THE ROLE OF RESIDUAL PESTICIDES IN STORED-PRODUCT INSECT CONTROL

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Abstract

Residual pesticides provide the basis for the most flexible methods available for pest management in stored product pest control. In many circumstances where facilities, technologies, or storage husbandry are not ideal, they may be the only means of containing the infestation problem, while in more favourable situations, they may give the most cost-effective result. Irrespective, economic control is transient, responding to management efficiency, resultant changes in pest-pesticide interactions, and consumer pressures.

A continuing role and dependence on residual pesticides in pest control systems is accepted and supported, and means of enhancing this are discussed. The integration of these materials into these systems is considered in the context of the level of control that is really required and of the residues in commodities both as desirable insect toxicants and as undesirable contaminants in end use. The interrelated problem of pesticide resistance, together with means of lessening its impact, is also considered. Particular attention is given to the strategic development of technology and methodology to optimize the benefits that can accrue from exploitation of the residual characteristics of this type of pesticide.

As a basis for the comprehensive economic evaluation of the benefits and costs stemming from the introduction of particular technologies into the pest control programs, Hedley's 1972 model of economic threshold levels of pesticide control was extended to include qualitative losses from increased pesticide residues in addition to potential yield increases normally associated with increased pesticide use. An obvious paradigm is that the price depressing effect of increased pesticide residues may be sufficient to offset the extra returns from increased yields associated with increased pesticide use, implying that the social optimum threshold level of pesticide control is at a lower level than that indicated in Hedley's original model.

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Introduction

Pesticides provide the basis for the most flexible and effective methods available for pest management in stored product pest control. Dependence on such pesticides is usually greatest in situations where storage facilities, technologies, or management are not ideal and create conditions conducive to development of serious pest infestations. Prevention of loss from these infestations often involves high levels of pest control throughout production, storage, and marketing, and on a cost-benefit basis, it has been found that satisfactory results can only be obtained with pesticides.

Residual pesticides will remain for the foreseeable future an integral part of pest control programmes for protection of stored products. It is difficult to conceive of any other situation if the constraints of the capital and operating costs of alternative technologies are taken into account. Whilst such costs can be manipulated, the twin realities of reliability and effectiveness provide final incentive. Irrespective, the role of residual pesticides can only be seen as fluid because management deficiencies and changes in pest-pesticide interactions will lead to limiting problems such as pesticide resistance, and consumer pressures will influence attitudes to pesticide residues.

Exploiting Residual Pesticides

The design of integrated systems to optimally exploit residual pesticides requires a detailed understanding of a number of interacting dynamic systems driven particularly by grain temperature and moisture. Grain temperature alone has profound effects. It is a prime determinant of the rate of chemical breakdown of a pesticide deposit (or other form of loss of pesticide for example by vaporisation or partition among various substrates) - with losses generally conforming with accepted chemical theory. This immediately introduces an element of predictability.

Effects of grain moisture are similarly predictable. Thus, the decay of residues can be described by models which enable rate constants of decay and half-lives of the pesticides on particular grains to be calculated for particular temperatures and grain moistures (more accurately water activities or interstitial relative humidities). As rate constants depend on water activity at particular temperatues, they are independent of the type of commodity involved and, provided water activities are known, information on the half-life of a pesticide on one commodity can be used to calculate half-lives on other commodities (Desmarchelier and Bengston 1979). It is thus possible to accurately program pesticide application rates to grain to ensure that residues whilst in storage are adequate for pest suppression but meet market requirements when grain is moved out from storage.

Desmarchelier (1986) recently considered the applicability of these models of the distribution and breakdown of residual pesticides to general storage situations with a view to the optimisation of their usage - particularly by tailoring application rates to storage conditions. He referred to the concept of an ideal grain protectant, one which protects grain but leaves no residues. He described 3 approaches to the ideal based on conformity with predictable chemical behaviour. In the kinetic approach

high thermal dependence of stability is sought so that the pesticides will be stable during storage but destroyed by the high temperatures e.g. of cooking. Methacrifos, whose half-life is halved for each 5°C rise of temperature is a good example of this type of material. In the equilibrium partitioning approach, protectants are applied in carriers such as dusts which are removed when the commodity is taken out of storage. These dusts give longer protection than conventional sprays and allow removal of 90% of the residue present. In the third type, the nonequilibrium partitioning or chromatographic approach, the movement of pesticide, potentially both for introduction and removal, is controlled by air movement as exemplified by labile fumigants at one end of the scale and dichlorvos type materials at the other.

In practice, increasing temperature generally results in a series of undesirable effects that reduce the efficacy of pesticides. These include an accelerated loss of residue which may be exacerbated by reduced toxicity of these residues at the elevated temperatures as well as an increase in the rate of proliferation of the target insects. Decreasing temperature has the opposite effect. Efficacy increases from the reduced breakdown of the residues and the slowing of pest proliferation but these effects must be balanced against the reduction in toxicity that occurs with most pesticides as temperatures are decreased. Fortunately, all pesticides do not behave in this manner. The pyrethroids are negatively correlated in their temperature-activity relationships and can be the appropriate choice where cooling is practised as with aeration, or where grain temperatures are naturally low. Moreover, the deliberate combination of cooling with decreased pesticide levels can be cost-effective as well as toxicologically more desirable. Thus Longstaff (1981) demonstrated that cooling from 27°C to 21°C reduced the amount of deltamethrin necessary to achieve control of *Sitophilus oryzae* to about 10% of the original dose. This type of knowledge is prerequisite to development of control programs integrating both physical- and chemical-based technologies to optimise the level of pest control. The most appropriate pesticide and dose rate can be chosen for the circumstances and interfaced with other pest-suppressing technology such as cooling, drying, or alteration of the storage atmosphere so providing the most cost-effective strategy.

Pesticide Resistance

Most major pest species have been reported resistant in some measure to most pesticides in common use. In the most recent summary of world occurrences of resistance, Champ (1986) listed 31 species of insect and mite pests involved including 18 species of Coleoptera, 7 of Lepidoptera, and 6 of mites. This compares with 23 species in 1981, 19 in 1979 and 14 in 1970. The range of pesticides and related compounds is very large and totals 90 materials including 18 chlorinated hydrocarbons, the pyrethrins and 14 synthetic pyrethroids, 43 organophosphorus (OP) compounds, 5 carbamates, 5 juvenile hormone mimics, 1 organo-tin compound, and 1 organosulfite compound. Many of these resistances are of academic interest only while others are significant constraints to maintaining control in commercial operations. Resistances based on physiological changes only are included. Changes in behavioural patterns have not been considered although they may have parti-

cular significance in stored product pest control, as for example, with repellency or with irritancy which reduces exposure to treated surfaces.

Early records of malathion resistance in the *Tribolium* spp., *Rhyzopertha dominica*, and some of the phycitid moths were specific to malathion and only included OP compounds that could be degraded by carboxyesterases. This was short-lived and all species now appear to have resistance to a wide range of OP compounds. The most significant recent changes have been the greater frequency of reports of malathion and other OP compound resistances among the major pest species, and the increasing incidence of resistance to synthetic pyrethroids.

Because of the widespread occurrence of malathion resistance, malathion usage is declining and has been abandoned in some areas. The problem is compounded by the differing susceptibilities to the current generation of OP compounds and synthetic pyrethroids of resistant strains of predominant pest species, particularly *Sitophilus oryzae*, *Tribolium castaneum*, and the multi-resistant strains of *Rhyzopertha dominica*. The former group of species can be controlled by the OP compounds, fenitrothion, chlorpyrifos-methyl, etrimphos, or pirimiphos-methyl; whereas carbaryl, or the synergised pyrethroids, bioresmethrin, fenvalerate, permethrin, IR-phenothrin, or pyrethrins are necessary for control of *R. dominica* (Bengston 1986). Methacrifos and deltamethrin are the only materials that currently control all typically-resistant strains. These data have been derived specifically for grain protection but have general application throughout stored products.

OP compound resistance in *Oryzaephilus surinamensis* appears to be on the increase. This species had been effectively suppressed by malathion for a considerably longer period than the other major pest speies. *Cryptolestes ferrugineus* and *Sitotroga cerealella* also have been included as malathion-resistant species. In addition to these, there have been significant additions to the list of resistant bruchids and mites including in the latter, resistance to OP compounds such as pirimiphos-methyl, etrimphos, and chlorpyrifos-methyl.

Containing Resistance and Maintaining Control

Resistance is a world wide problem and involves all major residual pesticides and most of the important pests of stored products. Control failures in the field have been unequivocally associated with resistance and have forced the use of materials to be abandoned in some areas. Because of this, resistance must be an integral consideration at all stages of research and development from basic biological studies through to planning of control programs.

Considerable attention has been given to modelling strategies to overcome resistance. The more complex models attempt to predict the future significance of resistance problems for economic decision making but are constrained by unknown gene frequencies, dominance, and selection rates in the field. Currently, they have little practical application. The simpler models have proved more useful in demonstrating by case studies some consequences of resistance selection. The models have shown the importance of avoiding unnecessary pesticide applications, and of minimising the pest

population growth by alternative means such as integrated pest management. Similarly, the demonstrated growth potential of the surviving subpopulations has highlighted the necessity for rigorous hygiene - and of course the obvious conflicts of provision of refuges and immigration to maintain susceptibility in the population.

Containing the resistance problem should be an integral part of normal pest control programs for stored products. These programs should exploit to the fullest extent the advantages of other technologies such as drying, cooling, hygiene, and good warehouse keeping. It should be realised by all concerned that protection of grain against pests in storage, can only be based on the well-tried and proven principles of sound storage practice. The principles have been clearly understood for a very long time and it is mandatory that all control be based on them.

Economic Threshold Levels of Pesticide Use

While applied modelling work has been able to identify those relationships which are important in pesticide application, there has been recently considerable interest by economists, particularly applied economists, in evaluating the costs and benefits of pesticide application. The economist's main interest has been in defining the optimum application levels of pesticide which themselves rely heavily on the technical efficiency models of entomologists. This work is summarised briefly below together with an important extension to include quality consideration as well as quantitative loss.

Hedley (1972) first defined the optimum or economic threshold level of pesticide use at the point at which extra returns from control equals the extra costs incurred from control. The economic threshold level recognises that there will be some losses above which control becomes uneconomical. This level of control is defined in terms of loss in yield or quantitative loss only. It does not, for example, recognise that there may be substantial qualitative losses in terms of pesticide residues which influence consumer preferences and hence prices.

To express the concept in Hedley's original form consider the following model cast in terms of the individual agent as decision-maker.

$$\pi = Py\,Y - C \qquad (1)$$

where

π = profit per unit yield

Py = net return per unit

Y = product yield per unit time

C = cost per tonne of control

Product yield per unit of time increases with level of pesticide control (x) applied such that:

$$Y = f(x) \qquad (2)$$

Costs of control can also be expressed as a function of level of control (x) such that:

$$C = g(x) \qquad (3)$$

When these relationships are substituted in (1), the optimum or threshold level of control is where:

$$\frac{\partial \pi}{\partial x} = Py \frac{\partial Y}{\partial x} - \frac{\partial C}{\partial x} = 0 \qquad (4)$$

However, this formulation together with extensions by Hall and Norgard (1973) ignores the simple fact that prices (Py) may also be affected by pesticide control levels.

In terms of grain quality, the price per unit can be expressed as simple functions of grain quality characteristics (s).

$$Py = {}_i\Sigma P_i h_i(S_i) \qquad i = 1, \ldots\ldots, n \qquad (5)$$

where P_i are implicit prices of each characteristic (S_i).

However each characteristic (S) can be affected by the level of control (x) such that

$$S_i = k_i(x) \qquad (6)$$

By incorporating (5) and (6) in (4) the model becomes

$$\frac{\partial \pi}{\partial x} = Py \frac{\partial Y}{\partial x} + Y \frac{\partial Py}{\partial x} - \frac{\partial C}{\partial x} = 0 \qquad (7)$$

Increasing quantities of pesticide (x) are likely to have a price depressing affect on Py (increased pesticide residue) such that the second term of (7) is likely to be always negative and hence Hedley's model in (4) will significantly overstate the economic threshold level (x).

The paradox is that in surplus grain markets in which increased yields impose a downward pressure on prices, this decline is likely to be exacerbated by losses in quality due to pesticide residues. Alternatively lower pesticide control levels (and therefore residues) provide a premium over and above the prices which would have prevailed with greater use of pesticides.

The simple model examined above shows that the wider community may in fact incur substantial losses from the use of pesticides through qualitative loss relative to those potential increases in yield through application of pest control. If qualitative losses are perceived to be more important by the discriminating consumer relative to the benefits of increased return by the producer then the obvious paradigm is that pest control programs may in

fact be uneconomic at *any* level of pesticide use. It would therefore seem prudent for policy makers to carefully evaluate the consequences of registering additional pesticides, in terms of its impact on society as a whole. In many countries registration procedures are effective constraints on the adoption of improved pest control methods but in the light of the foregoing analysis their approach is probably rational in terms of the potential consequences to society as a whole. Entomologists are therefore encouraged to elicit the support of economists at least in the ex-post evaluation of their products. They also should provide not only production functions of the form of (2) but also quality functions of the form of (6) with respect to pesticide levels of control so that consumer as well as producer benefits can be evaluated.

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