COMPARATIVE EFFECTIVENESS OF SOME INSECTICIDES, REPELLANTS AND SEED-PELLETING IN THE PREVENTION OF ANT REMOVAL OF PASTURE SEEDS

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SUMMARY

From a series of field experiments it has been shown that lime pelleting was the only form of seed dressing to significantly reduce removal of pasture seeds by ants from 8 different genera. There was no significant difference in repellant effect between gum arabic and cellofas as stickers used in the pelleting. Observations of ant behaviour indicated that the dusty coating on pelleted seeds either repelled ants completely or caused them to drop the seeds soon after picking them up. The repellant effects of the insecticides used were hardly superior to the standard repellant but non-toxic substances tested, viz: diesoline, kerosene and oil of citronella.

Laboratory experiments showed that, even under conditions of greatly increased contact with D.D.T., dieldrin, chlordane, lindane, folidol and derris only lindane killed ants in less than one hour. This explains the lack of effect of insecticides under the conditions of our experiments.

The experiments were carried out with the seeds of three legumes, *Medicago sativa* cv. Hunter River, *Phaseolus atropurpureus* cv. Siratro, and *Glycine javanica* cv. Cooper and two grasses, *Sorghum almum* cv. Crooble, and *Panicum maximum* var. *trichoglume*. Within this range of species the ants concerned showed marked preferences, apparently based on seed size, with decorator ants being less selective than harvester ants.

It is suggested that more effective repellants could be developed from compounds resembling myrmecoidal secretions.

INTRODUCTION

Experiments on the establishment of mixed pastures from seed broadcast after burning of fallen brigalow forest on heavy clay soils indicated a high but variable reduction due to seed-removing ants (Russell and Coaldrake, 1965).

Field observations confirmed earlier findings (Champ, Sillar and Lavery 1961; Leslie, 1965; Morrison, 1966) that the problem lay in the removal of seed by ants from the surface to sites where germination was prevented or full development was impossible. Among ants responsible for this type of problem in our environment are seed-harvesters chiefly in the genera *Meranoplus, Melophorus, Monomorium, Chelaner* and *Pheidole*. They are mostly small ants which eat the seed underground, or after storing it in surface caches, where uneaten seeds that do subsequently germinate often have the plumules eaten thus preventing development (Greaves, T., 1966—pers. comm.). Ants causing these types of removal will be referred to as "harvesters". Again, some larger ants, mainly in the genera *Iridomyrmex, Rhytidoponera* and *Polyrhachis* remove seeds as playthings or to decorate their nests. This type of seed removal is important because such seeds are generally put in exposed places where seedling development is impossible, even if initial germination occurs. Ants responsible for this second type of removal will be referred to as "decorators".

The use of insecticides on pasture seed at sowing sometimes leads to successful establishment instead of failure due to ants (Anslow, 1958; Champ, Sillar and Lavery, 1961; Leslie, J. K., pers. comm.; Paull, C., pers. comm.; Campbell, 1966).

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Our initial field observations suggested that the insecticides frequently did not kill ants before they removed seeds to points where germination and development is prevented. Laboratory studies confirmed the delayed action of a range of insecticides and thereafter the field experiments included studies on repellants as well as insecticides.

In particular these investigations were aimed at studying the effects after the broadcasting of seed on burnt fallen forest of brigalow (*Acacia harpophylla*). Here seed lying exposed on bare soil surfaces or lightly buried in ash for periods of up to several weeks before a germinating rain, is very susceptible to ant removal.

Ancillary experiments tested the effects of some of the toxic materials used on germination since other authors (Reynolds, 1958; Champ, Sillar and Lavery, 1961; Jones, 1965) indicated variable effects from such compounds. In earlier work two of the present authors (Russell and Coaldrake, 1966) found that the hydrocarbon insecticides used in the present experiments had little effect on the nodulation of lucerne and *Glycine javanica* when they were correctly inoculated.

MATERIALS AND METHODS

The following seeds, insecticides and repellants were used in the experiments —

Legumes	No. per lb	Seed shape and coat characteristics
Medicago sativa cv. Hunter River (Lucerne)	200,000	Kidney shaped, fairly smooth.
Phaseolus atropurpureus cv. Siratro	38,000	Spherical, smooth.
Glycine javanica cv. Cooper (glycine)	75,000	Angular, rough.
Grasses		
Sorghum almum cv. Crooble	68,000	Smooth coat but with remains of floret attached.
Panicum maximum var. *trichoglume* (Green panic)	880,000	Caryopsis within lemma, or whole floret.

Insecticides	Repellants
Dieldrin	Diesoline (Diesel distillate)
Chlordane	Kerosene (Lighting)
D.D.T.	Oil of Citronella
Telodrin	
Endrin	
Lindane	
Derris	
Folidol	

All insecticides were used at 1 gm active ingredient per lb of seed except telodrin where indicated. Derris was dusted on; the rest were applied in water. The necessary volume of water to wet unit weight of each species of seed was determined prior to making up the solution and then the correct volume of solution to give this level of application (i.e. 1 gm act. ing./lb seed) was measured from a burette. The solution and seed were tumbled in a jar to wet all seed surfaces.

In the experiments on pelleting the non-pelleted seeds were tumbled with a thin paste of peat inoculum in water 24 hours after pre-treatment with insecticide or repellant. To avoid dilution of active ingredient only enough peat slurry was added to coat the seeds. Pelleted seeds were prepared by the method described by Norris (1964) which uses peat inoculant and sticker followed by an excess of plasterer's lime ($CaCO_3$). Stickers were gum arabic (gum acacia), used as a 45% w/v solution in water, and Cellofas A as a 5% w/v solution of methyl cellulose (I.C.I.) in water. This technique leaves the seeds with a dusty outer coating.

In field experiments a "plot" was located by a 3" white-painted nail standing in the ground, at the foot of which 10 seeds were placed in a heap. These nails were placed in a grid at 8-inch centres.

A—Laboratory Experiments

Experiment I — Effect of repellants on legume germination

The germination of lucerne, Siratro and glycine one week and 13 weeks after treatment with diesoline, kerosene and oil of citronella was compared with controls. The repellants were applied liberally in order to freely coat the seeds which were then drained and dried. Germination tests were conducted at room temperature on filter papers moistened with water in petri dishes and final germination was measured on the 15th day.

Experiment II — Measurement of the toxicity of insecticides on ants

Strips of blotting paper were impregnated with 2% solutions of dieldrin, D.D.T. and folidol and dried, or, in the case of derris, dusted liberally. This approximated to the concentrations used for seed dressing. Decorator ants of one species (*Iridomyrmex* sp.) were forced to run over these briefly or for long periods. The time taken for the ants to become affected and to die was measured.

In a second series of tests ants were confined in jars with seed, treated with insecticide by the method described above. The jars were placed either upright without lids, which forced the ants into continuous contact with the seeds, or on their sides, when the ants continually ran on and off the seeds. Three species of ants from three genera (*Melophorus, Meranoplus* and *Iridomyrmex*, i.e. two harvesters and one decorator) were used in these tests. The insecticides used were dieldrin, chlordane, lindane, D.D.T. and derris. Time taken for the ants to die was measured.

B—Field Experiments

Experiment III

Seeds of lucerne, glycine and Siratro treated with oil of citronella, kerosene or diesoline were laid out as five locality replications on a sandy ridge with solodic soils carrying iron-bark (*Eucalyptus crebra*), and open tussock pasture chiefly of *Bothriochloa decipiens* at the Queensland Agricultural College, Lawes, on 27-8-64.

Ant activity was carefully watched and seed removal recorded at the end of the second day. Ants removing seed were collected and identified.

Experiment IV

This was a repeat of Experiment III with two additional seed treatments — chlordane and derris. It was laid down in the same area two days later, and seed removal recorded at the end of the third day.

Experiment V

Seeds of lucerne, glycine and Siratro were treated with dieldrin, D.D.T., chlordane or folidol. Seeds previously treated (33 weeks before and kept in closed containers) with dieldrin, D.D.T., lindane, telodrin (at two rates — 0.33 gm and 1 gm act. ing. per lb seed) or endrin were also included in the experiment. Seeds treated with dieldrin or telodrin, or not treated, were pelleted with gum arabic or with cellofas. There were three untreated controls: (a) dry seed; (b) soaked in water for two hours; and (c) soaked until sprouted. The experiment was laid down on the same location as experiments III and IV on 20-10-64.

In Experiments III, IV and V there was wide variation in ant removal of seed from site to site depending on proximity of ants. In the later experiments replication was increased to overcome this difficulty.

The two final experiments (VI and VII) were attempts to measure the repellant effect of six seed pre-treatments and three types of pelleting on removal of five species of pasture seed of various sizes and seed coat textures. The treatments were based on the apparent differences in Experiments III, IV and V.

Experiment VI

Experiment VI was carried out in December, 1964. The treatments were —
Species: Glycine, Siratro, Lucerne, *Sorghum almum,* Green panic.

Seed pre-treatment with:
Control (nil), Dieldrin, Chlordane, D.D.T., Lindane, Derris, Diesoline.

Pelleting:
Control (not pelleted), Gum arabic, Cellofas.

The treatments were set out in a fully factorial layout in a randomized block design. There were five replications laid down on five sites on an area of freshly burnt, fallen, brigalow forest at Roundstone, 30 miles west of Moura (lat. 24°S) on 17 and 18-12-64. The vegetation, soils and climate of this region have been described by Isbell (1962).

The experiment was sited on a newly burned area of fallen forest in which brigalow, yapunyah (*E. thozetiana*) and wilga (*Geijera parviflora*) were the prominent species. Ant removal of aerially sown pasture seed on burnt scrub land had interfered with earlier sowings of experimental and commercial pastures nearby. The burn was thorough and much of the surface of the gilgaied clay soil was baked hard with some patches of soft ash. The five replications were located on the shoulders or sides of gilgais in the vicinity of nests of seed harvester ants. The species of ants taken in the area are listed in Table 1.

Experiment VII

This Experiment was a repeat of Experiment VI laid down in six replications 19-4-67. The delay in starting this experiment was caused by drought as explained below.

It was originally planned to do this experiment in March, 1965 on deep gilgaied clay soils of former brigalow forest at Meandarra, Queensland. The authors were very fortunate in having the assistance of Mr. T. Greaves of the C.S.I.R.O. Division of Entomology over this period. As a result of preliminary tests it became apparent that there was no seed-harvester ant activity on the heavy clays and very little on adjacent lighter soils. This was related by Mr. Greaves to drought and the experiment was not therefore laid down. However, a good deal of the taxonomic work done at Meandarra was relevant to the other experiments and ants present are included in Table 1 under site 3.

RESULTS

The ants found at each site are listed in Table 1. Identification of all ants was made by Mr. T. Greaves of the Division of Entomology, C.S.I.R.O. Because of current difficulties in the taxonomy of Australian ants identification was not generally carried beyond the level of the genus.

TABLE 1.

Ant Genera Implicated in Seed Removal at each Site.

Numbers indicate approximate order of importance of genus in seed removal at each site.

N.B.—Where a genus is written more than once, more than one species is involved.

Harvester Ants	Notes	Decorator Ants	Notes
Site 1 — LAWES: Sandy forested ridge. Experiments III, IV and V —			
1. *Monomorium*		3. *Iridomyrmex purpureus*	Smith — (Meat ant) large nest in vicinity of 2 reps.
2. *Meranoplus*		6. *Iridomyrmex*	— extensive network of pads in vicinity of 2 reps.
4. *Monomorium*		7. *Rhytidoponera*	"Green head ants".
5. *Meranoplus*		9. *Pheidole*	
8. *Pheidole*		10. *Paratrechina*	
Site 2 — ROUNDSTONE: Fresh ash from fallen-brigalow forest on gilgaied clay soils with surface pebbles. Experiment VI —			
1. *Monomorium*	Both active mainly on Rep. III. Although removal on Rep. II was of similar size the species order was different: the ants responsible were not seen and thus were probably nocturnal. (see Discussion).	3. *Iridomyrmex purpureus*	— responsible for most or all of the seed removal on Rep. IV.
2. *Meranoplus*		4. *Iridomyrmex*	Other species of *Iridomyrmex*, were common but none were seen to remove seed.
Harvester Ants		**Decorator Ants**	
Site 3 — MEANDARRA: Clay soils under brigalow associations or cleared and under grass. The observations were in March, 1965 under hot, drought conditions.			
Melophorus	active in bright sunshine but not when temp. exceeded 90°F.	*Iridomyrmex purpureus*	
Meranoplus	seen early morning and at dusk but not through the day.	*Iridomyrmex*	
		Iridomyrmex	
Monomorium	not seen in bright sunshine but numerous as soon as cloud obscured the sun (and humidity increased with storm activity).	*Rhytidoponera*	
		No species of *Pheidole*, a major harvester genus, were seen presumably due to drought.	
Chelaner	seen in early morning one day but not the next due probably to slight, unapparent weather changes.	Many more harvester ants were seen on loamier, red, non-cracking soils than on the heavy, cracking, gilgaied clays (grey soils of heavy texture).	
Site 4 — LAWES: Sandy colluvium thinly overlaying clay loam. Experiment VII —			
		REP. I	
1. *Meranoplus*		4. *Iridomyrmex*	
2. *Pheidole*		5. *Polyrhachis*	
3. *Chelaner*		6. *Iridomyrmex*	
		7. *Rhytidoponera*	
		REP. II	
1. *Chelaner*		2. *Iridomyrmex*	
		3. *Iridomyrmex*	

A—Laboratory Experiments

Experiment I

Table 2 shows that the germination of the legumes was not seriously affected when freshly treated with the repellants used but after 13 weeks there was a depressive effect on Siratro and glycine. Apparently, this was more severe on Siratro than on glycine which may relate to the fact that the Siratro seed was scarified.

TABLE 2.

Experiment I — Effect of seed treatment on germination of three legumes. Single dishes of 100 seeds for 15 days.

Seed	Nil Treatment	Diesoline	Kerosene	Citronella
Siratro	75%	76%	73%	62%
Glycine	44%	41%	32%	44%
Lucerne	93%	92%	86%	88%
At 13 Weeks After Treatment —				
Siratro	78%	38%	67%	43%
Glycine	49%	38%	34%	35%
Lucerne	92%	89%	87%	91%

Experiment II

Table 3 shows that there were differences in the toxicity of the insecticides used to harvester and decorator ants as measured by times taken to cause death.

TABLE 3.

Experiment II — Degree of Toxicity of some insecticides on three species of ants in bench tests.

TREATMENT	EFFECT Ant Species Tested *Melophorus sp.*	*Meranoplus sp.*	*Iridomyrmex sp.*
A.—Green panic seed treated with 1 gm active ingrd/lb seed of:	Continuous contact with seeds in bottles	Continuous (a) or intermittent (b) contact with seeds in bottles:	Continuous (a) or intermittent (b) contact with seeds in bottles:
DIELDRIN	Ants affected in 40 mins, dead in 69mins.	(a) Dead in 93 mins. (b) Dead in 4¼ hrs.	(a) Dead in 50 mins. (b) Dead in 7 hrs.
CHLORDANE	Ants affected in 48 mins, dead in 3 hrs.	(a) Dead in 86 mins. (b) Dead in 6½ hrs.	(a) Dead in 80 mins. (b) Dead in 7 hrs.
LINDANE	Ants affected in 12 mins, dead in 20 mins.	(a) Dead in 26 mins. (b) Dead in 32 mins.	(a) Dead in 13 mins. (b) Dead in 3 hrs.
D.D.T.	Ants affected in 34 mins, dead in 54 mins.	(a) Dead in 30 mins. (b) Dead in 6½ hrs.	(a) Dead in 90 mins. (b) Dead in 7 hrs.
DERRIS (Dusted on seed)	Ants affected in c. 4 hrs, dead in 7 hrs.	(a) Dead in 2 hrs. (b) Dead in 4¼ hrs.	(a) Dead in 90 mins. (b) Dead in 6½ hrs.
B.—Paper impregnated with 2% solution and dried:			
DIELDRIN	NOT TESTED	NOT TESTED	Contact period 20-60 secs—no effect after 45 mins. Contact period 30 mins—death shortly after.
D.D.T.	NOT TESTED	NOT TESTED	Contact period 20-60 secs—no effect after 45 mins.
FOLIDOL	NOT TESTED	NOT TESTED	Contact period 5 mins —death shortly after.
DERRIS (paper heavily dusted)	NOT TESTED	NOT TESTED	Contact period prolonged—no effect.

It is considered that the exposure to insecticides in these laboratory experiments was greater than would be the case with harvesting of treated seed in the field. There is also the possibility that toxicity was increased through exposure to fumes, especially in the tests in closed jars. Lindane appeared to be most toxic and derris the least but even the most rapid death from exposure to treated seed did not occur for 13 minutes, and in the majority of cases the ants were still active after one hour (Table 3). It is therefore apparent that when ants carry off treated seed they will not be affected soon enough to prevent removal of a seed to a site where it cannot germinate and develop. This result is further assured by the communal efforts of ants. Therefore, under the small plot conditions of the experiments in this series, the parameter measured, seed removal, was a measure only of the repellant effect of the seed treatments.

B—Field Experiments

Experiments III, IV and V were preliminary investigations of the extent of variation of ant removal from site to site and of the extent of suppression of ant removal of seed by different seed treatments.

Experiments III and IV

Since the differences obtained in Experiment III were repeated at the same levels of significance within the wider range of treatments used in Experiment IV, only the results from Experiment IV are presented here (Table 4).

TABLE 4.

Experiment IV — Effects of some insecticides and repellants on ant removal of seed of three legumes.

Numbers of seeds removed from a total of ten per plot: Means of 3 replications.

Legume	Repellants and Insecticides							Significant Differences	
	Control	Citronella	Kerosene	Diesol	Chlordane	Derris	Means	P<1%	P<5%
Lucerne	8.33	7.33	6.00	5.67	6.67	6.67	6.78	a	a
Glycine	4.00	4.33	7.00	6.33	2.67	2.67	4.50	ab	b
Siratro	6.00	1.67	1.67	1.67	0.33	1.00	2.06	b	c
Means	6.11	4.44	4.89	4.56	3.22	3.44			

Repellant and Insecticide Means not significantly different from Control.

Legume Means: Duncan's Multiple Range Test R_2 at $P<5\% = 2.00$; R_3 at $P<1\% = 2.80$.

There were significant differences in the removal of seed between species of plants in both experiments but no significant differences between repellant and insecticide treatments and the control. However, it appeared that oil of citronella and diesoline might be superior to kerosene as repellants but that these might not be as effective as the two insecticides used.

The results of Experiment V have been split for ease of comparison and analysis and are shown in Tables 5 and 6.

TABLE 5.

Experiment V — Effect of various seed treatments on ant removal of seed of 3 legumes. Seed freshly treated.

Numbers of seed removed from total of ten per plot: Means of 3 replications.

Legume	Seed Treatment							Significant Differences P<1%
	No Insecticide		Insecticides					
	Bare Seed	Soaked	Dieldrin	D.D.T.	Folidol	Chlordane	Mean	
Lucerne	8.67	10.00	9.33	8.33	10.00	8.33	9.11	a
Glycine	8.00	9.00	7.33	6.00	8.00	5.33	7.28	a
Siratro	1.33	9.67	3.00	3.67	3.33	1.33	3.72	b
Mean	6.00	9.56	6.55	6.00	7.11	5.00		
Significant Differences from control		3.56**	n.s.	n.s.	n.s.	n.s.		

L.S.D. for seed treatment Means at P<1% = 3.41.

Legume Means: Duncan's Multiple Range Test R_2 at P<1% = 3.00; R_3 at P<1% = 3.14.

TABLE 6.

Experiment V — Effects of insecticide treatment and pelleting of lucerne and Siratro on ant removal of seed.

Legume	Seed Treatment										
	No Insecticide			Pelleted with Cellofas			Pelleted with Gum arabic			Mean	Sign. Diff.
	Bare Seed	Soaked	Sprouted	Nil Ins.	Dield.	Telo-drin	Nil Ins.	Dield.	Telo-drin		
Lucerne	8.67	10.00	10.00	7.67	7.33	9.33	7.00	4.33	6.00	7.81	5.11***
Siratro	1.67	9.67	8.00	1.33	0.33	2.67	0.33	0.00	0.33	2.70	
Mean	5.17	9.84	9.00	4.50	3.83	6.00	3.67	2.17	3.17		
Significant Differences from Control (Bare seed)		+4.67**	+3.83*	n.s.	n.s.	n.s.	n.s.	—3.00*	n.s.		

L.S.D. for Treatment Means at P<1% = 4.03; P<5% = 3.00.

L.S.D. for Legume Means at P<0.1% = 3.66.

Apart from significant differences between species there were significant increases in removal of seed between the control and soaked and sprouted lucerne and Siratro seed. There was a significant decrease in removal of pelleted seed (gum arabic sticker) treated with dieldrin.

Ant removal of seed varied considerably between locations. The smaller harvesters tended to remove small seed and unpelleted seed. Decorators, particularly meat ants, tended to remove seeds nearest their pads irrespective of treatment; they were quite capable of carrying the largest seeds. However, they did avoid pelleted seeds.

Experiment VI

The final count for Experiment VI was made six days after laying down each replication. The exposed position of the trial caused considerable wind dispersal of green panic seed and results for green panic are thus not included in Table 7.

TABLE 7.

Experiment VI — Effect of six pre-treatments of seed of three legumes and one grass pelleted in three ways; Decembr, 1964 on freshly brigalow land.

SPECIES	SEED PRE-TREATMENT Total seeds removed per treatment (150 seeds: means of 5 replications, 10 seeds per plot).									
	Nil	Dieldrin	Chlordane	D.D.T.	Lindane	Derris	Diesoline	Total	Mean*	Sig. Diff. P<5%†
Glycine	25	21	11	34	14	13	12	130	1.24	b
Siratro	23	34	18	16	21	27	21	160	1.52	ab
Lucerne	15	54	28	10	30	35	35	207	1.97	ab
Sorghum almum	53	34	30	21	34	24	39	235	2.24	a
TOTAL	116	143	87	81	99	99	107	732		
PELLETING	Total seeds removed per treatment (200 seeds: means of 5 replications, 10 seeds per plot)								Mean‡	L.S.D.
Unpelleted	53	66	35	35	35	42	46	312	2.23	0.55 P<5%
Gum arabic	41	49	29	23	38	33	21	234	1.67	
Cellophas	22	28	23	23	26	24	40	186	1.33	
TOTAL	116	143	87	81	99	99	107	732		

† Duncan's Multiple Range Test.

* Mean of 105 single plots for species—i.e. 7 insecticide treatments each with 3 pelleting treatments and 5 replications.

‡ Mean of 140 single plots—i.e. 7 insecticide treatments on 4 species with 5 replications.

S.E. of Species (Seed) Means 0.304
S.E. of Pelleting Means 0.199

There are no significant differences between the nil (control) and any seed pre-treatment means.

Pelleting significantly ($P<5\%$) reduced seed removal compared with non-pelleting but there was no significant difference in repellant effects between gum arabic and cellofas used as stickers.

Removal of *Sorghum almum* was significantly ($P<5\%$) greater than removal of glycine but not greater than removal of lucerne and Siratro. Nor was removal of lucerne and Siratro greater than glycine. This result was ascribed to decorators being more active than harvesters, since decorators are less discriminating between different types of seed.

Apart from the effect of pelleting there were no significant differences between seed pre-treatments and the control.

Experiment VII

Owing to rain after 30 hours there was insufficient data from either replication on two sites (on clay loam) but due to higher ant activity on the third site (on colluvial sandy loam) the seed removal from both replications gave analysable results. These are given in Table 8 and the list of ant species involved is given under Site 4 in Table 1.

Pelleting again showed a significant reduction at ($P<1\%$) in seed removal compared with unpelleted seed and there was again no difference in removal between other seed pre-treatments and the control.

In contradistinction to Experiment VI lucerne, was, on this occasion, removed to a significantly ($P<1\%$) greater extent than the other species. Siratro was removed to a significantly lesser extent than the two grasses ($P<1\%$) and then glycine ($P<5\%$). It can be seen from Table 1 that the proportion of decorators to harvesters was less than in Experiment VI and this is the probable explanation. It seems likely that the small seed harvesters remove small seed preferentially — in this case lucerne and green panic.

Due to high variability in Experiment VI and insufficient replication in Experiment VII the differences in ant removal between pelleted seed in which cellofas was used as the sticker compared with pelleted seed with gum arabic as sticker, were not significant. However, the consistent apparent differences suggest that cellofas is less attractive to ants than gum arabic.

DISCUSSION AND CONCLUSIONS

In the field experiments the seeds were not caged so that the behaviour of ants could not be affected; this leaves the possibility of some removal of seed by birds. In the case of Experiment VI the plots were tended by two observers from dawn till darkness and, furthermore, birds are always noticeably absent from the extensive areas (1,000 to 3,000 acres) involved in the burning of newly cleared brigalow land. The consistency of preferential selection based on seed size between this experiment and those at Lawes, the fact that there were always some seeds left in the heap at each "plot", and the deterrent effect of the closely patterned (8 inches square) upright nail markers all point to the fact that our results were not affected through partial removal of seeds by birds. In only one experiment (not included in this paper) disturbance of the nails indicated interference by some nocturnal animal.

Pelleting, i.e. surrounding a seed with a firmly stuck layer with a dusty surface does appear to check removal of seed by all classes of ants. Campbell (1966) recorded preliminary observations of a similar effect with seeds of clovers and temperate grasses, but did not investigate further. Our field observations showed two main responses by ants to pelleted seed. In most cases the ants moved on after a brief stroking of the seed with the antennae. In some cases (chiefly with decorators) the ant picked up the seed and began to carry it. Then within a few inches of travel the ants dropped the seed and moved on after "cleaning" their

TABLE 8.

Experiment VII — Effect of six pre-treatments on seeds of three legumes and two grasses pelleted in three ways; April, 1967 on open tussock pasture on loamy sand.

Numbers removed from 10 seeds: (Treatment Totals. Means from 2 replications)

SPECIES	SEED PRE-TREATMENT: Total Seeds removed per treatment (60 Seeds: means of two replications, 10 seeds per plot).										
	Nil	Dieldrin	Chlordane	D.D.T.	Lindane	Derris	Dicsoline	Total	Mean*	Significant Difference † P<1%	Significant Difference † P<5%
Glycine	14	16	9	6	10	11	8	74	1.76	bc	b
Siratro	2	0	0	7	4	4	5	22	0.52	c	c
Lucerne	41	31	40	35	21	46	26	240	5.71	a	a
Sorghum almum	32	3	3	17	13	19	24	111	2.64	b	b
Green Panic	12	25	29	4	22	12	16	120	2.86	b	b
TOTAL	101	75	81	69	70	92	79	567			
PELLETING	Total Seeds removed per treatment (100 seeds: means of two replications, 10 seeds per plot).								Mean*	L.S.D.	
Unpelleted	50	27	44	35	34	47	28	265	3.79	1.25 at $P<1\%$	
Gum arabic	14	22	36	8	15	29	37	161	2.30		
Cellophas	37	26	1	26	21	16	14	141	2.01	(R_3 at $P<1\% = 1.37$‡	
TOTAL	101	75	81	69	70	92	79	567			

† Duncan's Multiple Range Test.

* Mean of 42 single plots—i.e. 7 insecticides with 3 pelleting treatments and 2 replications.

‡ Mean of 70 single plots—i.e. 7 insecticides on 5 species with 2 replications.

S.E. of Species (Seed) Means 0.434

S.E. of Pelleting Means 0.336

There are no significant differences between the nil control and any seed pre-treatment means.

forelegs with an action equivalent to handwashing. Thus, while the response to the pellet may vary the net result is to leave the seed untouched. The ant removal of pelleted grass seed mentioned by Greaves (1959) may have been due to pellets which were not dusty since, in our experience, it is the dustiness which "repels".

For this "repellant" effect an outer coating of some other finely divided, inert dust may well be as effective as plasterer's lime. Such materials as magnesite and limonite already used for insect control by Ratcliffe, Gay and Fitzgerald, 1940 (grain weevil) and Helson, 1942 (potato tuber moth) may be useful for this purpose even though the mode of action is probably different in ants. Our experience suggests that relative humidity is not so critical with ants as it was with the insects in the work quoted above.

Since it is often advantageous to pellet legume seeds with lime or rock phosphate dust (Norris, 1967) the added protection from ant removal is a welcome bonus. However, as Norris points out, pelleting with either of the above compounds may be harmful with some species. In these cases the use of inert dusts such as those mentioned above may achieve the repellant effect without causing harm to the

In the case of more expensive legume and grass seeds, in areas of variable inoculant. Any further work with such inert compounds as repellant dusts would require that these should also be checked for any deleterious effects on nodulation when used on legumes.

One apparent limitation on the use of pelleting for its repellant effect on ants is illustrated by our experience with Experiment VII where light rain (0.30 inches) after 30 hours broke down the pellets. But the consequent imbibition may make the seeds unattractive to ants (Campbell, 1966), and protection for even 24 hours before rain can be vital. By contrast with Campbell's results our results (Tables 5 and 6) show significantly greater removal of soaked and sprouted seed under arid conditions. It is likely that in our experiments the aridity of the surroundings made the imbibed seed attractive to ants under conditions of water shortage. But pelleting seems to have real possibilities as an ant repellant in areas of variable rainfall where seed may have to lie on the ground for several weeks waiting for a germinating rain.

Our results in Table 2 agree with previous findings by Reynolds (1958) and Champ, Sillar and Lavery (1961) that most hydrocarbon insecticides have little general effect on seed germination. However, Jones (1965) found that endrin reduced germination of *Phaseolus aureus*. Again Russell and Coaldrake (1966) found that the hydrocarbon insecticides used in the experiments described in this paper had little adverse effect on the nodulation of lucerne and glycine, although they point out that other insecticides (especially in the organo-phosphorus group) were found to be deleterious by other authors. Thus, there is no reason against using insecticides for control of ant removal of seed under conditions such as those discussed below.

Good results often occur from the overall application of an insecticide to broadcast and sown pasture seeds. Dieldrin, aldrin (Leslie—pers. comm.) or lindane (Paull—pers. comm.) are commonly used. This may result from annihilation of all seed-removing ants in the area by removal and hence contact with a proportion of the seeds (Campbell, 1966), leaving the remainder to germinate. When seed is cheap, it may be economical to broadcast an excess of seed so treated. However, variable results may be expected depending on the population of seed-removing ants, which cannot easily be estimated beforehand, and on weather conditions. Most harvester ants are nocturnal but are also active in cloudy and damp weather. Species of *Monomorium* are particularly sensitive to humidity, while

Melophorus harvests in hot, bright sunshine (Greaves, T.—pers. comm.). It appears likely from our experiments that at least in some cases, superior establishment of large seeded species is also due to lesser removal by seed-harvesting ants.

rainfall, it is probably safer to pellet subject to the restrictions set out by Norris (1967) and confine plantings to larger-seeded species. Smaller-seeded species may be sown into prepared seed beds following cultivations (e.g. with cropping) to reduce ant populations. Leslie (pers. comm.) recommends spraying of small areas to be used for experiments, with an insecticide (aldrin or dieldrin) to eliminate ants.

Finally, it is suggested that further work on repellants should investigate not only the use of inert dusts but also the effect and persistence of compounds related to myrmecoidal secretions. Recent accounts of ant secretions by Roth and Eisner (1962) and by Cavill and Robertson (1965) indicate that these may be found in the cyclopentanoid monoterpene group. There is however, considerable variation between ant genera in the specific alarm substance secreted and this will pose problems.

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