While not all threatened species are horticultural subjects it is hoped that all can be saved from extinction. Some difficult-to-grow species may only be conserved in their natural habitats, others can be easily maintained in cultivation.

It is important that every effort be made to save these plants as most have not been assessed for their potential. Some may be important sources of pharmaceuticals. Others closely related to crop plants may be useful for breeding purposes. Once gone, however, they cannot be replaced.

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INTEGRATED PEST MANAGEMENT WITH REFERENCE TO PLANT PROPAGATION

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INTRODUCTION

Since the large scale production of synthetic pesticides following World War II, the most common approach to pest control in agriculture and horticulture has been prophylactic application of chemicals, based on potential insect and disease threats. Recent increased awareness of the limitations and side effects of pesticides is causing this attitude to be rethought. Problems associated with pesticide use include widespread resistance in insect and mite pests and pathogens, elevation of organisms to pest status through elimination of natural suppressive agents, major environmental damage from some pesticides, and human health and safety concerns (in particular mutagenic effects of pesticides). With a number of crop plants, phytotoxic injury from pesticides is a major problem, and there is evidence that regular pesticide use may suppress plant growth (15). In addition, while the presence of pests constitutes barriers to international trade, so do unacceptable levels of pesticide residues.

The rate at which new pesticides are being developed is not able to keep pace with their removal from the market place. Two recent Australian examples are the withdrawal of the fungicide Captan, and the miticide Cyhexatin. Pesticide companies realize that a more rational use is essential to ensure longevity of other currently registered pesticides.

The response to the above is a shift from a chemical basis of pest control to a biological one, where emphasis is placed on management of pests by integrating a number of control methods. Integrated pest management (IPM) is defined by FAO as a "system that, in the context of the associated environment and population dynamics of the pest species, utilizes all suitable techniques in a compatible manner, and maintains the pest populations at levels below those causing economic injury" (14). Such an approach is dynamic, and involves continuous monitoring and evaluation, intervening with pesticides only when necessary. In practice, most successful IPM schemes have been developed in perennial plantation crops (e.g. fruit trees), because of their long term ecological stability. However, excellent results have also been obtained in nurseries and protected crops (15).

This paper discusses integrated pest management strategies with potential in nurseries and plant propagation. Limits to widespread adoption of IPM are also discussed.

COMPONENTS OF IPM PROGRAMMES

Insect and Mite Pests

Biological Control. This has been the major alternative strategy to pesticide use for insect control, and has been incorporated into most IPM programmes. Biological control encourages or augments natural organisms such as predators, parasites, pathogens and competitors to suppress pest populations or their activity. With ornamental and nursery plants, the most effective method has been the introduction of mass produced biological control agents. European and North American programmes have been directed at glasshouse pests with high reproductive rates, such as spider mites, white flies, aphids, thrips and scale insects.

The most spectacular and widespread programme has been control of spider mites, *Tetranychus* spp., by the phytoseiid predatory mite *Phytoseiulus persimilis* (15). Research in Australia by C.S.I.R.O., several state Departments of Agriculture, and private companies has led to commercial production of this agent, which is now available from HAWKAID INTEGRATED PEST MANAGEMENT SERVICE, RICHMOND, N.S.W. and BIO-CONTROL PTY. LTD., WARWICK, QUEENSLAND. The former company is working closely with the N.S.W. Department of Agriculture, and additionally provides a monitoring and technical service to participants in the programme (27). One important area of ongoing research is the testing of pesticides for compatibility with predatory mite use in protected structures (Goodwin, S., personal communication).

Other successful biological control campaigns in overseas glasshouse crops, using commercially available predators and parasites, are:

- Whitefly, *Trialeurodes vaporariorum*, by the parasite *Encarsia formosa* (29).
- Leafminers, *Liriomyza* spp., by the parasites, *Opius pallipes, Dacnusa* spp. and *Diglyphus isgea* (21).
- Aphids, particularly *Myzus persicae* and *Aphis gossypii*, by parasites of the families *Aphidiidae* and *Aphelinidae* (25).
- Thrips, *T. tabaci*, by the predatory mites, *Amblyseius mackenziei* and *A. cucumeris* (22).
- Mealybugs, *Pseudococcidae*, with the predatory ladybird, *Cryptolaemus montrouzieri*, and the parasite, *Leptomastix dactylopii* (7, 8).
- California redscale, *Aonidiella aurantii*, by the parasites *Aphytis melinus* and *A. lingnanensis* (9).

A number of insect pathogens have been tested for biological control, but few have been commercialized. The most widespread is the spore-forming bacterium, *Bacillus thuringiensis*, the common strain of which is specific for control of lepidopterous pests. Other strains with different specificity are being developed. The commercial use of strains of the fungus *Verticillium lecanii* for aphids, whitefly, and thrips control in European glasshouses (12), has been limited by conditions of temperature and relative humidity required for its success (Scopes, personal communication). Insect viruses have also had limited commercial success. Nuclear polyhedrosis virus for budworm, *Heliothis* spp., control is registered in Australia and U.S.A.

Insect nematodes have been successfully trialled in Australia and elsewhere in horticultural crops. Examples include use of *Steinernema bibionis* to control currant borer, *Synanthedon tipuliformis*, in blackcurrant cuttings, *Heterorhabditis heliothidis* to control black vine weevil, *Otiorhynchus sulcatus*, in potted plants in commercial nurseries in Tasmania (3) and California (30) and control of citrus root weevil in Cuban nurseries by *Neoaplectana* P2M (20).

Lures and Traps. Lures and traps (including food lures, sticky traps, coloured traps, light traps, and pheromones) have been used for many years in insect pest control with limited success. Their chief benefit has been their ability to monitor pest populations to enable accurate decision-making (24). The incorporation of pesticides into food lures (such as insect, mollusc, and rodent baits) has been more effective in direct pest control.

The recent successful use of pheromones to reduce pest damage by disrupting mating in oriental fruit moth, *Cydia molesta* (17), gives a model for further development of this technique.

Resistant/Tolerant Cultivars. This method has not been greatly explored for insect control. The two most significant examples are woolly aphid resistant apple cultivars and the use of American grape rootstocks in Europe and Australia for *Phylloxera* aphid (14). The economic viability of further developments in this area relies on ease of incorporation of resistant genes by genetic engineering.

Pathogens

Biological Control. Biological control has not received the same degree of attention for control of diseases as it has for insects or weeds. Recent interest centres around control of soil- and media-borne diseases (4). The aim is to reduce pathogen numbers or their ability to produce disease by antibiosis and competition (2, 18). This is achieved by maintaining or encouraging natural bacterial and fungal antagonists through cultural practices such as manipulating media composition, composting and pasteurizing or by the addition of specific organisms into the media or on to plant tissues.

Media in which peatmoss is the only organic component are generally not suppressive, and are therefore conducive to pathogen colonization and spread (13). Composted plant materials, particularly hardwoods, are more suppressive for damping-off diseases such as *Pythium, Rhizoctonia,* and *Fusarium* (32). Hoitink and Fahy (13) indicate compost quality may be the key factor in determining success in suppression of soil-borne diseases.

Inoculation of previously-treated soil or media with specific organisms has shown some spectacular results. Broadbent et al. (5), using *Bacillus* spp., and Chang et al. (6), using *Trichoderma harzianum,* both reported increase in growth rate in a range of bedding plants.

Plant surface inoculation with the antagonistic organism *Agrobacterium radiobacter* has been commercially successful in controlling crown gall, *A. tumefaciens,* in plants of the family *Rosaceae* (11, 19). Other examples include inoculation of fresh cut surfaces of carnation with *B. subtilis* to prevent disease caused by *Fusarium roseum* (1), control of *Fusarium oxysporium* by inoculating with *F. solani* on cut sweet potato, and biological control of rusts (28) and fire blight, *Erwinia amylovora* (16) on ornamentals.

Cross-protection is the ability of mild strains of a disease to prevent the deleterious effects of more severe strains. It has been used successfully for control of several virus diseases. With citrus tristeza virus, inoculating with mild isolates imparts a high degree of resistance. This technique, initiated in Brazil is now used worldwide. Other examples include woodiness virus in passionfruit, pawpaw ringspot in Hawaii and Taiwan, sun blotch in avocado (26) and stone and pome fruit viruses, especially in U.S.A. There is evidence that cross protection may break down with time (31), and while cross protection may be suited to specific crops, use of disease-resistant annual plants, such as TMV resistant tomatoes, is more economic.

Resistant cultivars. The majority of modern plant breeding programmes include selection for resistance to diseases, particularly air-borne fungi, viruses, and soil-borne pathogens. The use of disease-resistant rootstocks for controlling soil-borne diseases in perennial crops such as citrus, stone fruit, and avocado is widespread.

Modification of Environment. Many bacteria and fungi thrive under the high humidity conditions found in poorly ventilated nursery structures. Improved design of protective structures should significantly reduce disease incidence, thereby reducing the need for other control measures. Modification of the soil/media environment to reduce disease outbreaks has been discussed previously.

Cultural Procedures. Sanitation procedures, such as disinfestation of structures, equipment and media by chemicals, heat, or irradiation are likely to reduce carry-over of pests. Other operations include roguing and destruction of plants with disease symptoms, quarantining of new plant material, restricting entry of personnel, chlorination of water supply, rotation of plant species, and timing of cultural practices to avoid pests. When incorporated into IPM programmes, these further reduce the need for other control methods.

Use of Pesticides

Intervention with pesticides is an integral part of many IPM programmes. This may be done with reduced rates of application when it is desired to temporarily redress the pest/biological control agent imbalance.

The selection of pesticides which minimally disrupt other strategies, particularly biological control, is critical. More research is needed to determine non-toxic effects of pesticides on biological control agents (such as reduced fecundity), and also on pesticide residue activity in protected environments.

DEVELOPMENT OF IPM PROGRAMMES IN PROPAGATED CROPS

Integrated pest management programmes may be considered to be "all things to all men" (23), where each programme developed can be unique to that industry or enterprise. All, however, adhere to the same philosophy of understanding pest-plant-environment interactions and continuous data gathering and decision making, based on an awareness of alternative strategies and their consequences. Inherent in all programmes is a pest or damage threshold above which intervention is economically warranted. In practice, however, these economic thresholds are imprecise, often based on past experience or "gut-reaction" (33).

There are a number of factors which limit the development of IPM programmes in propagated or ornamental plants. The first is the low tolerance of pest damage. Classical biological control, for example, is not immediate in its effects, and reduces, but does not eliminate pest incidence. A second factor is the requirement for continuous monitoring by trained staff. In large enterprises, this could be the specific personnel responsible for plant protection. Alternatively, contract monitoring by private companies may be more appropriate. In either case, the technique of monitoring based on removal of plant leaves for later examination is not feasible in ornamental plants. Another limit to IPM development is the rapid turnover and, hence, short term nature of propagated plants. Thirdly, diversity of plants in a confined area also complicates development of successful programmes.

In conclusion, the scenario of reduced pesticide availability and effectiveness will continue and, despite the limits outlined above, the need to move to integrated management of pests will become more obvious.

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