

Agroecological Crop Protection: Concepts and a Case Study from Reunion

Jean-Philippe Deguine¹, Pascal Rousse² and Toulassi Atiama-Nurbel¹

¹*CIRAD, UMR PVBMT, Saint-Pierre, La Réunion*

²*Chambre d'agriculture de La Réunion, La Réunion
France*

1. Introduction

In crop protection, chemical control rapidly revealed its limitations, as well as its possibilities, and alternative solutions to pest management problems have been recommended since at least the 1960s. A new strategy was developed under the rubric 'integrated control', envisaging the employment of a range of different control measures, constrained by their compatibility and the requirement for minimizing noxious effects on the wider environment. Despite these difficulties, a biological, then ecological, orientation has underlain the development of crop protection over the last 50 years (Pimentel, 1995; Walter, 2003). This process has been marked by multiple and diverse interpretations of the concept of IPM (Kogan, 1998). Numerous technical innovations have been proposed, without, however, bringing any really significant change in the management of pests in major crops (Lewis et al., 1997), due no doubt to an unrealistic approach to the complexities of the phenomena concerned. The debate has been re-activated recently, both by the spectacular success of the recent advances in biotechnology and by genuinely taking into account the need to preserve biological diversity. As much for socio-economic as for ecological reasons, this has given rise to a reexamination of farming systems as traditionally practiced, through an innovative agroecological approach (Dalgaard et al., 2003).

This chapter questions how agroecological concepts may contribute to sustainable pest management. In a first part, a panorama of the principles of agroecological crop protection is provided. Then, the concepts of agroecology are applied to the case study of the management of fruit fly populations in Reunion Island, describing some results obtained in research studies. Finally, an illustration of the results obtained in commercial farm conditions in Reunion Island is given.

2. Agroecological crop protection: Basis and principles

Since the 1970s, the evolution of plant protection has been driven by an improved understanding of the functioning of ecosystems (Bottrell, 1980). At this time, the desire to explore these issues favored the development of computer-based simulation models for risk assessment. The approach to these problems was considerably improved; taking into consideration the development of the plants in the particular soil/ moisture/ nutrient content and insolation context and considering the suite of pests present in the same crop.

This forms the basis for the development of a concept of integrated control and then of integrated production or integrated crop management.

The UN Conference on the Environment and Development in Rio de Janeiro in 1992 drew attention to the need to preserve the biological diversity of ecosystems in general and agroecosystems in particular. The subsequent publication of diverse works aimed at advancing the IPM paradigm, helped in the national adoption of IPM strategies. The simultaneous elaboration of the scientific principles underlying this field of agro-ecology, rendered these calls more credible (Altieri, 1995; Dalgaard et al., 2003). It was then necessary to move to the practical stage of conceiving growing systems which capitalized on the resilience of agroecosystems (Clements & Shrestha, 2004). To this end, 'agro-ecosystems management' or 'agro-ecological engineering' is today recognized as one of the up and coming concepts in crop protection (Clements & Shrestha, 2004; Gurr et al., 2004; Lewis et al., 1997; Nicholls & Altieri, 2004). More generally, this development is presented in the form of an 'IPM continuum' (Jacobsen, 1997), where it is clear that much of what is necessary will be a continuous evolution of traditional concepts and understanding in crop protection (Clements & Shrestha, 2004). The principles of a bio-centered agriculture, developed during the last few decades, have led to new orientations to crop production which will require a return to utilizing knowledge and skills progressively lost over the last few decades. IPM has been the fundamental paradigm in plant protection since the late 1960s. A major contribution of IPM to agriculture, is the incorporation of ecological principles into pest management while ensuring high productivity and profitable harvests. In agreement with this conceptual foundation, agroecological pest management largely relies on IPM.

Preserving ecosystems and biodiversity, while reducing fertilizer and pesticide use, is a challenge that must now be addressed to ensure that agriculture will be both intensive and environmentally friendly. Agroecology was defined as the study of the interactions between plants, animals, humans, and the environment within an agroecosystem (Dalgaard *et al.*, 2003). The agroecology concept was thus introduced to advocate agroecosystem-wide stand management. Agroecological pest management is thus based on ecological processes occurring between the crop and its pests (Carroll et al., 1990), but also the natural enemies of these pests (Weiner, 2003), in a quest for increased beneficial interactions that keep pest populations in check (Altieri & Nicholls, 2000; Gliessman, 2007). This crop protection strategy helps maintain bio-ecological balances between animal and plant communities within agroecosystems, while also preserving and improving the "health" of soils and plant biodiversity (Ratnadass et al., 2011). Agroecological crop protection is based on prevention at broader spatiotemporal scales. It combines plant and animal community management and thus contributes to conservation and biological control.

Deguine et al. (2009) give a definition of Agroecological Crop Protection as a crop protection system based on the science of agroecology. By prioritising preventative measures, the system seeks to establish bioecological equilibria between animal and plant communities within an agroecosystem with the goal of foreseeing or reducing the risks of infestation or outbreaks of pests. To this end, the system emphasises the conservation and improvement of the "health" of soils (fertility, biological activity, structure, etc.) and the maintenance or incorporation of plant biodiversity in the agroecosystem. Beyond the classical techniques of integrated crop protection, emphasis is placed on cultural practices and plant management

systems which help maintain or create habitats to attract indigenous beneficial fauna and/or repel pest fauna. Agroecological crop protection operates at larger scales in time and space, from a single crop cycle to several years, and from a single field to an agroecosystem or a landscape. It brings together the management of plant communities (crops and non-cultivated plants in areas surrounding the field and in the wider agroecosystem) with that of the animal communities of pests, beneficials and pollinators. Agroecological crop protection thus requires concerted action by stakeholders, notably farmers and land managers. As with integrated crop protection, curative practices are only a last resort to be used in the case of absolute necessity, and then only using methods compatible with the functional biological groups which ensure the provision of ecological services. According to these criteria, the future use of pesticides may only be short term, at least in their present form, given the current status of many pesticides whose use is already restricted for environmental and toxicological reasons. According to this vision, prophylaxis, habitat management, and biological control are the principal components of crop protection.

Deguine et al. (2009) also propose a five strategy to implement the agroecological crop protection approach:

- Step 1.** Respect international, national and regional regulatory measures.
- Step 2.** Prioritise the use of preventative measures through the management of plant populations (whether cultivated or not): (i) Grow healthy plants and ensure good soil health utilising prophylaxis, varietal selection, crop rotations, whole-farm crop planning, cultural practices (such as sowing under plant cover and minimum tillage), management of weeds, rational irrigation and fertilisation, use of organic fertilisers; (ii) Reduce pest populations and increase populations of beneficial organisms (at the level of the individual field, its surroundings, of the farm and of the entire agroecosystem): crops or trap crops, planting of refuge areas, plant associations and intercropping, the *push-pull* technique, establishment of field margins, planning of ecological compensation structures (corridors, hedgerows, grassy and flowering strips etc.), techniques designed to incorporate vegetative diversity; (iii) Favour concerted actions in time and in space within the agroecosystem.
- Step 3.** Evaluate the real socio-economic and environmental risks by using pest scouting techniques appropriate for one field, a group of fields, a farm, or the whole ecosystem, with the assistance of the regional agricultural extension services.
- Step 4.** Take only need-based decisions on curative measures: (i) With the aid of decision tools and in collaboration with fellow producers, accounting for local and ever-changing multiple criteria, intervention thresholds (economic, social, environmental) and of the risk of development of resistance; (ii) In the framework of whole-of-farm management and at a range of time scales (short to long term), account for the agroecological characteristics of the agroecosystem as a whole (the spatial dimension).
- Step 5.** Only in the case of absolute necessity, apply curative measures: (i) Give priority to alternative control measures: cultural techniques (e.g. defoliation, plant topping), biological control, physical and biotechnical control measures; (ii) Only as a last resort: use the chemical pesticides with the lowest ecological impact, chosen to avoid the emergence of resistance.

3. Application of agroecological crop protection to the case of cucurbit fruit flies on Reunion

Fruit flies (Diptera: Tephritidae) are among the most destructive and widespread pests of horticultural systems in the tropical and subtropical areas of the world (White & Elson Harris, 1992). Although they have been the subject of many studies because of their economic impact, their control is problematic in most cases and requires large amounts of pesticides. This situation is emphasized under insular and tropical conditions as is the case of Reunion Island.

In Reunion Island, three species belonging to the Dacini tribe attack Cucurbit crops: *Bactrocera cucurbitae* (Coquillett, 1899), *Dacus ciliatus* (Loew, 1901) and *Dacus demmerezi* (Bezzi, 1917) (Fig. 1).



Fig. 1. The three species of fruit fly (Diptera, Tephritidae) which attack Cucurbits on Reunion (Photos: A. Franck – Cirad). (a) *Bactrocera cucurbitae*; (b) *Dacus ciliatus*; (c) *Dacus demmerezi*.

After oviposition by the females (Fig. 2), the damage caused by the larvae feeding on the fruit can reach 90% of the crop yield of zucchini, cucumber, pumpkin or chayote (Ryckewaert et al., 2010).



Fig. 2. Females of *Dacus demmerezi* laying eggs on a zucchini fruit (Photo: JP. Deguine - Cirad). (a) and their eggs before hatching (b) (Photo: A. Franck – Cirad).

The chemical protection currently used is not effective and also has many side effects: toxicity to natural enemies and pollinators, pollution and sanitary damage to biodiversity and to humans. There is now a demand for sustainable and agroecological crop protection (Augusseau et al., 2011).

The application of agroecological crop protection to a case study requires consideration to both the pests and to the context. It also requires knowledge and research. For the last several years, research has allowed us to obtain knowledge about the bioecology of cucurbit fruit flies, making it possible to apply the principles of agroecological crop protection. Complementary research has been developed to design and implement agroecological techniques or practices adapted to the management of Cucurbit fruit flies. Furthermore, a large-scale initiative (GAMOUR program, see Part 6.) was proposed since 2009 to assess the efficacy of agroecological cucurbit fruit fly management in agricultural pilot areas.

4. Research on bioecology of the flies

The aim of this research was to improve knowledge on the biology and ecology of the three cucurbit fruit fly species and particularly on the interactions between fly adults and host or non-host plants.

4.1 Attractiveness of non-host plants to fly adults

The study aimed to compare corn and Napier grass attractiveness on fly adults in field cages (Atiama-Nurbel et al., to be published). The two plants were established in pots and presented to adult flies in field cages. In each cage, a cohort consisting of 100 adults (50♀ and 50♂) of *B. cucurbitae* and *D. demmerezi* of known age was released. The experiment was replicated four times. The number of adult flies on the different plants as well as their location on the plant was recorded. The results showed that corn was more attractive than Napier grass to adults of the two fly species whatever their sex and their maturity.

4.2 Circadian rhythm of fly adults

The study was conducted in cucurbit crops during austral summer in a range of altitude (750 to 1,150 m) corresponding to the main areas of cucurbit cropping. The methodology consisted of recording living adults present in the cultivated field or roosting on corn planted around cucurbit fields, distinguishing species, sex and kind of activity for each adult observed. The observations were performed each hour of the day from 7:00 am to 6:00 pm. The results showed that in the fields, cucurbit fruit fly adults typically roost on corn planted around the field. The three species of FF showed circadian rhythms, and females typically move at specific times of the day from roosting sites to host fruit in order to lay eggs. Fig. 3 gives an example of the circadian rhythm of male and female adults on a zucchini crop and a corn border during the photoperiod of a day.

5. Research on agroecological techniques for fruit fly management

Taking into account the knowledge on bioecology of the Cucurbit FF, the aim of this research was to design and implement agroecological techniques. Three techniques were tested: (i) sanitation using the augmentorium technique, (ii) trap plants using corn and (iii) 'Attract and Kill' using spinosad-based bait.

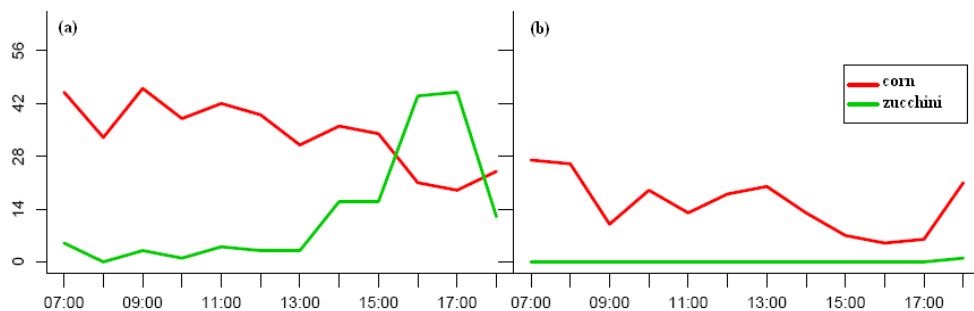


Fig. 3. Number of adult females (a) and males (b) of *Dacus demmerezi* observed on corn (56 m²) and on zucchini (616 m²) on the 13th February 2008 in Atiama-Nurbel (2008).

5.1 Sanitation using the augmentorium technique

Instead of the curative approach to reduce existing populations, the first step proposed for their management was sanitation. It is known to be an effective measure (Liquido, 1993). This method is based on an original technique originally developed by USDA in Hawaii utilizing a tent-like structure called an “augmentorium” (Jang et al., 2007; Klungness et al., 2005) which aims to sequester adult flies emerging from infested fruit while allowing the parasitoids to escape, via a net placed at the top of the structure. A prototype of augmentorium with an appropriate net mesh was developed in Reunion (Deguine et al, 2011) (Fig. 4).



(a)



(b)

Fig. 4. Sanitation using the augmentorium technique (Photos: JP. Deguine - Cirad). (a) An augmentorium in a zucchini crop (see the net at the top of the augmentorium); (b) Flies adults sequestered by the net inside the augmentorium.

A first study aimed to determine the potential of numbers of flies that could be sequestered in a sanitation technique such as the augmentorium. This potential was estimated by measuring in the laboratory the emergence of several species of flies from infested fruit collected in the field from 2009 to 2010 in different sites of the island. Emergence of fly adults was measured for three species of flies: (i) *Bactrocera cucurbitae*, *Dacus ciliatus* and *Dacus demmerezi* attacking three species of Cucurbits (pumpkin: *Cucurbita maxima*;

cucumber: *Cucumis sativus* and zucchini: *Cucurbita pepo*). Collections of infested fruits showed the following means of emerged adults per kg of fruit: 217 for cucumber, 340 for pumpkin and 594 for zucchini (Jacquard, personal communication).

A second study focused on the performance and the efficiency of the augmentorium prototype recently tested in Reunion Island and particularly (i) the number of adult flies that can potentially be sequestered in an augmentorium in the field; (ii) the efficacy of the net mesh for fly sequestration and parasitoid escape (Deguine et al., 2011). The sequestration of three of these fly species (*B. cucurbitae*, *B. zonata* and *C. capitata*) and the escape of two species of their parasitoids (*Psytalia fletcheri* and *Fopius arisanus*) were assessed on four mesh types in the Cirad laboratory in Saint-Pierre in 2008. The methodology of the experiments is described in the paper of Deguine et al. (2011). The results showed that the efficiency of the mesh chosen for the prototype of augmentorium (hole area 1.96 mm²) proved to be perfectly effective in the laboratory with 100% of sequestration of adult flies. In the same way, 100% of the parasitoids were able to escape from the mesh if they choose to do so (Fig. 5).

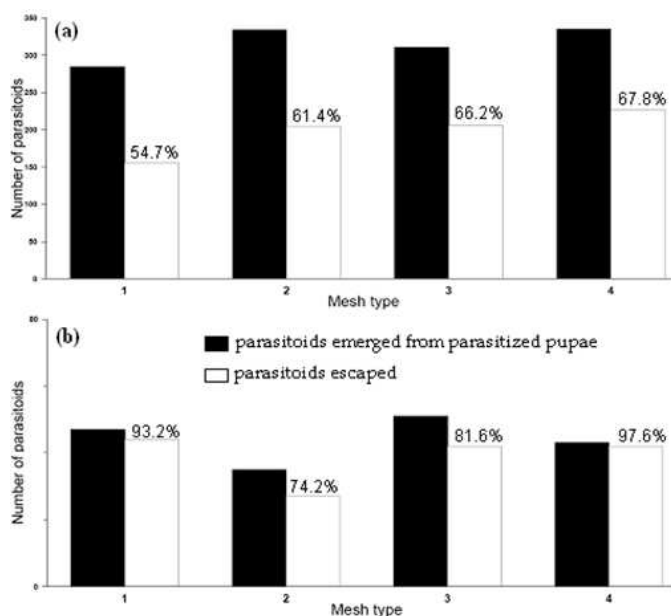


Fig. 5. Total results of the effect of four mesh sizes on *P. fletcheri* escape (a) (3 replications) and on *F. arisanus* escape (b) (2 replications): (i) number of parasitoids emerged from parasitized pupae of *B. cucurbitae* and (ii) number of escaped parasitoids. The percentage indicates the proportion between these two numbers (ii)/(i) in Deguine & Atiama-Nurbel (2010).

A third study aimed to evaluate the faisability of producing compost with infested fruit collected in the field. Preliminary tests on the feasibility of producing compost were then conducted in Saint-Pierre in 2009, mixing zucchini and other components. We showed that a ratio of 50:30:20 of zucchini, sugar cane stem and chicken litter respectively was well adapted to produce compost.

These results lead us to confirm the relevance and the efficiency of the augmentorium in agroecological crop protection. As a sanitation technique against fruit flies, the augmentorium sequesters large amounts of adult flies per kg of infested fruit. As a biological control method, it may contribute to increase parasitoid populations which are often low because of the previous and significant pesticide pressure. The augmentorium can also be considered as a useful tool to produce compost in the context of sustainable agriculture. The technique of sanitation using the augmentorium is now well accepted by farmers in pilot areas in Reunion Island.

5.2 Trap plants using corn

Corn was selected on Reunion because preliminary research showed it was attractive for fly adults (see Part 4.) and it was easily available and usable by farmers. The studies were conducted in cucurbit crops during austral summer at a range of altitudes (750 to 1,150 m) corresponding to the main areas of cucurbit cropping, in four locations during three years. We recorded the living adults present in the cultivated field or roosting on corn planted around cucurbit fields, distinguishing species, sex and kind of activity for each adult observed. The observations were performed each hour of the day from 7:00 am to 6:00 pm.

The first study focused on the adult population levels on corn and zucchini. The results showed that in the field, corn concentrated more than 95 % of fly populations. Fig. 6 gives

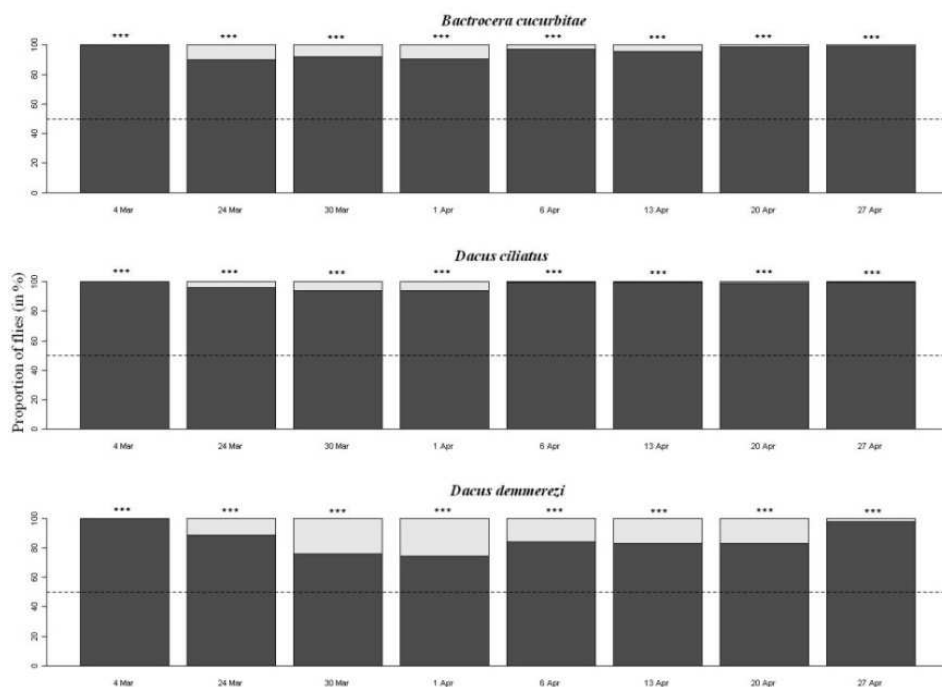


Fig. 6. Proportion of fly adults on corn (in black) and on zucchini (in grey) for the three species of Cucurbit flies at different dates (Tan Rouge, 2010). Binomial tests (5%) with H0: proportion of flies on corn (P_c) = 0.5 and H1: (P_c) \neq 0.5 (***) = $P < 0.001$ in Bonnet (2010).

an illustration of such a concentration of the fly adults. Roosting corn plants could thus be used as trap plants and became the place to manage the populations instead of the crop, as it was showed in other parts of the world (Mc Quate et al., 2003; Mc Quate & Vargas, 2007).

The second study aimed to compare corn patches and corn strips within the field in the situation of Tan Rouge in 2010. The fly community was dominated by *B. cucurbitae*, more than 50% throughout the observation period. Corn was hosting the majority of the population (over 99% of adults observed). The sex ratio was stable on corn and only the females went to the crops. Corn was a refuge for the majority of the community during the day, where the entire population was roosting. The results of the study showed that the shape and the size of the inclusion of corn did not affect the concentration of flies. Both corn patches and corn strips were effective to trap 99 % of the fly adults. As a conclusion, different designs of trap corn plants can be recommended: borders around the cultivated field, patches or strips within the field (Fig. 7).

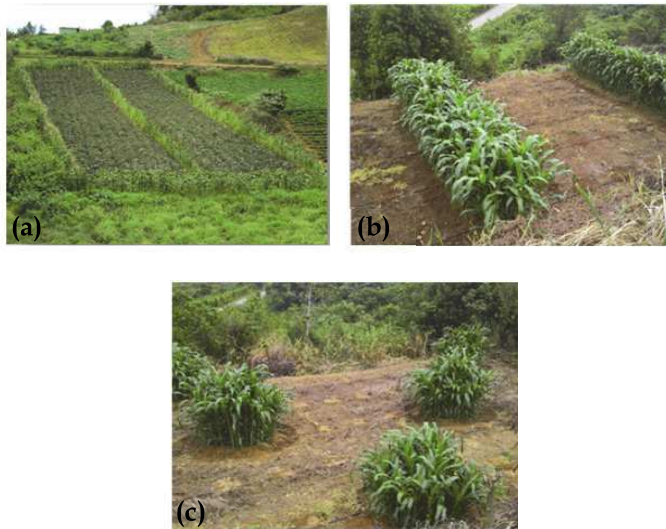


Fig. 7. Different designs of trap corn plants (Photos: JP. Deguine - Cirad). (a) borders of corn around the cultivated field; (b) strips of corn within the cultivated field; (c) patches of corn within the cultivated field.

5.3 Attract and kill using spinosad-based bait

Spinosad-based baits have been largely tested against fruit flies (Prokopy et al., 2004). The study was conducted to test the effectiveness of Synéis-appât® (Dow Agrosciences), a spinosad-based bait (Deguine et al., to be published). Experiments were conducted in field cages to compare efficiency of the bait on reared adult flies of the three species according ages and sexes. A total of 4.5 ml (equivalent to 5 sprays) of the bait was applied on two leaves in the upper stratum of the corn plant placed in the field cage. The bait was applied at 09.30 a.m. Adult flies were released 15 minutes after the bait application. At the beginning of each test, a release cage (30cm X 30 cm X 30cm) was placed in each field cage. At 9.45 a.m.,

the release cage was opened to let the adult flies (100 males and 100 females) out. At 10.00 a.m., the release cage was removed. Attractiveness and mortality were the two criteria used for measuring the efficiency of Synéis-appât®. Attractiveness and mortality were recorded from 15 minutes to 7 hours after application (a total of 29 observations for each field cage). The 15 minutes observations only continued for the 1st hour and a half, with hourly observations thereafter (for a total of ~ 13 observations). Mortality was defined as the ratio between the number of dead flies and the number of flies released in the field cage. The number of dead flies fallen on the floor of the field cage was recorded every hour from 2h to 7h after the application.

This product appeared to be effective to attract adult flies and to induce their mortality after ingestion. *B. cucurbitae* was more attracted to the bait in the first 45 minutes after application than *D. demmerezi* and *D. ciliatus*. The mortality of adult flies was significantly higher for *B. cucurbitae* than for *D. demmerezi*, and was significantly higher for the latter than for *D. ciliatus*. In conclusion, fly populations concentrated on corn trap plants could thereafter be suppressed by this food bait.

6. Evaluation of agroecological crop protection under commercial farm conditions

In Reunion Island, a pioneer project (called GAMOUR, a French abbreviation for agroecological management of cucurbit flies on Reunion), was implemented during three years from 2009 to 2011. The aim of the project was (i) to assess the efficacy of agroecological cucurbit fruit fly management under commercial farm conditions and (ii) to evaluate the economic outputs for the farmers. 26 “conventional” and 4 organic farms were contractualized to apply GAMOUR methodology during cucurbit growing season. The “conventional” farms were distributed in three pilot villages: Entre-Deux, Petite-Ile and Salazie. These pilot areas totalized about 50 ha of vegetable crops, of which 10 ha were devoted to chayote (perennially cultivated) and a variable part to other cucurbits (mainly zucchini, pumpkin, and cucumber).

The study reported below concerns the socioeconomic evaluation of the GAMOUR techniques previously tested (sanitation, traps crops, attract and kill). The economical outputs of GAMOUR application was achieved by the technical support of producers. All of them were weekly visited during two years, for material supply and for registration of yields, losses and insecticide cover sprays. These data were mostly based on farmers’ declarations, even though yields were confirmed as soon as possible by cooperative’s certificates. The fly damages were also assessed in the field by a counting of infested fruits on a randomly chosen 20 m cultural line. In order to compare these outputs to a classical situation, we proceeded similarly in Piton Hyacinthe with two farms experiencing similar cultural and climatic conditions than the pilot area of Petite-Ile (non perennial crops). The multiannual comparative yield production of chayote (perennial crop) could also be plotted in Salazie for the pre-GAMOUR (2007 - mid 2009) and GAMOUR application periods (since mid 2009).

From September 2009 to January 2011, we supplied the farmers with a grand total of 65 augmentoria, 636 traps baited with 2492 cue-lure blocks, 69 kg of corn seeds and 136 l of protein baits.

Table 1 shows that zucchini yields tend to be slightly higher in GAMOUR farms and losses due to fly infestations appear to be lower than in control. The more striking difference is however the mean number of insecticide sprays, which have nearly disappeared in GAMOUR farms.

Production data		Control	GAMOUR
Field surface (m ²)	mean	1980	1180
Insecticide cover sprays	Mean number per cycle	4.2	0.08
	mean	13.1	19.3
Yield (t/ha)	min	3.2	4.1
	max	20.9	31.4
	mean	34	13
Losses (%)	min	5	0
	max	70	60

Table 1. Consolidated data of the technico-economical survey of GAMOUR and control farms (sources: Vivéa, Terres Bourbon, farmers' declarations and field observations on 24 zucchini cultural cycles from 2009 to 2011).

Fig. 8 shows that chayote production was maintained at high level after the beginning of GAMOUR field application, comparable or higher during the previous years. For comparison, the reference value of the Chambre d'Agriculture for chayote yield in Reunion Island ranges from 50 to 100 t/ha/week. All along the project, no insecticide spray and a variable losses percentage of 5-25% were recorded on these crops.

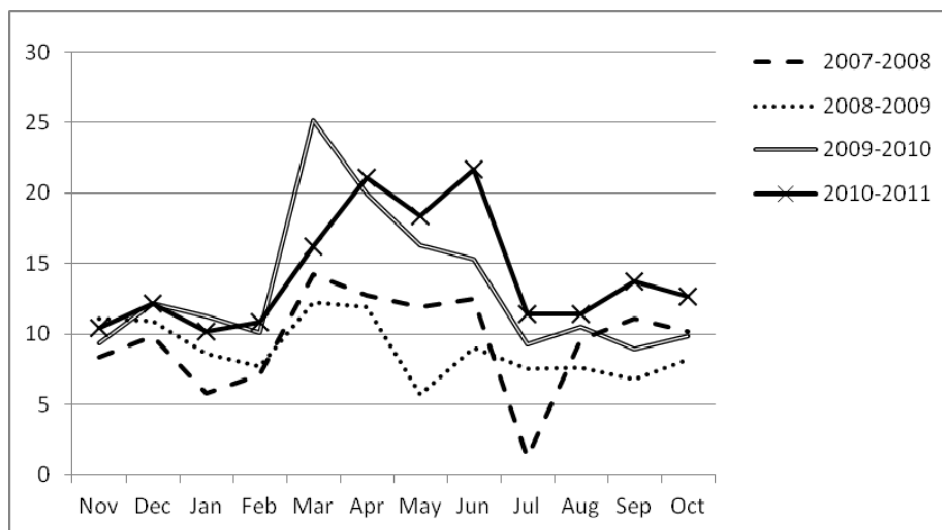


Fig. 8. Multiannual yield comparison of chayote in the Salazie pilot area. Red: before GAMOUR application; green: during GAMOUR application (source: Vivéa Réunion).

We must cautiously consider the data of yield and losses. Many of them are indeed provided by farmers' declarations, and the cross-checking with cooperatives recordings (when available) showed that they were often misevaluated despite the good faith of farmers. Moreover, the yields and losses were also influenced by additive phytosanitary, technical and climatic parameters which could not always be accurately assessed. Without any reliable comparative statistics, yield and losses are here considered as sharing the same ranges in control and GAMOUR farms.

Considering these results as a whole, we conclude on the other hand that stopping the chemical cover sprays over crops and replacing them by agroecological practices had, at worst, no negative impact on production. This answers to the main cause of concern initially expressed by the farmers in the pilot areas. A global comparative estimation of the cost of crop protection was already published (Augusseau *et al.*, 2011), combining the material and manpower costs. It assessed that GAMOUR methodology is 1.2 to 2.4 times cheaper than classical chemical protection. The farmers' are somewhat more optimistic, comparing their ancient practices, and estimate GAMOUR's protection to be at least twice cheaper. The difference between both estimations is mainly explainable by the fact that most farmers are owners of their farms and therefore not included manpower charges. Despite their lack of accuracy, all these data are another milestone for cucurbit crop protection and, further, for the evolution of agricultural practices. Agreeing with other cost-benefits analyses of similar programs (McGregor, 2005), they show that environmentally friendly agricultural practices may be profitable. This is a major step for their extension, since economical viability is fundamental for sustainable development programs: few farmers will agree to preserve their environment if they cannot "make both ends meet".

7. Conclusion

The scientific, technical and economical data presented above agree on a global objective: agroecological management of cucurbit fly populations in Reunion Island developed a sustainable methodology that farmers readily appropriate. A satisfaction survey is currently ongoing and shows that 80% of the farmers involved in the GAMOUR program are satisfied or very satisfied with the two years and half field results. Their involvement was besides recently recognized by a national award within the framework of the "Trophées de l'Agriculture Durable" (trophies for sustainable agriculture). The following step is now to extend this methodology beyond pilot areas: this will be mainly the task of education units for the next years. In parallel, the lessons of the last three years enable us now to shift the agroecological protection fundamentals on other cultures in Reunion Island.

This paper confirms that agroecology is a suitable alternative to agrochemistry for crop protection purposes.

8. Acknowledgments

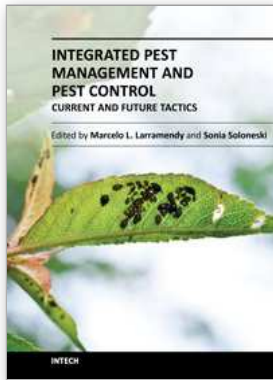
The present chapter is a synthetic overview of the vast effort provided by many people who unfortunately cannot be extensively quoted here. Concerning the research studies, we acknowledge Marie-Ludders Moutoussamy, Cédric Ajaguin-Soleyen, Serge Quilici, and Elisabeth Douragua. GAMOUR was operated by a fruitful collaboration between ASP, DAAF, Chambre d'Agriculture de La Réunion, Cirad, Farre, FDGDON, GAB, Université de

La Réunion, Takamaka Industries, SCA Terres Bourbon and Vivéa Réunion. The project was mainly funded by Europe, Conseil Régional de La Réunion, Conseil Général de La Réunion and Ministère de l'Alimentation, de l'Agriculture et de la Pêche through a CAS-DAR grant. It also received the financial support of Office de l'Eau and Crédit Agricole de La Réunion. More information is available on the website <http://gamour.cirad.fr>. We acknowledge all the people that have been involved in the GAMOUR project, including the farmers.

9. References

- Altieri, M. A. (1995). *Agroecology. The Science of Sustainable Agriculture*, 2nd ed., Westview Press, Boulder, CO.
- Altieri M.A. & Nicholls, C.I. (2000). *Applying agroecological concepts to development of ecologically based pest management strategies*, Natl Academies Press, Washington.
- Atiama-Nurbel T., 2008. Interactions entre les Mouches des Cucurbitaceae et les plantes de bordures dans les systèmes horticoles à La Réunion. Master 2 Biodiversité des Ecosystèmes cultivés, Université de La Réunion, Saint-Denis, 39 p.
- Augusseau, X.; Deguine, J.-P.; Douraguia, E.; Duffourc, V.; Gourlay, J.; Insa, G.; Lasne, A.; Le Roux, K.; Poulbassia, E.; Roux, E.; Suzanne, W.; Tilma, P.; Trules, E. & Rousse, P. (2011). Gamour, l'agroécologie vue de l'île de La Réunion, *Phytoma – La défense des végétaux*, No 642, pp. 33-37.
- Bonnet E., 2010. Interactions entre les Mouches des Cucurbitacées (Diptera, Tephritidae), une plante hôte (courgette) et une plante piège (maïs), disposé en bandes et en patches intra-parcellaires à La Réunion. Master 2 Biodiversité des Ecosystèmes cultivés, Université de La Réunion, Saint-Denis, 35 p.
- Bottrell, D. R. (1980). *Integrated Pest Management*. Council on Environmental Quality, U. S. Government Printing Office, Washington, DC.
- Carroll, C.R.; Vandermeer, J.H. & Rosset, P.M. (1990). *Agroecology*. McGraw-Hill Inc., New York.
- Clements, D. & Shrestha, A. (2004). *New Dimensions in Agroecology*. Food Product Press, The Haworth Press, Inc., Binghamton, NY.
- Dalgaard, T.; Hutchings, N. J. & Porter., J.R. (2003). Agroecology, scaling and interdisciplinarity, *Agriculture, Ecosystems and Environment*, No 100, pp. 39-51.
- Deguine J.-P., Atiama-Nurbel T., 2010. An original sanitation technique for the management of pests in organic agriculture in Reunion Island. *Proceedings of the International Conference on Organic Agriculture in Scope of Environmental Problems*, 03-07 February 2010, Famagusta (Cyprus), 139-148.
- Deguine, J.P.; Atiama-Nurbel, T. & Quilici, S. (2011). Net choice is key to the augmentorium technique of fruit fly sequestration and parasitoid release, *Crop Protection*, No 30, pp. 198-202.
- Deguine, J.P.; Ferron, P. & Russell, D. (2009). *Crop protection : from agrochemistry to agroecology*, Science Publisher, Enfield, NH, USA.
- Gliessman, S.R. (2007). *Agroecology: the ecology of sustainable food systems*, CRC Press.
- Gurr, G. M.; Wratten, S. D. & Altieri, M.A. (2004). *Ecological Engineering for Pest Management. Advances in Habitat Manipulation for Arthropods*, CSIRO and CABI Publishings, Collingwood VIC, Australia and Wallingford Oxon, UK.
- Jacobsen, B. J. (1997). Role of Plant Pathology in Integrated Pest Management, *Annual Review of Phytopathology*, No 35, pp. 373-391.

- Jang, E.B.; Klungness, L.M & McQuate, G.T. (2007). Extension of the use of augmentoria for sanitation in a cropping system susceptible to the alien Tephritid fruit flies (Diptera: Tephritidae) in Hawaii, *Journal of Applied Science and Environmental Management*, No 11, pp. 239-248.
- Klungness, L.M.; Jang, E.B.; Ronald, F.L.; Vargas, R.I.; Sugano, J.S. & Fujitani, E. (2005). New sanitation techniques for controlling tephritid fruit flies (Diptera: Tephritidae) in Hawaii, *Journal of Applied Science and Environmental Management*, No 9, pp. 5-14.
- Kogan, M. (1998). Integrated Pest Management : Historical Perspectives and Contemporary Developments, *Annual Review of Entomology*, No 43, pp. 243-270.
- Lewis, W. J.; van Lenteren, J. C.; Phatak S. C. & Tumilson J.H. III. (1997). A total system approach to sustainable pest management, *Proceedings of the National Academy of Science*, No 94, pp. 12243-12248.
- Liquido, N.J. (1993). Reduction of Oriental Fruit Fly (Diptera: Tephritidae) populations in papaya orchards by field sanitation, *Journal of Agricultural Entomology*, No 10, pp. 163-170.
- McGregor, A. (2005). *An Interim Report on the Economic Evaluation of the Hawaii Fruit Fly Area-Wide Pest Management Program*. University of Hawaii Extension Service.
- McQuate, G.T.; Jones, G.D. & Sylva, C.D. (2003). Assessment of corn pollen as a food source for two tephritid Fruit Fly Species, *Environmental Entomology*, No 32, pp. 141-150.
- McQuate, G.T. & Vargas, R.I. (2007). Assessment of attractiveness of plants as roosting sites for the melon fly, *Bactrocera cucurbitae*, and oriental fruit fly, *Bactrocera dorsalis*, *Journal of Insect Science*, No 7, pp. 45-57.
- Nicholls, C.I. & Altieri, M.A. (2004). Agroecological bases of ecological engineering for pest management, In: *Ecological Engineering for Pest Management. Advances in habitat manipulation for arthropods*, Gurr, G.M.; Wratten, S.D. & Altieri, M.A. (eds), pp. 33-54, CSIRO, Collingwood (Australia) & CABI, Wallingford (UK).
- Pimentel, D. (1995). Ecological Theory, Pest Problems, and Biologically Based Solutions, In: *Ecology and Integrating Farming Systems*, Glen, D.M.; Greaves, M.P. & Anderson, H.M. (eds), pp. 69-82, J. Wiley & Sons, Chichester.
- Prokopy, R.J.; Miller, N.W.; Piñero, J.C.; Oride, L.K.; Chaney, N.; Revis, H.C. & Vargas, R.I. (2004). How effective is GF-120 fruit fly bait spray applied to border area sorghum plants for control of melon flies (Diptera: Tephritidae)?, *Florida Entomologist*, No 87, pp. 354-360.
- Ratnadass, A.; Fernandes, P.; Avelino, J. & Habib, R. (2011). Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review, *Agronomy for Sustainable Development*, DOI 10.007/s13593-011-0022-4.
- Ryckewaert, P.; Deguine, J.P.; Brévault, T. & Vayssières, J.-F. (2010). Fruit flies (Diptera: Tephritidae) on vegetable crops in Reunion Island (Indian Ocean): state of knowledge, control methods and prospects for management, *Fruits*, No 65, pp. 113-130.
- Walter, G. H. (2003). *Insect Pest Management and Ecological Research*. Cambridge University Press.
- Weiner, J. (2003). Ecology - the science of agriculture in the 21st century, *Journal of Agricultural Science*, No 141, pp. 371-377.
- White, I.M. & Elson-Harris, M.M. (1992). *Fruit flies of economic significance: their identification and bionomics*, CAB International, Wallingford (UK).



Integrated Pest Management and Pest Control - Current and Future Tactics

Edited by Dr. Sonia Soloneski

ISBN 978-953-51-0050-8

Hard cover, 668 pages

Publisher InTech

Published online 24, February, 2012

Published in print edition February, 2012

Integrated Pest Management is an effective and environmentally sensitive approach that relies on a combination of common-sense practices. Its programs use current and comprehensive information on the life cycles of pests and their interactions with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means and with the least possible hazard to people, property, and the environment.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Jean-Philippe Deguine, Pascal Rouse and Toulassi Atiama-Nurbel (2012). Agroecological Crop Protection: Concepts and a Case Study from Reunion, Integrated Pest Management and Pest Control - Current and Future Tactics, Dr. Sonia Soloneski (Ed.), ISBN: 978-953-51-0050-8, InTech, Available from: <http://www.intechopen.com/books/integrated-pest-management-and-pest-control-current-and-future-tactics/agroecological-crop-protection-concepts-and-a-case-study-from-reunion>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.