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A historical review of research on the weaver ant *Oecophylla* in biological control

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Abstract

1 Although the weaver ant *Oecophylla* is the first written record of biological control, dating from 304 AD, there have been fewer than 70 scientific publications on this predator as a biological control agent in Asia, from the early 1970s onwards, and fewer than 25 in Africa.

2 Apart from crop-specific ecological and perceptual factors, a historical review shows that political and market forces have also determined the extent to which *Oecophylla* was incorporated into research and development programmes.

3 In Africa, research on weaver ants in biological control concentrated on export crops, such as coconut and cocoa, whereas, in Asia and Australia, research focused on fruit and nut crops, primarily destined for domestic markets.

4 Increased evidence of pesticide inefficiency under tropical smallholder conditions, changing paradigm shifts in participatory research and a growing scientific interest in local knowledge in the early 1990s opened up new avenues for research on conservation biological control.

5 Lobbying and advocacy have been needed to ensure that *Oecophylla* was recognized as an effective biological control agent.

6 With an increased market demand for organic produce, holistic approaches such as conservation biological control, particularly the use of *Oecophylla*, are increasing in importance.

7 Multi-stakeholder strategies for collaborative learning are proposed for a better control of major fruit, nut and timber tree pests in Africa, Asia and Australia.

Keywords Africa, agricultural research, Asia, biological control, cashew, citrus, cocoa, coconut, collaborative learning, local knowledge, mango, *Oecophylla*, predation, timber.

Introduction

Classical biological control has achieved some tremendous successes over the past century, yet scientists recognize that the opportunities are limited and that greater attention is needed to increase the impact of native natural enemies (Greathead, 1991). A review of manipulative field studies showed that, in 75% of cases, generalist predators, whether single species or species assemblages, reduced pest numbers significantly (Symondson *et al.*, 2002).

Ants make up one of the most abundant and omnipresent arthropod groups on earth and play a major role in regulating the environment (Hölldobler & Wilson, 1994), yet relatively few entomologists have studied them in a pest management context. The last reviews on the role of ants in pest management in the tropics were written by Majer (1986) and Way and Khoo (1992). More recently, scientists studied endemic predatory ants in various tree crops in Australia (Peng *et al.*, 1995), Southeast Asia (Van Mele & Cuc, 2001), Latin America (Perfecto & Castineiras, 1998) and Africa (Seguni, 1997).

The tree-inhabiting weaver ant *Oecophylla* effectively protects tropical tree crops as it actively patrols canopies and preys upon or deters a wide range of potential pests. Recent research showed that Vietnamese citrus farmers who took care of weaver ants spent, on average, half the amount of money on agrochemicals compared with those farmers who did not have *Oecophylla* in their orchard, yet obtained similar yields (Van Mele & Cuc, 2000). Up to 20% of the orange growers produced their crop entirely without pesticide by making optimal use of the weaver ant. In Australia, weaver

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ants controlled all major cashew pests (Peng *et al.*, 1999) and increased profits by at least 35% (R. Peng, personal communication).

The importance of native natural enemies became obvious only after broadspectrum pesticides had swept aside many of the natural enemies and triggered secondary pest outbreaks, such as the brown planthopper in Asian rice fields during the early 1980s (Kenmore *et al.*, 1987). As pesticide misuse was identified, entomologists were increasingly asked to provide input in farmer training programmes, such as farmer field schools based on agroecology. Habitat manipulation to increase the impact of native natural enemies (an approach broadly known as conservation biological control) gained in importance (van Emden & Williams, 1974; Andow, 1991; Barbosa, 1998; Altieri & Nicholls, 1999).

During the same time, the agricultural research and development (R&D) system's attitude towards local knowledge changed, as reflected in various bodies of literature. These include anthropology (Rhoades & Booth, 1982; Bentley, 1992), farmer first (Chambers *et al.*, 1989), participatory research (Vernooy & McDougall, 2003), farmers' experiments (Bentley, 1994; Sumberg & Okali, 1997) and systems of learning (Röling & Wagemakers, 1998).

Within this context of a paradigm shift towards farmer participation and a growing environmental awareness, conservation biological control remained under-explored for smallholder tree crop farmers in the tropics. The present study analyses the historical context of research on *Oecophylla* in crop protection, and suggests ways of collaborative learning on conservation biological control.

Oecophylla research in the colonial era

In the early 1900s, various scientists in Europe and the U.S.A. worked on natural history research. Plant, animal and insect specimens were sent in from the colonies for identification and classification, establishing collections, which continue to be expanded and consulted today. Nowadays, only two species of the weaver ant *Oecophylla* are recognized: *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae) in Africa and *Oecophylla smaragdina* (Fabricius) in Asia and northern Australia, making it a relevant subject to evaluate agricultural R&D in a geopolitical context.

Science and culture in the Far East

Gordon Alexander, working at the University of Chulalongkorn in Siam (Thailand), urged biologists to study *Oecophylla*. Explorers before him had already noted how weaver ants were intricately linked to local culture. In his records, Barton (1918) recorded those ants being used in tattooing in South Eastern New Guinea.

But it was not until the 1950s that Joseph Needham started his series of books on *Science and Civilization in China*, which is still continued today (van Lenteren, 2005). *Oecophylla* is listed as the first written record of insect predators, dating from 304 ad (Huang & Yang, 1987).

In 1974, De Bach described ant husbandry practices in northern Burma (Myanmar) that were very similar to the ones in China: ant nests being collected and sold to farmers, and bamboo bridges being constructed between the citrus trees (Needham *et al.*, 1986). Also in the Mekong Delta of Vietnam, weaver ants are intricately interwoven with the culture. Almost everyone in Ho Chi Minh City can talk about *kien vang*, or the yellow ant, and its effect on citrus. Before and during the Vietnam War, people in the Mekong Delta made their sour soup with weaver ants, now replaced by other ingredients. Some Vietnamese scientists even claim that the origin of using weaver ants in citrus lies in their country, not in China (V. Mai, personal communication). Along these lines, in his search for the origin of the description of insect parasitism, which has been dated back to 1096 in China, van Lenteren (2005) urges scientists interested in biological control to consult Vietnamese literature. This strong cultural importance of weaver ants in Asia influenced the way in which researchers studied weaver ants (see below).

Science and cash crops in Africa

Quite a different picture emerges from Africa. Not only has sub-Saharan Africa a tradition of oral history, but also large parts of the interior were unvisited by Europeans until well into the 19th century.

French people living in Senegal at the end of the 17th century explored the inlands of West Africa. For many years from 1788 onwards, the African Association chaired by Sir Joseph Banks sent out a range of travellers to observe and write about the peoples, their culture, organization and natural resources (Sattin, 2003). There are no apparent records mentioning *Oecophylla* in Africa until a century later, when European rulers divided the continent and colonial researchers entered the scene.

The Belgian entomologist Steyaert (1946) gave a detailed account of the status of agricultural research in Belgian Congo since the turn of the 20th century, and how it had been affected by global events such as the World Wars, coffee overproduction and harsh market competition for cocoa from the Gold Coast (Ghana). Along with two other ant species, he mentioned *O. longinoda* to be a nuisance to coffee pickers and pruners, who avoid infested trees. The trees, unpicked and abandoned, became breeding places for the coffee berry borer *Stephanoderes hampei* Ferrari (Coleoptera: Scolytidae). Steyaert described a bait being used against *Oecophylla*. The other two species were controlled by transferring a nest of yet another predacious ant, harmless to humans.

According to Greathead (2003), 'The first applied entomologists appointed by the British colonial government had to use their wits to devise effective crop protection and became enthusiastic about the opportunities offered by introducing natural enemies that offered permanent control without the need for input from farmers'. In this context, research on *Oecophylla* did not thrive. For a long time, scientists in Africa even considered weaver ants injurious insects. However, Swanzy (1952) wrote that 'there is little news of the East African islands, beyond the discovery in Zanzibar that the bug *theraptus* is responsible for the "gumming"

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disease of coconuts, and can be biologically controlled by the large red ant *Oecophylla longinoda*'.

In subsequent years, British entomologist Michael Way pioneered work on *Oecophylla* as a biological control agent in coconut. His early publications provide great details on the biology, behavior and ecology of the weaver ant, at the same time suggesting how this knowledge can be used to improve the ants' effectiveness in controlling pests (Way, 1953, 1954a, b). Similar research on coconut was soon pursued in the Solomon Islands (Brown, 1959a, b). Research was mainly conducted on plantations without the involvement of farmers.

Oecophylla research after independence

Changing contexts

With emerging national research and extension systems still weak, international research centres such as the International Centre of Insect Physiology and Ecology and the International Institute of Tropical Agriculture were created, initially mainly focusing on subsistence food crops. The success of cassava mealybug control in Africa in the 1980s, launched by Hans Herren, increased confidence and triggered a new wave of investment into classical biological control (Neuenschwander, 2003). Publications on biological control doubled from the early 1980s to the early 1990s (Table 1). During the past 30 years, only 7–14% of these dealt with predators against mites and aphids amongst others. Although ants make up one of the most abundant arthropod groups, only 1% of all publications on biological control address the role of ants.

Research on *Oecophylla* as a biological control agent was mainly conducted by applied entomologists, with biologists and ecologists focusing on ant mosaic studies (Hölldobler, 1979; Dejean *et al.*, 2000), weaver ant behavior (Hölldobler & Wilson, 1983; Peeters & Andersen, 1989; Dejean, 1990) and their role in tritrophic relationships (Blüthgen & Fiedler, 2002; Offenberg *et al.*, 2004). Research on *Oecophylla* was relatively high in the 1970s, dipped in the 1980s and then steadily increased from the 1990s onwards (Fig. 1).

From 1972 onwards, the number of publications dealing with *Oecophylla* as a biological control agent has been far lower for Africa than for Asia (Table 2). However, some early work in Africa on ant mosaics in cocoa was specifically carried out to see how the distribution of ants might be manipulated, yet *CAB Abstracts* did not assign the descriptor 'biological control' to these studies.

Although the key role of *Oecophylla* in integrated pest management (IPM) is increasingly recognized in Asia and Australia, the book *Biological Control in IPM Systems in Africa* (Neuenschwander *et al.*, 2003) makes no reference to weaver ants. International agricultural research organizations, until recently, conducted hardly any research on perennial commodities and, when they did, they focused mainly on classical biological control.

Commodities

Most peer-reviewed publications deal with weaver ants in coconut and cocoa, but, subsequent to 1995, more research has been conducted on citrus smallholdings in Vietnam, and commercial cashew and mango plantations in Australia. The traditional use of weaver ants in citrus and the fact that biological control with predators originated in this crop probably account for its frequency on the Internet (Fig. 2).

Coconut. British scientists working in the Solomon Islands in the 1930s focused their attention on biological control of coconut pests, and suggested importing parasitoids (Lever, 1937). At about the same time, Phillips (1940) reported, 'Planters, managers and investigators alike have noticed that where *Oecophylla* is present, the trees almost invariably bear well'. This observation was taken seriously by Michael Way, working in Zanzibar, who found that the 'coconut gumming disease' was actually caused by bugs sucking the nuts. Because the coreid bug *Pseudotheraptus* is a low-density pest (ten bugs per hectare can cause significant damage), this had never been observed before, nor had this 'disease' ever been successfully controlled. Way demonstrated experimentally that coreid bugs could be controlled by weaver ants (Way, 1953). After him, research on *Oecophylla* in coconut resumed in the 1970s in those countries that stayed under British rule (O'Sullivan, 1973; Stapley, 1974, 1979, 1980a). It took another 40 years, however, before an acceptable method of weaver ant establishment and management was developed.

Close proximity of non-crop vegetation strongly influenced dispersal of *O. smaragdina* in coconut plantations in the Solomon Islands (Greenslade, 1971). Weaver ants in coconut were also enhanced by interplanting with citrus (Rapp & Salum, 1995). This confirmed earlier work by Way (1954b) who found that coconut intercropped with clove, cashew or citrus had more stable weaver ant colonies. This ecological knowledge is quite common among smallholders in Zanzibar. As part of the weaver ant colony establishment, the control of non-beneficial predatory ants was considered a key research challenge.

A few farmers and scientists had come up with the idea of killing competing ants to allow *Oecophylla* to establish or thrive, but without success (Phillips, 1940). For the removal

Table 1 Evolution of publications related to biological control in *CAB Abstracts*

Keywords	1972–1978	1979–1983	1984–1989	1990–1994	1995–1999	2000–2004
Biological control	10 613	11 961	18 563	21 245	20 618	23 500
Predator	1073	1198	1516	1488	2169	3215
Ant and biological control	111	152	203	219	197	288

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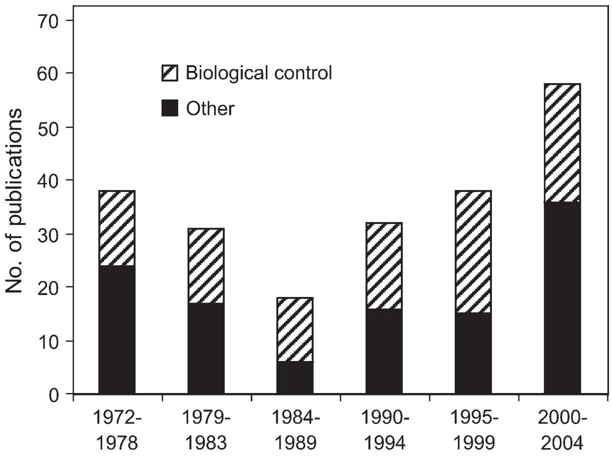

Figure 1 Number of publications related to *Oecophylla* in *CAB Abstracts* database subsets. The number of hits for biological control were verified and adjusted because some referred to the ant interfering with biological weed control programs, and hence did not reflect research on the predatory role of *Oecophylla*. Other publications mainly referred to behavioral and ecological studies.

of the ground-nesting ant *Pheidole megacephala* (Fabricius), Stapley (1980b) suggested spraying the base of the palm with the insecticide dieldrin and killing the weeds round the base with paraquat. This contrasted with earlier observations by Way (1953) who noticed that a good ground cover provided seed and Homopterans for *Pheidole*, thus reducing its foraging high in the trees where it raids *Oecophylla* nests. Later on, Seguni (1997) showed that regularly slashing, rather than spraying with herbicides or clean weeding, was both effective to establish weaver ant colonies and acceptable to farmers. More, however, was needed to suppress *Pheidole*.

In Tanzania, Löhr and Oswald (1989) found that colonization of palms by *O. longinoda* increased nut yield significantly, and that insecticide use could be significantly reduced. Varela (1992) tried to exclude *P. megacephala* from coconut palms by sticky barriers on the tree trunks. Tests failed because the barriers did not last, but promising results had been obtained in experiments that demonstrated the effectiveness of the fire ant bait Amdro (hydramethylnon), developed in the late 1970s by scientists in Hawaii to control fire ants in pineapple, in controlling *Pheidole* (Oswald, 1991; Varela, 1992; Zerhusen & Rashid, 1992). Triggered by these research findings, the Tanzanian government registered Amdro in the 1990s but, to date, the product is still not available on the market. Farmers who were not involved in the research did not know about the existence and importance of the Amdro bait, and private businesses were not tempted to establish a market as long as there was no national demand. Collaborative learning with farmers about the management of pests in their plantations may lead to the development of alternative *Pheidole* control methods. Mass media campaigns, on the other hand, may help to create demand for technical innovations such as the Amdro bait.

Cocoa and coffee. With a focus on export-oriented plantation crops and its success in coconut plantations, research on *Oecophylla* was also initiated in cocoa plantations (Majer, 1972, 1976; Bigger, 1981; Way & Khoo, 1989). The ants drive off a range of pests, including weevils *Pantorhytes* (Stapley, 1980b), coreid bugs *Amblypelta* and *Pseudotheraptus* (Lodos, 1967) and capsids and mirids (Leston, 1970; Way & Khoo, 1991). However, the complex ant mosaic created particular challenges, especially with regard to managing the undesirable co-dominant ant *Pheidole* (Taylor & Adedoyin, 1978), as well as ants of the genus *Crematogaster* (Majer, 1978) and *Camponotus* (Fataye & Taffin, 1989). The ant mosaic is also affected by the shade regime, with *Oecophylla* being reduced by shade thinning (Leston, 1970). Depending on the cropping system, having sufficient food and good nesting sites all year round may also affect *Oecophylla* populations (Khoo & Chung, 1989). On top of the complexity of managing the ecological system in cocoa plantations, plantation workers considered weaver ant aggression as a hindrance, and therefore *Oecophylla* was often classified a pest (Way & Khoo, 1992). Apart from these ecological and perceptual factors, political and market forces have determined the extent to which weaver ants have been incorporated into a cocoa IPM system.

The recommendation to avoid spraying cocoa trees where weaver ants are abundant was formulated approximately 30 years ago (Julia & Mariau, 1978; Majer, 1978), but was never given much attention. The recommendation was part of a broader IPM strategy for cocoa in Ghana (Majer, 1974) that was not implemented at the time (J. D. Majer, personal communication). Because of the new government priorities, recent efforts to get IPM established in cocoa through farmer field schools have been disrupted by blanket-spraying, which is known to encourage the less desirable ant *Crematogaster* and reduce the distribution and abundance of *O. longinoda* (Majer, 1978).

A recent drop in world cocoa prices and increased costs of insecticides triggered a renewed interest in research on *Oecophylla* to help farmers capture markets for organic

Table 2 Evolution of publications related to *Oecophylla* as biological control agent in the Asia-Pacific and Africa (total hits in subsets of *CAB Abstracts*)

	1972–1978	1979–1983	1984–1989	1990–1994	1995–1999	2000–2004
Asia-Pacific	10	11	10	7	12	17
Africa	3	3	1	6	9	3
Key crops	Coconut, Cocoa	Coconut	Citrus, Coconut	Coconut	Cashew, Coconut	Citrus, Cashew, Mango
Key authors	Leston, Majer	Stapley	Various	Way and Khoo	Peng *et al.*	Van Mele and Cuc, Peng *et al.*

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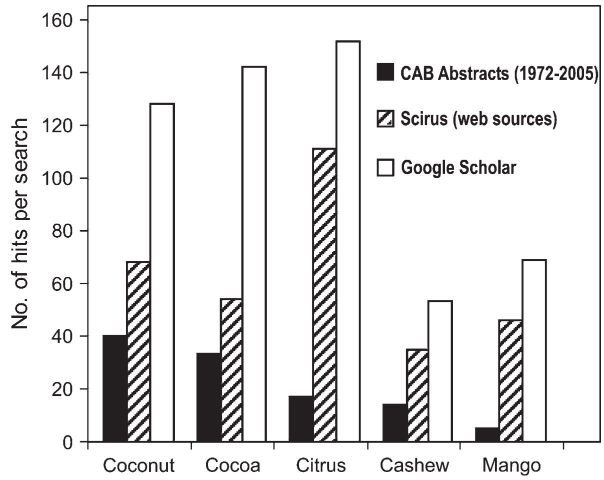

Figure 2 Number of hits for *Oecophylla* in specific tree crops. Note that Scirus searches the web for scientific content only [Date of search, December 2005].

cocoa. Although researchers initially objected to the idea, farmers of the local agricultural research committees insisted they investigate the potential of *Oecophylla* as a solution to their pest problems (Ayenor *et al.*, 2004). As control against capsids is mainly effective when high weaver ant abundance is high, botanical insectides such as neem extracts (*Azadirachta indica*) were successfully tested to complement biological control (van Kessel & van Wijngaarden, 2006).

Research on the use of weaver ants in coffee has been very limited (Venkataramaiah & Rehman, 1989; Balakrishnan *et al.*, 1992), partly because of its mutualistic relationship with scales and its hindrance to harvesters.

Citrus. Although weaver ant husbandry is a centuries-old tradition in China and Vietnam, scientific research on ants in smallholder citrus took off only gradually, starting in China after problems of insecticide resistance (Yang, 1983; Huang & Yang, 1987; Yang, 2002) and in Vietnam during the 1990s (Cuc, 1995; Barzman *et al.*, 1996; Van Mele & Cuc, 1999). Weaver ants were reported to control a range of pests, including the citrus stinkbug *Rhynchocoris humeralis* (Thnb.) (Hemiptera: Pentatomidae), the aphids *Toxoptera*, leaf-feeding caterpillars *Papilio*, inflorescence eaters, coleoptera and various other pests (Yang, 1984; Van Mele *et al.*, 2002). By contrast to the above examples, research on *Oecophylla* in citrus was driven by national scientists working closely with farmers, their culture and their knowledge system. Due to pressure from the pesticide industry, the use of weaver ants in citrus orchards decreased during the 1990s (Van Mele & Cuc, 2000). However, various small-scale financial injections made from the mid 1990s onwards, media coverage and involvement of farmer associations have reversed this trend (N. T. T. Cuc, personal communication).

Although competition between dominant ant species proved a key challenge to researchers in Africa, experienced Vietnamese citrus farmers developed ingenious ways to optimize the performance of weaver ants. They trap the black ant *Dolichoderus thoracicus* (Smith) and avoid the intercropping of sapodilla fruit trees, because black ants favor these trees as nesting habitat (Van Mele & Truyen, 2002). Newcomer citrus farmers, however, unless informed by citrus farmers, naively introduced sapodilla as an intercrop to diversify their source of income and because this fruit tree requires little care. This apparently worthwhile attempt to combine two valuable crops has misfired. Under competition from the black ant, *Oecophylla* stopped protecting citrus from stinkbugs and leaf-feeding caterpillars. The ecological conditions that traditionally sustained natural pest control in citrus were disturbed, and trapped newcomer farmers in the pesticide treadmill (Van Mele & Chien, 2004).

Cashew. By contrast to Asia and Africa, the weaver ant does not face any serious competition from other ant species in Australian orchards (Peng *et al.*, 1997). *Oecophylla smaragdina* was identified as a good candidate as a biological control agent in cashew, controlling the four most important pests; the tea mosquito bug *Helopeltis*, the mango tip borer *Penicillaria*, the fruit spotting bug *Amblypelta* and the leaf-roller *Anigraea* (Peng *et al.*, 1995). Because the nuts drop (attached to the ripe fruit) at harvest time, laborers do not experience any nuisance from the ants. The success with *Oecophylla* in cashew, controlling all major pests and significantly increasing profits and nut quality (Peng *et al.*, 1997, 1999, 2001), triggered new research in other countries, such as Vietnam. The major emphasis has been on managing weaver ant colonies. Although weaver ants can effectively control the pests of cashew and mango, fierce boundary fights between weaver ant colonies can limit their populations and control efficiency. Weaver ant husbandry was also introduced by the author in West Africa in 2006 for cashew and mango. Discovery learning exercises were developed in Africa and Asia for use in farmer field schools, potentially contributing to more sustainable production and better quality fruits and nuts.

Mango. In mango, management has proved to be more complicated than in cashew. Apart from controlling major pests, such as mango leafhoppers, thrips, seed weevils, fruit flies and tip borers, weaver ants also protect scales and mealybugs in mango, and so chemicals such as white oil and potassium soap were tested as part of an IPM package (Peng & Christian, 2004, 2005, 2007). Trees in traditional mango orchards in Vietnam and Thailand are often up to 15 m high, influencing farmers' observation power and their subsequent knowledge and practices. In 1998, only two out of 93 farmers interviewed in Vietnam mentioned the weaver ant as predator in mango, despite its well-known role in citrus (Van Mele *et al.*, 2001). The size of the trees also influences the harvesting practices. Long picking poles may be used but, in many cases, harvesters still have to climb the trees. Local people in Asia and Africa have developed a range of solutions to reduce the nuisance of ants during harvest by adjusting their cultural and harvesting practices, reducing the ant population or repelling the ants (Van Mele & Cuc, 2003).

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Despite a common negative perception, some African farmers have witnessed the ants' benefits and encourage them in their orchards. In Guinea, women told me that the quality and production was more elevated when weaver ants were present in mango, citrus and cola. In the latter case, people think that ants improve flowering. In various African countries, including Benin, Burkina Faso, Mali and Guinea, ants were also considered to protect mangos from being stolen. The Bambara name for *Oecophylla* is *kowulu*, meaning dog of the lowlands. African farmers commonly state that snakes will not enter those trees with ants and that their presence makes climbing trees safer. Future research will need to accommodate both social and biological dimensions and draw on local knowledge from Asia and Africa. Also, developing evidence about its economic benefit to African fruit growers will be necessary to change people's negative perception.

Preliminary observations on mango fruit fly control in Benin, West Africa, indicate that most of the 17 mango cultivars studied support *Oecophylla* nests (J.-F. Vayssières, personal communication). Fruit loss caused by fruit flies was significantly less in cultivars and orchards where weaver ants are very abundant (Van Mele *et al.*, 2007). Recent trends in exporting organic mangos and citrus from West Africa to European markets have created a demand for farmer training in weaver ant husbandry.

Timber trees. The beneficial effect of weaver ants has been observed in *Eucalyptus* and other tropical trees (Leston, 1973; Macfarlane & Jackson, 1976). Shoot borers *Hypsipyla* feed on timber species of Meliaceae (Newton *et al.*, 1999; Taveras *et al.*, 2004; Soto *et al.*, 2007). A preliminary study on the prospects for biological control of the mahogany shoot borer *Hypsipyla robusta* in Malaysia showed that the weaver ant is capable of reducing damage by this pest on *Khaya ivorensis* (Lim & Kirton, 2003).

Although researchers have frequently called for more research on pest management in agroforestry systems, the reported tendency of weaver ants to bite people (Rao *et al.*, 2000) probably hinders research to develop its potential.

Bringing multi-stakeholder perspectives into the research agenda

The commodity-based case studies discussed above illustrate that major breakthroughs took place in those cases where research built on local knowledge and where market forces created a demand for more sustainable solutions to pest management.

Table 3 presents some of the key insect pest families controlled by weaver ants, indicates some researchable topics and explores the potential involvement of farmers in each of these. For crops such as citrus and cashew, weaver ants have proven to keep all major pests at bay. Apart from participatory learning and action research, mass media programmes could be developed for the use of weaver ants in these crops. Further research on the relationship between *Oecophylla* and citrus leafminer parasitoids (Hanssen, 2001) could shed new light on predator–parasitoid interactions. For coconut, cocoa and mango, *Oecophylla* plays a key role in pest management,

Table 3 Reports of *Oecophylla* as beneficial predator and scope for farmer involvement in research and development activities

Commodity	Pests controlled by weaver ants[a]	Scope for additional action with farmers[b]
Coconut	Beetles (Chrysomelidae) and bugs (Coreidae)	Integrate control of coconut mite (Eriophyidae) and rhinoceros beetle (Scarabaeidae); develop methods with farmers to control the competetive ant *Pheidole*; jointly explore the effect of habitat manipulation such as mixed cropping
Cocoa	Bugs (Coreidae and Miridae) and rodents	Conduct participatory learning and action research to build farmers' confidence; integrate *Oecophylla* with use of sex pheromones and neem extracts; explore most suitable intercrops/shade trees
Citrus	Aphids (Aphididae), caterpillars (Papilionidae), inflorescence eaters (Pyralidae), leafminers (Gracillariidae) and stinkbugs (Pentatomidae)	Enhance participatory learning and develop mass media programs; explore influence of *Oecophylla* and mixed cropping on suppression of citrus psyllids, vector of greening disease
Cashew	Bugs (Coreidae and Miridae), leafrollers and tip borers (Noctuidae)	Introduce participatory learning and develop mass media programs; explore influence of orchard design and native vegetation on stability of ant colonies
Mango	Bugs (Coreidae), fruit flies (Tephritidae), leafhoppers (Cicadellidea), seed weevils (Curculionidae), thrips (Thripidae) and tip borers (Noctuidae)	Conduct participatory learning and action research; explore the use of soft chemicals or other alternatives to control mealybugs and scales; develop and test fruit fly baits with farmers
Timber trees	Bark beetles (Scolytidae and Platypodidae) and shoot borers (Pyralidae)	Conduct action research on the control effectiveness of *Oecophylla* against major forestry pests

[a]This list is not comprehensive. *Oecophylla* being a generalist predator, many more insect families are controlled. Here, only major pests are included. Note that various pests can be found on multiple hosts.
[b]Other topics may be added depending on local context, whereas more generic research topics such as ant colony management and the reduction of nuisance during harvest are presented in text.

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but ideally needs to be integrated with other technologies. To control coconut mites, ant-friendly technologies such as habitat manipulation (to promote predatory mites) and the application of botanical insecticides, could be tested with farmers.

Weaver ant aggression has been an obstacle for its use in many parts of the world, mainly in plantations, and therefore *Oecophylla* has often been considered a pest (Way & Khoo, 1992). In the book *Ants as Friends*, Van Mele and Cuc (2003) describe how to reduce ant bites when collecting nests or harvesting fruit by dusting the hands with wood ash. This is an effective local practice (Brigitta, 2003) that was developed independently in Asia and Africa. Wood ash proved to be better than ash from herbs, and was acting as a hindrance to the ants rather than a deterrent. Irrespective of the crop, and for reasons of consumer safety and conservation of natural enemies, developing environmentally-friendly ways to reduce hindrance from ants during harvest should be a key research priority (Van Mele, 2000). By interviewing farmers in Guinea, 21 ways to reduce nuisance were collected and are being studied. In Burkina Faso, mango harvesters faced discomfort only in those cases where weaver ants are extremely abundant in individual trees. This is mainly the case in orchards where farmers mismanaged *Oecophylla* colonies, namely where they refrained ants from expanding their colonies to neighbouring trees (P. Van Mele, unpublished).

Continuous efforts are needed to fully incorporate proven weaver ant husbandry technologies in the curriculum of the national extension and education systems and to counterbalance the constant pressure from the agribusiness to expand their pesticide market. Lessons from experienced, often smallholder, fruit farmers in habitat manipulation and weaver ant husbandry should be included in farmer training programmes. Once farmers have learnt the basic principles of weaver ant ecology and management through farmer field schools or other adult educational approaches, further knowledge can be obtained through discovery learning exercises, such as those developed in Vietnam for citrus (Cuc *et al.*, 2005). Apart from stimulating farmers' curiosity and creativity, the potential to conduct collaborative research will be equally raised through such approaches.

Conclusion

Although interest in conservation biological control and documenting farmers' practices in pest management has increased subsequent to the early 1990s (Altieri, 1993), this rarely led to incorporating farmers' knowledge and perspectives in setting national and regional research priorities. Opportunities to learn from and with farmers are beginning to contribute to an increased *Oecophylla* knowledge base.

Although IPM has been successfully applied in some food crops in Asia, the low potential of cost-savings in Africa indicates that IPM is more likely to be successful here if it focuses on host-plant resistance, biological control and high-value commodities rather than on subsistence crops (Orr, 2003). This review shows the significant role and potential of *Oecophylla* as a predator in tree crops, either when used alone or integrated with other pest management practices, and indicates the role farmers can play in research and development. Emerging markets for organic and sustainably-managed fruit, nut and timber products are likely to boost investment in weaver ants. Well-targeted research interventions to optimize *Oecophylla* should be linked to innovative strategies of collaborative learning, communication and marketing if it is to benefit the millions of smallholder farmers in tropical countries.

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