INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY Vol. 2, No. 1, 2004
1473-5903/04/01 0067-10 $20.00/0


# Farmers, Biodiversity and Plant Protection: Developing a Learning Environment for Sustainable Tree Cropping Systems

Paul Van Mele[1] and Ho Van Chien[2]

[1]CABI Bioscience UK Centre, Egham, Surrey, UK; [2]Southern Regional Plant Protection Centre, Tien Giang, Vietnam

**More diverse, perennial cropping systems often have better natural mechanisms for keeping pests at bay. But while scientists emphasise the broad benefits of conservation in terms of effective ecosystem functioning, farmers are more interested in biodiversity for the provision of food or of services such as shade or windbreaks. Because of their limited knowledge of the role of biodiversity in plant protection, farmers sometimes unconsciously disturb natural regulatory mechanisms. Some citrus farmers in Vietnam introduced sapodilla as an intercrop to diversify their source of income, and because this fruit tree requires little care. However, this apparently worthwhile attempt to combine two valuable crops has misfired. The ecological conditions that traditionally sustained natural pest control in citrus have been disturbed, thus trapping farmers in the pesticide treadmill. The weaver ant *Oecophylla smaragdina* stopped protecting citrus from stinkbugs and leaf-feeding caterpillars after facing competition from the black ant *Dolichoderus thoracicus*, which favours sapodilla trees as a nesting habitat. To avoid similar scenarios in the future, methods for linking scientific research on ecosystem functions with farmers' own knowledge, experience and priorities are presented. Examples are given of ways in which farmers in perennial cropping systems learn, and how scientists can facilitate this learning process.**

**Keywords:** agricultural knowledge system, biological control, functional biodiversity, participatory approaches, research and extension

## Introduction

How do we accommodate ecological concerns in rural development policies and programmes where conservation is not the primary aim (Grimble & Laidlaw, 2002), and what role can scientists play? Plant protection specialists approach biodiversity at three different levels:

(1) Genomic: How can we use the genetic diversity within crops and their wild relatives to develop pest- and disease-resistant varieties?
(2) Taxon: Which beneficial organisms and micro-organisms could we enhance or introduce for biological control? What is the pathogenecity of specific strains?
(3) Ecosystem: How can we improve habitats at farm and higher system levels to optimise biological control and integrated pest management (IPM)?

In this paper we will focus on the ecosystem dimension of pest management, because it offers good opportunities to elaborate on the shifting role of scientists in contributing towards sustainable tree cropping systems and biodiversity conservation.

Habitat manipulation, being one component of IPM, has increasingly been recognised by natural scientists as an important factor in improving biological control with both exotic and indigenous natural enemies (Altieri & Nicholls, 1999; Andow, 1991; Gurr *et al.*, 1998; Speight, 1983). So do more diverse systems harbour fewer pests? World literature suggests that no blueprints can be provided; understanding the ecological functions of complex agro-ecosystems remains one of the main challenges presented to scientists (van Emden & Williams, 1974).

IPM, however, does not imply that new technologies or crop designs have to be developed by scientists. Many of the non-insecticide crop protection methods have been developed by the farmers themselves and are an integral part of their crop husbandry. To integrate control methods into cropping systems, traditional pest management practices have been studied and results used as inputs for developing IPM packages (Bentley, 1992; Bentley & Baker, 2002; Thurston, 1992; Van Mele, 2000).

As farmers are one of the driving forces within the ecological knowledge system, joint learning and understanding of the learning processes become more important. In other words, more professionalism is needed in thinking about people (Röling & Jiggins, 1998). To be successful, IPM in perennial cropping systems requires a broad community-level perspective (Pretty, 1995; Prokopy, 1994; Van Mele & van Lenteren, 2002). Farmers easily adopt small modifications of their existing pest management practices (Matteson *et al*., 1984), but how does this translate to perennial cropping systems where flexibility in testing and selecting different crop designs is hampered?

Apart from these concerns, farmers and scientists often have different perceptions about the role of biodiversity in agro-ecosystems. Farmers rarely diversify their perennial cropping system to optimise plant protection, but to support their livelihoods, spread risk, labour and income generation. Although deep knowledge about pest management in tree crops exists in some cases (Van Mele, 2000), it is our experience that farmers in perennial cropping systems often do not closely observe interactions between pests, natural enemies and the environment and have limited knowledge about smaller organisms like insects and pathogens.

Diversity in cropping systems results in diversity in knowledge systems. The following paper will relate the impact of transforming a cropping system on pest predation to the agricultural knowledge system in Vietnam. It will also present a number of scenarios that illustrate how farmers learn about pest management within complex perennial cropping systems, and how scientists can play a role in enhancing the knowledge base and learning environment to improve farmers' livelihoods.

## Methods

Data are presented based on a survey conducted in 2001 in three provinces of the Mekong Delta: Ben Tre, Tien Giang and Vinh Long by staff from the Southern Regional Plant Protection Centre. In each of the three provinces, 30 citrus farmers were selected based on the presence of beneficial weaver ants, *Oecophylla smaragdina*, in their orchard and information was gathered using semi-structured interviews. Questions covered the type of plants selected as intercrop or fence, the reason behind this selection, their major pest problems and pest management practices. Each interview lasted 30–45 minutes.

Survey data were encoded and analysed, using spreadsheet and statistical software programmes. Results were compared by one-way ANOVA with Students' *t*-tests or Chi-squared with Cramer's V. Cramer's V values close to 1 indicate a high degree of association between the variables.

## Results and Discussion

### Are more diverse orchards more sustainable?

Most farmers interviewed grow sweet orange (*Citrus sinensis*) intercropped with either Tieu mandarin (*C. reticulata*), pomelo (*C. grandis*), lime (*C. aurantifolia*), or a mixture of these (Table 1). At

**Table 1** Number of farmers growing citrus and other perennials in Ben Tre, Tien Giang and Vinh Long provinces of Vietnam, 2001

| | *Ben Tre* (n = 30) | *Tien Giang* (n = 30) | *Vinh Long* (n = 30) | *Cramer's V*[a] |
|---|---|---|---|---|
| Sweet orange | 22 | 21 | 16 | 0.18 |
| Tieu mandarin | 2 | 8 | 0 | 0.36** |
| Pomelo | 2 | 10 | 13 | 0.35** |
| Lime | 11 | 12 | 1 | 0.37** |
| Multiple citrus varieties | 6 | 21 | 0 | 0.64*** |
| Other perennials around orchard | 15 | 24 | 20 | 0.26* |
| Other perennials in orchard | 23 | 27 | 22 | 0.18 |
| Age of farmer (yr) | 48.2 ± 10.8 | 44.5 ± 10.7 | 44.8 ± 11.4 | |
| Area of orchard (ha) | 0.5 ± 0.3 | 0.5 ± 0.2 | 0.5 ± 0.2 | |

[a]Cramer's V values close to 1 indicate a high difference between provinces, with *significant at 5% level, **at 1% level and ***at 0.1% level

first glance, we would be tempted to believe that the citrus orchards in Tien Giang are more diverse and hence better managed in terms of environmental sustainability. Nothing could be further from the truth. We will illustrate how careful we need to be with generalisations about diversity.

However, before taking a closer look at the scientific implications of different perennial cropping systems, we will first elaborate on farmers' decision criteria in designing their agro-ecosystem and how plant protection comes into the picture. This is followed by examples of how farmers learn about biodiversity through observation and experimentation.

## On-farm biodiversity reflects farmers' needs

The complexity of orchard agro-ecosystems is the result of a decision-making process at the farm household level based on their needs, preferences and opportunities, and linked to the local market and policy environment. Results indicate that the choice of perennials in the Mekong Delta of Vietnam is primarily based on its direct use for human consumption, and to a lesser extent on the services they provide such as shade, windbreak or ant nesting habitat (Table 2).

Even though scientists attribute importance to biodiversity in terms of ecosystem functioning, farmers will in the first instance consider its use–value function. Our results show that, despite the living tradition of using weaver ants in citrus in the Mekong Delta of Vietnam (Figures 1 and 2), only seven out of 90 farmers interviewed purposefully grow trees or shrubs in or around their orchard to provide a shelter for these ants. This is clearly not a decisive factor in selecting specific plants. Besides, those trees selected for keeping ants all have other applications.

Although some trees are favoured nesting sites for weaver ants, the following example clearly illustrates that its potential as nesting site depends on how people make use of the tree. The kapok tree *Ceiba pentandra* is a popular multi-purpose tree in Can Tho province (Van Mele, 2000). If the trees are not lopped, kapok will be the main product harvested. When used as a fence, however, the trees are regularly lopped and the leaves are used for processing incense sticks. Obviously in the latter case, weaver ants will never choose the kapok tree as a nesting site. When selecting trees to promote certain ecosystem functions, local practices will need to be considered.

Tall trees are generally better as refuge, because ants can build their nests in an undis-

**Table 2** Occurrence and multiple uses of trees and shrubs in and around citrus orchards in Ben Tre, Tien Giang and Vinh Long provinces of Vietnam, 2001 ($n = 90$)

| *Tree or shrub* | *Scientific name* | *Presence in or around orchards (%)* | *Farmers' reason for planting tree or shrub* |
|---|---|---|---|
| Coconut palm | *Cocos nucifera* | 46.6 | Food, shade, windbreak |
| Sapodilla | *Sapodilla manilkara* | 25.6 | Food, ant refuge (1)[a] |
| Mango | *Mangifera indica* | 25.6 | Food, windbreak |
| Longan | *Euphoria longan* | 20.0 | Food |
| Spondias | *Spondias dulcis* | 17.8 | Food, shade, windbreak |
| Rose apple | *Syzigium* sp. | 16.7 | Food, shade, windbreak, ant refuge (1) |
| Banana | *Musa* sp. | 10.0 | Food |
| Mangrove tree | *Dolichendrone spathacea* | 10.0 | Fence, shade, ant refuge (3) |
| Hibiscus | *Hibiscus rosa-sinensis* | 8.9 | Fence, ornamental, ant refuge (2) |
| Star apple | *Chrysophyllum cainito* | 7.8 | Food, shade |
| Durian | *Durio zibethinus* | 4.4 | Food |
| Sesbania | *Sesbania grandiflora* | 4.4 | Wood, flowers for soup |
| Water coconut palm | *Nypa frutescens* | 3.3 | Shade, windbreak, thatch |
| Beetle palm | *Areca catechu* | 1.1 | Nut, shade |
| Mangosteen | *Garcinia mangostana* | 1.1 | Food |

[a]Numbers in brackets indicate the number of farmers reporting this specific use

**Figure 1** Weaver ants make their nests in trees by stitching living leaves together with the silk of their larvae

**Figure 2** Farmers have learned that by connecting trees with a rope, weaver ants will better protect their trees from harmful insects

turbed place (Van Mele & Cuc, 2003). This is particularly important for harbouring nests with queens. Palm trees, mango, plum, and mangrove trees are mainly grown around orchards. Spondias is equally tall and has a sparse canopy; the tree has very few pests and because the fruit is entirely for home consumption, it is never sprayed, making it an ideal intercrop.

Apart from learning about farmers' decision-making criteria, scientists can gain useful knowledge by investigating how and what farmers have learned about the environment around them.

## Farmers learn through observation

Farmers have the advantage over scientists in that they often have a life-long experience of growing their crop; experience which has been built up through regular observations and exchange of information through formal and informal actor networks.

In Tien Giang province, farmers growing king orange (*Citrus nobilis*) have over the years found that their trees remain healthier when they use windbreaks of the water coconut palm *Nypa frutescens*. These trees were initially grown to protect citrus from the strong sunshine, yet over time it became clear that these border trees also offered other unexpected benefits. One of the major citrus diseases in Vietnam and the region is huanglongbing or citrus greening. The bacterium is transferred through either grafting or through the psyllid *Diaphorina citri*. Although farmers do not know about the spreading mechanisms of this disease, some have seemingly developed certain management strategies to overcome or reduce harm, for instance by making use of these *Nypa* windbreaks.

In some cases farmers have acquired deeper ecological knowledge than scientists. Mr Nguyen Van Cung from Giong Trom district, Ben Tre province explained to me in great detail one day how weaver ants (*Oecophylla smaragdina*) and black ants (*Dolichoderus thoracicus*) use different strategies in communicating and making warfare. He explained everything in military terms and his life-long observations have helped him to manipulate these different species to the benefit of his crop (Van Mele & Truyen, 2002).

In Vietnam, the black ant is commonly used as a biological control agent in sapodilla (Van Mele & Cuc, 2001). In citrus, which has a completely different pest–natural enemy complex, the beneficial weaver ant plays a central role. In those provinces where farmers have developed an extensive knowledge of these biological control agents and their interactions, farmers know that both ants compete and never interplant sapodilla with citrus or vice versa (Van Mele & Cuc, 2000).

Results of our research illustrate the geographical variability of this knowledge base, and how farmers who lack the knowledge of ant competition are easily trapped in the pesticide treadmill. Indeed, even the most promising biological control agents do not meet the expectations if their habitat is not conducive.

## Farmers learn through experimentation

All over the world, farmers experiment with their crops. In his research with agroforestry farmers in Rwanda, Den Biggelaar (1996) found it difficult to differentiate experiments from normal practice. For farmers, each season is an 'experiment' in which new knowledge is obtained and new ideas are generated. The tree experts consulted in his study described knowledge production through experimentation as an activity interwoven with everyday agricultural activities, not separated from them, as is the case in the scientific knowledge system.

In Vietnam, fruit farmers are very responsive to changing market conditions and may change or diversify their farming system with tree crops about which they had no prior experience. Increased farmer experimentation with new perennial cropping designs offers huge opportunities for scientists to learn from farmers, as will be discussed later.

Farmers also experiment under stimulus of outside agents. Collaborative research offers great learning opportunities for farmers, extension staff and scientists alike (Bentley & Baker, 2002; van de Fliert, 1993; Van Mele, 1999). Both farmer field schools (FFS) and local agricultural research committees (CIALs) make use of small-scale experiments with farmers (Braun *et al.*, 2000). Across the world, multiple approaches have been developed to work more closely with farmers (Figure 3), but elaborating on this would be beyond the scope of this paper.

We will instead look at the potential applicability of a powerful learning tool to study the impact of habitat manipulation, namely the agro-ecosystem analysis as used in FFS. With this exercise farmers draw what they observe in the

**Figure 3** Group learning is a powerful approach for farmers, extensionists and scientists alike, especially for knowledge-intensive technologies such as pest management

field at regular intervals in the cropping season. Specific attention is paid to the status of crop and non-crop plants, natural enemies, insect pests and diseases, and outcomes are discussed within the group. This tool helps farmers to decide on the efficiency of certain treatments and on what future actions should be taken (van de Fliert, 1993). For developing FFS in complex fruit cropping systems, the impact of habitat manipulation on pest management can be studied through experimentation, yet only to the extent of manipulating the undergrowth (Van Mele & van Lenteren, 2002). Comparisons between farms rather than between treatments within a farm are a more feasible option to evaluate the impact of different perennial intercrops. We therefore strongly recommend the facilitation of group learning across orchards.

Participatory research will have the highest impact in enhancing farmer innovation in those cases where local knowledge is assessed first and the processes that generate it are fully understood (Saad, 2002). Incorporation of learning tools such as agro-ecosystem analysis and discovery learning into participatory research programmes will substantially add to farmers' ability to innovate.

## More crop diversity, yet more pests?

Now that we have gained a better understanding of farmer learning processes, we will move back to our example of Vietnamese fruit farmers. Orchards in Tien Giang are considered more diverse than those in the other provinces, as we have seen earlier. Equally important in studying biodiversity of agro-ecosystems is to investigate why farmers avoid certain trees. Up to 70% of the interviewees in Tien Giang intercrop their citrus with sapodilla, whereas none in the other provinces do so.

The reason why farmers in Tien Giang use the highest number of pesticide sprays is attributed to the fact that they had no previous experience in growing sapodilla, lack knowledge on ant competition and hence have not been aware of the need to avoid growing sapodilla trees in citrus orchards (Table 3).

The reduced efficiency of weaver ants in citrus due to this intercrop can be clearly deduced from the major pests reported in this province (Table 4). Under normal conditions, weaver ants control citrus stinkbugs (*Rhynchocoris humeralis*) and leaf-feeding caterpillars (*Papilio* spp.) (Van

**Table 3** Occurrence (%) of trees in and around citrus orchards in Ben Tre, Tien Giang and Vinh Long provinces of Vietnam, 2001

| *Tree* | *Ben Tre* **(n = 30)** | *Tien Giang* **(n = 30)** | *Vinh Long* **(n = 30)** | *Cramer's V*[a] |
|---|---|---|---|---|
| Coconut palm | 18 | 14 | 10 | 0.22 |
| Sapodilla | 1 | 21 | 1 | 0.72*** |
| Mango | 5 | 11 | 7 | 0.19 |
| Longan | 11 | 3 | 4 | 0.30* |
| Spondias | 4 | 3 | 9 | 0.23 |
| Rose apple | 2 | 9 | 4 | 0.26* |
| Mangrove tree | 0 | 9 | 0 | 0.47*** |

[a]Cramer's V values close to 1 indicate a high difference between provinces with * significant at 5% level, ** at 1% level and *** at 0.1% level

**Table 4** Number of citrus farmers reporting pests in different provinces of the Mekong Delta, Vietnam, 2001

| *Pest* | *Ben Tre* **(n = 30)** | *Tien Giang* **(n = 30)** | *Vinh Long* **(n = 30)** | *Cramer's V*† |
|---|---|---|---|---|
| Citrus leafminer | 20 | 29 | 18 | 0.37* |
| Citrus stinkbug | 2 | 14 | 6 | 0.39** |
| Leaf-feeding caterpillars | 2 | 15 | 2 | 0.50*** |
| Mites | 4 | 11 | 3 | 0.30* |
| Mealybugs | 9 | 2 | 13 | 0.34** |
| Aphids | 11 | 3 | 9 | 0.26* |
| Number of sprays per farmer (mean ± SD) | $4.2 \pm 4.1^{a}$ | $7.5 \pm 1.9^{c}$ | $5.0 \pm 3.1^{bc}$ | |
| Number of sprays of most farmers (mode) | 2.0 | 8.0 | 6.0 | |

†Cramer's V values close to 1 indicate a high difference between provinces with * significant at 5% level, ** at 1% level and *** at 0.1% level. One-way ANOVA with LSD test was conducted for the number of sprays. [a,b,c]Different letters indicate significant differences at the 5% level and 1% level

Mele *et al*., 2002). In Tien Giang, where more recently citrus is intercropped with sapodilla, the weaver ants will concentrate on fighting the black ants, and abandon the task for which they were so valued. To avoid pest damage, farmers start to spray pesticides, in turn triggering secondary pest outbreaks from citrus leafminer (*Phylocnistis citrella*) and mites. Because they lack knowledge, farmers are clearly trapped in the so-called pesticide treadmill. The wrong choice of one single component (sapodilla) in designing a diverse citrus agro-ecosystem can clearly have tremendous impact on the sustainability of the whole system.

About one third of the farmers in Ben Tre and Vinh Long mentioned mealybugs (*Pseudococcus* sp.) and aphids (*Toxoptera* spp.), compared to 10% in Tien Giang. However, these insects were probably present to the same extent in the other provinces, but farmers were only requested to state the major insects present. Clearly, stinkbugs that directly damage the fruit, and leaf-feeding caterpillars with highly visible damage were reported as more important than the less conspicuous aphids or mealybugs.

## Science reveals the unobservable

Farmers in general have no or little knowledge of the role of pollinators, or the pathogens causing diseases and their mechanisms of spread. Science can build on a different set of tools than those available to farmers. Below some examples are given of the acquired insights on the role of windbreaks in pest management, disclosed through scientific research.

Careful observation and experimental designs have for instance yielded the scientific insights

**Figure 4** Farmers in Thailand learn to evaluate the presence of predatory mites on the composite flowers of *Ageratum conyzoides*, a common 'weed' in orchards

that the incidence of citrus canker *Xanthomonas axonopodis* pv. *citri* is directly related to the activity of the citrus leafminer *Phyllocnistis citrella* (Gottwald *et al*., 1997). Once the disease is established, the most important ways of disease spread are rain splash and wind, helping the bacteria to penetrate the stomatal pores or wounds. Clearly the type and density of windbreaks are important factors to be considered in preventing or reducing canker infestations. The same is true for preventing pesticide drift, which is equally difficult to observe.

Also the role of non-crop plants in providing alternative food to natural enemies is an unknown concept to farmers, especially with regard to parasitoids and predatory mites (Van Mele & van Lenteren, 2002). All these observations are very difficult to make with the naked

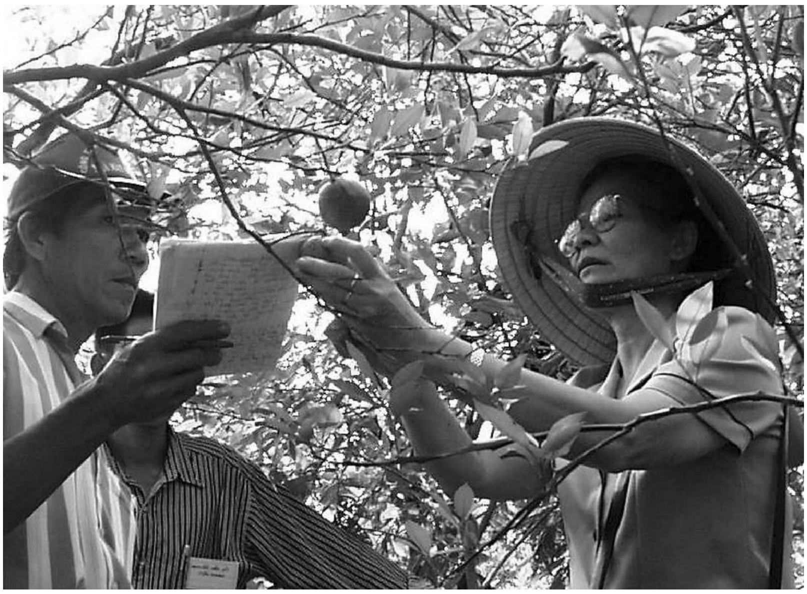

**Figure 5** Dr Nguyen Thi Thu Cuc from Cantho University interacts with fruit farmers during a weaver ant expert workshop

**Table 5** Knowledge-based framework for exploring scientists' niches in moving towards sustainable tree cropping systems

| | |
|---|---|
| 1. Local Knowledge Available | • Explore local knowledge, perceptions, needs and priorities with regard to biodiversity use-values and service functions (including plant protection) |
| | • Identify farmers with expertise on specific biodiversity components or on specific ecosystem functions |
| | • Build on local expertise to develop extension programmes (farmer-to-farmer, mass media, ...) |
| 2. Scientific Knowledge Available | • Explore what is scientifically known about functional biodiversity for the given situation, and identify cornerstones of the agro-ecosystem |
| | • Identify trees with use-values that are preferred by the community and that can help fulfilling required ecosystem functions |
| | • Incorporate principles of relevant ecosystem functions in farmer training programmes by developing appropriate discovery learning tools |
| 3. Local and Scientific Knowledge Missing | • Jointly explore, discuss and prioritise common knowledge gaps |
| | • Check feasibility of using participatory approaches to fill these gaps |
| | • Develop research strategies that help provide input for 2. |

eye and science has the potential to offer technical backstopping and develop appropriate learning tools (Figures 4 and 5).

## Bridging the gap

We have highlighted several examples where farmers have gained tremendous insight into plant protection and manipulating biodiversity in their orchards. On the other hand, we have learned that despite the importance that scientists attribute to biodiversity in terms of ecosystem functioning, farmers will in the first instance consider its use-values.

The limitations of farmers' power of observation clearly define a role for science. Discovery learning tools can be developed based on scientific and validated local knowledge, but there are certain practical limitations to applying all these exercises in perennial cropping systems. Observing a tree canopy is just not as easy as looking at a cabbage. However, by using annual crops as a learning vehicle, ecological principles that underlie pest management could be equally conveyed for perennial crops (Van Mele, 2003). This approach of using homologies also offers opportunities to learn with tree crop farmers in other settings than their orchard or homegarden, such as in markets or other public places. Extension conducted in public places has been recently described as Going Public (Bentley *et al*., 2003).

Science always underpins the development of discovery learning exercises. A review by Vandermeer *et al*. (1998), however, indicates that information on the functional attributes of more complex agro-ecosystems remains largely descriptive. Besides, interactions between generalist predators, and between the predators and their prey, remain difficult to predict within multi-species systems (Symondson *et al*., 2002). Clearly, the scientific toolbox and knowledge base is far smaller for these systems compared to monocultures such as rice, emphasising the need for scientists to optimally build on local knowledge when dealing with highly complex systems. A framework on how this can best be achieved is presented in Table 5.

Scientists clearly have an important role to play in all three instances, although different skills and interdisciplinary collaboration are required at each stage. Exploring ecological interactions and developing good sustainable practices in plant protection and biodiversity use is one thing, building training curricula and learning platforms another.

## Conclusion

This paper is part of a concerted attempt to develop more demand-led research and innovative extension programmes for sustainable fruit cropping systems in Vietnam and the wider region. Huge achievements have been made in assessing the local knowledge and understanding the processes that generate it. Changing market conditions and a favourable policy have stimulated farmers to experiment with new tree cropping designs, although with variable success. It is our opinion that this dynamic situation offers a goldmine for those who accept the challenge to study the interface between farmers, biodiversity and plant protection.

So do more diverse systems harbour fewer pests? Often yes, but not always. Rather than diversity *per se*, we have suggested that the deliberate selection of tree species and design of tree cropping systems is important for optimising crop protection through natural regulatory processes.

In cases where natural enemies or pests are highly visible and have a serious impact on the livelihoods of people, some farmers have developed deep insights about the interactions within their agro-ecosystem. However, this knowledge differs from place to place and from farmer to farmer. This has implications for extension and research. Scientists need to keep an open eye for opportunities to learn from farmers, especially given that financial resources and the scientific toolbox are often inadequate in addressing the complex natural and human interactions.

Our research has also indicated the limitations in farmers' knowledge with regard to the role of biodiversity in plant protection. Farmers sometimes unconsciously disturb certain natural regulatory mechanisms, thus becoming trapped in the pesticide treadmill. To avoid similar scenarios in the future, shifts in scientific and political mindsets are needed. The conceptual framework developed in this paper describes key areas where scientists can contribute best towards building sustainable tree cropping systems.

### Correspondence

Any correspondence should be directed to Paul Van Mele, CABI *Bioscience* UK Centre, Bakcham Lane, Egham, Surrey TW20 9TY, UK (p.vanmele@cabi.org).

### References

Altieri, M.A. and Nicholls, C.I. (1999) Biodiversity, ecosystem function, and insect pest management in agricultural systems. In W.W. Collins and C.O. Qualset (eds) *Biodiversity in Agro-ecosystems* (pp. 69–84). Boca Raton: CRC Press.

Andow, D.A. (1991) Vegetational diversity and arthropod population response. *Annual Review of Entomology* 36, 561–586.

Bentley, J.W. (1992) The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In R.W. Gibson and A. Sweetmore (eds) *Proceedings of Seminar on Crop Protection for Resource-Poor Farmers* (pp. 107–118). CTA/NRI.

Bentley, J.W. and Baker, P.S. (2002) *Manual for Collaborative Research with Smallholder Coffee Farmers*. Egham, UK: CABI *Commodities*.

Bentley, J.W., Boa, E., Van Mele, P., Almanza, J., Vasques, D. and Eguino, S. (2003) Going Public: A new extension method. *International Journal of Agricultural Sustainability* 1 (2), 108–123.

Braun, A.R., Thiele, G. and Fernández, M. (2000) Farmer field schools and local agricultural research committees: Complementary platforms for integrated decision-making in sustainable agriculture. *Agriculture, Research and Extension Network Paper* 105.

Den Biggelaar, C. (1996) Farmer experimentation and innovation. A case study of knowledge generation processes in agroforestry systems in Rwanda. *Community Forestry Case Studies Series* 12. Rome: FAO.

Gottwald, T.R., Graham, J.H. and Schubert, T.S. (1997) An epidemiological analysis of the spread of citrus canker in urban Miami, Florida, and synergistic interaction with the Asian citrus leafminer. *Fruits* 52 (6), 383–390.

Grimble, R. and Laidlaw, M. (2002) Biodiversity management and local livelihoods: Rio Plus 10. *Natural Resource Perspectives* 73. London: ODI.

Gurr, G.M., van Emden, H.F. and Wratten, S.D. (1998) Habitat manipulation and natural enemy efficiency: Implications for the control of pests. In P. Barbosa (ed.) *Conservation Biological Control* (pp. 155–183). New York: Academic Press.

Matteson, P.C., Altieri, M.A. and Gagné, W.C. (1984) Modification of small farmer practices for better pest management. *Annual Review of Entomology* 29, 383–402.

Pretty, J.N. (1995) *Regenerating Agriculture. Policies and Practice for Sustainability and Self-Reliance*. Washington: Joseph Henry Press.

Prokopy, R.J. (1994) Integration in orchard pest and habitat management: A review. *Agriculture, Ecosystems & Environment* 50, 1–10.

Röling, N.G. and Jiggins, J. (1998) The ecological knowledge system. In N.G. Röling and M.A.E. Wagemakers (eds) *Facilitating Sustainable Agriculture* (pp. 283–311). Cambridge: Cambridge University Press.

Saad, N. (2002) Farmer processes of experimentation and innovation. A review of the literature. Working Document of the CGIAR System-wide Program on Participatory Research and Gender Analysis No. 21, p. 22.

Speight, M.R. (1983) The potential of ecosystem management for pest control. *Agriculture, Ecosystems and Environment* 10, 183–199.

Symondson, W.O.C., Sunderland, K.D. and Greenstone, M.H. (2002) Can generalist predators be effective biocontrol agents? *Annual Review of Entomology* 47, 561–594.

Thurston, H.D. (1992) *Sustainable Practices for Plant Disease Management in Traditional Farming Systems*. Oxford: Westview Press.

van de Fliert, E. (1993) Integrated pest management: Farmer field schools generate sustainable practices. A case study in Central Java evaluating IPM training. PhD thesis, Wageningen University.

Vandermeer, J., van Noordwijk, M., Anderson, J., Ong, C. and Perfecto, I. (1998) Global change and multispecies agro-ecosystems: Concepts and issues. *Agriculture, Ecosystems and Environment* 67, 1–22.

van Emden, H.F. and Williams, G.F. (1974) Insect stability and diversity in agro-ecosystems. *Annual Review of Entomology* 19, 455–475.

Van Mele, P. (1999) Participatory learning: Extension possibilities for IPM in fruit production in Vietnam. In P. Van Mele and N.V. Huynh (eds) *Proceedings of the Second Symposium on Fruit Production in the Mekong Delta Focusing on Integrated Pest Management* (pp. 9–20). Vietnam: Cantho University.

Van Mele, P. (2000) Evaluating farmers' knowledge, perceptions and practices: A case study of pest management by fruit farmers in the Mekong Delta, Vietnam. PhD thesis, Wageningen University.

Van Mele, P. (2003) Promising practices for knowledge generation on tree and forest management. In P. Van Mele (ed.) *Way Out of the Woods: Learning How to Manage Trees and Forests* (pp. 135–143). Newbury: CPLPress.

Van Mele, P. and Cuc, N.T.T. (2000) Evolution and status of *Oecophylla smaragdina* as a pest control agent in citrus in the Mekong Delta, Vietnam. *International Journal of Pest Management* 46 (4), 295–301.

Van Mele, P. and Cuc, N.T.T. (2001) Farmers' perceptions and practices in use of *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) for biological control of pests of sapodilla. *Biological Control* 20 (1), 23–29.

Van Mele, P. and Cuc, N.T.T. (2003) *Ants as Friends: Improving your Tree Crops with Weaver Ants*. Egham, UK: CABI *Bioscience*.

Van Mele, P. and Truyen, V.T. (2002) Observations and farmer experimentation with predatory ants. *LEISA* 18 (1), 28–29. On WWW at http://www.ileia.org/2/18-1/28–29.PDF

Van Mele, P. and van Lenteren, J. (2002) Habitat manipulation for improved control of citrus leafminer and mite pests in a mixed orchard-ricefield landscape, Mekong Delta, Vietnam. *Agriculture, Ecosystems and Environment* 88 (1), 35–48.

Van Mele, P., Cuc, N.T.T. and van Huis, A. (2002) Direct and indirect influences of weaver ant *Oecophylla smaragdina* husbandry on citrus farmers' pest perceptions and management practices. *International Journal of Pest Management* 48 (3), 225–232.