JASSA

Journal of Applied Science in Southern Africa
The Journal of the University of Zimbabwe

Volume 4, Number 2, 1998 ISSN 1019–7788

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Published by University of Zimbabwe Publications
P.O. Box MP203, Mount Pleasant, Harare, Zimbabwe

Typeset by University of Zimbabwe Publications
Printed by Mazongororo Paper Converters

Inaugural lecture

New directions for pesticide use.

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Intruduction

Great progress has been made in meeting food needs during the last 30 years as a result of the 'green revolution'. However, because of the scope for expanding cultivated areas was limited, yield increases were the major source of food production growth in all developing regions except Africa, contributing about 80 per cent of increased cereal production in developing countries as a whole. According to the United Nations, the current world population of 5.5 billion will double to 10 billion by 2050. About 97 per cent of this increase is projected to occur in the Third World (Anon, 1994). Thus, over the next 50 years, farmers and policy makers in developing countries will be challenged to provide food at affordable prices for about 100 million more people every year. Moreover, the increase in food production will have to come from further intensification of the existing cultivated land since expansion of cultivated land is no longer feasible (Oudejans, 1991). At present, with the intensification of agriculture and widespread use of high-yielding varieties, chemical pesticides have been increasingly used to protect crops from pests. However, their use has been challenged because of economic, environmental, and social concerns. Considerable evidence now shows that routine application of some pesticides, particularly insecticides, is both unnecessary and undesirable, and can create pest outbreaks, upset natural ecology, pollute the environment, and harm the health of both farmers and consumers.

The use of chemicals has become the most common way of combating pests in many countries. The efficiency of many chemical pesticides has led to the misconception that pests can be eradicated, rather than simply controlled. And so, farmers continue to apply pesticides on a routine basis, and sometimes needlessly, during the cropping season. The effects of pesticide-induced outbreaks and pesticide resistance can combine to cause a phenomenon known as the **pesticide treadmill.** When farmers observe that their pesticides are becoming less effective as shown by the numerous pest outbreaks or the development of resistance in the pest, they usually respond by applying more pesticides. This aggravates the problem by making the pest more resistant to the chemicals and by killing even more of the pests' natural enemies. The result is an upward spiral of pesticide use, increasing input costs for the farmer, and declining income as uncontrollable pests reduce yield.

Integrated Pest Management (IPM) Programme

It should be acknowledged that pesticides have contributed to impressive agricultural productivity, but at the same time their use has and is causing serious health and environmental problems. They have been the backbone of insect pest control since the early 1950s when the organochlorine insecticides were first introduced. Subsequently however, the wisdom of widespread use of pesticides has been questioned with the advent of the more ecologically sound, Integrated Pest Management (IPM) approach to pest control. Today, more and more national and international organi-sations, including farmer groups, are re-evaluating the need for and use of pesticides.

Higher yields of most of the major crops have been obtained by selecting new cultivars, some with significant levels of resistance to some pests. However, achieving the potential yield of these cultivars has also depended to a large extent on increasing inputs, such as fertiliser, and ensuring effective weed, insect and disease control. While the search for complementary and alternative methods of controlling pests, diseases and weeds, such as resistant varieties and improved agricultural practices, will continue, the use of insecticides, fungicides and herbicides will remain essential for the foreseeable future. Over the last 40 years, the farmer has been able to select and purchase from a wide range of pesticides to control the many different pests that attack crops. However, there is increasing concern that many of these chemicals have adverse effects on the environment.

The long term future of pesticides does not now lie in their wholesale use as the sole means of pest control, but rather in their judicious use in appropriate situations, dictated by the objectives of an IPM programme. There will always be certain pest species that cannot be entirely controlled by any other means than pesticides. However, for the majority of pest species the use of pesticides should only be a last resort, for situations where it is known that prophylactic methods such as host plant resistance, natural enemies or cultural control have not constrained the pest to acceptable levels. Then, the pesticides should only be applied after an action threshold of pest numbers has been reached (Matthews, 1984). The proper use of pesticides involves a thorough understanding of:

- pest population dynamics and how this is influenced by the pesticidal control;
- the infestation/yield loss relationship and the economics of pesticide use.

It is necessary to ensure the use of appropriate application techniques and to avoid the misuse of what are toxic, hazardous chemical substances. The proper use of pesticides is therefore a complex business for which farmers require training and readily available advice. In situations where there is an adequately trained, equipped and motivated extension service the proper use of pesticides by farmers can be envisaged. However, it would seem unwise to encourage pesticide use by farmers in situations where an extension service is not readily available or where there is insufficient monitoring of pesticide quality standards or the use of inappropriate packaging or instructions. This is particularly important when the misuse of a pesticide can potentially cause illness or even kill the users, as well as having serious harmful effects on the environment.

In the final chapter of her book *Silent Spring*, Rachel Carson (1962) referred to Robert Frost's poem 'The Road Not Taken.' She suggested that human societies, through their extensive use of chemical pesticides, were following a road that while attractive at the start, could lead to disaster. She recommended taking the other road, the nonchemical road. Frost suggested he would like to travel on both roads, but being one person, he could not do so. One might say that, having explored one of the roads some distance, he could have returned to the other road and explored that also. Frost doubted that he ever would. In a way, Frost's thought, that he would never take the other road is correct. We cannot return the world to the condition it was in the early 1940s and follow the road which we could have followed had we abstained from pesticide use. The world has changed too much and many of the changes are not in our power to reverse. The road that could have been followed no longer exists and cannot be recreated. Yet we can change our course and indeed we have begun to do so. From the 1940s to the 1980s the amounts of synthetic pesticides used increased rapidly. In the 1980s the amounts used stabilized. There is evidence now that the amounts used in agriculture will begin to be significantly reduced (Pimentel and Lehman, 1993).

The other road, as conceived by Rachel Carson, involved the use of biological and other nonchemical controls rather than chemical control of pests. However, she claimed that she was not advocating total elimination of chemical methods of control. Thus, if we pursue the metaphor of a road, we should not think of the other road as one on which chemical methods of pest control are prohibited. The new road we appear now to be following includes the judicious use of synthetic pesticides. Reductions in pesticide use envisaged in the next decades are to be obtained through a number of approaches including applications of pesticides which are more precisely targeted, applications timed so as to be more effective (Matthews, 1989), use of newer, more 'environmentally friendly' pesticides which are effective in small doses, development of varieties of crops that are genetically resistant to pests, and other methods of nonchemical control including crop diversification, timing of planting, rotations and education of farm workers.

The intended destination of the new road is no longer the achievement of total control of any pest. The new road is that of 'Integrated Pest Management' (IPM): a system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury. The tactics which can be used in an IPM programme are shown in Figure 1 (Matthews and Thornhill, 1994).

The suggestion that following the new IPM road is a moral virtue should not be interpreted as implying that every one who advocates following the old road is evil and selfish, is working to advance the interests of chemical corporations, is a naive

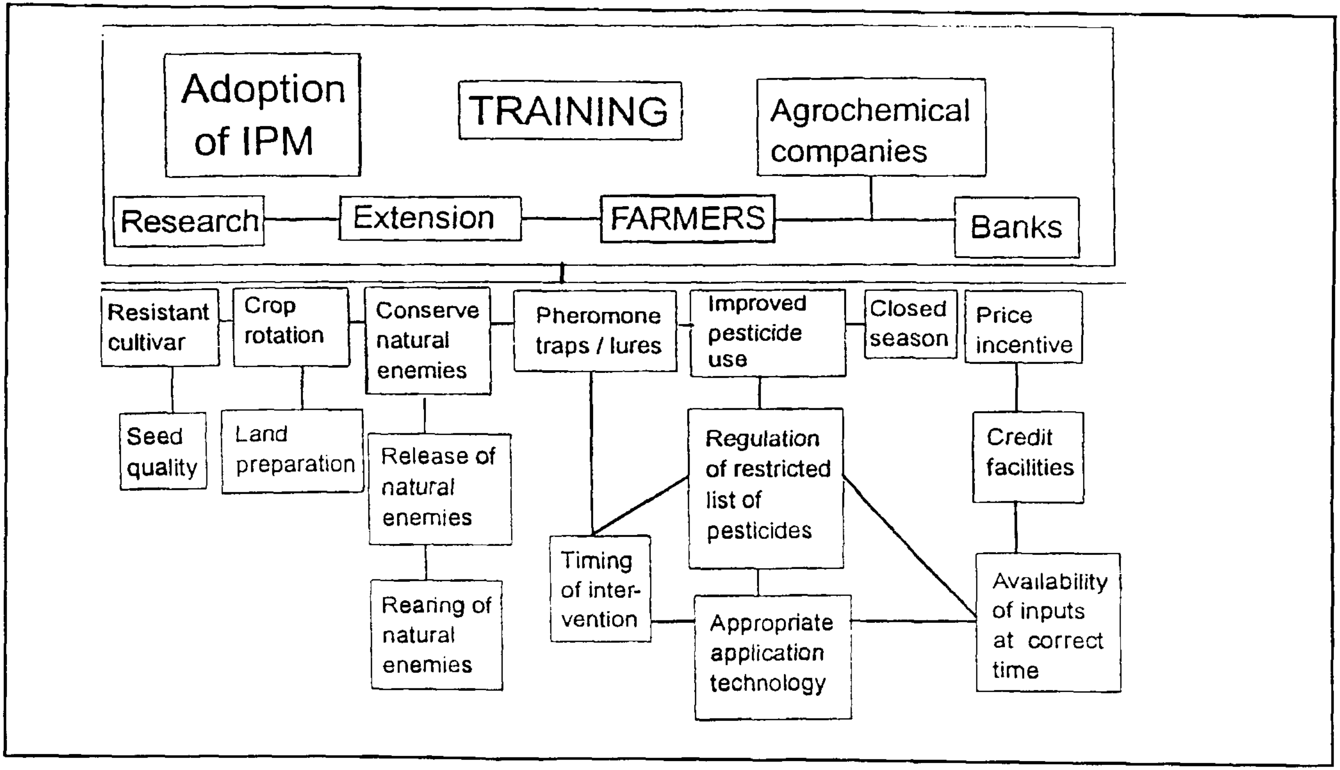

Figure 1: Tactics which can be used in an integrated pest management (IPM) programme

puppet of such corporations — that ecologists and environmentalists are good, while, agriculturists are evil. There is no doubt that agricultural scientists who advocated intensive and extensive pesticide use were motivated to eliminate hunger and malnutrition. We now recognise that we ought not destroy our environment by overuse of pesticides, we must also not forget that we must continue to produce food in sufficient quantities.

Discerning the direction of the new road, and where we do perceive the new road, are not easy tasks. Eradication or elimination of pests is a clear, unachievable objective. Management of pests is not so clear. How much pest damage should we tolerate? Many people argue that we should reduce 'cosmetic standards' in foods -- that is, tolerate increased presence of insects and insect parts and insect damage. A higher tolerance on our part would lead to reductions in the amounts of pesticide required (Pimentel *et al.*, 1993).

An objective of the old road was to reduce the cost of food and maximize production. This again is a clear objective. On the new road, our objectives are more complex. The consumer of food is also a resident of the environment and may be adversely affected by the introduction of pesticides in the air, water and food. Food containing residues, even in minute amounts may cause illness; even if such food does not cause illness it often provokes concern as to whether it does not cause illness.

Whereas cheap and abundant food is a great benefit to the people, illness and concern of possible illness are harmful. Yet, total elimination of pesticide residues would lead at least in the near future, to higher food prices and reduced harvests. It is not as if we can replace the clear objective of cheapest possible food with another equally clear objective. Somehow we must strike a balance amongst competing objectives.

The proper use of any pesticide is an involved and complicated process (Figure 2) (Dent, 1991) and so the first question that should be asked when they are being considered as a control option is, are there alternative control methods that could be used, or should combinations of measures be considered? Only when no alternatives are available or applicable, should a pesticide be used on its own as a control measure.

Pesticides still have an important place in sustainable pest control. Their role is changing, however. This is influenced by international pressures, and by legislation policy. Public pressure arising from perceived health and environmental risks is also important. Industry is under pressure to produce more IPM-compatible products. However the greatest pressures come from the development of resistance to the pesticide in the target pests.

Resistance in pests to pesticides is the greatest single problem facing crop protection. Approximately 500 arthropod species have become resistant to insecticides and acaricides with many species developing resistance to all the major classes of such products (Georghiou, 1986; Georghiou and Saito, 1983). The development of resistance affects IPM, by reducing the number of pesticides that remain effective and by applying pressure for applications at higher doses and

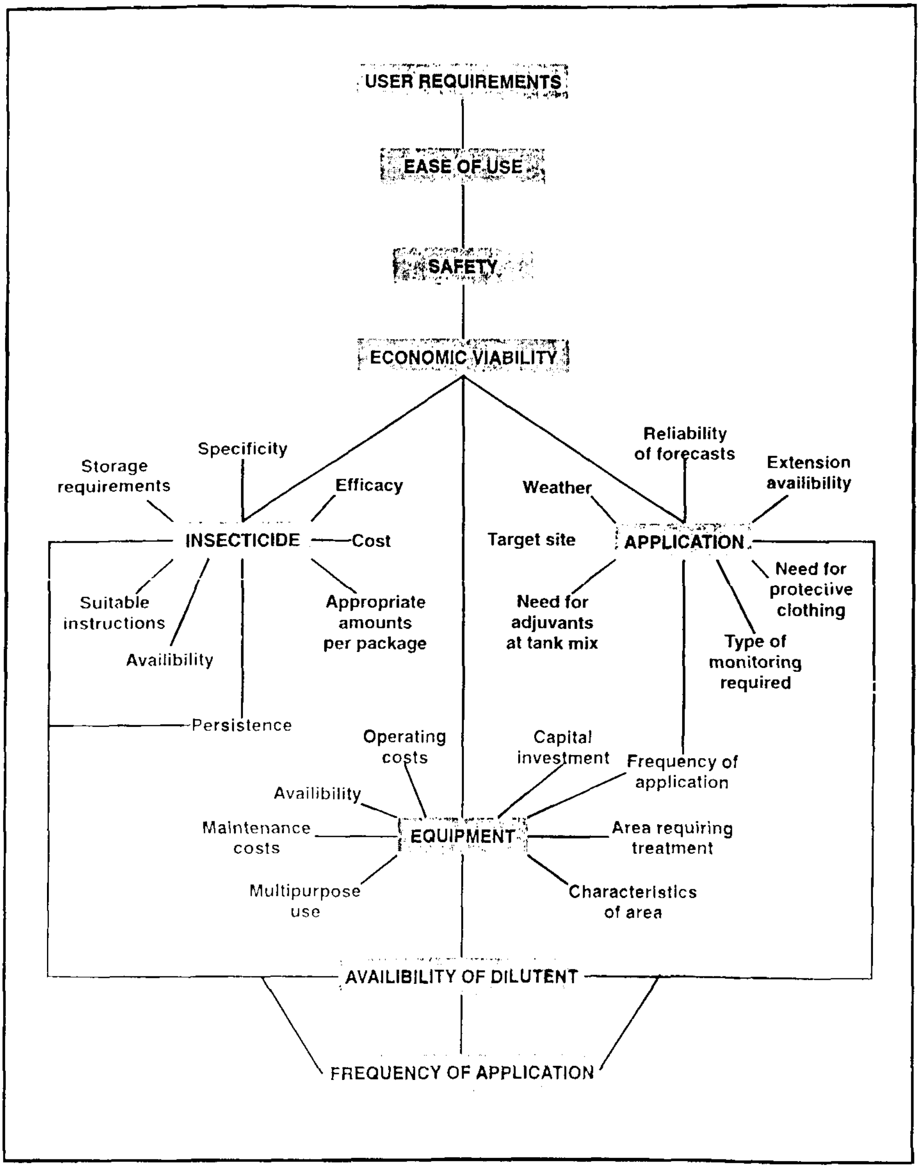

Figure 2: Abiotic factors goverining the use of insecticides

frequencies (with ptentially devastating implications on biological control). There is also a decreasing incentive for industry to market more highly specific compounds. This, coupled with the escalating costs of pesticide development, has resulted in a fall in the number of materials available for use in IPM programmes. Since the judicious use of pesticides is a critical part of IPM, it is vital that the current pesticides are not allowed to be lost through resistance.

Attempts to manage pesticide resistance generally has involved making relatively minor tactical shifts in use patterns. What we need is a major shift in thinking about pesticide development and use, if we are to develop effective resistance mana-gement tactics. It is time to recognise that effective management begins before the product is registered (Hoy, 1995). The strategy thus should be to manage the pesticide, even before it is fully developed and registered, with the goal of delaying resistance development. If this strategy is adopted, decisions on application rates and numbers of applications per growing season will be made with the understanding that they affect the speed with which resistance will develop. In some cases, new products may not be developed because they are toxic to biological control agents and thus disrupt effective IPM programmes already in place. This would only speed up the development of resistance in specific pests. While altering the way in which pesticides are re-registered and labelled is difficult, the potential benefits are great for both IPM and resistance management programmes.

Scientists have approached the problem of resistance in a variety of ways. Fundamental research over the past 40 years has produced some insights into resistance mechanisms and the mode of inheritance of resistance in arthropods (Scott, 1990). Simulation models have been developed to evaluate various options for managing resistance, but debate over whether to recommend alternation or mixtures ('cocktails') of different pesticides as appropriate methods for slowing resistance remains unresolved (Tabashnik, 1990). The hypothesis that the reduced fitness that is often associated with resistance alleles could be used in management programmes continues to be controversial. Various monitoring techniques have been developed to identify resistant individuals and detect their establishment and spread, but effective monitoring is difficult and expensive (French-Constant and Roush, 1990). No effective paradigm for resistance management has been adopted. Once a pesticide has been registered and used, resistant individuals have been detected in populations, and developing and implementing a resistance management programme is exceedingly difficult to execute in sufficient time to have a significant effect. Waiting until the pest has become resistant before instituting a resistant management programme is an ineffective strategy. Thus a proactive and not a reactive strategy is required (Hoy, 1992).

A more effective means of managing resistance in arthropods will involve altering pesticide use patterns, and nearly everyone will agree that reducing pesticide use is an effective resistance management tactic. To achieve altered use patterns, changes are needed in the way products are developed. Furthermore, resistance management must be recognised as a broad-based, multitactic endeavour (Croft, 1990; Tabashnik, 1990).

It seems reasonable, conservative, and fiscally responsible to assume that nearly all major insect and mite pests develop resistances to all classes of pesticides given sufficient pressure and time. While new pesticide classes have been proclaimed to be potential 'silver bullets', and not amenable to resistance development, these hopes have been misplaced to date (Hoy, 1992). The pests are winning the battle! It seems appropriate to assume that the development of resistance is nearly inevitable and the issue is not whether resistance will develop, but when. With this assumption, resistance management programmes have the goal of delaying, rather than preventing, resistance.

Innovative Ways of Pesticide Application

Pest management experts cannot afford to rely on pesticides as their primary management tool, as has been done for the past 30 years. There are increasing social, economic, and ecological pressures to reduce use and to increase the use of nonchemical control tactics. There is increasing priority given by research scientists, regulatory agencies, legislators, and the public on using pesticides that are nontoxic to biological control agents and have minimum impact on the environment. The issue of compatibility of pesticides with natural enemies and other nonchemical tactics is critical, not only for improving pest management and environmental quality, but also in managing resistance to pesticides in pest species. Enhancing compatibility of pesticides and biological control agents is complex and sometimes difficult, but can pay dividends in improved pest control and pesticide resistance management (Croft, 1990; Hoy, 1985a; Metcalf, 1994).

The way pesticides are registered must be changed as part of an effective resistance management strategy. These changes are also essential in achieving improved IPM. For example, some pesticides are relatively nontoxic to important natural enemies in cropping systems at low rates, but the recommended application rates are too high (Hoy 1985b). Use at high rates disrupts effective biological control, leading to additional pesticide applications, which exerts unnecessary selection for resistance in the pest. Under these circumstances, it may be appropriate for the label to contain two different directions for use; one rate could be recommended for the traditional strategy of relying on pesticides to provide control and a lower rate could be recommended for use in a programme that employs effective natural enemies. This approach to labelling would reduce overall pesticide applications and rates and also selection pressure in the target and nontarget pests in the cropping system.

Another innovation in pesticide registration would require that the toxicity of the pesticide to a selected list of biological control agents be determined. This information should be provided on the label and in readily-available computerised data bases, perhaps via the internet. Without such information, pesticides are used that disrupt effective biological control agents. This often results in unnecessary use of pesticides, leading to more rapid evolution of pesticide resistance. Enhancing biological control can not only lead to improved pest management, but is an essential tool in managing pesticide resistance.

Rates of application should be based on manufacturer's recommendations but it should be realised that these will be influenced by factors such as the speed at which the operator walks, the swath width and nozzle type. The spray coverage depends on the type of pest, the pesticide used, and where the pest is found on the host plant. These factors need to evaluated on an individual pest/crop/pesticide basis (Dent, 1991). The timing and number of pesticide applications used on a particular crop will depend on the type of strategy that has been adopted by the farmer. A number of factors will influence farmer decision-making but they may choose to use scheduled prophylactic applications or applications based on pest populations and pest threshold values (Dent, 1991).

A scheduled prophylactic application means that the pesticide is applied to the crop at regular intervals without information on the level of pest infestation. On each occasion the level of infestation is unknown or assumed to be sufficient to justify application. When pesticides are used prophylactically over a number of years, pesticide resistance, secondary pest resurgence, destruction of natural enemies, and loss in viability of the pesticide results. The possible damage to the health of the farmers as a result of over exposure to poisonous chemicals or their residues must be taken into account. Prophylaxis, although attractive in the short term, will rarely have any place in the context of IPM strategies that utilise pesticides.

A more rational strategy for pesticide application utilises pest monitoring techniques. The level of pest infestation is monitored and assessed relative to a defined action threshold which identifies the point at which a pesticide should be applied to prevent economic loss (Matthews, 1984). The action threshold takes into account the cost of the pesticide and the extent of potential yield loss due to pest damage. The successful use of action thresholds requires a monitoring procedure which is reliable and robust and the action threshold itself must be based on a knowledge of the levels of infestation, the potential yield loss at different plant growth stages, the cost of the damage/ yield loss and cost of the pesticide. Where such information is available the use of monitoring and an action threshold would provide the most economical and judicial use of pesticides. However, while this strategy provides the goal to which one aims, there are few examples of versatile monitoring/pesticide application strategies that are reliable, and even applicable to the farmers in developing countries.

Crop Protection

Effective crop protection will continue to depend to a considerable extent, and for the foreseeable future, on the intelligent use of chemical technology. This is particularly true of tropical agriculture in developing countries where the need for intensification is greatest. Ensuring that pesticides are used safely, effectively and appropriately by small farmers will remain a high priority for the agrochemical industry. Where does the agrochemical industry go from here? The primary task facing the industry is to rectify the prevalent adverse public perception of its activities. The agrochemical industry has taken many steps to change its image, which include:

- more widespread availability of information on pesticides and their benefits
- closer involvement and collaboration with environmental pressure groups
- increasing attention to farmer training and product stewardship, especially in the developing world
- modifications to formulations, labels, packaging and application systems to optimise safety to users and the environment
- the development of new active ingredient products with inherently improved safety and environmental profiles.

There are still many product opportunities for the industry even though there are few crop protection problems for which no practical, chemically-based control measure exists. The opportunities arise because there is a continual need to replace existing active ingredients and formulations to satisfy the changing environment, user and economic demands.

The new products should be:

- safer to the environment, the user and the consumer of treated crops
- very highly active and cost-effective
- flexible and convenient in use
- compatible with other products and suitable for use in IPM programmes.

New leads emerging from a variety of sources for example natural products, random screening and patents are being exploited by companies using modern techniques including computer aided design.

Biotechnology applied to crop protection has made rapid advances and will lead to the introduction of novel microbial products and crop varieties in the next few years. The techniques of molecular biology are poised to make a major impact in crop protection. The most important contribution of biotechnology to agriculture will be the introduction of modified crop varieties. Crop resistance to insect pests and fungal pathogens will replace some pesticide use, although it will take decades before complexes are controlled exclusively by this technology without supplementary use of agrochemicals. Biotechnology will generate potentially important new crop protection products in the future but their rate of commercial introduction is likely to be constrained, not only by technical and economic considerations, but by the very demanding legislative framework which is being established in a number of countries.

Conclusion

More than 30 years ago, Rachel Carson's *Silent Spring* appeared as a landmark of literary achievement which contributed greatly to the foundation of the modern environmental movement. Rachel Carson contrasted two roads, *The insecticide road* and *'The other road'*. The future however, belongs to a third road -*'The middle road'* of IPM. In the book *Beyond Silent Spring*, van Emden and Peakall (1994) cited an East Asian proverb 'He who takes the middle road is likely to be crushed by two rickshaws'. Neither the environmentalists nor the chemical industry are likely to be satisfied with the middle road being advocated here. Those who hold the middle position are not usually as vociferous as those who put forward more extreme arguments; hence the phrase the 'silent majority' (van Emden and Peakall, 1994). However, the middle road is an alternative and a valid one; one can support it just as strongly as others hold their opinions.

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