not found for two hours, though not more than two feet from the ant nest and with no obstacle in front of it; the one on the block of wood was not discovered in twenty-four hours. This suggests that ants are not attracted to honey by its odor from a distance, but that it is discovered by the ceaseless reconnaisance of foraging ants, who spread the news to the rest of the colony. Later experiments seemed to confirm this.

The experiment was then reversed. Twenty ants were placed in the center of each of the two heaps. In two hours, all but one had made their way out of the sand heap, though not without considerable trouble.

A few of the ants in the sulphur heap succeeded in getting half way out before they died; but the rest succumbed without getting far from the center of the heap.

On damping the sulphur heap with a spray, the ants were able to travel more easily but became clogged with sulphur and subsequently died.

ELECTRICAL CONTROL

The idea of repelling ants by a weak electric current, requiring the minimum of expense, attention and upkeep is an attractive one. A paper from Turkestan (8) reports the use of copper and zinc rings connected with wire. This simple appliance was said to require no attention and remain active for an indefinite period; it was used to protect beehives from ants.

On May 12 and 13, 1932, attempts were made to duplicate this experiment here. From the results obtained, it can only be assumed that the morale of Turkestan ants is remarkably low, for the insignificant current generated had no noticeable effect on Pheidole; further it was found that this ant would cross from one copper plate to another with a difference of potential up to 25 volts: alternating current was used.

ANT FENCES

Their Use in Ant Control:

The 'ant fence', the idea of a pineapple company official, at first indifferently regarded and even ridiculed, has in a few years become one of the most important defences we have against ants.

At present it is used by one company only in their fields on Oahu, Maui and Molokai. On the last-named island there can be no doubt as to its value; on the first it is perhaps questionable. This is partly because large fields with a small perimeter in relation to their volume are necessary in order to cut down the expense of this measure--as expense is proportionate to the perimeter of the field--partly because ant fences are of little use against a deep nesting ant, which burrows under them.

On Molokai the fields are large and Solenopsis is absent; on Oahu the fields are small or long and narrow and Solenopsis is present in much of the area concerned.

It is not strange that ant fences were at first taken less seriously than their merits warrant, for to stage such an elaborate defence against so small a creature savours somewhat of Heath Robinson methods. But it is not appearance but results by which a control measure should be judged.

The ant fence, which completely encircles a field except for road and drainage gaps, consists of a line of six-inch boarding placed vertically in the ground, three inches above, three inches below the surface, and dipped and sprayed with standard mix. The fence is sprayed twice a week by a motor sprayer, working at 20-25 lbs. pressure. The spraying arm runs on a wheel, travelling along the top of the fence; it has five nozzles, two spraying on each side and one on the top. A man seated in a chair extension of the spraying machine directs the operation of the spraying arm (pp. 318 & 319).

Standard mix

A number of mixtures have been used in the past but the one found most successful and now in use consists of 75 per cent Avon weed killer and 25 per cent 'Avon' Threading compound; it cost 10 cents a gallon. Though suitable for the power-spray, it is too viscous for hand-sprayers, so a thinner mixture (50/50 per cent) of the two ingredients is used.

Hand Spraying

This measure is auxillary to power-spraying. It is done in gaps in the fence and in boxes where drains and roads cross it (p.320). These places are sprayed daily and in special cases, such as when there is heavy traffic on roads, twice daily.

Cultivating

Every other day, a strip cultivator or disc is run around the fence on both sides. A tractor goes around the entire area twice a week on days when the fence is not being sprayed. Thus, a strip is kept constantly cultivated on each side of the fence. By spraying and mulching alternately, the effectiveness of each measure is at its optimum at the time that of the other is at its minimum.

The object of cultivation is to disintegrate the top few inches of soil into fine powdered ridges. This not only breaks up any ant nests, which may be present, but also hinders ants from approaching the fence, for they find it extremely difficult to cross any powdery surface, particularly when that surface isgraded, as shown by experiments given elsewhere (p. [illegible] - [illegible]). Cultivation alone or dry mulching as it is called, is often used alone on field edges to prevent ant encroachment. In such areas (e.g. Molokai homestead areas), inspection shows that it does not keep out ants. The weak point is that as soon as the surface becomes damp, it clogs and no longer forms an obstacle to ant advance. It is precisely at such times, that ant movements are at their maximum. During the winter months, for instance, it usually rains during a portion of the night; in the early mornings before the sun dries it, the mulched border is very easily crossed and foragers are particularly active at this time.

But in dry areas, there is an even more serious drawback to cultivation of strips adjacent to ant fences. The wind, which is nearly always present in Hawaii, is continually blowing dust on the fence and thus rendering the mix easier to cross. An ant fence on the Kula Road in Maui is a good example of how dust destroys the effect of an ant fence. In addition to clouds of particles from the mulched strips, dust is continually thrown on the fence by passing cars from the road. Not only is it impossible to keep the fence viscous with mix, but the accumulation of dust at the bottom of the fence has reduced its height to about one inch in places. As a consequence ants and mealy bugs were found in considerable numbers inside the fence. By withdrawing the fence on this side one block interiorly and spraying the unprotected block at intervals with petrotine, economies in material and labor could have been effected and the interior made far more secure against insect attack.

In general, however, the ant fence is very effective, though the company using it does not rely on it solely to keep out ants, They maintain, in addition, special ant and mealy bug patrols. Every field is patrolled systematically. For example, in one inspection round, the man examines every third row; the next time examination will be similar but starting from a row not examined the previous time, so that the entire area is patrolled in three inspections. If ants or mealy bugs are noticed, a red stake is placed by the infected plant.

Men with hand sprayers go around and spray the infected plants and their surroundings with petrotine; the red stake is replaced with a white one and the place carefully scrutinized next time for further signs of insects. The cost is approximately 75 dollars per 100 acres but is of course rather variable. The laborers who attend to this work are said to develop great speed and expertise at spotting bugs with practice; nevertheless, the fact that very badly infected areas were noted in isolated cases indicates that the method or its practice might be improved.

In nearly all cases examined, the insect-affected area was not on the edge of the field, showing that it was not due to infection from without. The cause is usually dirty planting material. During the recent years of rapid expansion, planting material was obtained from many sources and it was impossible to insist on its cleanliness from bugs. Today the demand for planting material has decreased and the supply is more than ample to meet all needs; consequently a far higher standard is in existence and internal infections may be expected to be less frequent.

As to the ants, before a field is planted it is ploughed a number of times. This is effective against *Pheidole* nests and the ants disappear magically. Nevertheless, it is very unlikely that the field is entirely cleared of them and probably a few small colonies are left, which increase as the crops mature. As to winged queens flying over the fence and establishing nests, as has been suggested, experiments detailed earlier show that this is highly improbable. I have made a number of attempts to establish a colony with a queen without workers and never succeeded; *Pheidole* appears to be a species, whose queens must have a worker nucleus before a colony can be established, at any rate in these islands.

But even if colonies could be founded by fertilized queens flying over the ant fence, such a queen would first have to find a nucleus of workers--in itself an improbability inside the fence--and then two months must elapse before the first new worker became mature and even after a year the population of such a nest would not be very large. It seems improbable that nests founded in this way--if they ever are so founded--early in the field's history, could be of any economic importance until the formation of a ratoon crop or later.

The usual way the nests of *Pheidole* become established in pineapple fields is by invasion from old nests on the borders. They are not founded by solitary queens with a small nucleus but by a complete nest unit--queens, soldiers and workers; immature stages are transferred from the old nest as well. Nests colonized in this manner are able to extend and ramify under the mulching paper with very great rapidity and so it is important to establish the fence before planting begins.

Though *Pheidole* is quite capable of digging below the surface, it seldom digs deep and for some reason, these ants never seem to burrow underneath the shallow fence and so pass below and inside it. One reason is, I think, that the mix drips from the bottom of the fence and soaks into the ground three times a week; this substance seems unpleasant to *Pheidole*--though it will cross dried fence boards--and seems sufficient to deter it from burrowing.

In the case of *Solenopsis*, the position is very different. This ant has nests of great depth and when the field is ploughed up, there can be no doubt that the lower part of the nest is untouched. Consequently an internal ant population is present in the field and makes itself evident in course of time, seldom appearing or increasing during the early stages of the crop, for this ant is not omnivorous like *Pheidole* but lives mainly on mealy bug excretions and the seeds of weeds; both of these are missing at first but become more numerous as the crop ages.

In any case, even were it possible to destroy the fire ant population before planting, it would not be possible to keep them out by means of the ant fence, for they will burrow underneath it, Evidence of this is to be seen at Waipio and Kupehau on Oahu. Fortunately Solenopsis is not found on Molokai, Maui, Kauai or Lanai as far as is known.

Effect of the Ant Fences on Molokai:

The beneficial effect of the ant fence is very clearly exemplified on Molokai, where there are protected and unprotected areas showing very great contrasts. The company which uses ant fences has its fields exceptionally clear of ants and mealy bugs, save for a few isolated internal populations due to unclean planting material. It is able to obtain up to three ratoon crops from such fields with fruit of exceptional quality.

Adjacent to this area are the little fields of the homestead area, run by small, independent, native growers; these fields are unprotected by ant fences but they usually have a dry mulch running around them. The plants, especially those near the borders of the fields, are overrun with ants and mealy bugs; there are wilted patches everywhere and much of the area will hardly yield even a respectable plant crop. Newly planted holdings, though clean at first, are doomed to rapid infestation on account of the large insect populations, which have been built up all around them. The only chance of running these holdings successfully is to combine them into larger fields of manageable size, which would warrant the expense of installing and maintaining ant fences. There is some possibility of this being done in the near future.

Experiments with Different Materials:

As pointed out above, the expense of installation and maintenance limits the use of the ant fence to certain areas. To extend its use it is necessary to bring down costs; moreover, the slump in trade and consequent low selling price of pineapples has, temporarily at least, further circumscribed the areas where the ant fence can profitably be employed.

The new standard mix has cut costs considerably, but it was felt that there might be possibilities of bringing down costs still lower.

Experiments were therefore made to find: (i) A substratum which would keep the mix tacky better than boarding. (ii) A material which would remain effective for a longer period than the standard mix or alternatively cost less.

To test the materials, three-foot squares of boarding fence were set up on ground which had been cleared of all weeds and fumigated with carbon disulphide. Sliced pineapple was placed inside each square as bait. A square of untreated boarding was used as a control and one treated with standard mix every three days was included for comparison. Page 321 shows the general layout.

The tests were made in one of the Libby, McNeill & Libby fields at Waipio and this firm also kindly supplied the labor for setting up and maintaining the ant squares.

Experiment 1 - March 18-28th, 1932

Ant fence experimental squares

Two sets of four squares (as under) were set up in the experimental area, with sliced pineapple as bait.

(a) Square of untreated boarding only.

(b) Square treated with standard mix every three days.

(c) Square treated with standard mix but not sprayed further but dusted with sodium fluosilicate on top of mix.

(d) Six inch wide barrier of sodium fluosilicate; no fence, no mix.

Ant nests were encouraged near the squares by placing boulders a few feet away from them; nests were soon found under the boulders.

The squares were examined on March 23rd with the following results:

(a) Full of ants.

(b) No ants inside square.

(c) The chemical had dried up the mix; dust had covered the top and the ants had walked over into the square.

(d) The ants burrowed underneath.

The experiment was repeated and on re-examination on March 28th the results were found to be similar. The tests showed that the methods used were inferior to the standard fence.

Application of standard mix on the plain surface of the ant fence boarding seemed to ensure it drying up in the shortest possible time; it seemed possible to me that an irregular surface with plenty of angles, nooks and crannies would keep the mixture 'tacky' for a longer period.

The waste at pineapple canneries contains pineapple 'bran', some of which is used for cattle feed and some thrown away. The discarded portion consists of irregular pieces of dessicated pineapple skin; it seemed possible that by compressing this and glueing it to the existing fence an irregular surface could be made which would hold the mix in a tacky condition for a longer period than plain board would, thus lengthening the intervals necessary for applying mix and greatly reducing costs. Moreover the added cost of material--a waste product--would be negligible.

Some difficulty was experienced in compressing the bran and glueing it to the board, for which a waterproof glue, consisting of water... 1350 cc., glue 600 cc., oxalic acid 33 gms. and paraformaldehyde 60 gms., was found to be necessary to prevent the bran being washed from the fence by rain. Compressed bran was also used by itself without boarding, but mixed with asphalt to give it cohesion. As an alternative to bran, excelsior was also used as a 'facing' on the fence.

In addition to these sample fences, three others were tested; the first consisted of a long-drying fish oil sprayed over the regular mix; it was hoped that its effect would last longer; the second was a mixture of corrosive sublimate 60 gms., ethyl alcohol 180 cc., shellac 92 cc., applied in three coats to the fence boards and reported by Horton (18) to be effective for one year and lastly a preparation of one part of flowers of sulphur to three parts of tanglefoot, said to remain effective for three months.

Experiment 2 - April 29th, 1932

Ant fence experimental squares

The sample fences were as follows:

(1) Control--made of untreated boarding.

(2) Square made of pineapple bran mixed with asphalt.

(3) Pineapple bran glued to square and treated with standard mix.

(4) Standard ant fence, sprayed every three days.

(5) Long-drying fish oil sprayed on standard mix once.

(6) Excelsior glued to square and treated once with standard mix.

(7) Mercuric chloride, shellac and ethyl alcohol, painted on fence.

(8) Standard ant fence, sprayed every three days.

(9) Tangelfoot and flowers of sulphur applied to wood fence.

Except in the case of (9), the ground at the foot of the different sample squares was treated with standard mix three times before starting experiments, to prevent ants burrowing underneath the fence. Observations were taken in the morning and in the afternoon. Square (5)appeared to attract the ants and had no deterrent action. In squares (3) and (6), the idea was to keep the standard mix from drying up as quickly as it does on the present ant fence by substituting an uneven for an even surface. This object was partly attained, but sufficient portions of the fence dried up for the ants to cross, after the second week.

Square (3) was on the same principle; it was not a success. In the case of square (7), a few ants got in during the second week. Square (9) appeared to act successfully, keeping ants out in one trial period for five weeks.

As the standard mix has to be applied every three days, squares (7) and (9) seemed to offer promising possibilities. Apart, however, from the problem of application on a large scale, the chief difficulty is to prevent ants from burrowing underneath the fences. The present standard mix does this automatically as it drips slowly from the fence after application and permeates the soil at the bottom of it.

It was decided to discard the bran fences and the fish oil and start another experiment using only those squares which had proved moderately successful together with any new ones which might appear to merit a trial. Accordingly Experiment 2 was brought to a conclusion at the beginning of July and on July 14th a third experiment was started.

Experiment 3 - July 14-August 4th, 1932

Ant fence experimental squares

The experimental squares were as follows:

(1) Control of untreated boarding.

(2) Abandoned as ants were found inside on the first day.

(3) Boarding treated with a solution of resin, castor oil, mercuric chloride and ethyl alcohol.

(4) Standard ant fence, treated every three days.

(5) Control of untreated timber.

(6) Abandoned as ants were found inside on first day.

(7) Sulphur, mercuric chloride and tanglefoot.

(8) Standard ant fence, treated every three days.

(9) Boarding treated with a solution of resin, castor oil, mercuric chloride and ethyl alcohol.

The new fences only succeed in keeping out ants for a few days; though not many were seen on the actual fences, plenty were found inside. They came, in some instances, through joins at the corners of the squares, in others by burrowing underneath the fence.

On August 15th, a new square treated with a mixture of furfural and pine tar oil was tried. This also kept out ants for a few days but by the end of the week, they had started to come in; by the beginning of September, ants were inside in considerable numbers and the experiment was abandoned.

Conclusions:

After six months of experiment, no method had been found which was an improvement on the standard fence. True, it was possible to apply materials which would remain effective for considerably longer periods than the standard mix; but this also meant that there was no bi-weekly soil percolation and the ants accordingly burrowed underneath the fence.

The experiments, however, had brought out one very important point, that it was this hidden soil percolation of the mix, quite as much as the fence itself, which was the important factor in keeping out ants.

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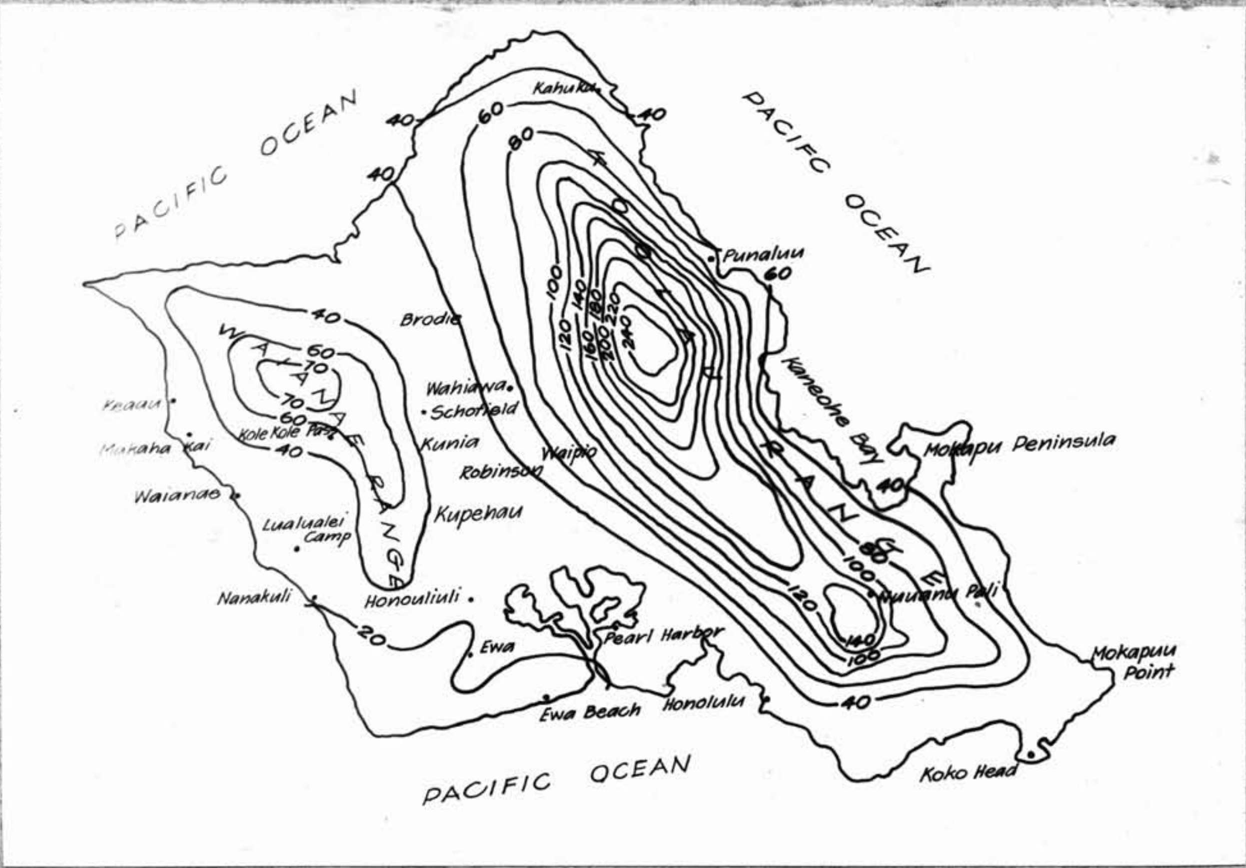
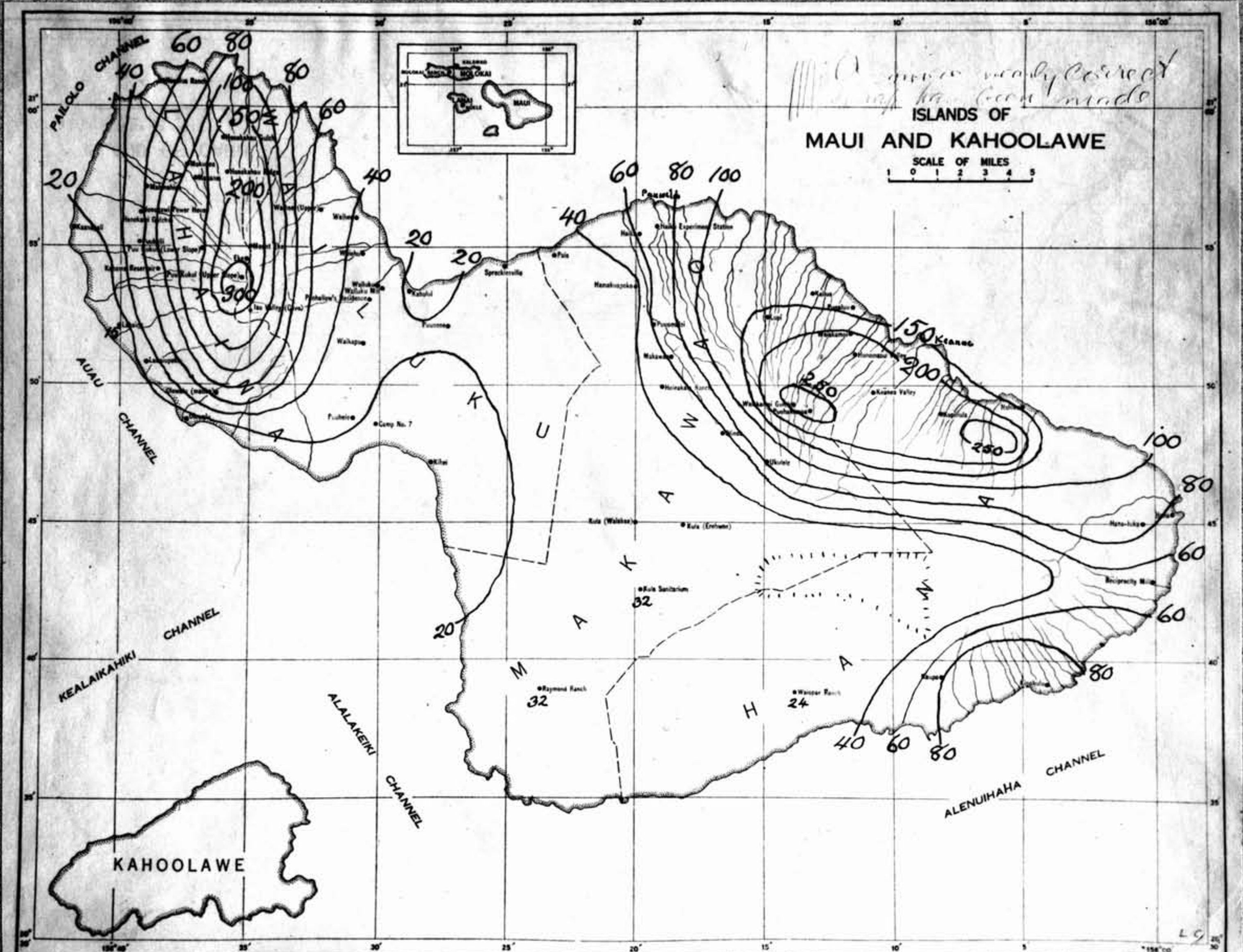
Turrets of _Pheidole megacephala_



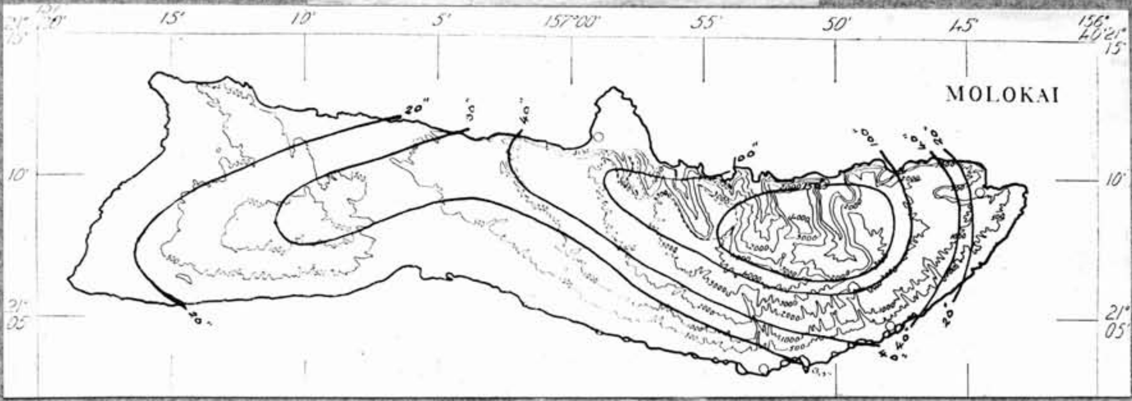
Rainfall Map of Oahu

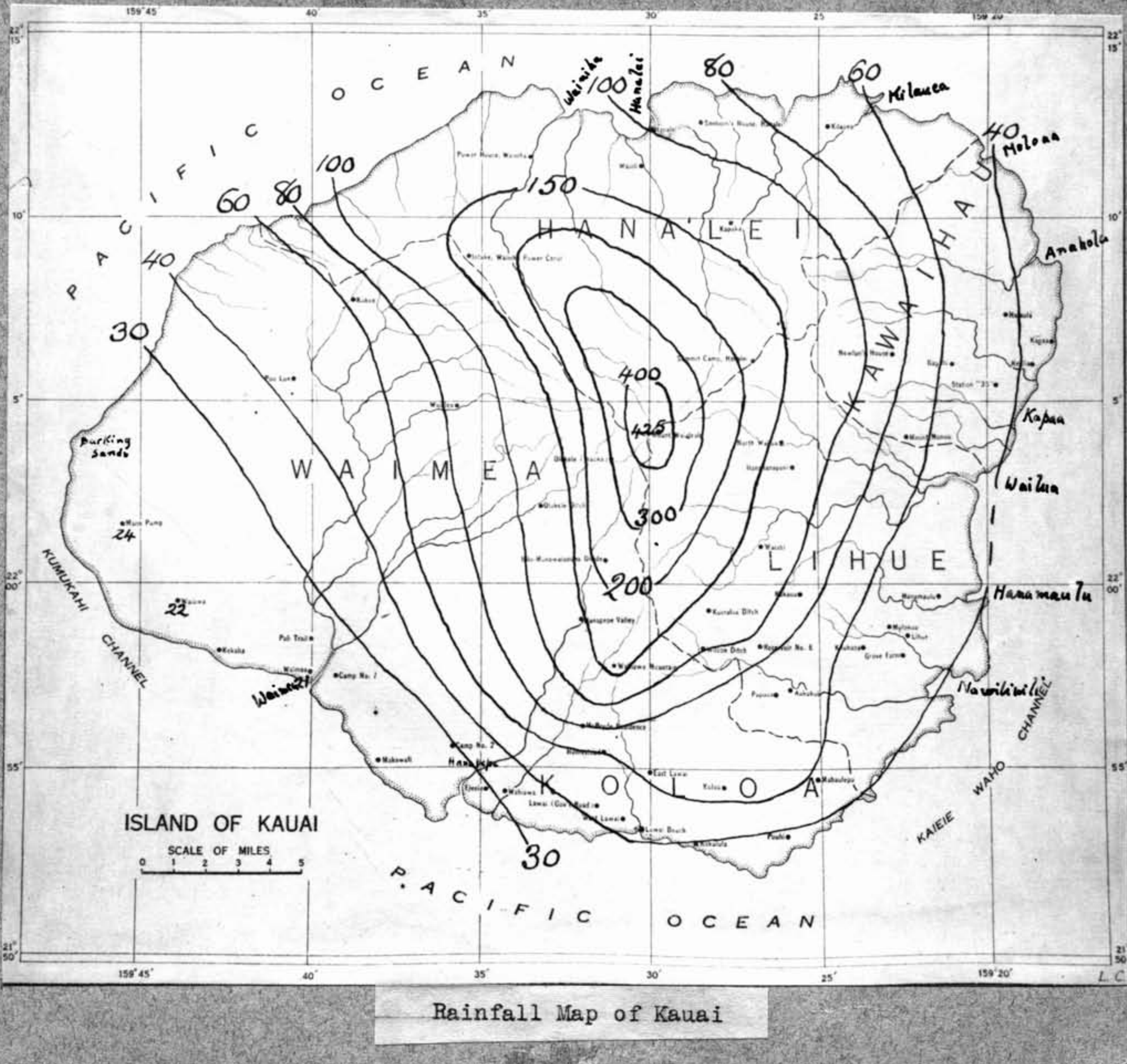
Rainfall Map of Lanai



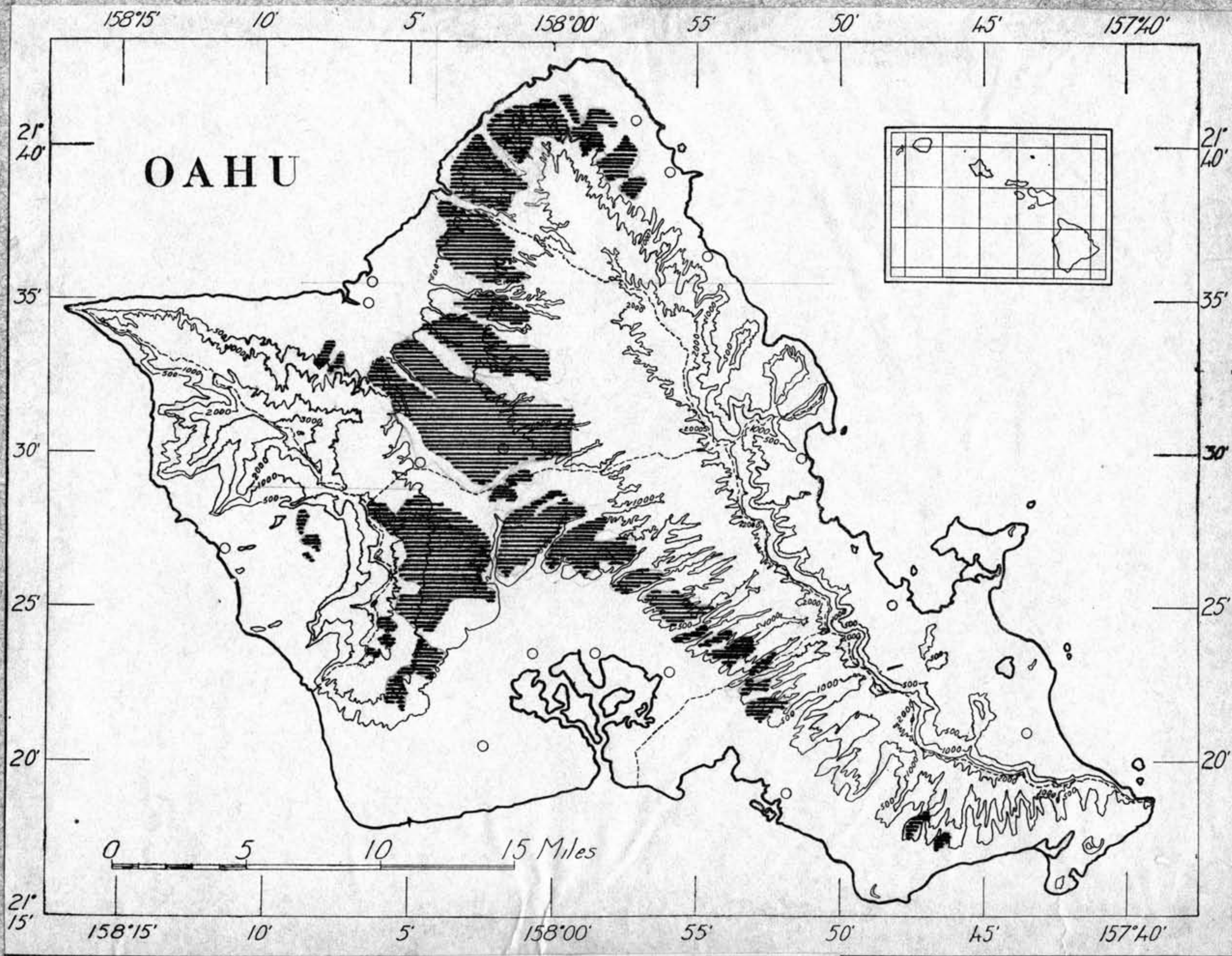
Rainfall Map of Maui

Rainfall Map of Molokai



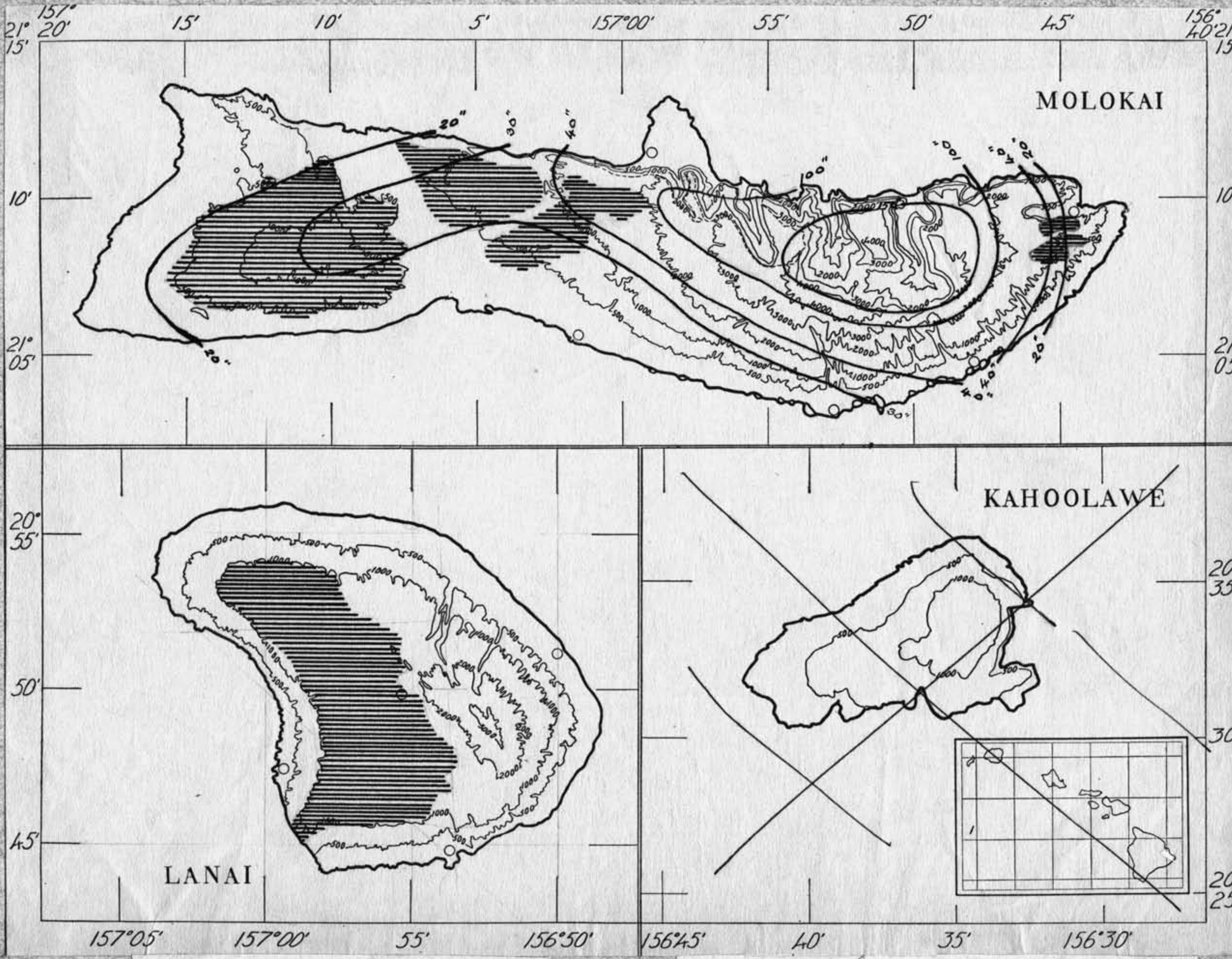


Rainfall Map of Kauai



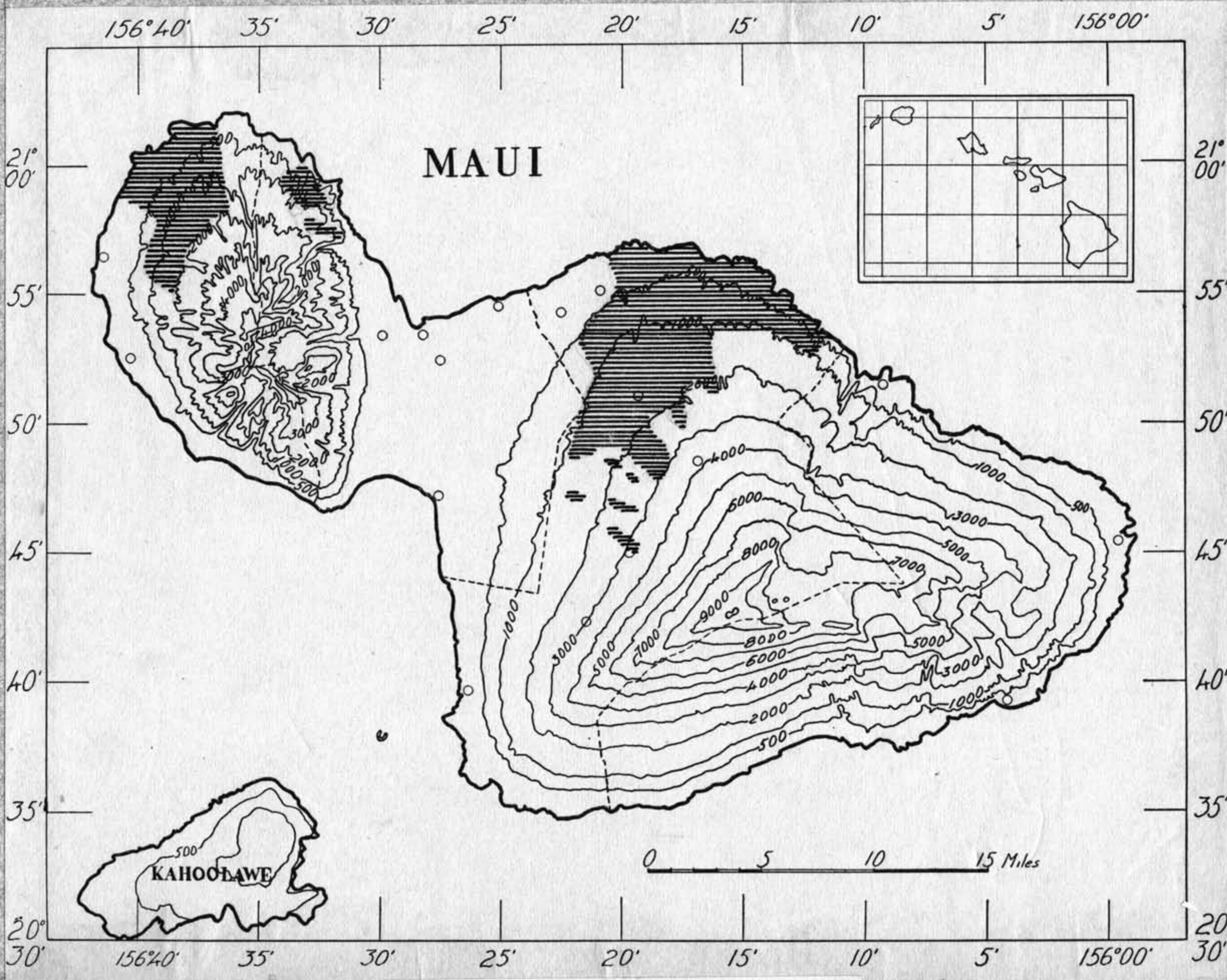
Pineapple Distribution on Oahu

~~Fig 10~~ ~~Froft of~~

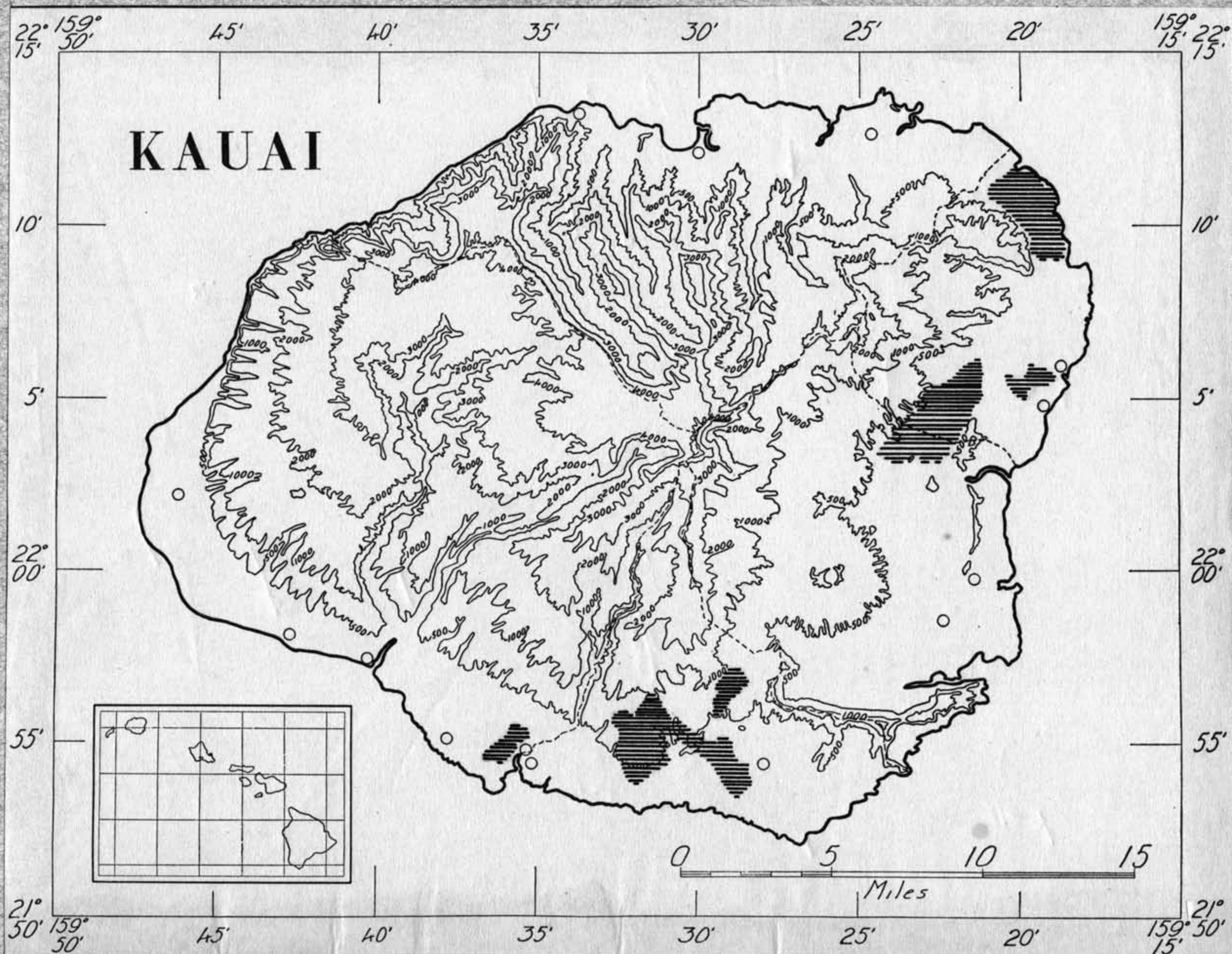


Pineapple Distribution on Lanai

Pineappple Distribution on Molokai



Pineapple Distribution on Maui



Pineapple Distribution on Kauai

Newly-planted Pineapple Fields, showing Mulching Paper

Guard Rows (on left); main field (on right) .

Fly Control Experiment - Apparatus

Humidity Experiment - Apparatus

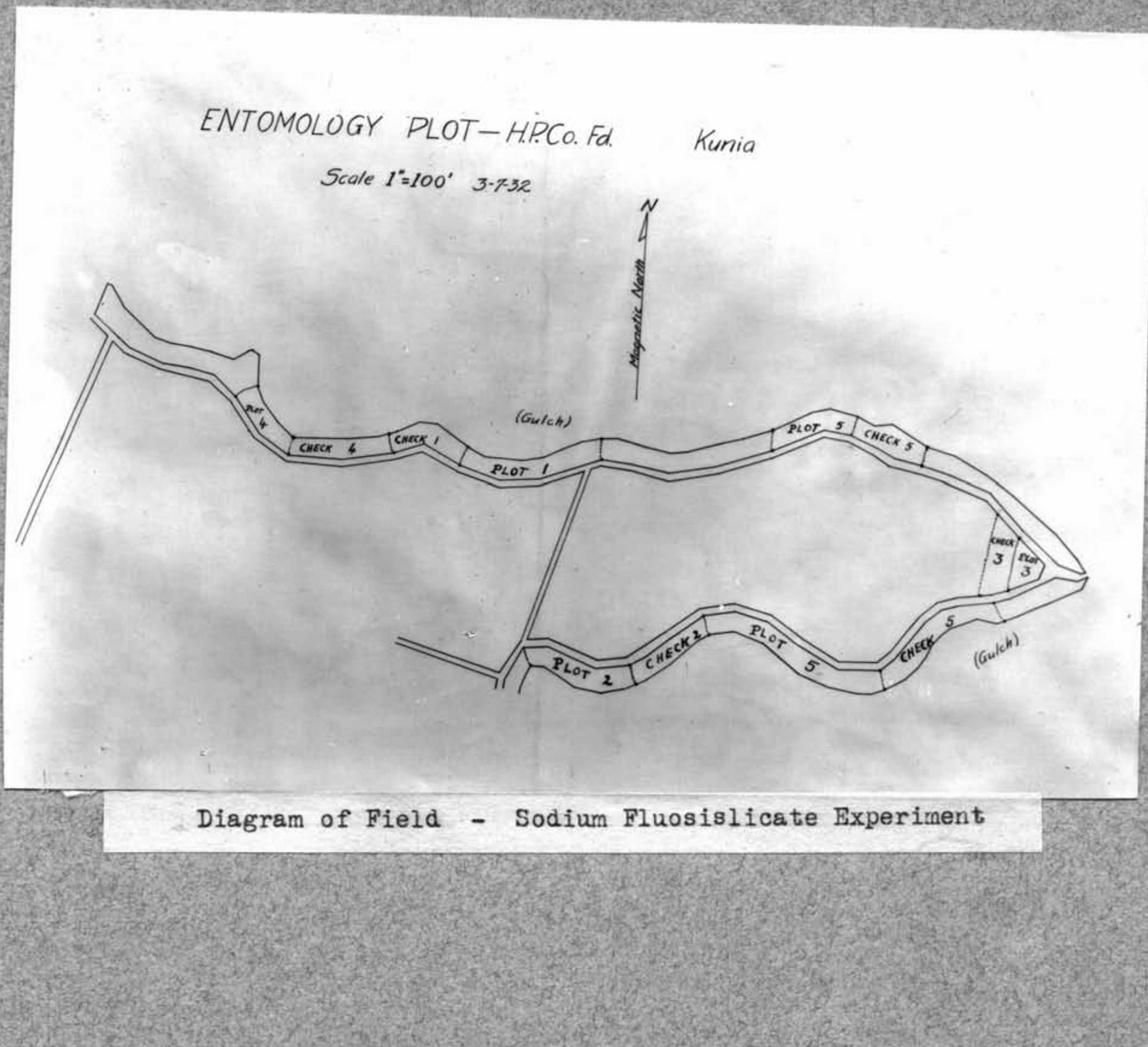


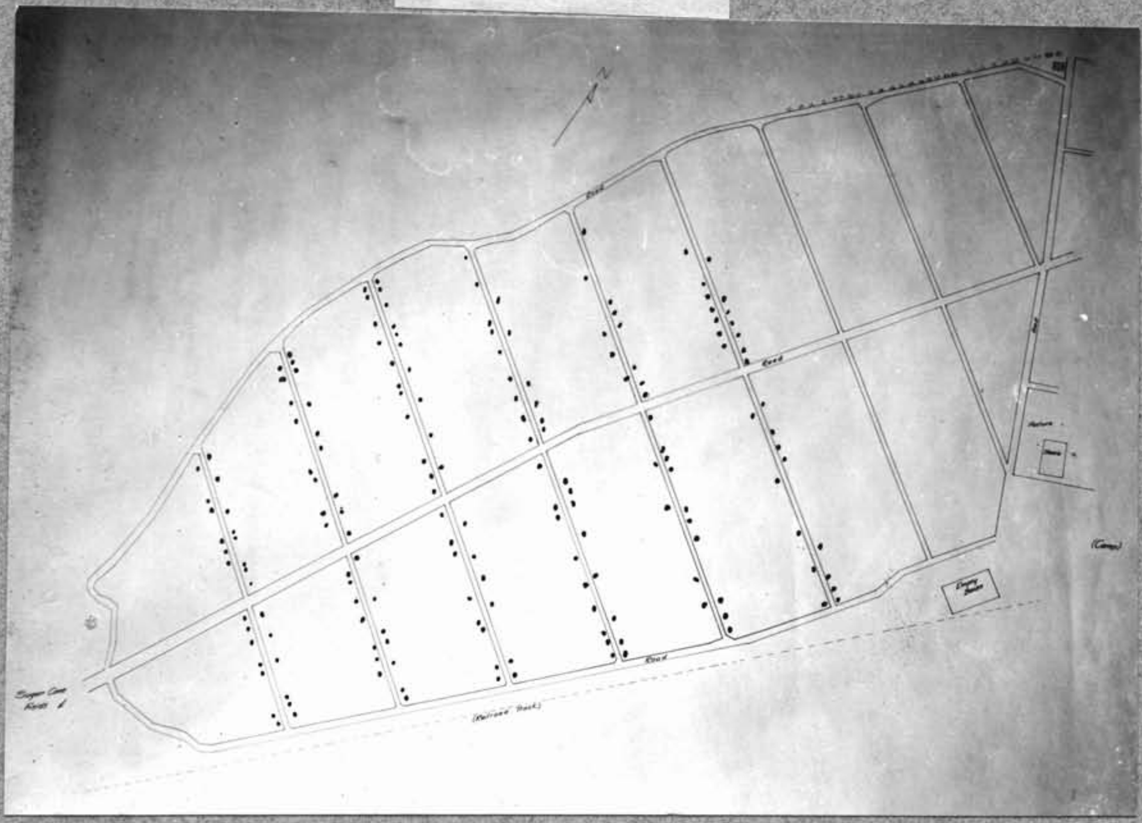
Diagram of Field - Sodium Fluosislicate Experiment

SodiumFluosilicate Barrier

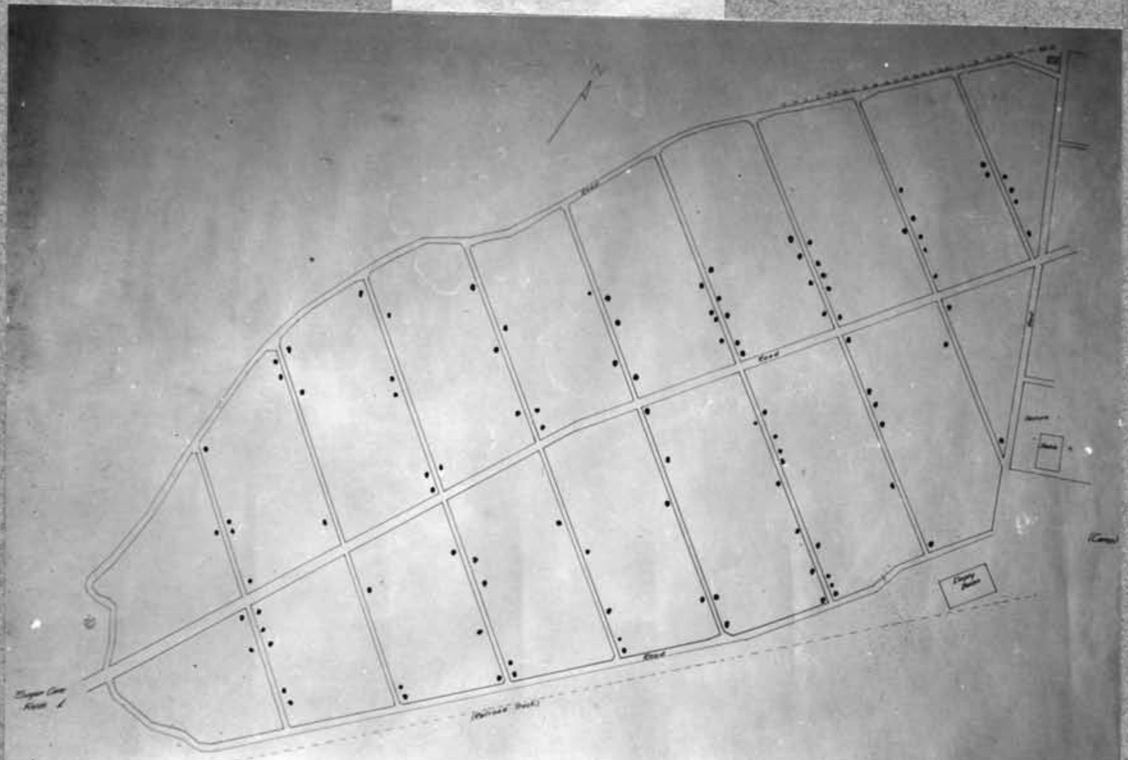
A Poison Bait Container on a Fire Ant Nest

Map of Poison Bait Experiment Area
W a i p i o

September 1932

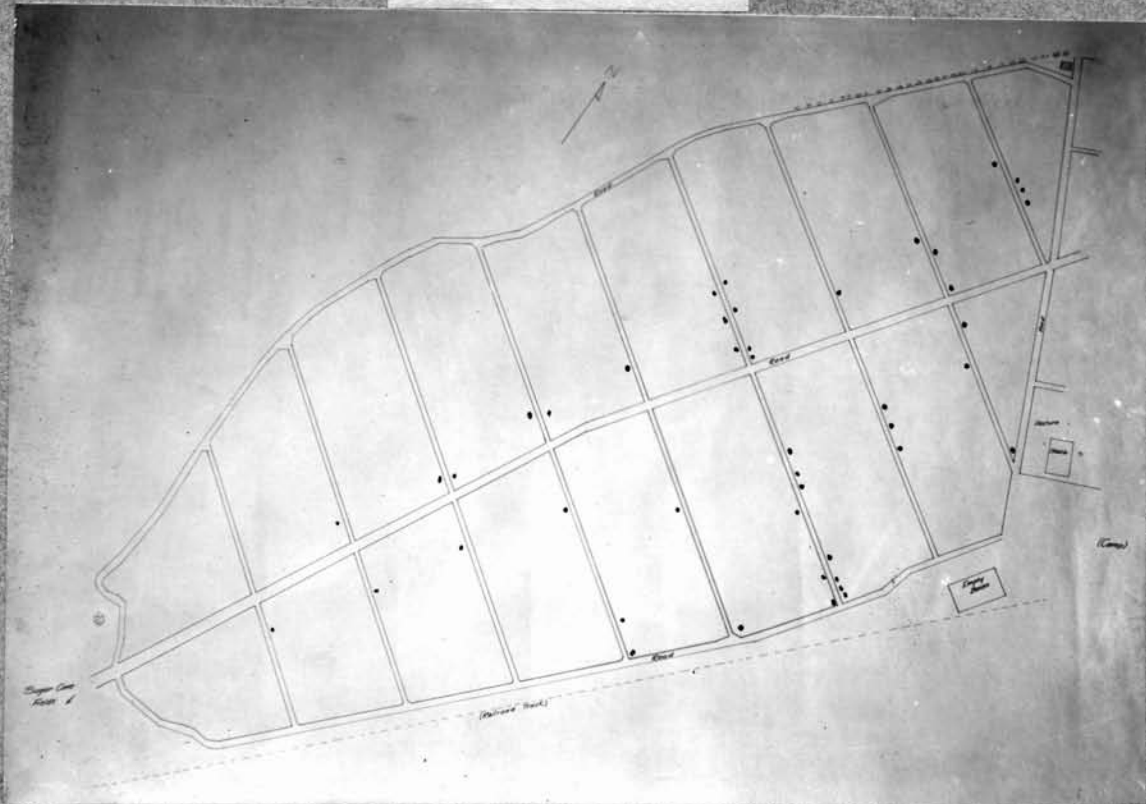


November 1932



Map of Poison Bait Experiment Area
W a i p i o

January 1933



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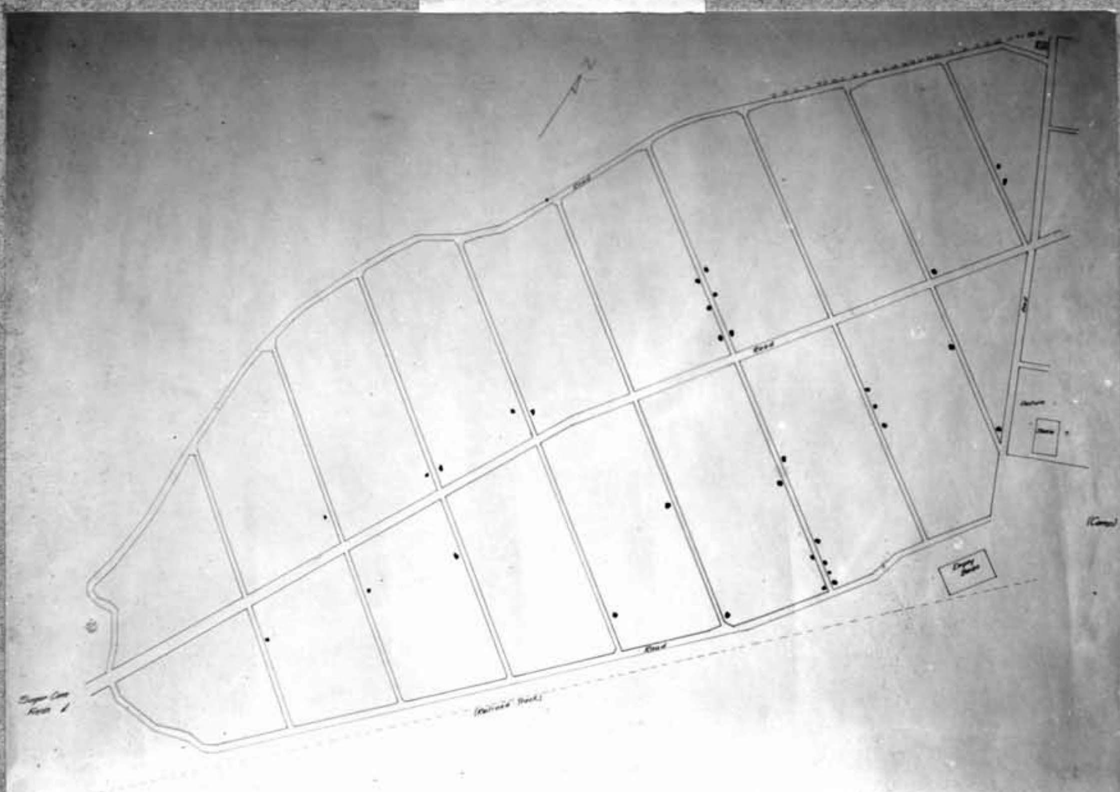

Ant Fence Sprayer - Molokai

Ant Fence Sprayer - Molokai

Ant Fence - Wahiawa Experiment Station

Ant Fence Experimental Squares

Spraying a Pineapple Field

Pineapple Fruit, infested with ants and mealybugs at base.