

CONSERVATION AND ENHANCEMENT OF BIOLOGICAL CONTROL HELPS TO IMPROVE SUSTAINABLE PRODUCTION OF BRASSICA VEGETABLES IN CHINA AND AUSTRALIA

Shu-sheng LIU¹, Zu-hua SHI¹, Michael J. FURLONG², and M. P. ZALUCKI²

¹Institute of Applied Entomology, Zhejiang University
Hangzhou 310029, China
shshliu@zju.edu.cn, zhshi@zju.edu.cn

²School of Integrative Biology, The University of Queensland
Brisbane, Qld 4072, Australia
m.furlong@uq.edu.au, M.Zalucki@uq.edu.au

ABSTRACT

Brassicas comprise a major group of vegetable crops in Zhejiang Province, China and south-east Queensland, Australia. In Zhejiang, heavy reliance on chemical control to manage insect pests in brassica vegetable production has resulted in insecticide resistance, increased costs of pest control and insecticide residues hazardous to human health. In southeast Queensland, reliance on chemical control has also resulted in increased cost of pest control, control failures due to insect resistance and reduced profits. To improve sustainable production of brassica vegetables in the two regions, a group of Chinese and Australian scientists have undertaken a joint project to develop practical integrated pest management (IPM) strategies for these crops.

In both regions, major efforts have been made to evaluate the complexes of endemic natural enemies under different pest management practices, and to conserve and enhance these natural enemies as the central elements of effective management programs. In Zhejiang, field trials were conducted across crops, seasons and localities to test and improve an IPM system that emphasized the use of proven action thresholds for different crop growth stages and strategic application of selective insecticides to promote the impact of natural enemies. Compared with conventional methods, IPM practices were associated with substantially higher natural enemy activity, a 20-70% reduction in input of insecticides, and no yield loss. The improved IPM system has been implemented to various degrees in major vegetable production areas in Zhejiang, and has improved the safety and profitability of production.

In southeast Queensland, as an important part of the IPM development and implementation effort, a three-year experimental field study was conducted to evaluate the impact of endemic natural enemies on independent farms practicing a range of pest management strategies. Natural enemy impact was greatest on farms adopting IPM and least on farms practicing insecticide intensive conventional pest control strategies. On IPM farms, the contribution of natural enemies to pest mortality permitted the cultivation of marketable crops with no yield loss but with an average of 70% less insecticide inputs compared to conventional farms.

The field studies and IPM implementation in China and Australia indicate that naturally occurring biological control can be substantially enhanced to form the central element of effective IPM programs and improve vegetable production. Demonstration of the effectiveness of biological control in the two regions through an international joint effort not only made the evidence more convincing but also promoted the adoption of the improved IPM strategies by farmers.

INTRODUCTION

Brassicaceae constitute a major group of vegetables in China. Depending on the region, brassicaceae account for 35-45% of all vegetable crops. In Zhejiang province, the proportion of brassica vegetables has decreased in recent years due to an increase in other vegetable crops, but they still account for approximately 30% of all vegetables and a total area of 235,000 ha was cultivated in 2004 (calculated on single crops). Brassica vegetables are mostly grown by small landholders (<0.5 ha) around urban centers, and in specialized production areas where farms can be much larger. The crop systems are complex and erratic, revolving around intercropping practices (growing more than one crop on a small piece of land at the same time) throughout the entire year. In Zhejiang, a complex of insect pests attacks brassica vegetable crops. The major species include the diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae), the cabbage white butterfly, *Pieris rapae* L. (Lepidoptera: Pieridae), the cluster caterpillars, *Spodoptera litura* F. (Lepidoptera: Noctuidae), the beet armyworm, *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae), the green peach aphid, *Myzus persicae* Sulzer (Hemiptera: Aphididae), and the turnip aphid *Lipaphis erysimi* Kalténbach (Hemiptera: Aphididae) (Liu *et al.* 1996).

The brassica industry in Queensland grows a total of 2,300 ha of crops per annum (Heisswolf *et al.* 1997). The major production region is the Lockyer Valley, a river system about 100 km inland from Brisbane and farm sizes range from 40-100 ha. Planting of crops begins in February (later summer) and weekly or fortnightly plantings are made until September (early spring), final harvests are collected in late spring/early summer. On many farms, regular weekly plantings used to be continuous and crops were grown all year around. A suite of lepidopterous pests attack brassica vegetable crops in the region. These include DBM, cabbage white butterfly, centre grub, *Hellulla hydralis* Guenee (Lepidoptera: Pyralidae), *Hellulla undalis* F. (Lepidoptera: Pyralidae), cabbage cluster caterpillar, *Crociodolomia pavonana* F. (Lepidoptera: Pyralidae), cluster caterpillar, and *Helicoverpa* spp. (Lepidoptera: Noctuidae). DBM has been the most difficult pest to manage, largely due to its resistance to a range of commonly used insecticides (Heisswolf *et al.* 1997).

In Zhejiang, the control of insect pests on brassica vegetable crops has relied heavily on the use of chemical insecticides since the 1970s, resulting in insecticide resistance, increased costs of pest control and insecticide residues hazardous to human health (Liu and Yan 1998; Liu *et al.* 1996). In southeast Queensland, reliance on chemical control in the 1970s and 1980s also resulted in increased cost of pest control, control failures due to insect resistance and reduced profits (Heisswolf *et al.* 1997). To improve sustainable production of brassica vegetables in the two regions, a group of Chinese and Australian scientists undertook a joint

project to develop practical integrated pest management (IPM) strategies for these crops (Zalucki and Liu 2003).

A JOINT VENTURE IN IMPROVING BRASSICA IPM

This project was started in 1995 to build on existing studies to develop sound, sustainable brassica IPM strategies that significantly reduce pesticide hazards, and are acceptable to the growers in Zhejiang and Shanghai, east China, and Queensland, Australia. The project involved five institutes in China, working in close collaboration with two institutes from Australia (Liu *et al.* 1996; Zalucki and Liu 2003). The working strategy consisted of three overlapping and ongoing phases: problem definition, research and development, and implementation. Structured problem definition workshops, involving all groups of stakeholders and in particular farmers and extension workers, were organized at the start of the project to promote information flow, determine priority issues, address priority needs, and propose action plans (Liu *et al.* 1996). Work has since concentrated on the following five, interacting components: (1) survey and evaluation of natural enemies?, (2) rational application of insecticides, in particular promoting use of biological insecticides, (3) development of action thresholds, (4) development of management strategies through season-long in-field IPM trials, and (5) IPM implementation activities.

RESEARCH, DEVELOPMENT, AND IMPLEMENTATION IN EAST CHINA

SURVEY AND EVALUATION OF ARTHROPOD NATURAL ENEMIES

Regular sampling in both farmers' fields and unsprayed fields in Hangzhou showed that a range of parasitoids attack each of the major pests. For example, DBM is attacked by at least 8 species of parasitoids, of which *Cotesia plutellae* Kurdjumov (Hymenoptera: Braconidae), *Oomyzus sokolowskii* Kurdjumov (Hymenoptera: Eulophidae) and *Diadromus collaris* Gravenhorst (Hymenoptera: Ichneumonidae) are the major larval, larval-pupal and pupal parasitoids respectively (Liu *et al.* 2000). The cabbage white butterfly is attacked by a suite of at least 7 species of parasitoids, of which *Cotesia glomeratus* (L.) (Hymenoptera: Braconidae) and *Pteromalus puparum* L. (Hymenoptera: Pteromalidae) are often most abundant.

Insect parasitoids are active in fields despite the heavy use of chemical insecticides in the crop systems over the years. For example, in fields that have not been heavily sprayed during a growing season, parasitoids usually achieved 10-60% parasitism of DBM larvae and pupae during June to early July and September-November each year when DBM was most abundant (Liu *et al.* 2000). IPM field trials demonstrated that both parasitoids and arthropod predators were several-fold more abundant in fields that were sprayed with selective insecticides, than in fields that were sprayed with wide-spectrum chemical insecticides (Lin *et al.* 2002; Yu *et al.* 2002; Zhang *et al.* 1999).

EVALUATION OF BIOLOGICAL AND SELECTIVE INSECTICIDES

Biological and chemical insecticides were bio-assayed in the laboratory and tested in the field. A number of Bt and NPV products were shown to have high efficacy in killing the target pests with no side effects on the beneficials (Shi and Liu 1998; Shi *et al.* 2004). Other insecticides showing selectivity include abmectin, avermectin, spinosad and fipronil against DBM and *P. rapae*, chlorfluazuron and chlorfenapyr against *S. litura* and *S. exigua*, and imidacloprid against aphids (Guo *et al.* 1998; Guo *et al.* 2003; Zalucki and Liu 2003).

DEVELOPMENT OF ACTION THRESHOLDS

Laboratory and greenhouse trials demonstrated that several cultivars of common cabbage and cauliflower could endure some defoliation without reduction of head weight at harvest. There was evidence of over-compensation for defoliation at the pre-heading stage. However, the plants were more sensitive to defoliation at the cupping stage. For example, 10% defoliation of common cabbage (cultivar Jin-Feng No.1) at the pre-heading, cupping or heading stages respectively resulted in mean head weights at harvest 9.8% heavier, 4.3% lighter and 3.3% heavier than undamaged controls (Chen *et al.* 2002; Liu *et al.* 2004). These data were used to assist in developing action thresholds for practical application (Table 2). Of particular value was the characterization of crop growth stages sensitive to insect damage. Thus, farmers and extension officers were asked to monitor the insect pests more closely at both the seedling and cupping stages.

IPM FIELD TRIALS

Based on the findings of studies of various components and information from literature, management strategies were formulated and tested in the field to evaluate the effects of different management strategies on pest and natural enemy populations and to develop practical IPM guidelines and protocols. The major components in the IPM strategy included use of action thresholds in decision-making and strategic use of biological and selective insecticides (Tables 1 and 2). In each location, a field trial with a crop of approximately one ha was divided into 2-3 plots. Each plot was managed by an IPM or a conventional, insecticide intensive, approach for an entire season. Regular sampling was conducted through the season and pest control action was taken according to the guidelines in Tables 1 and 2. At the end of each trial, crop yield and quality, input of insecticides and levels of natural enemy activities of different plots were compared (Table 3). Field IPM trials with common cabbage were conducted in Hangzhou from 1996 to 2000 and in 2000 trials were conducted at five sites in Zhejiang and Shanghai (Lin *et al.* 2002; Liu *et al.* 2004; Yu *et al.* 2002; Zhang *et al.* 1999). In 2001 and 2002, field IPM trials with cauliflower, broccoli or Chinese cabbage were conducted at three sites in Zhejiang and Shanghai (Zalucki and Liu 2003). The results showed that biological and selective insecticides could offer effective control of all the insect pests and that the activities of natural enemies were promoted (Table 3). Compared with conventional practice, IPM practice could reduce insecticide input by 20-70%, with no risk of crop loss (Fig. 1; Zalucki and Liu 2003).

Table 1. Summary of designs of field IPM trials in China.

Treatment	Description	Application of insecticides
IPM	Use of action thresholds, apply biological and selective insecticides	Spray Bt for control of DBM and <i>Pieris rapae</i> , spray chlorfluazuron and NPV for control of <i>Spodoptera</i> spp. and spray imidacloprid for control of aphids
Conventional	Simulation of typical practice by farmers, or recording of farmer's practice	Basically calendar sprays with mixtures of broad-spectrum chemical insecticides such as chlorpyrifos, fenvalerate, methomyl, fipronil, and methamidophos

Table 2. Action thresholds (mean number of insects/plant) used in IPM treatment in China.

Pests	Cabbage Growth Stages			
	Transplants	Pre-heading	Cupping to Early Heading	Heading to Mature
Lepidoptera ^a	0.5	1.0	1.0	4.0
Aphids	5	500	500	2000

^a Number of lepidopteran larvae were converted to "standard" insects by the following formula: 1 standard insect = 1 *Pieris rapae* = 1 *Spodoptera exigua* = 0.5 *Spodoptera litura* = 5 *Plutella xylostella*.

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Table 3. Examples of results of field trials including plots managed with IPM or conventional (Con) pest control strategies in Hangzhou, China, in autumn 1998 and autumn 2000.

Assessments ^a	1998		2000	
	IPM	Con	IPM	Con
Mean head weight (kg)	1.23 a	1.11 a	1.18 a	1.02 a
% marketable heads	94.4 a	88.0 b	95.6 a	91.1 a
% heads without insect damage	52.5 a	16.7 b	76.7 b	96.7 a
Number of sprays ^b	7(8)	8(23)	3(5)	5(8)
Cost of insecticide application per ha (RMB Yuan)	2,700	3,780	680	1025
Mean % parasitization of DBM larvae	19.4 a	2.0 b	35.2 a	7.1 b
Mean % parasitization of DBM pupae	32.6 a	1.3 b	18.8 a	13.0 a

^aFigures in the same row of the same year followed by the same letter do not differ ($p > 0.05$, Student-t test).

^bIn the IPM treatment, usually one insecticide and only rarely a mixture of 2 insecticides was used per spray, while in the conventional treatment, usually a mixture of 2-3 insecticides was used per spray. Figure in brackets indicate the relative amount of insecticide input calculated on the basis of one insecticide in one spray at the recommended rates.

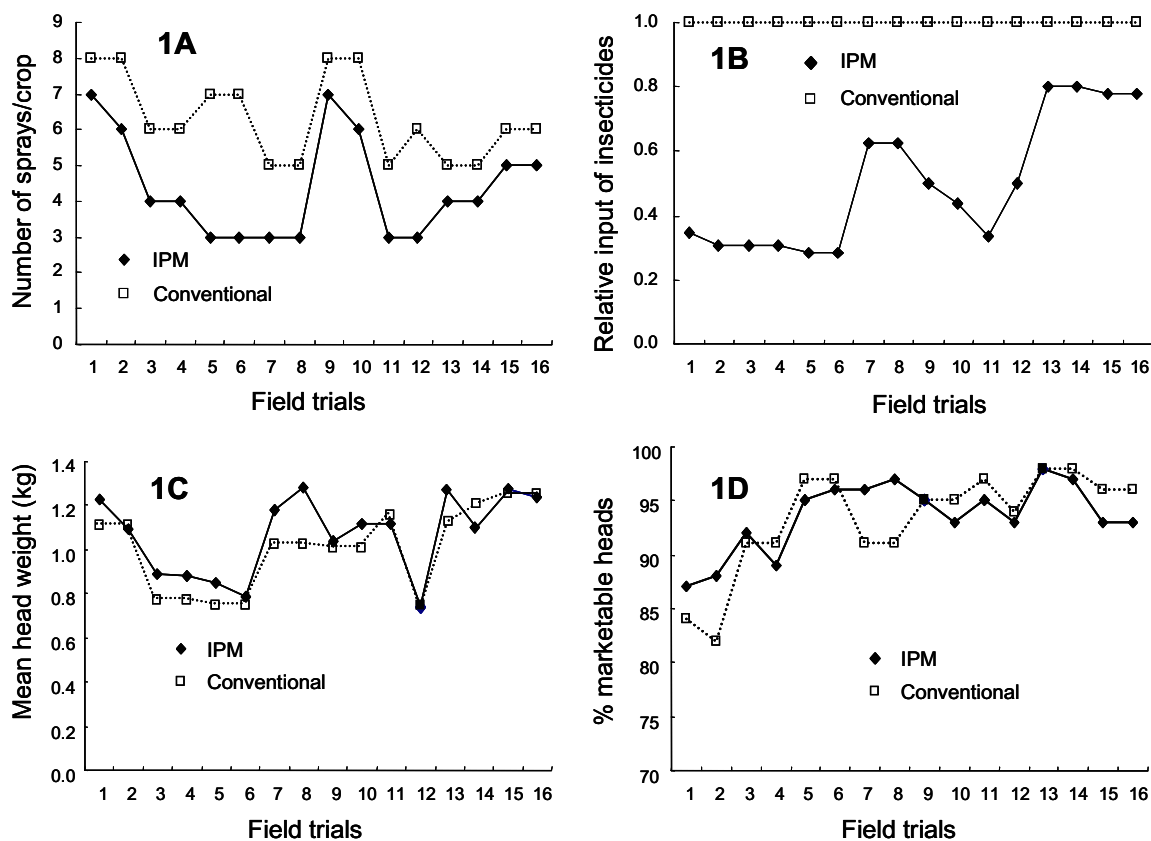


Figure 1. Comparison of insecticide input and crop yield between field plots managed by IPM or conventional approaches at each of 16 field trials at various locations in Zhejiang and Shanghai, China, from 1999 to 2001. 1A: number of insecticide applications per crop; 1B: relative quantity of insecticide input with that of conventional approaches set as unity (see footnote of Table 3 for further explanation); 1C: mean head weight in kg at harvest; and 1D: % of marketable heads.

IMPLEMENTATION

Implementation activities included grower involvement in field trials, field days and participatory workshops, frequent dissemination of fact sheets, as well as short training courses for extension officers and growers (Liu *et al.* 1996; Zalucki and Liu 2003). An independent project evaluation in the project areas showed substantial improvement in farmers' knowledge, attitude and approaches towards IPM (Liu and Qiu 2001). For example, by 2001, 36% of the growers in the project areas conducted regular monitoring of insect pests on their crops and usually tried to use biological or selective insecticides if required, compared with only about 20% in the non-project areas; growers in the project areas had more frequent contact with extension officers than growers in the non-project areas (Liu and Qiu 2001). An extensive survey by the agricultural departments in Zhejiang and Shanghai in late 2002 showed that in 10 major, project-associated production areas, which involved some 50,000 farming families and produced some 2 million tons of brassica vegetables in a year, input of chemical insecticides was reduced by 30-60% in a period of five years. Legally excessive pesticide residues on brassica vegetables from August to October (the season of the year when insecticides are mostly applied) were reduced steadily from 20-40% in the mid 1990s to 0-10% (0% in the central project areas) in 2002 (Zalucki and Liu 2003).

RESEARCH, DEVELOPMENT, AND IMPLEMENTATION IN SOUTHEAST QUEENSLAND, AUSTRALIA

DEVELOPMENT AND IMPLEMENTATION

The effort to develop an IPM approach for the control of insect pests in brassica vegetable crops in Queensland began in late 1980s when many growers encountered frequent spray failures with chemical insecticides. In many cases control failures were so severe that crops failed completely. A resistance management strategy was implemented in 1988 with widespread support of the industry. This strategy included a summer production break, improved spray application, an understanding of insecticide resistance and the need for insecticide rotation on farms (Heisswolf *et al.* 1997; Niemeyer 2004).

In the early 1990s, development work to reduce the reliance on conventional insecticides began by focusing on the crop system level of pest management and introducing Bt into the emerging IPM system. Research and extension activities involved a series of demonstration plantings at the local research station and on commercial farms. Data on pest activity, abundance of natural enemies, yields and quality of harvested products were collected. Results were then shared with growers and used to recommend improvements to management regimes with particular emphasis on spray decision making (Heisswolf *et al.* 1997; Niemeyer 2004).

Following the start of the joint brassica IPM project between Australian and Chinese scientists in 1995, more field trials were conducted to focus on issues such as protocols for monitoring pests and parasitoids, action thresholds, insecticide spray coverage, and development of decision-making tools (Deuter and Liu 1999; Heisswolf *et al.* 1997; Zalucki and Liu 2003). Insect identification workshops were held for growers and field days were organized for growers to view the field trials and discuss the implications for improving pest management on their farms. Many growers started to appreciate the principles of IPM and recognized the potential impact of natural enemies and the capacity of crops to tolerate some damage particularly at the pre-heading stage. Seeing the benefits of IPM and the value of information exchange between growers and extension and research scientists, about 30 growers in the Lockyer Valley formed the Brassica Improvement Group in February 1998. This group met once a month during the growing season each year to share and exchange information with researchers, industry and other growers. These research and extension activities promoted the acceptance of IPM concepts and more and more growers gradually shifted from reliance on regular sprays of broad spectrum chemical insecticides to a reasonably integrated strategy, which included a combination of a summer production break, regular crop scouting, threshold-based decision making, strategic application of selective insecticides, and conservation of natural enemies (Deuter and Liu 1999; Furlong *et al.* 2004a; Zalucki and Liu 2003). One of the key elements in the IPM systems is always to start a growing season with a “soft approach”, that is to spray a selective insecticide only if needed, to ensure conservation of natural enemies and to aid the promotion of their activities later in the season (Niemeyer 2004).

ON-FARM EVALUATION OF THE IMPACT OF NATURAL ENEMIES ON THE SUCCESS OF IPM

Adoption of IPM programs is usually gradual and slow (Trumble 1998), and the brassica IPM program in the Lockyer Valley has not been an exception. Despite the intensive development and implementation effort and wide support from the industry, growers varied in their perception and approaches to the alternative pest management strategies. By 2000, a wide spectrum of pest management practices, ranging from the conventional calendar sprays to reasonably sophisticated approaches, was observed on different farms (Furlong *et al.* 2004a). As many farms in the valley grow a comparable range of vegetable crops and the general features of the ecosystem (climate, soil type and non-crop vegetation) are similar throughout the area, the wide spectrum of pest management strategies on different farms offered a unique opportunity to measure the effect of pest management practices on pest and natural enemy populations and crop production at the farm level. Mechanical exclusion with cages and life table analysis were used as the major techniques in this on-farm evaluation study, and the major pest DBM was used as the target pest (Furlong *et al.* 2004a,b).

This on-farm experimental study was conducted on 10 independent farms between 2000 and 2002. Individual farms, each of an area of 45-80 ha, were assessed and the management practices (production breaks, conservation of natural enemies, regular crop scouting, threshold based decision making, use of broad-spectrum insecticides, number of insecticide applications per crop, and tank mixes of insecticides) were scored and summed to produce a management index (Furlong *et al.* 2004a). For example, as regards threshold based decision making, a farm scored -2 for no action or +3 if decisions were based on the population density of pests as well as parasitoids. Farms with an overall score of >5.2 were categorized as IPM, farms with a score <0 as conventional practices, and those in between as intermediate. Each farm operated independently and thus formed a somewhat independent crop ecosystem. Such an approach allowed the long-term management practices to be included as a single variable in the analysis, and the effects of adopting different strategies on the efficacy of natural enemies could be evaluated (Furlong *et al.* 2004a).

During the study, three species of larval parasitoids *Diadegma semiclausum* Hellén (Hymenoptera: Ichneumonidae), *Apanteles ippeus* Nixon (Hymenoptera: Braconidae) and *O. sokolowskii* and two species of pupal parasitoids *D. collaris* and *Brachymeria phya* Walker (Hymenoptera: Chalcididae) attacked immature DBM. *Diadegma semiclausum* was the only parasitoid abundant over the course of the study (Furlong *et al.* 2004a; also see Wang *et al.* 2004). The most abundant groups of predatory arthropods caught in pitfall traps were Araneae (Lycosidae) > Coleoptera (Carabidae, Coccinellidae, Staphylinidae) > Neuroptera (Chrysopidae) > Formicidae. On crop foliage, Araneae (Clubionidae, Oxyopidae) > Coleoptera (Coccinellidae) > Neuroptera (Chrysopidae) were most common. The abundance and diversity of natural enemies was greatest at sites that adopted IPM, correlating with greater DBM mortality at these sites. Over the course of the study, the mean mortality of immature DBM caused by the natural enemy complex was 73% of the original test cohorts at IPM sites but

only 20% of the original cohort at conventionally managed sites (Fig. 2). At IPM sites the contribution of natural enemies to pest mortality permitted the cultivation of marketable crops with no yield loss (Fig. 3) and a substantial reduction in insecticide inputs.

On average the number of sprays per crop was 8.6 on conventionally managed farms and 2.3 on IPM farms, an impressive more than three fold difference. Furthermore, these 2.3 sprays on IPM farms were almost all Bt formulations or selective insecticides (Furlong *et al.* 2004a).

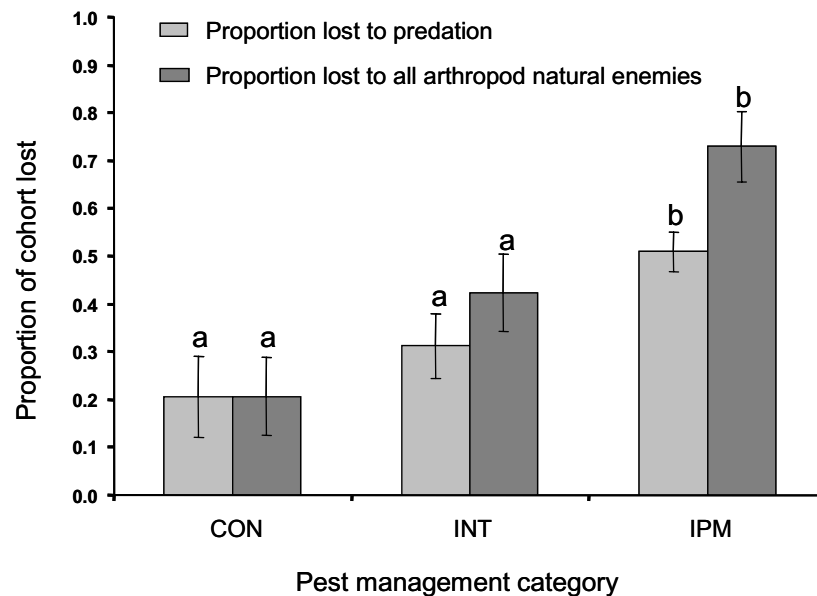


Figure 2. Estimated mean proportion (\pm SE) of original *Plutella xylostella* cohorts lost to predation and lost to the combined effects of the endemic arthropod natural enemy complex at sites practicing conventional (CON), integrated (IPM), and intermediate (INT) approaches to pest management (2000-2002) in the Lockyer valley, southeast Queensland, Australia. Columns of the same color marked by different letters are significantly different (LSD; $P < 0.05$) (adopted from Furlong *et al.* 2004a).

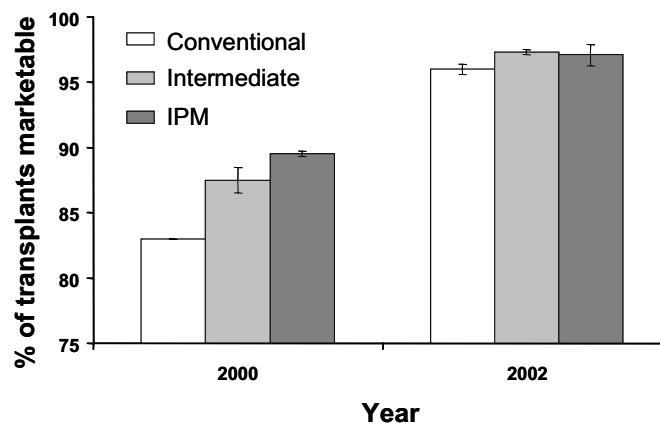


Figure 3. Cabbage yield at sites practicing conventional (CON), integrated (IPM) and intermediate (INT) approaches to pest management in 2000 and 2001 in the Lockyer valley, southeast Queensland, Australia (adopted from Furlong *et al.* 2004a).

DISCUSSION AND CONCLUSIONS

The history of pest control in the last century has repeatedly shown that sustainable pest management can only be achieved by utilizing endemic biological agents as part of a total ecosystem approach to crop management (Lewis *et al.* 1997). Many modern agricultural practices, which often reduce the ecological complexity of habitats and rely extensively on chemical pesticides, require revision. In this international cooperative project on brassica IPM, joint efforts were made to carry out research, development and implementation in two regions in Australia and China. While the brassica crops in the two regions share some of the same major pests, the crop ecosystems differ in many ways (see Introduction), and on-farm evaluation of the impact of natural enemies required different experimental setups in the two countries.

In Zhejiang and Shanghai, China, field trials were conducted for single seasons on a rather small scale, using plots within the same field, although extensive effort was made to repeat the same trials in different locations and years (Lin *et al.* 2002; Liu *et al.* 2004; Yu *et al.* 2002; Zhang *et al.* 1999). In such circumstances movement of natural enemies between treatments can confound results and the effectiveness of the natural enemy complex at the important agro-ecosystem level cannot be addressed. In the Lockyer Valley, brassica crops are grown on relatively large (50-100 ha) independent farms responsible for making their own pest management decisions. As the continuum of pest management practices included in the field study evolved over a course of approximately 10 years, the comparative experimental analysis between farms reflected the outcomes from different pest management strategies at the realistic crop ecosystem level over time (Furlong *et al.* 2004a; Heisswolf *et al.* 1997). Despite the differences in crop ecosystems between the two regions and the differences in experimental methods, the results indicate that in both regions naturally occurring biological control can be substantially enhanced to form the central elements of effective IPM programs and improve vegetable production.

One of the major features of this cooperative project has been the frequent interchange of visiting studies by both sides and frequent exchange of information. Experimental results and information on recent developments in IPM implementation in both regions were delivered to all team members through annual reports and project review meetings. Effort was made to convey the information to the growers in various extension activities (Deuter and Liu 1999; Zalucki and Liu 2003). Data on the effectiveness of naturally occurring biological control, as affected by pest management practices, in both geographic regions helped the extension scientists and growers to build up their confidence for a shift from chemical control to an IPM strategy. There is ample evidence that the improvement in pest management achieved through this joint project has promoted the sustainability of the brassica industry in the two regions of China and Australia (Zalucki and Liu 2003).

ACKNOWLEDGEMENTS

This work has been supported by the Australian Centre for International Agricultural Research (Projects: CS2/1992/013, CS2/1998/089), and the Department of Science and Technology, Zhejiang Province, China (Projects: 959218, 001106124). About 20 scientists from

China and 10 scientists from Australia contributed substantially to the achievements and many others participated in activities at various stages. Their names are not listed here because of space.

REFERENCES

- Chen, Y. N., Ma, J., Yuan, Z. M., Chen, C., Jiang, J. X., and Xiao, X. P. 2002. Study on the influence of artificial defoliation on the yield of common cabbage and the action thresholds for main leaf-mass consuming insects. *Journal of Hunan Agricultural University (Natural Sciences)* **28**, 308-313 (in Chinese with an English summary).
- Deuter, P. L., and Liu, S. S. 1999. ACIAR Project CS2/1992/013: Improvement of integrated pest management of brassica vegetable crops in China and Australia, Final Report (1 July 1995 - 30 June 1999). Australian Centre for International Agricultural Research, Canberra, Australia.
- Furlong, M. J., Shi, Z. H., Guo, S. J., Liu, Y. Q., Liu, S. S., and Zalucki, M. P. 2004a. Experimental analysis of the influence of pest management practice on the efficacy of an endemic arthropod natural enemy complex of the diamondback moth. *Journal of Economic Entomology* **97**, 1814-1827.
- Furlong, M. J., Shi, Z. H., Liu, S. S., and Zalucki, M. P. 2004b. Evaluation of the impact of natural enemies on *Plutella xylostella* L. (Lepidoptera: Yponomeutidae) populations on commercial Brassica farms. *Agricultural and Forest Entomology* **6**, 311-322.
- Guo, S. J., Lin, W. C., Wang, X. G., Liu, S. S., and Song, H. M. 1998. Toxicity of insecticides to *Oomyzus sokolowskii*, a parasitoid of diamondback moth. *Chinese Journal of Biological Control*, **14**, 97-100 (in Chinese with an English summary).
- Guo, S. J., Lin, W. C., Zhang, J. M., Xu, X. G., and Liu, S. S. 2003. Selective and persistent toxicity of insecticide mixtures to the diamondback moth, *Plutella xylostella* and its parasite, *Oomyzus sokolowskii*. *Acta Agriculturae Zhejiangensis* **15**, 231-236 (in Chinese with an English summary).
- Heisswolf, S., Houlding, B. J., and Deuter, P. L. 1997. A Decade of Integrated Pest Management (IPM) in Brassica Vegetable Crops - The Role of Farmer Participation in its Development in Southern Queensland, Australia. In "The Management of Diamondback Moth and other Crucifer Pests." (A. Sivapragasam, W. H. Loke, A. K. Hussan, and G. S. Lim, Eds.), pp. 228-232. Proceedings of the Third International Workshop, Kuala Lumpur, Malaysia. Malaysian Agricultural Research and Development Institute. Kuala Lumpur, Malaysia.
- Lewis, W. J., van Lenteren, J. C., Phatak, S. C., and Tumlinson, J. H. 1997. A total system approach to sustainable pest management. *Proceedings of the National Academy of Sciences, USA* **94**, 12243- 12248.
- Lin, W. C., Guo, S. J., Zhang, J. M., and Liu, S. S. 2002. Effects of different control practice on lepidopterous insect pests and beneficials in autumn cabbage. *Acta Agriculturae Zhejiangensis* **14**, 150-154 (in Chinese with an English summary).

- Liu, S. S., and Yan, S. 1998. Brassica IPM in Asia: Successes, Challenges, and Opportunities. In "Pest Management - Future Challenges." (M. P. Zalucki, R. A. I. Drew, and G. G. White. Eds.), pp.85-97. Proceedings of the Sixth Australasian Applied Entomological Research Conference, Brisbane, Australia, 29 September - 2nd October 1998, Volume 1.
- Liu, S. S., Brough, E. J., and Norton, G. A. 1996. ACIAR Workshop Report: Integrated Pest Management in Brassica Vegetable Crops. Cooperative Research Centre for Tropical Pest management, Brisbane, Australia.
- Liu, S. S., Shi, Z. H., Guo, S. J., Chen, Y. N., Zhang, G. M., Lu, L. F., Wang, D. S. Deuter, P., and Zalucki, M. P. 2004. Improvement of Crucifer IPM in the Changjiang River Valley, China: from Research to Practice. In "The Management of the Diamondback Moth and Other Crucifer Pest" (N. M. Endersby, and P. M. Ridland, Eds.), pp.61-66. Proceedings of the Fourth International Workshop, Melbourne, Australia, 26-29 November 2001, the Regional Institute Ltd, Gosford, NSW, Australia.
- Liu, S. S., Wang, X. G., Guo, S. J., He, J. H., and Shi, Z. H. 2000. Seasonal abundance of the parasitoid complex associated with the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) in Hangzhou, China. *Bulletin of Entomological Research* **90**, 221-231.
- Liu, Y. G., and Qiu, G. J. 2001. Socioeconomic Study on Farmer's Adoption of IPM Strategies in Brassica Vegetable Crops in China. Study report submitted to ACIAR, Centre for Integrated Agriculture Development, China Agricultural University, Beijing.
- Niemeyer, K. 2004. A Change in Attitude – Seeing Pests from a Different Perspective. In "The Management of the Diamondback Moth and Other Crucifer Pests" (N. M. Endersby, and P. M. Ridland, Eds.), pp.409-411. Proceedings of the Fourth International Workshop, Melbourne, Australia, 26-29 November 2001, the Regional Institute Ltd, Gosford, NSW, Australia.
- Shi, Z. H., Guo, S. J., Lin, W. C., and Liu, S. S. 2004. Evaluation of selective toxicity of five pesticides against *Plutella xylostella* (Lep: Plutellidae) and their side effects against *Cotesia plutellae* (Hym: Braconidae). *Pest Management Science* **60**, 1213-1219.
- Shi, Z. H. and Liu, S. S. 1998. Toxicity of insecticides commonly used in vegetable fields to the diamondback moth, *Plutella xylostella*, and its parasite, *Cotesia plutellae*. *Chinese Journal of Biological Control* **14**, 53-57 (in Chinese with English summary).
- Trumble, J. T. 1998. IPM: Overcoming Conflicts in Adoption. *Integrated Pest Management Reviews* **3**, 195-207.
- Wang, X. G., Duff, J., Keller, M. A., Zalucki, M. P., Liu, S. S., and Bailey, P. 2004. Role of *Diadegma semiclausum* (Hymenoptera: Ichneumonidae) in controlling *Plutella xylostella* (Lepidoptera: Plutellidae): cage exclusion experiment and direct observation. *Biocontrol Science and Technology*, **14**, 571-586.
- Yu, Y. J., Lu, L. F. Xu, F. C., Wu, Y. H., and Yu, C. H. 2002. An investigation of different management strategies of lepidopterous pests on autumn cabbage. *Plant Protection*, **28**, 23-26 (in Chinese).

Zalucki, M. P., and Liu, S. S. 2003. ACIAR Project CS2/1998/089: Improvement of Integrated Pest Management of Brassica Vegetable Crops in China and Australia, Final Report (1 July 1999 - 30 June 2003). Australian Centre for International Agricultural Research, Canberra, Australia.

Zhang, G. M., Liu, Y. Q., Shi, Z. H., Liu, S. S., and Shen, J. H. 1999. Development of Practical IPM systems in Autumn Cabbage Crops. *In* "Recent Developments in Research of Sustainable Management of Pests in Agricultural Crops in China" (The National Agricultural Technology Extension and Service Centre, Ed.), pp.379-386. Agriculture Press, Beijing (in Chinese with English summary).