INTEGRATED PEST MANAGEMENT (IPM) - ECOLOGICAL BACKGROUND

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1. Introduction

The title of this conference, "Organic and Conservation Farming - Bridging the Gap", excludes the name conventional farming and perhaps indicates that, to avoid or alleviate the problems of an industrial, mechanistic approach to agriculture, we need to, in a sense, "go back to nature" to achieve sustainability in farming systems. My talk recognises this, and suggests that study of the complex, natural relationships and processes involving pests will allow us to gain useful insights and knowledge to improve the control/management of pests in agricultural systems in the future. However, I will try to argue that a complete reliance on nature for pest management assistance is inappropriate, since agricultural systems have some important differences compared with natural ones.

First, to some definitions with respect to the title of my talk: "The Ecological Background to Integrated Pest Management (IPM)".

Ecology: stems from the Greek word *oikos* meaning 'house' and means 'study of the home', that is, the study of organisms in their environment (Recher *et al*. 1986).

Pest: involves all organisms which interfere with our interests/goals. I shall concentrate on insects and related pests, since I am more familiar with these. However, some general comments will be applicable to other pest groups, especially pathogens and weeds.

Management: recognises that in most situations pest populations can only be managed, not eradicated.

Integrated: a recognition that a multi-pronged attack at weak points in pest life cycles is often more effective in the long-term than using only one method of control.

2. Phases/Eras Of Pest Control

During the 1940s to 1950s the control of insect pests was based on preventative applications of broad-spectrum pesticides. The focus of research was heavily weighted towards chemical control. For example, 80% of articles in research journals were in the chemical/toxicological areas, with the remainder on pest biology (12%) and crop ecology (8%). This was the phase of **"Exploitation"** or era of **"Optimism"** (1942-1962), when chemicals seemed to be the solution to all pest problems.

However, reliance on pesticides as the major weapon to control pests, as we all know, has led to serious problems of pesticide resistance, secondary pest development and environmental problems due to residues. Thus, "Exploitation" led to phases of **"Crisis"** or the era of **"Doubt"** (1962-1976) and in some cases to **"Disaster"** - where crop protection failed despite the use of all chemical options. Resistance to insecticides has now developed in about 500 insect/mite species (Figure 1). Australia has experienced the crisis phases in terms of resistance to pesticides in heliothis in summer crops (especially cotton), mites in orchards, insects in stored grain, blowflies attacking sheep, cattle tick and internal roundworm parasites of livestock. In addition, resistance has developed to fungicides in some plant pathogens, and to herbicides with some weed species. The "Disaster" phase was reached in the Ord irrigation area when heliothis control failed and cotton growing ceased after only a 10 year period (1963-1972).

Figure 1. Rate of development of insect pests resistant to insecticides

3. Changes In Approach - To Manage Pests

The 1960s was a period of ecological awakening - the search for more scientific, rational and ecologically compatible methods of pest control - leading to the era of **Integrated Pest Management**, 1976-present (Metcalf, 1980).

In terms of trying to work with nature, rather than subjugating it to our wishes, let us first examine some important differences between ecosystems, both natural and agricultural (Table 1).

Table 1. Differences Between Natural and Agricultural Ecosystems

Agricultural ecosystems are often established and managed to support a single (or few) plant species; they are sown at the one time, emerge in a synchronised way and develop through uniform growth stages to maturity. The quality of plant material is enhanced through breeding and fertiliser usage. They are therefore highly vulnerable to adapted pests. At the same time, many pasture and crop species have been selectively bred for yield and quality criteria, often at the expense of physical and chemical defence mechanisms against herbivory. There may be some degree of tolerance to pest damage by compensatory growth in pasture and crop plants where pests attack the non-yield forming organs (roots, stems and leaves) (Figure 2a).

Such tolerance is reduced where pests attack the product directly, especially where flowering, fruit formation and seed maturation are tightly synchronised (for example in determinate crops such as winter cereals) (Figure 2b). Where the reproductive phase of plant growth is less synchronised (for example in indeterminate crops such as canola, field peas, cotton, lupins), some degree of pest damage may be tolerated.

Figure 2. Generalised curves of relationship between yield and pest injury where (a) is to non-yield forming organ, i.e. indirect, and (b) injury is to yield forming organ, i.e. direct.

For product pests, especially where the product is exported or graded for quality, the matter is further complicated by the market standards which may demand either very low (fresh fruit and vegetables) or no pest damage (export grain). These so-called "cosmetic" standards demand a very high level of pest control. It is difficult to imagine that "organic farming", in which there is no use of synthetic pesticides, could in the foreseeable future maintain the quantity and quality of agricultural production needed to satisfy the requirements of fastidious markets.

To summarise then, the degree of intervention by farmers, in terms of pest control, depends on the crop type and value, the type of pest (non-product or product), the farmer's economic situation and perceptions of pest problems (risk-taker or risk averse).

To improve pest control practices we need to appreciate the complex interrelationships between pest populations, the host plant/animal and the environment with which these interact (Figure 3).

Figure 3. Important interrelationships associated with pest problems

The factors and processes associated with pest population rises and falls need to be studied and quantified. This includes such factors as reproductive ability, natural mortality factors, migration and the influence of weather. The impact of the pest population on the host plant also needs to be studied and quantified.

Economic Threshold and Types of Pests

Pest populations over time follow the pattern shown in Figure 4 with fluctuations about a general equilibrium position (GEP). In terms of economic pests, two further points on the curves may be described in terms of economic damage: the economic injury level (EIL) represents that population size which causes economic damage. That is, where the loss of revenue due to pest damage equals/exceeds the cost of controlling the pest. The economic threshold level (ET) is that population size at which controls should be applied, to prevent increasing pest numbers from reaching the EIL (Stern, 1965). Pests may be further categorised as severe (GEP above EIL), perennial (GEP below EIL but regularly reaches EIL each season), occasional (GEP below EIL, but reaches EIL irregularly, say 2 in 5 years), or uneconomic (where GEP and population peaks are always below the EIL) (Figure 5).

Figure 4: Theoretical pest population changes over time and its general equilibrium position (GEP), economic-injury level (EIL) and economic threshold (ET).

Figure 5. Categories of crop pests and their population levels with respect to EIL or damage threshold

In Australia, some severe pests would be heliothis in cotton, stored grain pests, sheep blowflies - where significant inputs are essential to reduce pest populations. Perennial pests require regular control inputs and are exemplified by red-legged earthmite in southern Australia in establishing pastures and some field crops. Occasional pests require irregular control and include such pests as the Australian plague locust, wingless grasshopper, cutworms and armyworms.

Life Cycle Strategies of Pests

Pests vary considerably in their reproductive abilities or fecundity (the ability to produce multiple offspring), the number of generations per year and competitive ability.

From an ecological viewpoint, pests range across a continuum from so-called **"*r*"- to "*K*"-** type pests.

***r*-pests** have high fecundity and short generation times - they are the opportunistic pests which may rapidly build up to high population levels in agricultural systems. They are especially adapted to short-term, potentially unstable cropping systems (for example heliothis and aphids). Populations reach damaging levels often before competition between natural enemies or between individuals of the pest population itself causes a crash in pest numbers. They have a "boom and bust" type of population development.

***K*-pests**, on the other hand, are adapted to more stable, natural ecosystems, and devote much of their energy to warding off competition from natural enemies. Such pests have low fecundity and long generation intervals (for example, codling moth, many scarab beetles). They tend to attain fairly stable populations, limited by the resources in the environment. Many agricultural pests are intermediate between these two extremes (Figure 6).

Figure 6. Model of insect population growth

The natural enemy ravine (Figure 6) is highly developed in the intermediate region and indicates the potential capacity of natural enemies to regulate pest populations.

4. Responsibility In Pest Management

The efficiency of modern pesticides has greatly improved. Less active ingredients are applied per hectare than was previously the case (Figure 7). This is due both to new chemical groups and improvements in application technology (e.g. ultra-low volume; controlled droplet application). Despite this, the use of chemicals for routine, preventative pest control has often created enormous problems of pest resistance, resurgences and secondary pests. The model shown in Figure 6 provides a basis for an ecological view of the role of pesticides in IPM. Natural enemy conservation and enhancement are key factors in any IPM strategy to control intermediate pests. Australia, particularly through the work of CSIRO, has had a major commitment to biological control for many years and is a world leader in this field. Where a range of pest types is present, the use of insecticides against *"r"* and *"K"* pests should not impact adversely on natural enemies present (Metcalf, 1986). The value of five major control technologies for *"r/K"* pests is shown in Table 2.

Figure 7. Increased efficiency of insecticides used for cotton insect control

Table 2. Impact of Control Strategies on Insect Pests of the r, K Continuum

Realistic ETs must be established for the key pests of our pastures and crops. These should be practicable for farmers, unless the cropping system is such that professional 'scouts' are affordable (as, for example, in cotton). Critical thresholds based on levels of crop damage are especially useful. The determination of ETs for Australia's pests is in its infancy. ETs are established for key pests of cotton (Shaw, 1992). There are in NSW, for example, critical thesholds placed on either pest numbers or damage to a range of summer crops (for example: soybeans, sunflowers, grain sorghum, maize) (Sykes, Goodyer and Dale, 1991). These thresholds are linked to critical inspection times for the various crops - thus of great value to the farmer.

For winter crops, only nominal thresholds are suggested in some cases as guides to timing control (Goodyer and Sykes, 1991). For example, in a range of grain legume crops for heliothis, one or more 10 mm caterpillar per square metre is suggested as the ET. Thus more research is needed to refine thresholds in some pasture/crop situations.

Short-term Strategies to Improve Pest Control

These centre around trying to preserve/enhance biocontrol. In a classical sense, this is **integrated control** which often involves the judicious use of chemicals against key pests (based on pest monitoring and forecasting) to allow biocontrols to operate. For example, in pome fruit orchards, codling moth (the key pest) has to be controlled using several organophosphorus (OP) insecticide applications each year. At the same time, orchard mites are controlled biologically by *Typhlodromus occidentalis*, a predatory mite of the pest mite, which is resistant to OP insecticides selected for use against codling moth. This is a useful example of pesticide resistance!

Other short-term strategies are currently operating to cope with pesticide resistance through **resistance-management strategies**. These are in a sense trying to create breathing space to protect existing pesticides, to allow more sustainable, long-term pest management strategies to be developed. A good example is the "Pyrethroid Strategy" which applies to summer crops, cotton in particular (Shaw, 1992). To try to prevent increasing resistance to synthetic pyrethroids, they are restricted in their application to only one (of three) generations of heliothis. Other pesticide groups alternate with pyrethroids. Resistance management strategies have been developed to cope with resistance in various pests, for example grain pests, orchard mites, internal parasites of sheep (e.g. DrenchPlan and others), some plant pathogens and weeds. They usually involve monitoring pest activity and use of pesticides as mixtures, or alternating ones from different chemical groups (i.e. with different modes of action). Whilst somewhat cautious initially, the agro-chemical industry is now cooperating in resistance management and the development IPM schemes - they have had to take account of the growing public concern over environmental issues and have, of course, a vested interest to protect (Haskell, 1987).

Long-term Strategies to Improve Pest Control

These are embraced by the term **Integrated Pest Management (IPM)**. They involve a systems approach to the management of pest problems. IPM rests on detailed knowledge and understanding of the complex interrelationships between key pests, their host(s) and the environment. Studies leading to IPM are necessarily long-term, complex and costly. IPM aims to permanently reduce pest populations below the EIL (Figure 8).

Figure 8. The aims of IPM

Whilst theoretically IPM could be developed for the total pest complex of a crop, that is weeds, insects and pathogens, in practice IPM is often developed against the key pest, or a small group of the most important pest species. For example, great advances have been made in the IPM of stored grain pests. The use of physical controls, such as improved silo design (or sealing), modified atmospheres, low temperature storage and thermal disinfestation, promise to greatly reduce the level of pesticide use in the future. The control of spotted alfalfa aphid in lucerne rapidly progressed from sole reliance on chemical control to IPM based on host plant resistance and biocontrol using the parasitic wasp *Trioxys complanatus*. This is claimed to be a world first in the successful biocontrol of an aphid pest (Hughes *et al.* 1987). In cotton, where the pyrethroid strategy is operating, research is seeking to increase the resistance of the crop to pests, especially heliothis. Genetically altered or transgenic cotton is being trialled which incorporates the gene producing endotoxin - the toxin present in *Bacillus thuringiensis* or *B.t.* This bacterium causes a lethal disease in caterpillars of the moth when it is sprayed on the foliage. Future cotton varieties may therefore have inbuilt protection to this pest, however care in the use of such varieties will be necessary to avoid further resistance problems (Forrester, *pers.comm.*, 1991). Other host plant resistance mechanisms are being researched against moth pests of cotton. Genetic manipulation research is revealing potential improvements in the management of other crop pests, sheep blowflies and the screwworm fly, should this cattle pest beat Australia's quarantine barriers.

It can be seen from the above that Australia is responding in a most responsible manner to the problems associated with past misuse/abuse of pesticides. Research is proceeding in developing alternative IPM strategies for important pests. Meanwhile, where economic, pest activity is being monitored to reduce and better time chemical controls. Pesticide resistance is monitored and strategies developed to manage this. Biocontrol against many pests continues to be a most active line of research. Genetic manipulation of crops and pests promises new weapons in the fight against pests in the future. Most of the problems associated with pesticide residues in the environment relate to pesticide groups whose use has been discontinued - our food is amongst the safest in the world to consume. Educational programs are underway to improve the knowledge and safe use of pesticides.

Conclusions

• IPM is the direction of future management of key pests in agriculture.

• IPM should provide strategies which are sustainable, economic and minimally damaging to the environment.

• Pesticides will continue to form an integral part of IPM for the foreseeable future if pest management is to remain rational. Their use could be greatly reduced if consumers could be educated to accept lower "cosmetic" quality of products.

• It is difficult to imagine that "Organic Farming", with no use of synthetic pesticides, could sustain the quantity and quality of agricultural products needed now and in the future.

1. References

2. Fenemore, P.G. (1982). *Plant Pests and Their Control*. Butterworths, Wellington.

3. Forrester, N. (1991). *Pers.Comm.*

4. Goodyer, G. and Sykes, J. (1991). Insect and Mite Control in Winter Crops 1991. NSW Agriculture and Fisheries (Agdex 100/604).

5. Haskell, P.T. (1987). *Natural selection in crop protection.* **In** "Rational pesticide use', Eds. K.J. Brent and R.K. Atkin, pp.3-4 (Cambridge University Press: Cambridge).

6. Hughes, R.D., Woolcock, L.T., Roberts, J.H. and Hughes, M.A. (1987). Biological control of the spotted alfalfa aphid *Thereoaphis trifolii f. maculata*, on lucerne crops in Australia by the introduced parasitoid *Trixys complanatus. J. Applied Ecology* **24**, 515-537.

7. Metcalf, R.L. (1980). Changing role of insecticides in crop protection. *Ann. Rev. Entomol.,* **25**, 219-256.

8. Metcalf, R.L. (1986). *The ecology of insecticides and the chemical control of insects.* **In** 'Ecological Theory and Integrated Pest Management Practice", Ed. M. Kogan, pp.251-298.

9. Recher, F., Lunney, D. and Dunn, I. (1986). *A Natural Legacy - Ecology in Australia*. 2nd ed. Pergamon Press, Sydney.

10. Shaw, A.J. (1992). Cotton Pesticides Guide 1991-92. NSW Agriculture. (Agdex 151/680).

11. Solomon, M.E. (1973). Ecology in relation to the management of insects. **In** 'Insects: studies in population management', ed. P.W. Geier *et al.*, pp.153-167 (Ecol. Soc. Aust.).

12. Southwood, T.R.E. (1977). Entomology and Mankind. *Am. Sci.* **65**, 30-39.

13. Stern, V.M. (1965). Significance of the Economic Threshold in Integrated Pest Control. *Proc. FAO Symp. on Int. Pest Control - Part 2*. pp.41-56, Rome.

14. Sykes, J.D., Goodyer, G. and Dale, A.B. (1991). Insect Control in Summer Crops 1990-1991. NSW Agriculture and Fisheries. (Agdex 100/614).