Protecting and enhancing yield, while reducing our dependence on synthetic pesticides

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Introduction

I have taken the liberty of modifying the allocated title to this presentation for several reasons. In its original form the title *Protecting Y ield - Biologically* was restrictive. Broadening it to *Enhancing* not only allows some inspection of the various options for pest management that are now available, or that might come on line in the next decade; but it also allows me to draw attention to several biological aspects of Australian agriculture which do not receive adequate recognition or support, and which can impinge greatly on yield. These are soil biology and pollination biology, both of which represent biological options for increasing yield in a sustainable manner without adding greatly to production costs.

The second liberty I have taken with the title concerns the constraining term *Biologically.* Addressing solely this term would fail to recognise that there are no clear or sensible boundaries between 'biological', 'chemical' or 'biotechnical' when discussing plant protection. It also grates with a central tenet of modem pest management - the value of integrating a range of methods of pest management, an approach commonly called IPM. It represents a philosophy that has economic, social and environmental value since its principal objective is to protect yield yet, at the same time, reduce dependence on synthetic pesticides. Hence the new title!

What is covered by the terms chemical, biological or biotechnical in protecting yield?

To illustrate the interrelatedness between biological, chemical and biotechnical, we can consider the various plant protection uses of the insect pathogen, *Bacillus thuringiensis (Bt). Bt* was first used for biological control over fifty years ago in France against the European corn borer, *Ostrinia nubilatus.* The early formulations consisted of a mixture of endotoxins, exotoxin, a living bacteria and spores. More recent and improved formulations comprise the dry remains of bacterial fermentations of selected *Bt* strains processed in 100,000 L tanks. The active constituent of modem formulations is endotoxin and *Bt* spores.

In an alternative approach, *Bt* genes have been transferred to other bacterial species, namely *Pseudomonas* spp., which are not spore forming organisms. Under controlled fermentation conditions, and with appropriate regulation over gene expression, the resulting formulation represents endotoxin crystals surrounded by cell walls of the killed *Pseudomonas.* These preparations lengthen the useful life of the active ingredient since the endotoxin is protected to some degree from degradation by ultra-violet light. In future uses, we may also see the endotoxin coated in natural polymers to provide a similar protective shield. In these applications, no living material is released, yet we might like to distinguish these biological chemicals from control measures that use persistent broad spectrum synthetic pesticides such as endosulfan or synthetic pyrethroids.

In yet other applications, *Bt* endotoxin genes are being encoded into living micro-organisms such as baculo-viruses designed to increase the likelihood of the toxic molecule reaching its target site. Here we see a biological delivery system carrying a toxic chemical but with narrow specificity. We also see the same complex interrelationship with entomopathogenic nematodes whose symbiotic bacteria deliver, in a most precise manner to target host insects, a highly toxic set of chemicals that do not enjoy the same specificity as the various *Bt* endotoxins.

Perhaps the more popular perception of *Bt* genes in modern pest management relates to transgenic plants. Over 50 species of crop plants have now been modified by the insertion of *Bt* toxin genes which express in various tissues. Here we have a chemical method of control, mediated biologically through transgenic plants following application of modem biotechnology.

There is yet another connection we need to consider. Susceptibility to *Bt* toxins by target insects such as *Heliothis armigera,* is best perceived as a fmite resource which could easily be squandered by frivolous application. To provide a trivial example: suppose the *Bt* endotoxin gene was incorporated into sorghum, for which *H. armigera* represents a minor pest compared to cotton. This use could easily engender resistance in *H. armigera* to *Bt* endotoxin and deny its more valuable use for cotton, or destroy its value as the active ingredient in *B* t formulations under which circumstances resistance is less likely to evolve. The concept of 'ownership' of susceptibility to *Bt* toxin, whether susceptibility itself represents a finite resource, and its effective management in the public interest, are all questions that require a holistic approach to pest management.

The need to take such a comprehensive perspective is accentuated by some recent molecular engineering within the *Bt* endotoxin gene itself. The gut wall receptor-binding moiety of the endotoxin gene has been replaced with viral DNA which also codes for a cell wall binding protein. Such hybrid genes therefore code for a hybrid molecule in which the binding protein derives from a virus while the *Bt* DNA contributes the 'cork-screw' component which distorts the channels or pores that permit chemicals to pass through the cell wall. Hybrid genes, or indeed a set containing an array of binding elements, could be inserted into *Bt,* a virus or a genetically engineered plant. It appears probable that a number of such viral proteins exist and represent an important source of genetic diversity for addressing the problem of resistance.

Another issue I would like to allude to briefly is the distinction between synthetic chemical pesticides and biological pesticides, where the former are made by chemical engineers and the latter by some biological process - often under the watchful eye of chemical engineers! Our major classes of synthetic insecticide are neuro-toxins, for example, organochlorines (OCs) and organophosphates (OPs). Some might be viewed as useful by-products of attempts to improve nerve gases for warfare purposes. Others, such as the synthetic pyrethroids (SPs), actually owe their genesis to the natural plant product, pyrethrin. While it is fair to say that most entomologists regard SPs *as* synthetic pesticides like the OPs and OCs, there is a widespread belief even amongst the informed in the community that natural products are inevitably safe, while synthetic products are not. However, it only makes sense that an organism like *Bt* which invests considerable metabolic energy and resources into the production of endotoxins, will 'design' a molecule that serves to enhance its own evolutionary fitness, hence the high affmity for receptor sites in its potential host. Specificity, on the other hand, is often an incidental by-product of evolution. There are examples where the natural product is highly damaging to non-host organisms, for example, aflatoxins and anthrax. The focus, therefore, should be on efficacy and specificity, not on natural *versus* synthetic. For this reason we should treat with some caution the terms 'chemical pesticide' and 'biological pesticide'.

Clearly, if we wish to inform ourselves about the various options open to protect yield against invertebrate pests, weeds or pathogens, it is increasingly difficult to do so under headings like `Biological', 'Chemical' or `Biotechnicar. Often the need to integrate two or more of those `competing' or 'alternative' approaches, should strengthen our resolve to have a more comprehensive perspective. Accordingly, we need to jettison specific ideologies such as biological control or chemical control. Even IPM is sometimes promoted by its adherents with a self-righteous and proselytizing ring!

When we evaluate pest management options we should resort to operational criteria such as:

- cost effectiveness, especially against available alternatives;
- absence of negative externalities, especially impact on non-target organisms and on product quality;
- durability or sustainability, for example, resistance will not erode a treatment's effectiveness over time, or residue concerns will not lead to de-registration and withdrawal of a pesticide;
- ownership; it empowers the primary producer and the consumer. This criterion tends to receive scant attention;
- the likelihood of the need to integrate two or more approaches to deal with a pest or a pest complex. These could range from conventional plant breeding, cultivation practices, biological control, chemical pesticides or some novel method such as pheromones, nematodes, genetic engineering and so on.

Soil biology and enhanced yield

Australia has a richly deserved reputation for excellence in soil physics and soil chemistry, but our understanding of and commitment to soil biology, with perhaps the exception of pathology of root diseases, can only be described as pathetic. The displacement of woodlands by extensive open country in areas of temperate and mediterranean climates is likely to have a major impact on the abundance and distribution of native macro-fauna in Australian soils, dung-burying insects and possibly oligochaetes. All exotic oligochaetes in Australia are the result of accidental introductions. In creating a radically different landscape through clearing, pasture improvement and alien agricultural practices we have generated an environment where introduced earthworms predominate; in some situations they are doing very well, in most situations they are not. It is only recently that abundance and distribution of this group of soil fauna have begun to be studied. Even less has been done on determining impact of exotic or native oligochaetes on the structure and fertility of Australian soils, even though it is acknowledged that earthworms may be a key element in effective strategies to solve the problem of extensive soil acidity and decline in soil structure in Australian agriculture (2,3).

Similar concern could be expressed for the soil micro-flora and fauna. This complex fauna includes bacteria, fungi, nematodes, protozoans through to the invertebrates, especially mites and collembola. The term biodiversity takes on a real meaning when we inspect above, within, and below the A-horizon of any soil profile, especially in agro-ecosystems; yet the average person is likely to think of tropical rainforests when you seek meaningful examples of biodiversity. There are very few studies on soil biodiversity within Australia, and fewer still on the impact of agricultural practices, particularly soil cultivation and agrochemicals on soil biodiversity. Yet it is probable that soil biodiversity contains a major key to ecologically sustainable development in Australian agriculture (King and Hutchinson, these proceedings).

Since the early 1960s some 45 species of dung beetle have been introduced into Australia from Africa and Europe. Of these, 29 species have been recovered and some are now widely established. While the reasons behind these introductions have changed in emphasis over time, they have included: reduced abundance of dung breeding flies, such as the bush fly and the buffalo fly; reduced pasture pollution and rank growth, especially in the regions with higher stocking rates on irrigated pastures; reduced endoparasitic burdens for cattle; and, finally, enhanced nutrient recycling and soil aeration and fertility. It is believed that progress has been made in most or all of these objectives in a range of agroecosystems, but much of the supporting evidence is anecdotal or circumstantial.

It is reasonable to conjecture that pasture yield can be enhanced across much of Australia if greater attention is given to documenting the composition of both native and exotic macrofauna in areas devoted to field crops and pastures, and in determining ways in which this fauna can be enriched either by cropping and redistribution of both dung beetles and earthworms, or by the collection and introduction of additional species or biotypes of both groups of organisms. The level of effort both within State Departments of Agriculture and Soils, and within CSIRO could profitably be increased by an order of magnitude to document impact of the macrofauna on soil structure and fertility, water penetrability, nutrient cycling and soil acidity. It should be acknowledged that the commodity-oriented rural industry research and development corporations/councils have greatly strengthened Australia's competitiveness in agricultural production, but the leverage effects of these organisations on the research portfolios of State and Federal R&D organisations has further weakened Australia's capacity to address cross-commodity problems and longer term sustainability issues such as soil structure and quality, and the role of macro-soil organisms in its maintenance.

Thus, if a conference such as this one, is determined to make a lasting contribution to the theme `Enhancing Yield Biologically', it could well acknowledge that our ignorance of soil biology is so profound, that we can barely begin to imagine the benefits that might flow from a comprehensive understanding of our soil fauna: what we have, what it does, how we can conserve it; is it feasible to crop and redistribute native and beneficial exotic macrofauna; and how we might enhance it by enrichment with strategic introductions of overseas species in those cases where we can demonstrate that unavoidable and irreversible disturbances to established agro-ecosystems have left us with an impoverished soil fauna.

Improved pollination services as a means to enhance yield

At least 55 non-tropical crops, and 19 tropical crops grown in Australia are known to benefit from insect pollination. Only two of these are native, *viz Macadamia integrifolia* and *M. tetraphylla.* In some crops, for example, almond, *Prunus amygdalus,* flowering is at a time of the year (August) when native pollinators are either absent or not in sufficient numbers to ensure a commercially viable crop. Thus, the survival of the almond industry is dependent on professional pollination services provided by commercial beekeepers who are skilled in the preparation and placement of hives to ensure high seed set. For many crops including lucerne, apples, asparagus, blueberry, onion, white clover, pumpkin and squash, cucumber, fennel, raspberry, cabbage, etc, effective pollination with honeybees can enhance yields significantly; up to 400% for fennel and 500% for lucerne. It seems difficult to identify changes to other agricultural practices discussed at this Conference which can have the same high level impact on yield, and yet do so in such a cost-effective, environmentally friendly or sustainable manner.

Habitat changes since European settlement and widespread use of pesticides have reduced potential native pollinators from providing effective pollination. Further, incidental pollination by feral colonies of *Apis mellifera* is also sub-optimal as evidenced by enhanced yields after exposure of crops to higher densities of foraging honeybees in a series of trials funded by the Honey Research Council during the 1980s.

It is clear that commodity producers requiring insect pollination in Australia have largely relied on native pollinators and incidental pollination by feral A. *mellifera,* and unpaid pollination services by commercial beekeepers in return for nectar and pollen collected. Trends in New Zealand, Sweden and the USA have demonstrated the need for commodity producers to understand the benefits from investment in professional pollination services and for commercial beekeepers to become skilled in providing the service. R. Gill from the University of New England has estimated that the benefits of enhanced yield for those concerned range between 5600 million and $1.2 billion p.a. if the full potential of honeybee pollination is realised (1).

However, it is important for agriculturalists to realise that without positive action, these gains will not be realised. In fact, yields will decline considerably. There are several factors which support this contention:

- commercial beekeeping in Australia is likely to decline because of a loss of native flora for beekeeping. This loss has three principal causes: reduced access to public lands caused by pressure from environmentalists; an absolute reduction in the native flora through clearing in conjunction with agricultural and forestry practices; and, finally, a likely decline in exotic weeds such as blackberry species, Paterson's curse and thistle species, following biological control programs by CSIRO and State Departments;
- probable entry into Australia of additional exotic bee diseases in the foreseeable future;
- declining economic viability of honey production, depressed honey prices and increased production costs that lower profitability for commercial beekeeping. These trends will reduce the numbers of professional beekeepers and commercial hives available for incidental or commercial pollination.

Perhaps the only development countering this negative assessment on pollination, is the increasing use of hybrid seed which does not require open pollination.

To turn this position around, increased R&D effort is required to determine optimal conditions for pollination by A. *mellifera,* and perhaps to increase the species of pollinators available, for example, leafcutter bee, *Megachile pacifica,* or native *Trigona* spp.

The principal funder of pollination R&D within Australia is the miniscule Honey Bee R&D Council, yet the major benefits from this research are likely to be captured not by beekeepers but by the commodity producers. Unfortunately but understandably, the Horticultural R&D Corporation and the Rural Industry R&D Corporation have funded little or no research on pollination biology.

Consequently, if Australian agriculture is committed to enhancing yield of a significant number of its commodities, it will need to give attention to R&D on pollination requirements, and then support vigorous extensions of this knowledge to commodity producers and commercial beekeepers. Lack of action will witness a progressive decline in yield.

Crop protection with a non-chemicl emphasis

Lo-tech or traditional technologies

At a time when we can expect to see the major advances in plant and animal protection emanate from information technology such *as* expert systems, or from molecular biology through the development of transgenic organisms, occasionally we encounter some novel but simple, or even lo-tech ways of reducing our dependence on pesticides. In this context, I would like to cite two recent examples - the buffalo fly trap and the weed activated spray controller. Development of the former required an understanding of the behaviour of the buffalo fly and its hosts - in this case, the dairy cow and the dairy farmer. With this knowledge, R. Sutherst and R. Tozer of CSIRO designed a cage which is strategically placed at the entry/exit to the milking yard so that milking cows are forced to use the cage twice daily. Buffalo flies are dislodged by an array of dangling plastic belts as the host traverses the cage. The flies rise to the roof where the sun's heat disables them. The system uses no chemical pesticides, is cost-effective and resistance is unlikely to evolve. Admittedly, the system is removed from crop protection, but it shows that simple solutions can still be devised even late in the twentieth century!

Fallow weed control using a 37 nozzle (18 m) spray boom has been enhanced enormously by attaching a sensor and solenoid control valve to each nozzle. W.L. Felton and colleagues, NSW Agriculture at Tamworth, NSW, have designed the equipment so that each nozzle is independently activated if green vegetation is detected in the field of view. Felton estimates that average reductions in herbicide usage for fallow weed control exceed 90% which should result in a 'profound effect on the adoption of minimum tillage practices by farmers'. Thus, the obvious economic and environmental benefits of reduced herbicide applications could lead to soil cultivation practices which should protect biodiversity of soil fauna. Recent improvements in spray application technology, also developed within NSW Agriculture, have reduced the amount of petroleum oils required for pest control in citrus orchards.

Biological control

Because of Australia's island status, exotic weeds, pests and diseases which have been accidentally introduced, usually without their traditional natural enemies, are a major factor in reduced yields and increased production costs. It is therefore not surprising that classical biological control by means of the introduction and inoculative release of safe and effective natural enemies has a good record in Australia. In recent years, there has been a resurgence of interest in classical biological control of weeds in crops and pastures, and in the natural environment. Species include: from Europe - intermediate and broadleafed forms of skeleton weed, blackberry species, *Rumex* spp., common heliotrope, Paterson's curse, horehound, scotch broom, and thistle species; the Americas - *Mimosa pigra, Sida, Hyptis;* and South Africa - spiny emex, bitou bush and bridle creeper. Biological control agents range from mites and insects to bacteria and fungi, with Australia pioneering the use of fungal pathogens while demonstrating the existence of adequate levels of safety and efficacy. The fungal pathogens have included studies aimed at identifying centres of origin of pests (e.g., skeleton weed in western Turkey) and establishing field plots of the weed to screen for virulent strains of the rust *Puccinia chondrillina.* The passage of the Biological Control Act in 1985 at State and Federal levels was a significant element in this resurgence, largely by removing fear of legal action by minority groups to terminate costly programs at the eleventh hour.

Recent or current studies on invertebrates include millipedes, European snails, pea weevil, *Sitona* weevil and various aphid species. The recent introduction of a generalist natural enemy for the Russian wheat aphid, a species which will have a devastating impact on wheat and barley production demonstrates that biological control can be pre-emptive. The study took advantage of advanced computer technology, using CLIMEX to predict distribution and economic damage to crops should the aphid reach Australia, and has been coupled with a plant breeding program at Montpellier in France to evaluate existing commercial cultivars of Australian wheat, screen for resistant germ plasm from elsewhere in the world, and breed for resistance and tolerance to Russian wheat aphid. There remains considerable promise for classical biological control, with weeds like Bathurst burr (Argentina), African boxthorn (Africa), and arthropods like red-legged earth mite (South Africa) still on the waiting list.

Inundative release of natural enemies such as pesticide-resistant predatory mites, and egg parasites such as *Trichogramma* spp. are more advanced in Europe and the Americas than Australia. Again, this is a reflection of priorities, with the Australian emphasis being on classical biological control outside intensive production systems.

Areas where research effort is lacking would include inundative biological control of fungal diseases such as *Phytophthora cinnamomi* and exotic bacterial pathogens such as take-all. Research on crown gall would represent an exception. Mycoherbicides should be explored for controlling grass weeds where invertebrate natural enemies generally lack adequate specificity for their safe introduction.

Several fields in hi-tech biological control where Australia leads the world include entomopathogenic nematodes and *Agrobacterium tumifaciens.* The nematodes range from the use of *Deladenus* for sirex control, which usually involves one effective inundative release, to members of the families Steinematidae and Heterorhabditidae where repeated inoculative releases are required. A nonpathogenic strain of A. . *tumifaciens* has been selected by A. Kerr of the Waite Institute using classical technologies as a means of preventing pathogenic strains of the bacterium causing crown gall in stone fruits. A superior strain has recently been developed by Kerr using recombinant DNA techniques and currently is the only commercially available, genetically engineered natural enemy worldwide.

Behaviour-modifying chemicals

Pheromones, especially sex pheromones, are increasingly being used to monitor presence, abundance and even pesticide resistance status of a range of pests, generally lepidoptera, so that optimal chemical control can be effected. 'Lure and kill' traps may have an increasing role to play in future methods of pest control. Finally, the use of sex pheromones to disrupt mating has been shown to be effective for a few species, for example, oriental fruit moth, and is being evaluated for codling moth and *Heliothis armigera.* Elsewhere in the world, kairomones, produced by plants associated with the host of a parasitoid or predator, are being used to attract and retain natural enemies in crops when pest densities are low. Potentially, this strategy increases their efficiency in control. This methodology is very poorly developed in Australia.

Habitat manipulation to increase efficiency of natural enemies

This class of pest management is quite well developed in Europe but not in Australia. Examples include: artificial hedgerows to retain natural enemies and herbicide/pesticide free headlands in paddocks to provide nectar and other resource requirements for natural enemies.

Physical methods of control

A role has been demonstrated for physical methods, for example, heat disinfestation, cooling, and mechanical disruption to development for insect pests of grain storage. Controlled atmospheres, either with reduced 0_2 or increased CO_2, especially as membrane filter technology provides new methods of changing the 0_2 content oratmospheric air. With deregulation of Australia's grain industry, entry of new players into the storage, transport and marketing arenas for grain crops, and with increased on-farm storage, the risk of decline in grain quality and hygiene could offset any gains in pest control during the production phase for these commodities.

Integrated pest management

IPM is not simply one of a number of options on a list of plant protection methods for adoption by a pest manager. IPM came about in the 1960s in response to the over-dependence on pesticides, especially the organochlorines, such as DDT, dieldrin and related compounds. Most points of value about 1PM can be made by reference to rice pests in Indonesia, especially the pesticide-induced pest, the brown plant hopper (BPH) (5).

High input/high output rice production began in Asia around 1966 with the introduction of dwarf varieties that were fertiliser dependent. Pesticides were deemed necessary as these new varieties appeared susceptible to BPH. At that time, a 'cargo cult' mentality existed for agrochemicals and this outlook was reflected in Government policy in Indonesia with the result that pesticides were lumped in with fertiliser subsidies. In 1974 the hidden pesticide subsidy was US$7 million p.a.; by 1985 it had reached US$150 million. In the intervening period BPH-induced losses to the rice crop had cost Indonesia an estimated US$3.5 billion. Government policy dictated that the army ensured rice growers availed themselves of the 'intrinsically-good' pesticides. In an economic, social, health and political sense, pesticide usage had disempowered the rice farmer of Indonesia.

In today's Indonesia, the Government subsidy has been withdrawn and the Government actively promotes IPM for rice production. This is coupled with the use of a non-formal adult education program, through an FAO IPM program, which aims to transform illiterate farmers into expert managers of their rice crops. The FAO program is underpinned by three tenets:

rice in the tropics evolved with some herbivores and a wealth of natural enemies to combat them. In most instances, these latter will suffice to keep the herbivores below economic threshold levels.

Chemical pesticides represent a valuable resource which are resorted to only on those occasions when herbivores, like BPH, threaten to exceed economic threshold levels, and (iii) rice farmers, given appropriate training, are capable of becoming experts in pest management of rice herbivores. The FAO program has demonstrated the critical importance of putting the producer 'back in the driver's seat'.

It should be recognised that plant breeding was a key element in the Green Revolution that gave Asia the high input/high output production system for rice. Breeding also produced some of the BPH resistant varieties which seemed necessary under Green Revolution conditions. It now appears likely that the shift towards a narrower genetic base during selection for BPH resistance, introduced susceptibility to other pests such as white stem borer, promoting such herbivores to primary pests. This experience highlights the limitations of depending too much on any one approach to pest control, whether it be plant breeding, cultivation, pesticides or biological control (4).

The problems associated with pest management of local crops like rice in the tropics are very different to those of exotic crops in temperate Australia, like wheat, rice, cotton and so on. But the underlying principles of understanding the crop, its herbivores, their natural enemies, and then evaluating the array of options for dealing with pests, weeds and diseases are not dissimiliar.

IPM has reduced pesticide usage for cotton in the USA by 50% and a similar result has been achieved in Brazil for soybean pests. Examples where IPM philosophy has paid dividends in Australia include: spider mite control in pome orchards, grain pests in bulk storage facilities, and spotted alfalfa aphid. Perhaps the most ambitious IPM project about to be undertaken includes CS IRO and the Victorian and NSW Departments of Agriculture and will explore the use of nematodes, pheromones, growth regulators and pesticides for codling moth, which is a primary pest in pome orchards.

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