THE DYNAMICS OF INSECT/LETHAL GRAIN INTERACTIONS IN AN INSECTICIDALLY TREATED GRAIN BULK

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ABSTRACT: A study was made of the consequences that arise from an insecticidal treatment of bulk grain wherein only a small proportion of the grain received a high dose of the chemical. Two models are developed. The first examines the interactions between an insect population and the heavily treated (lethal) grain particles in the grain bulk. The second examines the interaction between treated grain particles themselves and the survival of their lethal status.

INTRODUCTION: In the use of chemicals for the protection of stored grain, the prime concern has generally been to achieve uniformity of application. However in recent years there have been indications [1-4] that control is achieved not so much by all grains carrying the insecticide at normal lethal levels, but by individual grains carrying the chemical at higher than normal levels even though the general overall level of dosage has been the same. Thus, a grain bulk treated with malathion at an overall dose rate of 10 ppm showed on examination that the amount of insecticide carried by individual grains varied from 0.1 to 425 ppm [3] whereas under ideal conditions, every grain should have been carrying a dose of 10 ppm. It has also been found [4] that only the quick acting type of chemical (e.g. malathion & baythion) produces effective grain treatment under these conditions. There is also the variable that an individual grain possessing a dose many times the normal lethal quantity may subsequently pass on to the grains surrounding it, quantities of the insecticide in lethal amounts.

The model considered here however requires that a treated grain carries only a lethal amount of quick acting chemical. In the experimental example given this lethal amount is 10 ppm of malathion.

THE DYNAMICS OF INTERACTION BETWEEN AN INSECT POPULATION AND A POPULATION OF LETHAL GRAINS IN A GRAIN BULK: Consider an insect population of 'N' individuals passing through a grain strip of thickness 'x' containing 'g' lethal grains. If the distribution of lethal grains in the grain mass is considered to be uniform throughout, then the fraction of the insect population removed dN/N in a thickness dx of the grain bulk is proportional to the number of lethal grains (g) per unit volume encountered by the insect population in the thickness dx.

thus:

$$\frac{dN}{N} \qquad dx \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

or:

$$\frac{dN}{N} = -\mu x \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

where μ is an appropriate proportionality factor. To solve this differential equation, we integrate and apply the boundary conditions,

$$N_t = N_o \text{ when } x = 0$$

we have

$$N_t = N_o e{-}\mu x \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

Denoting by σ the cross-section area of the grain bulk penetrated by the insects, we can further write that.

$$\mu = g.\sigma,$$

and hence

$$N_t = N_o e^{g\sigma x} \quad ,$$

or

$$\alpha = -\frac{1}{gx} \ln \frac{N_t}{N_o} \qquad \ldots\ldots\ldots\ldots\ldots(4)$$

The last equation is applied to compute the values of σ.

EXPERIMENTAL DETERMINATION OF σ: A set of experiments was performed to estimate the value of σ. Technical malathion was prepared in a solution mixture of 10 ml of risella oil to 15 ml. of petroleum ether to 500 gm of wheat to give a dose of 10 ppm of the active ingredient. The insecticide was used in oil to obtain a residual film on the grain particles. The experiments were performed using glass towers, made up of individual glass rings, each 3 cm high and 5 cm in diameter. Twenty-five one week old *Sitophilus oryzae* were introduced into each tower. Towers ranged from single ring to a block of 12 rings. The rings were welded together with wax. The reason for using rings instead of a complete column of glass was because the experiments were also designed to find, having released the insects at one end, the 'nth' ring at which there were no survivors. In the experiment described here (Table 1), the insects were introduced at one end, and the towers retained in a horizontal position 4 days before examination. There were 3 replicate towers in each series. The horizontal position was chosen because it has been shown [5] that in this position the insects readily move from one end of the column to the other. Examination on the fourth day was made by placing the tower upright in a deep tray and removing each ring with a swift motion, thus scattering the wheat on the tray. The live and dead insects from each ring were counted and removed separately. This was continued until the tower was complete. Calculation for σ were made using equation (4).

TABLE 1. The Estimation of σ Four Days After Introduction of *Sitophilus oryzae*.

Per cent Grains Treated		Number of Rings per Tower				
		1	2	3	4	5
5	Nt/No	0.0400	0.0133	0.0533	0.0526	0.0533
g = 0.7806	σ	1.3745	1.8446	1.2519	1.2576	1.2519
10	Nt/No	0.4266	0.4594	0.4400	0.3684	0.4266
g = 1.5612	σ	0.1818	0.1660	0.1753	0.2132	0.1818
20	Nt/No	0.8933	0.8933	0.9066	0.8784	0.8800
g = 3.1224	σ	0.0120	0.0120	0.0105	0.0138	0.0136

We see that as the proportion of the population killed increases σ becomes smaller. As complete control (total mortality) is achieved, σ approaches 0 (zero) as happens when the experiment using 20% treated grains was retained for 6 days. Our control strategy should therefore be to make σ as small as possible. The rate at which σ approaches 0 (zero) will depend on the behaviour of the pest species and also on the food materials in which it lives.

LETHAL GRAINS AS SELF-RENEWING AGGREGATES IN A GRAIN BULK: Following Feller [6] let us consider the lethal effect for a limited period, the list time of which is a random variable with distribution (fn). When each grain loses its lethality it is required to be replaced immediately by a new grain at time 'n'.

Given a population of 1000 lethal grains in a grain bulk with the initial age distribution:

$$v_0 = 600, v_1 = 150,\ v_2 = 100,\ v_3 = 75,\ v_4 = 50,\ v_5 = 25$$

and (from chemical analysis) the survival probabilities

$$f_1 = 0.4,\ f_2 = 0.25,\ f_3 = 0.15,\ f_4 = 0.125,\ f_5 = 0.05,$$

$$f_6 = 0.025$$

We obtain the relational function $U_{(s)}$,

$$U_{(s)} = S\frac{450.56+258.63s+144.91s^2+94.64s^3+36.25s^4+15s^5}{1-0.4s-0.25s^2-0.15s^3-0.125s^4-0.05s^5}$$

Using the renewal equations of Feller [6] we proceed to calculate the age distributions $\{v_r\ (n)\}$ for n = 1,2,3 ... and the limiting distribution (Table II). Thus with our age distribution as above, in the first replacement time n = 1 we have to introduce 450.57 new lethal grains at n = 2 we introduce 438.86 new lethal grains and so on.

TABLE II. Replacements of Lethal Grains Required At Each Interval of Time.

	n										
k	0	1	2	3	4	5	6	7	8	9	∞
0	600	450.57	438.86	433.09	445.18	444.75	446.54	443.93	444.18	444.28	444.54
1	150	360.00	270.34	263.32	259.86	267.10	266.86	267.92	266.36	266.57	266.72
2	100	87.50	210.00	157.70	153.60	151.58	155.81	155.66	156.29	155.38	155.40
3	75	57.14	50.00	120.00	90.11	87.78	86.62	89.04	88.96	89.30	88.78
4	50	28.12	21.42	18.75	45.00	33.79	32.91	32.48	33.38	33.35	33.45
5	25	16.67	9.38	7.14	6.25	15.00	11.26	10.97	10.83	11.12	11.11

Our renewal relationship helps us to decide on how much grain it is necessary to treat in practical situations. For example if our silo contains 100,000 tons of grain, and it is our practice to re-treat the whole amount when we consider the effect of the chemical has expired, we actually need to treat only 44,454 tons of the grain.

If we employ our earlier results (section 3) which show that treating 20% of the grains is as effective as treating the whole bulk, then using our above renewal equations again, we need re-treat only 8.890 tons of grain to maintain effective control.

PRACTICAL APPLICATIONS: The above ideas can be developed, to achieve large savings in the costs of treatment and re-treatment of grain, and also to reduce the amount of chemical in the human diet. A new system would have to be introduced into an existing silo complex (Fig. 1) so that the method can be used in practice. What we require is a subsidiary silo in which chemical treatment of the determined proportion of the grain can take place and this treated grain returned to the storage silo after being mixed proportionately with the whole amount. This re-mixing can take place by regulating the flow of treated grain from silo B and untreated grain from silo A, to silo C, so that the grain in silo C has treated grain in the right proportion. For re-treatment, the determined proportion is removed to silo D and after re-treatment re-mixed with grain from silo C by regulating the flow to silo E. This is a simplified description and the silo technology already exists to a fairly sophisticated level in the animal feed preparation industry.

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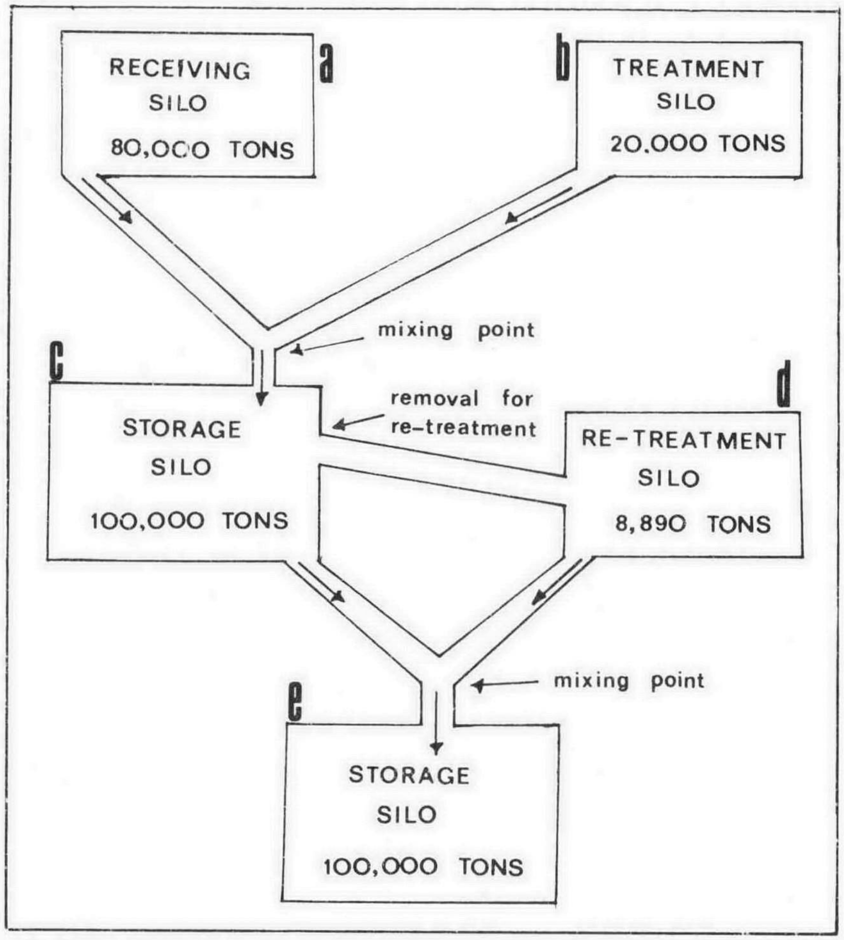

FIGURE 1. Treatment/Re-Treatment Scheme Under New Models