WAGENINGEN UNIVERSITY
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ANNUAL REPORT 2005

LABORATORY OF ENTOMOLOGY

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ANNUAL REPORT LABORATORY OF ENTOMOLOGY 2005

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Cover: The cover design is based on the cover of the PhD thesis by Isabel Silva

FOREWORD

In June 2006 the Entomology team has won the Battle of the Universities, a contest between teams of different Dutch Universities in which high quality research must be presented with a plan to communicate the research to the general public. This means that the Entomology team is now organising the festival – *Wageningen – City of Insects*, which will take place from 18-24 September 2006 (www.cityofinsects.nl).

In a recent publication in BioScience, John Losey and Mace Vaughan made a conservative calculation of the economic value of the ecological services provided by insects. This resulted in a figure of 57 billion US$ *per year* for only the United States. This figure amounts to circa 10% of the defense budget of the United States or ca 25% of the annual costs of the war in Iraq. The study by Losey and Vaughan excluded the economic value of insects that were deliberately reared for certain functions, such as honeybees or biological control agents. The most important functions provided by naturally occurring insects are food for wildlife, pollination, pest control and removal of dung. This study underpins the economic importance of insects and thus of the science of entomology. In addition to this, the science of entomology in itself is thriving as a fundamental science and makes important contributions to basic knowledge in ecology, physiology and molecular sciences, to name just a few relevant scientific fields.

Our aim at the Laboratory of Entomology is to carry out a research and teaching programme of excellent quality that is continuously updated so as to be internationally at the forefront. The research of the laboratory of Entomology is centred around three themes: (1) chemical and molecular ecology, (2) population and behavioural ecology and (3) functional biodiversity and agroecology. Our research programmes are curiosity-driven and we exploit the knowledge obtained in developing applied programmes, especially related to the health of man, animals and the environment. Applied research includes projects on e.g. malaria mosquitoes, integrated crop, soil, and pest management through a participatory approach and development of functional biodiversity studies to develop novel, durable, pest control strategies.
In our teaching programme we develop courses for BSc, MSc and PhD students, most of them in English, as well as for laymen so as to raise the interest of the general public for insects.

This annual report informs you about the major activities and achievements in our group in 2005. There were many memorable events.
More information about our activities, on our teaching and research programmes, on recent PhD theses, on our social activities and much more can be found on our website The URL of our website is: www.ent.wur.nl/uk.

Marcel Dicke
Head of the Laboratory of Entomology

June 2006

Laboratory of Entomology
Entomology is the life science that addresses the biology of insects. The laboratory of Entomology integrates fundamental and applied aspects related to the biology of insects. Studies within the new area of environmental genomics have been initiated, combining studies of subcellular mechanisms with population- and community ecology. The fundamental research concentrates on multitrophic interactions using on the one hand molecular, sensory physiological, neurobiological and behavioural biological approaches, and on the other hand ecological, population genetic and modelling approaches. Our strategic research focuses on finding sustainable and environmentally safe solutions to problems caused by insects in the agricultural and medical-veterinary sector in temperate and tropical zones, in collaboration with social scientists.

Position within Wageningen University and Research centre (Wageningen UR)
The Laboratory of Entomology is part of the Plant Sciences Group of Wageningen University and Research centre. All research in our group is part of the two graduate schools 'Experimental Plant Sciences (EPS)' and 'Production Ecology & Resource Conservation (PE&RC)'. The research within the graduate school EPS deals with chemical and molecular ecology as well as host plant resistance. The research within the graduate school PE&RC focuses on the ecology of bio-interactions involving plants and insects, humans and disease-transmitting-vectors, hosts and parasitoids, prey and predators, and also focuses on behavioural and population ecology, functional biodiversity and agro-ecology. The research themes in the group are closely connected and the staff members collaborate in different research themes. As a result, the research of the laboratory of Entomology is coherent and well-coordinated.

Mission and strategy
The mission of the laboratory of Entomology is to carry out excellent research and teaching in a continuously updated research programme that is nationally and internationally at the forefront and well-linked to the research of international collaborators, while working in a group in Wageningen with a very good and stimulating atmosphere and excellent internal collaboration. The group has an outstanding reputation in multitrophic interactions, biological control and malaria vector research. Multitrophic interactions will receive more attention by incorporating molecular approaches on the one hand and by engaging in research projects dealing with functional biodiversity and ecological approaches in agriculture on the other. Malaria vector research is also increasingly adopting molecular approaches. Molecular ecology will continue to receive major emphasis with more attention to mechanisms at the molecular level and by using molecular techniques in the study of ecological processes. In our tropical research programme, cooperation with social sciences ensures that societal stakeholders are included in the research process, and that research is centred around the needs and opportunities of farmers.

The year 2005 was characterized by many special publications. Nina Fatouros and co-workers published their study on the ride-and-kill strategy of the egg parasitoid *Trichogramma brassicae* in Nature. Ernst-Jan Scholte and colleagues published their investigations on the potential of entomopathogenic fungi for the control of the African malaria mosquito in Science. Iris Kappers and co-workers published on a transgenic approach to investigating the role of a terpenoid synthase gene in the attraction of the predatory mite *Phytoseiulus persimilis*. Over the past 30 years there is a clear increase in the number of publications in ISI journals (see figure 1).

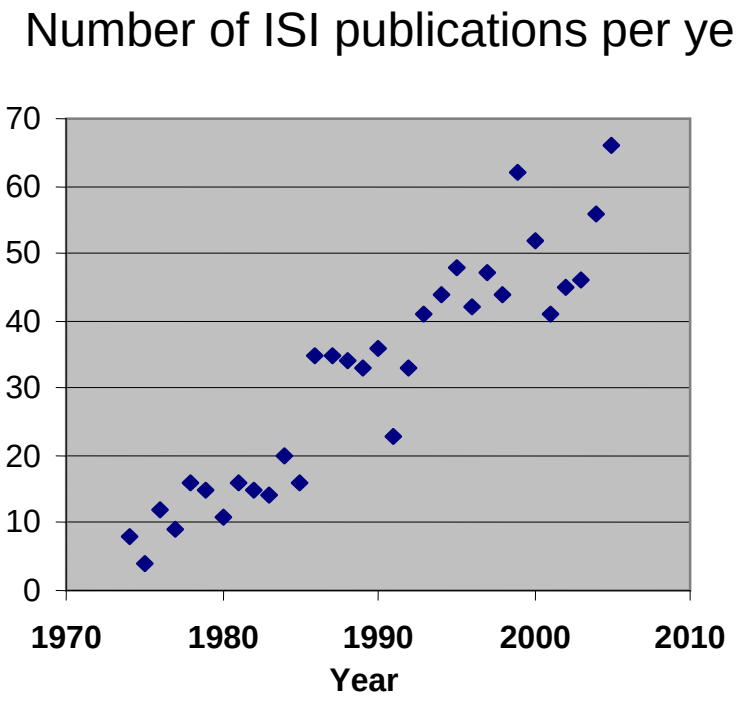


Figure 1: Number of publications of the Laboratory of Entomology from 1973 – 2005.

Louis Schoonhoven, Joop van Loon and Marcel Dicke pubished the second edition of the successful book *Insect-Plant Biology*. The first edition was sold out and has been extensively updated with many new references and new parts in many of the chapters.
In 2005 the medical and veterinary research programme has received a considerable financial input. Willem Takken and a team of international collaborators obtained a grant of 7 million € from the Bill and Melinda Gates foundation for their research on malaria mosquitoes. The ultimate aim of the programme is to lure away malaria mosquitoes in villages by using scent traps, so that the people living there are bitten less and therefore less infected by the malaria parasite. This is vital because most medicines against malaria are no longer effective. The disease causes almost a million deaths each year, mostly among children in Africa. Willem Takken and Bart Knols also obtained two grants for research on the potential of fungi for the control of malaria mosquitoes.
The laboratory of Entomology was awarded a teaching bonus from Wageningen University for the excellent developments made for the courses *Fundamental and Applied Biology of Insects* and *Insects and Society*. In addition, the laboratory of Entomology was also awarded the research bonus for the very good quality of its research.
In October 2005 Joop van Lenteren received the Shell Prize for Durability for his life-long achievements for sustainable agriculture as developed through biological control of insect pests. Over the past thirty years, Joop van Lenteren has contributed substantially to the development of evaluation of natural enemies and the environmental risk assesment of biological control. What's more, he did not just stay in the lab or behind his computer writing articles: he has worked hard to put biological pest control into practice. His work has resulted, for example, in the widespread use of the tiny parasitoid wasp *Encarsia formosa* in agriculture all over the world.
The Rank Prize Foundation announced that the 2006 Rank Prize for Nutrition is awarded to Joop van Lenteren, Louise Vet and Marcel Dicke for their collective work on fundamental studies of the interactions

between plants, their arthropod pests and the natural enemies of these pests, and the development of strategies for practical biological methods of pest control.
Ties Huigens has received the Veni grant from the Netherlands Organisation for Scientific Research, which is the first step in the prestigious Veni-Vidi-Vici programme. The Laboratory of Entomology now has been awarded a grant in each of the three steps of this programme: Huigens (Veni 2005), Knols (Vidi 2003) and Dicke (Vici 2002).
A total of 6 PhD students have successfully defended their theses in 2005. On average there were 7 PhD defences over the last 5 years, which is well above the average for Wageningen University as a whole being 2 PhD defences per group per year. The PhD defences in themselves are rather formal events that are open to the public. They are usually followed by a party that is enlivened by special songs and a sketch that are created for this special occasion.
To promote the interest in insects among the general public the Laboratory of Entomology has produced an insect quartet game. Each card represents an insect species with a photograph and some explanatory text. Furthermore Marcel Dicke wrote a popular book on insects in everyday life under the title *Killing two flies with one stone.*
The activities of the Laboratory of Entomology have been covered in a range of newspaper articles and interviews on radio and national television.

TEACHING

GENERAL

The laboratory of Entomology is involved in teaching to BSc, MSc, and PhD students. The BSc and MSc teaching relates mainly to the programmes of Biology and Plant Sciences, but also involves students in Animal Sciences, Biological Production Sciences, Molecular Sciences, Organic Agriculture and Environmental Sciences. The staff of the laboratory of Entomology teaches the following courses:

- Analysis and Prevention of Health Risks in Tropical Countries
- Bee Keeping
- Biology and Management of Plant Pathogens, Pests and Weeds I
- Biology and Management of Plant Pathogens, Pests and Weeds II
- Biology of Animal Production
- Biosystematics and Biodiversity
- Cutting Edge Ecology
- Ecological Aspects of Bio-interactions
- Ecology
- Ecophysiology of plants
- Evolutionary Biology
- Frontiers of Medical and Veterinary Biology
- Fundamental and Applied Biology of Insects
- Insect-Plant Interactions
- Insects and Society
- Molecular and Evolutionary Ecology
- Molecular Aspects of Bio-interactions
- Plant- and Crop Sciences I
- Plant- and Crop Sciences II
- Population Ecology

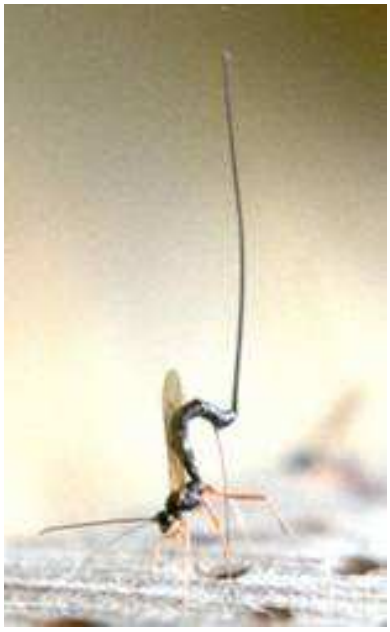
Teaching to PhD students is done through the teaching programmes of the Graduate Schools Experimental Plant Sciences (EPS:http://www.graduateschool-eps.info) and Production Ecology and Resource Conservation (PE&RC:http://www.dpw.wageningen-ur.nl/PEenRC).

In the academic year 2004/2005 a total of 28 students finished their MSc-thesis under the supervision of the staff of the Laboratory of Entomology.

STUDENT THESES 2005

- Lotte Joosten- Imperfect vertical transmission of parthenogenesis-inducing *Wolbachia* in natural populations of a parasitoid wasp (*Trichogramma kaykai*) – 05.01
- Anna Sáez Garcia - The effect of intercropping cotton with maize and sorghum on bollworms in Benin – 05.02
- Laura Lammerts - Influence of different diets on colony initiation and ovary development of *Bombus terrestris* (L.) – 05.03
- Jelle Duindam - Consequences of belowground induced defence – 05.04

- Pablo Jácome Estrella - Semiochemical cues used by *Uscana Lariophaga* Steffan (Hymenoptera: Trichgrammatidae) to locate its host *Callosobruchus maculatus* Fab. (*Cleoptera: Bruchidae*) – 05.05
- Dominique de Koning - Interactions between *Acyrthosyphon pisum* and *Megoura viciae* sharing a host plant and the parasitoid *Praon dorsale* – 05.06
- Silvie Huijben - The role of drug treatment, in response to clinical signs, on within-host competition and relative transmission of malaria parasites – 05.07
- Alexander van Holland - The use of parasitic wasps as bio-indicators for explosives: which species to use and how to train them – 05.08
- Dianne van den Heuvel - Development of an in vivo drosophila-based screening assay for antioxidant compounds – 05.09
- Esther Maria Penarrubia - Shape of clines in melanism in ladybirds and the possible role of migration – 05.10
- Fedor Gassner - Does grazing affect Lye disease risk? The impact of grazing livestock on tick populations and *Borrelia* infections in a natural woodland area in the Netherlands – 05.11
- Milan van der Meer - Geurkarakterisering van verschillende transgene aardappelplanten en de aantrekkingskracht hiervan op *Phytoseiulus persimilis* – 05.12
- Cock Middendorp - Vergelijking van de effectiviteit van gevleugelde en vleugelloze lieveheersbeestjes (*Adalia bipunctata* L.) bij de bestrijding van bladluizen – 05.13
- Stefan Borsboom - Interspecific host dicrimination and multiparasitism between Encarsia formosa and *Eretmocerus mundus* (Hymenoptera: Aphelinidae) on *Bemisia tabaci* (Hemiptera: Aleyrodidae). – 05.14
- Chris Veenemans - A comparative study on the foraging behaviour of the parasitoids *Diadegma semiclausum* and *Diadegma fenestrale*: the specificity and the use of herbivore-induced plant volatiles – 05.15
- Marion Munneke - Egg laying behaviour of the large pine weevil, *Hylobius abietis* – 05.16
- Francisco Maleno Martin - Behavioural differences between winged and wingless individuals of *Adalia bipunctata* – 05.17



- Laura Simpson - Does the experience of blood feeding or parasite infection affect aggregation or learning behavior in the malaria mosquito *Anopheles gambiae*? – 05.18
- Arjan Bergsma - Spatial behavior and gene expression: cloning and expression analysis of PKG in two species of *Cotesia* – 05.20
- Sara Mulder - Impact of nectar and honeydew on parasitization activity of *Diadegma* spp on *Plutella xylostella* – 05.21
- Anita Kikkert – Apprenticeship report on vegetable IPM in the South of Kyrgyzstan - 05.22
- Ana Rita Chico - Optimisation of the rearing method for the two spot ladybird (*Adalia bipunctata*). diet effect on oviposition and fertility rate – 05.23
- Anna Maria Costa i Rovira - Priming in induced gene expression and induced defense of brussels sprouts plant (*Brassica oleracea*) – 05.24
- Ana Rita Chico - The use of a wingless two spot ladybird *Adalia bipunctata* (Coleoptera: Coccinellidae) as a biological control agent of aphids – 05.25

- Saartje Hontelez - Variation in expression of the transcription factor CREB correlates to differences in learning abilities between *Cotesia glomerata* and *C. rubecula* – 05.26
- Jos van der Kaaden - Fenelogie en populatiedynamiek van *Anopheles maculipennis* s.l. ten noorden van het noordzeekanaal en het IJ. Terugkeer van inheemse malaria door natuurontwikkeling? – 05.27
- Celine Ronfort - Food preferences of the springtail *Cryptopygus antarcticus* from Signy Island – 05.28

PHD THESES 2005

A total of 6 PhD theses were completed and successfully defended:

- Ardeh, M.J. (2005) 'Whitefly control potential of *Eretmocerus* parasitoids with different reproductive modes'. Promotor: Prof.dr. J.C. van Lenteren, co-promotor: Dr. P.W. de Jong
- Bleeker, M.A.K. (2005) 'Associative learning in two closely related parasitoid wasps: a neuroecological approach'. Promotor: Prof.dr. L.E.M. Vet, co-promotors: Dr. J.J.A. van Loon and Dr. H.M. Smid.
- Gidding-Qiu, Y.T. (2005) 'Sensory and behavioural responses of the malaria mosquito *Anopheles gambiae* to human odours'. Promotor: Prof.dr. J.C. van Lenteren, co-promotors: Dr. J.J.A. van Loon, Dr. W. Takken.
- Tinzaara, W. (2005) 'Chemical ecology and integrated management of the banana weevil *Cosmopolites sordidus* in Uganda'. Promotors: Prof.dr. M. Dicke and Prof.dr. A. van Huis, co-promotor: Dr. C.S. Gold.
- Vugt, J.J.F.A. van (2005) 'Mode of action, origin and structure of the Paternal Sex Ratio chromosome in the parasitoid wasp *Trichogramma kaykai*'. Promotors: Prof.dr. J.C. van Lenteren and Prof.dr. R.F. Hoekstra, co-promotors: Dr. R. Stouthamer and Dr. H.J. de Jong.
- Winkler, K. (2005) 'Assessing the risks and benefits of flowering field edges. Strategic use of nectar sources to boost biological control'. Promotor: Prof.dr. J.C. van Lenteren, co-promotor: Dr. F.L. Wäckers.

(Hier overzicht met PhD-students)

RESEARCH PROGRAMME

The laboratory of Entomology investigates interactions between arthropods on the one hand and plants, animals and humans on the other. Our research aims at improving the understanding of multitrophic interactions in natural and agro-ecosystems and at (i) developing environmentally benign crop protection, (ii) improving health of animals and humans and (iii) conserving natural resources. The research relates both to temperate and tropical systems. The main focal points of our research are:

- chemical and molecular ecology
- behavioural and population ecology and
- functional biodiversity and agroecology.

Through both experimental and model approaches we address (a) the mechanisms that insects use to locate and evaluate their food sources and that plants and animals use to defend themselves against insects; (b) the causes of population fluctuations and differences in genetic composition among populations; (c) molecular aspects that underlie processes, interactions and evolutionary changes; (d) functional aspects of the characteristics of particular insect species and (e) the role of biodiversity in durable agriculture.

Our fundamental research concentrates on multitrophic interactions. On the one hand we investigate mechanisms of interactions, e.g. through molecular, sensory physiological and behavioural approaches. On the other hand ecological aspects of multitrophic interactions are investigated, through e.g. population genetical, population ecological and model approaches.

The applied research especially aims at finding durable and environmentally benign solutions to problems that are caused by insects. This relates to research on insects in common agricultural practices and in organic agriculture as well as in medical-veterinary problems.

All research of the laboratory of Entomology participates in the graduate schools Production Ecology and Resource Conservation (PE&RC - http://www.dpw.wageningen-ur.nl/PEenRC/index/index.htm) and Experimental Plant Sciences (EPS - http://www.graduateschool-eps.info/).

Progress in the research programmes is presented below:

Chemical and sensory ecology

Joop J.A. van Loon, Hans M. Smid; Renate C.S. Smallegange, Yu Tong Qiu, Maaike Bruinsma, Erik H. Poelman, Maartje A.K. Bleeker, Nina E. Fatouros, Michaël van den Berg, Wilant van Giessen, Suzanne Blatt, Limei Yang, Honglei Wang, Qingbo Tang, Jinying Peng, Baoping Pang, Guohong Wang.

Black mustard, *Brassica nigra* (L.) Koch (Brassicaceae) is subject to feeding damage by larvae of the large cabbage white butterfly, *Pieris brassicae* L. and related Pierid species, specialist herbivores of brassicaceous plants. Black mustard has been shown to tolerate leaf feeding from *Pieris brassicae* through compensation. Once the plants flower, *P. brassicae* preferentially migrate into racemes to feed on flowers and siliques (see Annual Report 2004). We studied to what extent this within-plant preference behaviour is guidede by glucosinolates, considered to be the main defensive secondary metabolites of brassicaceous plants against herbivory. To specialist herbivores like *Pieris*, however, these compounds act as strong feeding and oviposition stimulants. We investigated whether the glucosinolate profiles of flowers and leaves could offer an explanation for flower preference. We analyzed glucosinolate concentrations in leaves and flowers of three *B. nigra* genotypes. The dominant glucosinolate was sinigrin, which occurred at 100 times higher levels than five other glucosinolates. Leaves contained a number of unidentified glucosinolates not occurring in flowers. Flowers contain upto five times higher levels of glucosinolates than leaves in all three genotypes. Functional myrosinases, hydrolytic enzymes that degrade glucosinolates, seem to be absent in flowers. Flower feeding might represent a strategy to avoid the toxicity of isothiocyanates, products of hydrolysis, that are toxic even to specialist herbivores like Pieris caterpillars.

Observations of feeding behaviour of *Pieris brassicae* caterpillars under field conditions demonstrated a strong preference for flowers, confirming greenhouse observations. Two subsequent infestations with either unparasitized caterpillars or caterpillars parasitized by the larval parasitoid *Cotesia glomerata* (Hymenoptera: Braconidae) revealed that plants fed upon by parasitized caterpillars produced significantly higher seed numbers than plants attacked by unparasitized caterpillars. *Pieris brassicae* has 2 -3 generations in Western European conditions. These results demonstrate that parasitization by gregarious koinobiont larval parasitoids at average clutch sizes can benefit the fitness of plants that recruit such parasitoids by emitting herbivore-induced volatiles, an issue that has been repeatedly debated.

Progress of our projects on the compartive sensory ecology of learning in two closely related *Cotesia* species is reported under Evolutionary ecology.

Ecology, evolution and genetics of interactions between phytophagous insects, their host plants and their enemies.

Peter W. de Jong, Patrick Verbaarschot, Suzanne Lommen, Manabu Kamimura and David Calvo-Hernandez.

The interactions between phytophagous insects, their host plants, and their enemies provide ideal opportunities to study the ecology, evolution and genetics of adaptations in the field. In 2005, the line of research to study such interactions, which was started in the beginning of 2002, was further developed. The

work is carried out in close collaboration with Dr. Jens Kvist Nielsen in Copenhagen, and with Dr. Manabu Kamimura, who joined the team in may 2004, and continued to work on this system after his return to Tsukuba (Japan) in May 2005. The research programme is closely tied to the three major foci of interest of the Laboratory of Entomology, especially the first two: a) chemical- and molecular ecology; b) behavioural- and population ecology, and c) functional biodiversity and agroecology. The project focuses on the interaction between a flea beetle, its (natural) host plants, and its enemies. The chrysomelid flea beetle *Phyllotreta nemorum* lives on a limited number of Crucifers. The larvae are leaf miners, implying an intimate relation with the host plants, including (chemical) host plant defences. *Barbarea vulgaris* is an atypical host plant of this beetle: one chemically distinguishable form of this plant is unsuitable as host plant for the majority of *P. nemorum*. The adults do not eat from this plant, and the larvae die within three days when put on leaves of the plant. However, populations have been discovered that use this plant as their natural host. These beetles are apparently 'resistant' to the defences of *Barbarea*. We have found that this resistance is genetic, and involves genes with a major phenotypic effect. Some of these genes appear to be located on the sex chromosomes, whereas others seem to be autosomally inherited. The beetles are polymorphic for the presence of these genes; when collected on Barbarea in the field, all beetles have resistance genes, but on other host plants a major proportion of the beetles does not contain resistance genes. These observations raise a number of fundamental questions: 1) why are not all beetles resistant to *Barbarea* defence?; 2) what ecological and/or genetic factors limit the spread of resistance genes?; 3) how many loci are involved in the resistance, what is their inheritance, and if there is more than one locus involved, did they originate as independent mutations? Exciting progress in addressing these questions has been made in the past year, with the implementation of a 'population genomics' approach. The aim is to link variation at the population level at neutral (microsatellite) loci with that at the resistance loci. This will enable the assessment of the relative contributions of selection and migration to the present day distribution of resistance genes. To this aim, primers have been developed for a dozen of microsatellite loci (Verbaarschot, Calvo-Hernandez). Furthermore, Dr. Kamimura has applied a candidate gene approach to characterise the resistance genes at the molecular level. It is thought that beta-glucosidases are responsible for the different resistance-genotypes. Sampling the flea beetle populations in Denmark that had been earlier sampled (1997) has shown that the frequencies of resistant flea beetles on other plants than *Barbarea* are decreasing. This monitoring will be continued. Analysis of population structure of the flea beetles with allozymes has shown that different resistance-phenotypes are genetically differentiated.

Next to the work on the flea beetles, a new line of research has started on the two spot ladybird beetle. This work is done in collaboration with the Intitute of Biology in Leiden (group of Prof. P.M. Brakefield), and involves the use of wingless two-spot ladybird beetles in biocontrol of aphid-pests. Simultaneously, we have monitored natural ladybird populations to detect changes in gene-frequencies involved in colour polymorphism in ladybirds, possibly associated with climatic change. Finally, we have started monitoring the invasion of The Netherlands by the asian ladybird beetle, *Harmonia axyridis*.

Infochemicals in multitrophic interactions

Marcel Dicke, Rieta Gols, Adriana E. Alvarez, Colette Broekgaarden, Maaike Bruinsma, Tibor Bukovinszky, Deidre S. Charleston, Nina E. Fatouros, M.(Ties) E. Huigens, Iris F. Kappers, Marjolein Lof, Ludo L.P. Luckerhoff, Evarist Magara, Oscar Magenya, Roland Mumm, Vivian R. van Oosten, Ying-Jing-Peng, Remco M.P. van Poecke, Erik H. Poelman, Conny Schütte, Renate Smallegange, Tjeerd A.L. Snoeren, William Tinzaara, Martin de Vos, Limei Yang, and Si-Jun Zheng.

We investigate herbivore-induced plant volatiles that affect plant-insect interactions. This is done through different approaches including analyses of (1) transcriptomic changes, (2) metabolomic changes, and (3) ecological changes that result from herbivory.

Martin de Vos and Vivian van Oosten have compared the global changes in gene expression pattern in *Arabidopsis thaliana* in response to feeding damage by three herbivorous insects (the caterpillar *Pieris rapae,* the aphid *Myzus persicae* and the thrips *Frankliniella occidentalis*) or infection with two pathogenic microorganisms (*Alternaria brassicicola* and *Pseudomonas syringae*). This was complemented with phytohormone analyses. Each attacker induced its own phytohormone profile as well as transcriptome profile. Individual phytohormones cannot fully explain the transcriptomic changes. Most likely intensive crosstalk between signal transduction pathways influences transcriptomic changes (De Vos, Van Oosten et al. 2005, MPMI 18: 923-937).

Herbivory results in the induced production of terpenoids in many plants, including Arabidopsis and cucumber. Iris Kappers and Ludo Luckerhoff, in collaboration with our colleagues at Plant Research International have investigated the role of these terpenoids and the underlying biosynthetic genes. A linalool/nerolidol synthase gene was introduced into Arabidopsis by targetting the protein to the mitochondria, which resulted in the emission of the terpenoid (3S)-(*E*)-nerolidol and its derivative 4,8-dimethyl-1,3(E),7-nonatriene. In subsequent behavioural tests in an olfactometer and a multiplant setup predatory mites were tested. These predators feed on spider mites that induce the emission of the two terpenes in various plants. Predators were attracted to transgenic plants that emitted the terpenoids while they were not attracted to wildtype plants. This study shows how linking molecular genetics to metabolite analysis and behavioural assays can identify the function of a gene at different levels of biological integration (Kappers, Aharoni et al. 2005, Science 309: 2070-2072). The data are used to develop novel ways of pest control.

William Tinzaara completed his PhD-thesis on the use of an aggregation pheromone of the banana weevil. In field experiments he evaluated a 'lure and kill' system that combines the aggregation pheromone with the entomopathogenic fungus *Beauveria bassiana.* The data show that this autodissemination system has promise for a contribution to control a major banana pest.

Evolutionary Ecology

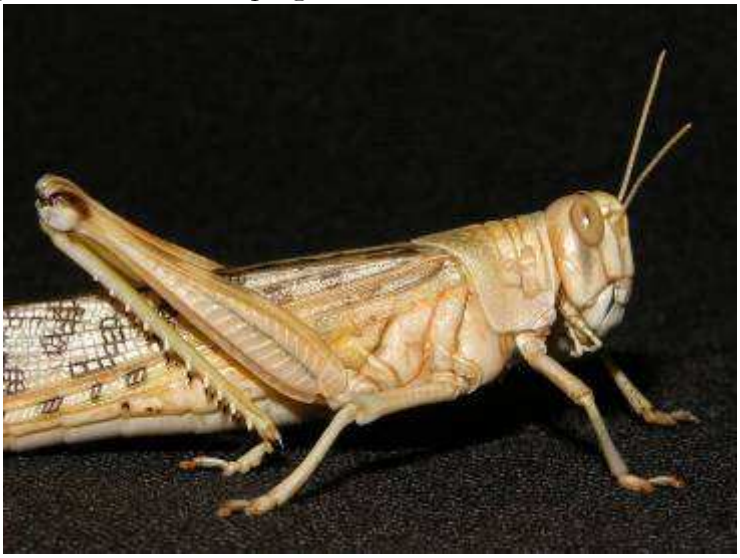
Louise E.M. Vet, Hans M. Smid, Maartje A.K. Bleeker, Joanneke Talsma, Roxina Soler, Hanneke van Leur. At NIOO in close collaboration with Wim van der Putten, Jeff Harvey, Felix Wäckers, and Nicole van Dam.

The research focuses on the ecology and evolution of multitrophic systems of plants, herbivorous insects and their natural enemies. Using a multitude of approaches we study the functioning of natural enemies in a spatially diverse multitrophic context. The behavioural ecological work investigates evolutionary aspects of phenotypic variation in foraging and life history traits. The chemical ecological approach focuses on the mechanism and function of chemical information conveyance between plants, herbivores and natural enemies and the influence of plant defence on the functioning of higher trophic levels. In addition we study

sensory physiological and neurobiological aspects, specifically the perception and information processing (learning and memory) of herbivore-induced plant volatiles by insect parasitoids.
In december 2005, Maartje Bleeker defended her PhD thesis. Insects are useful model organisms to study learning and memory. Their brains are less complex than vertebrate brains, but the basic mechanisms of learning and memory are similar in both taxa. We study learning and subsequent memory formation in two parasitoid wasp species that differ in associative learning of the odours of plants on which they have encountered a host caterpillar. After ovipositing in a caterpillar feeding on a certain plant species *C. glomerata* shifts its preference to the experienced plant odour, whereas *C. rubecula* does not shift plant odour preference after a similar experience. This difference in learning between these two closely related wasp species provides an attractive model to study physiological and ecological factors that could influence learning. The two wasp species display a high degree of similarity in morphology of the olfactory pathway at both the level of the sensilla, and the level of the glomeruli, the primary olfactory neuropile. We identified the octopaminergic neurons that could mediate the reward stimulus in the two wasp species, but the results did not reveal apparent dissimilarities between the species. We redefined the difference in preference learning between the two species in terms of associative and non-associative learning and analysed the temporal dynamics of the memory trace. Both wasps display associative learning after an oviposition reward conditioning, but the temporal dynamics differ. *C. glomerata* displays a stable memory for the experienced odour that lasts for at least five days, whereas in *C. rubecula* the memory starts to wane after one day.
We also studied the effect of physiological and ecological traits of hosts as possible factors influencing memory formation. For this we used two geographically disjunct populations of *C. glomerata* that differ in their host use. Both populations only change preference after an oviposition reward on their preferred host species, suggesting that physiological factors exert a major influence on learning in these two populations.

Tropical entomology
Arnold van Huis, Jeroen Spitzen, Godwin Ayenor, Emmanuel Dormon, Evarist Magara, Oscar Magenya, Suzanne Nederlof, Antonio Sinzogan, William Tinzaara.

Parasitoids use semiochemicals emitted by their host to locate their victims. The behaviour of the egg parasitoid *Uscana lariophaga* was studied in the location of their host *Callosobruchus maculates*. Instead of using beetle eggs we studied whether semiochemicals emitted by the adult beetle had an effect on the wasp. This in order to see whether phoresy occurs. Did the sex or the mating conditions of the beetle have an effect on the response of the wasp? Female wasps stayed longer in Petri dish quadrants with mated female and male beetles than in those with virgin ones. After mating male and female beetles attracted wasps more often than before mating. It seems that during mating, a substance is released by the male beetle acting as a semiochemical for the wasp. It is not clear whether phoresy plays a role in host location.



Vector biology and control

Willem Takken, Ernst-Jan Scholte, Krijn Paaijmans, Niels Verhulst, Jeroen Spitzen, Frans Jacobs, Yu Tong Qiu, Renate Smallegange, Wycliffe Wanzala, Susan Imbahale

Research continued to focus on mosquito-host interactions and biological control of mosquitoes. Significant progress was made with the sensory physiology of the African malaria mosquito *Anopheles gambiae sensu stricto*. Single-sensillum recordings with a group of 44 different chemicals revealed that the olfactory receptor cells of *An. gambiae* were sensitive to several compounds but that there was a high degree of variation in sensitivity depending on the chemical compound. Some cells never responded to specific cues. It was possible to classify the olfactory sensilla into different types according to the sensitivity of their underlying receptor cells. Behavioural studies in a dual-choice olfactometer revealed the importance of odour blends. *An. gambiae* proved receptive to NH_3, L-lactic acid and a mixture of carboxylic fatty acids (FA). There was a positive response to NH_3, no response to L-lactic acid and an aversion to FA. When these compounds were tested as a blend, a significantly greater response of the mosquitoes was observed, and the repellent effect of FA was turned into an attractive one.

Field studies with the entomopathogenic fungus *Metarhizium anisopliae* for the killing of wild *An. gambiae* demonstrated a strong effect of the fungus on adult mosquitoes: 3 weeks after application of the fungus to a cotton sheet suspended on the ceiling of a house in Tanzania, 23% of the mosquitoes collected in that house proved infected. These mosquitoes died several days later due the fungal infection. Our collaborating group in Edinburgh (Prof. A. Read et al.) had meanwhile shown the strong anti-*Plasmodium* effect of the fungus while in the mosquito: *Plasmodium* parasites in fungus-infected mosquitoes developed less well than such parasites in untreated mosquitoes. The combined effect of the fungus on mosquito survival and *Plasmodium*-development show strong promise for entomopathogenic technology for the purpose of controlling malaria in highly endemic regions.

In a field study on the effects of grazing by large herbivores on the population dynamics of *Ixodes ricinus* in the Netherlands, it was found that grazing by cattle appeared to have a negative effect on tick density. In a nearby woodland where no cattle could go, the tick density was markedly higher. There were also differences in *Borrelia* infections in ticks collected in the grazed-area as compared to ticks collected in the natural woodland. The results indicate that grazing has a negative impact on tick density and *Borrelia* infections. We propose that this study will be repeated to better understand the dynamics of the *Borrelia* infections in the ticks.

From behavioural and population ecology to functional biodiversity and agro-ecology

Joop van Lenteren, Mohammed Ardeh, Hajnalka Trefas, Giovanni Burgio, Valentina Lo Verde, Sara Ruschioni, Karin Winkler, Yde Jongema.

Until recent most of our work involved understanding of parasitoid behaviour and development of biological and integrated pest management programmes (Behavioural and population ecology, first paragraphs of this report), currently our main activities are in the field of Functional Biodiversity and

Agroecology (the third research theme of the Laboratory and the second paragraph of this report).
Behavioural and population ecology.
The PhD project concerning development of biological control methods by Mohammed Ardeh has been finished during this report period. Ardeh studied arrhenotokous and thelytokous strains of *Eretmocerus* species, and the benefits and costs of the use of thelytokous parasitoids in control of whiteflies (see publication list). Ardeh also studied the reaction of various *Eretmocerus* strains/species to pheromones and analysed intra- and interspecific host discrimination.
Valentina Lo Verde (University of Palermo) started her post-doc project on eleminiation of supernummerary parasitoid larvae in *Eretmocerus mundus*. Until now it was unclear whether elimination occurs when the parasitoid larvae are still outside the host (*Eretmocerus* lays its eggs between the host and the host plant), or that elimination occurs within the host after the parasitoid larvae have penetrated the host.
Work on risk assessment of importing and releasing of exotic natural enemies was continued in collaboration with Antoon Loomans (Plant Protection Service) and has resulted in several papers and book chapters (see publication list).
Sara Ruschioni, in a collaborative PhD project with the universities of Ancona and Perugia, studied the reaction of parasitoid ovipositors to different solutions related to host discrimination.
Functional Biodiversity and Agroecology
The general objective of the project on Functional Biodiversity and Agroecology is to determine how increased biodiversity leads to reduced pest development. The specific objectives are: (a) to study how functional groups of pests and their natural enemies survive and disperse in simple and diverse agro-ecosystems, (b) to specify the ecological conditions for conservation and augmentation of natural enemies by diversification, (c) to design agroecosystems of higher biodiversity within a landscape ecological framework that have a lower pest pressure, and (d) to provide strategies for sustainable use of biodiversity within the production function of biodiversity.
Karin Winkler finished her PhD project on the effect of the provision of nectar and pollen in field edges on the development of natural enemy populations. A spectacular finding of her work was that provision of nectar providing plants in the field led to dramatically increased life span and reproduction of parasitoids (see publication list).
Hajnalka Trefas determined the effect of mixed cropping on the predation by and reproduction of polyphagous predatory beetles. She found that vegetation characteristics by themselves may influence egg laying site preference, in addition to availability of prey for adults and larvae in the different plant systems.

Abiotic factors (e.g. light, humidity and structure) appeared to affect the selection of oviposition sites and egg survival of carabid beetles.
Giovanni Burgio (university of Bologna) is studying the effect of the degree of biodiversity in field edges and other landscape elements on natural biological control in several crops. His research, which is a combination of observations and determination of biodiversity indexes, will result in a thesis that will be defended at Wageningen University in 2006.

Projects within graduate school Experimental Plant Sciences:

- EPS2-2b28. Insect-plant interactions during stylet penetration by aphids. W.F. Tjallingii.
- EPS2-b128. Molecular characterisation of mechanisms of *Solanum* resistance to *Myzus persicae*. Impact on PLRV transmission. 2003-2007. A.E. Alvarez, W.F. Tjallingii, B. Vosman & M. Dicke
- EPS2-2d06. Induction of plant volatiles by herbivory: signal transduction and behavioural modification in a multitrophic context. M. Dicke, R. Gols.
- EPS2-2d04. Variation in foraging behaviour of the predatory mite *Phytoseiulus persimilis*. 1992-2006. C. Schütte, M. Dicke and J.C. van Lenteren.
- EPS2-2d05. Sensory, behavioural and nutritional effects of plant substances on host plant and host insect evaluation and utilization by insects. J.J.A.van Loon, H.M. Smid.
- EPS2-2d20. A new disease in the predatory mite *Phytoseiulus persimilis*: Pathogen identification, development of a detection method and prevention and cure in mass rearing. 1998-2005. C. Schütte, I.M.M.S. Silva, O. Poitevin, and M. Dicke
- EPS2-2d24. Chemical ecology and management of the banana weevil *Cosmopolites sordidus*. W. Tinzaara, C. Gold, A. van Huis and M. Dicke. 2000-2005.
- EPS2-2d22. Induced indirect plant defence and plant fitness: testing the "evolutionary enlistment" hypothesis. 2001-2005. R.C. Smallegange, J.J.A. van Loon, J.A. Harvey & M. Dicke
- EPS2-2d23. Cross-talk between signal-transduction pathways in induced defence of Arabidopsis against microbial pathogens and herbivorous insects. 2001-2005. V.R. van Oosten, C.M.J. Pieterse, L.C. van Loon & M. Dicke.
- EPS2-2d27 Genomics approach to integration of host plant insect resistance and biological control. 2001-2006. L. Yang, J.J.A. van Loon, M.A. Jongsma & M. Dicke.
- EPS2-2d28. Development of a method for breeding of cucumber for improved attraction of biological control agents. 2002-2007. I.F. Kappers, L. Luckerhoff, H.J. Bouwmeester & M. Dicke.
- EPS2-4a22. Mode of action of sex-modifying supernumerary chromosomes, 2000-2005. J. van Vugt, H. de Jong (Genetics, WU), J.C. van Lenteren, R. Stouthamer and L. Beukeboom (RUG).
- EPS-2c036. Phenotypic manipulation of induced plant defense in Brassica, 2004-2008. M. Bruinsma, M. Dicke, J.J.A. van Loon.
- EPS-2c037. Manipulation of plant genotype and effects on interactions with community members. 2004-2008. T.A.L. Snoeren, M. Dicke, P.W. de Jong.
- EPS-3c062. Metabolomics of indirect defence in cultivated Brassica oleracea varieties and its effects on insect biodiversity, 2004-2008. E.H. Poelman, J.J.A. van Loon, M. Dicke
- EPS-32c060. Identification and expression of genes related to herbivory, 2004-2008. C. Broekgaarden, M. Dicke, B. Vosman.
- EPS-new. Molecular ecology of terpenoids in plant-insect interactions. 2004-2007. R. Mumm and M. Dicke



Projects within graduate school Production Ecology and Resource Conservation:

- PE33-00b. Control of *Callosobruchus maculatus* and *Bruchidius atrolineatus* (Col.: Bruchidae), insects in storage or cowpea (*Vigna unguiculata*) by the egg parasitoid *Uscana* sp. (Hym.: Trichogrammatidae). A. van Huis and G.J.K. Pesch.
- PE&RC32-00aj. Factors that affect host searching by anopheline mosquitoes. W. Takken, J. Spitzen.
- PE32-94a. Understanding biological control of whiteflies by natural enemies. J.C. van Lenteren
- PE&RC-33-01a. Functional biodiversity: strategic use of nectar and pollen sources to boost biological control. 2000 – 2005. K. Winkler, J.C. van Lenteren, F. Wäckers.
- PE&RC31-00u. Learning-related differences at the neural level in two closely related parasitic wasps: a comparison between a generalist and a specialist. 2000-2005. M.A.K. Bleeker, H.M. Smid, J.J.A. van Loon & L.E.M. Vet.
- PE&RC. Enhancing the biocontrol of the Western Flower Thrips (*Frankliniella occidentalis*) with the predatory bug (*Orius laevigatus*) on greenhouse cucumber. 1998-2007. J. Hulshof, A.J.M. Loomans, J.C. van Lenteren.
- PE&RC prep29. Evaluation of the biological control capacity of *Eretmocerus* spp for the control of whiteflies on Gerbera. 2001-2005. M. Ardeh & J.C. van Lenteren.
- PE&RC.new. Temperature distribution in shallow water bodies: Influence of abiotic factors on the population dynamics of immature stages of African malaria vectors. 2003-2007. K. Paaijmans, A.F.G. Jacobs, W. Takken, A.A.M. Holtslag & M. Dicke.
- PE&RC new. Environment and *Beauveria bassiana* performance against banana weevil: The effects of agroecological conditions and banana crop management on Entomopathogenic persistence and infectivity. 2004-2008. E. Magara, M. Dicke, A. van Huis, C. Gold.
- PE&RC new. Interactions among leafhopper vector populations, maize streak virus disease, agro-environments and soil fertility. 2004-2008. O. Magenya, M. Dicke, A. van Huis.
- PE&RC-3204a. Spatio-temporal modelling of infochemicals in a food-web context. 2004-2008. M. Lof, L. Hemerik, M. Dicke & M. de Gouw.
- PE&RC 129/.02.1 Neural basis of associative learning in two closely related Cotesia parasitoid wasp species. 2005-2009. M. van den Berg, H.M. Smid, J.J.A. van Loon and M. Dicke.
- PE&RC The contribution of landscape elements to natural pest control. G. Burgio, J. van Lenteren
- PE&RC new: Behaviour and elimination of supernumerary parasitoid larvae in *Eretmocerus mundus*. 2005-2009. V. Lo Verde, J. van Lenteren
- PE&RC new: Behaviour, anatomy and sensory physiology of chemosensillae in parasitoids. 2005-2009. S. Ruschioni, J. van Lenteren
- PE&RC new: Evaluation of natural enemies in augmentative biological control. 2005-2009. K. Bolckmans & W. Ravensberg, J. van Lenteren
- PE&RC 034/02.1 Ethnobotanicals used for ectoparasites control in traditional livestock holdings 2004-2008. W. Wanzala, W. Takken
- PE&RC new: The effects of water management systems in traditional agriculture on Malaria Mosquitoes in Western Kenya. 2005-2009 . S. Imbahale, W. Takken, M. Dicke

REPRESENTATION IN EXTERNAL COMMITTEES

International:

- Consortium developing the SeaWaterGreenhouse, advisor crop protection (van Lenteren)
- ERA-MORE, European Network of Mobility Centres, Advisory Committee (Vet)
- European Branch Society of Vector Ecology 2002-2006 (Takken, president)
- European Meeting of the Society for Vector Ecology 2006 (Takken, scientific board)
- European Science Foundation (ESF), Steering committee programme Volatile Organic Compounds in the Biosphere-Atmosphere System (VOC-BAS) (Dicke)
- Expert Advisory Committee Canadian Network of Biocontrol Research (van Lenteren)
- FAO Technical Group of the Desert Locust Control Committee (Van Huis)
- Honorary Professor Beijing Normal University, China (van Lenteren)
- Honorary Professor University of Perugia, Italy (van Lenteren)
- International Organisation for Biological and Integrated Control of Noxious Animals and Plants (IOBC-IUBS) (2004-2008) (van Lenteren, President)
- International Congress of Entomology, Council (1998-2008) (Takken, secretary-treasurer)
- International Organization for Biological and Integrated Control of Noxious Animals and Plants, West Palearctic Regional Section (IOBC-WPRS), council member (van Lenteren)
- International Organization for Biological Control, IOBC, Steering Committee Working Group 'Induced Resistance' (Dicke)
- International Project *Convergence of Sciences* for better integrated soil and crop management, executed in Benin and Ghana (Van Huis, coordinator)
- International Symposium TERPNET 2005, Wageningen, April 2005, Local Organisation Committee (Dicke)
- International Working Group on Mediators of Bloodfeeding Arthropods (Takken, secretary)
- Measuring Behaviour 2005 -5th International Conference on Methods and Techniques in Behavioural Research- Scientific Program Committee (Vet, chair; Dicke member)
- OECD working group Regulation of Import and Release of Exotic Natural Enemies (van Lenteren)
- Panel of Experts on Environmental Management of Vectors (PEEM), WHO, Geneva (Takken)
- PhD examination committees at international university (van Lenteren, Vet)
- 'Professeure associée' at Laval University, Quebec, Canada (Vet)
- Selection Committee Professorship in Ecology, University of Bayreuth, Germany (Dicke)
- Visiting Professor, Institute of Zoology, Chinese Academy of Sciences, Beijing, China (van Loon)

National:

- Biological advisory board, Biologische Raad, KNAW (Vet)
- Board for the Authorisation of Pesticides "CTB" (van Lenteren).
- Board NWO Darwin Centre for Biogeology (Vet)
- Board of 'Landbouwexport fonds 1918', Wageningen (Dicke)
- Board Uyttenboogaart-Eliasen foundation (van Lenteren).
- Board Van Groenendael-Krijger fund (van Lenteren).
- Board National Science Museum (NEMO) (Vet)
- Committee on Functional Agrobiodiversity of LTO (van Lenteren)
- Committee on Genetic Modification (COGEM), Ministry of Environment (Dicke)
- Committee 'Studium Generale' of Wageningen University, involved in extracurricular teaching (Dicke)

- Department of Plant Sciences, Wageningen University, advisory committees and working groups (Dicke)
- Dutch Entomological Society (van Lenteren, vice-president).
- Dutch Entomological Society, Section Experimental and Applied Entomology (SETE-NEV) (de Jong, secretary).
- Earth and Life Sciences council of the Netherlands Organization for Scientific Research (Vet, Dicke)
- Evaluation Committee Eduweb/Educlass, Wageningen University (Dicke)
- International Conference on Agricultural Development (ICAD) of the Royal Netherlands Society for Agriculture (KLV) (van Huis, member)
- Graduate School Production Ecology & Resource Conservation, Scientific Advisory Board, (Vet).
- Graduate School of Production Ecology & Resource Conservation, Educational Committee (Takken, chairman).
- Graduate School of Production Ecology & Resource Conservation, Scientific Committee (van Huis).
- Hollandsche Maatschappij der Wetenschappen (Vet, van Lenteren)
- Institute of Biology Leiden University, Advisory Council (Vet)
- IUCN Netherlands, advisory committee (Vet)
- Jury Prins Bernhard Cultuurfonds, Prize for Nature Conservation (Vet)
- Library committee, Centre for Crop Protection, Wageningen University (de Jong)
- Policy Advice Committee of National Science Foundation ALW (Beleids Advies Commissie ALW) (Dicke)
- Member several PhD Examination committees (Dicke, van Loon, van Huis, van Lenteren, Takken, Vet)
- Ministry OCW on restructuring higher education (OCW-Profielcommissie N&T/N&G), advisory committee (Vet)
- National Graduate School Experimental Plant Sciences, Scientific Advisory Board (Dicke).
- National Graduate School Experimental Plant Sciences. Education committee (Dicke, chairman).
- National Graduate School Experimental Plant Sciences. Scientific Committee (Dicke).
- National Committee on the Prevention of Head Lice Infections, Ministry of Public Health (Takken)
- Natural History Museum Naturalis, Supervisory Board (Raad van Toezicht) (Vet)
- Netherlands Science Foundation (NWO), Selection committee VENI grants (Dicke)
- Noorderlicht VPRO (popular scientific radio programme), Scientific Advisory Board (Vet)
- Organising Committee of workshops of NWO Stimulation Program Biodiversity (Potting)
- Organising Committee Brassica 2006 – 15th Crucifer Genetics Workshop, September 30 – October 4, Wageningen (van Loon)
- Project Enhanced Biodiversity, Alterra, Laboratory of Entomology, Laboratory of Phytopathology, Laboratory of Plant Ecology and Weed Science (van Lenteren, coordinator)
- Royal Netherlands Academy of Arts and Sciences. (van Lenteren, Vet)
- Royal Netherlands Academy of Arts and Sciences, The Young Academy (Knols)
- Teylers Tweede Genootschap, Teylers Museum, Haarlem (Vet)
- User committee Brassica – role of surface waxes in resistance against diseases and pests (van Loon)
- Wageningen Plant Sciences Group-Wageningen UR-Expertise-unit Biointeractions and Health (Dicke, coordinator)
- Wageningen University, Biointeractions Laboratories within Department of Plant Sciences (Dicke, coordinator)

Journals:

- Animal Biology, special issue on learning in insects (Vet, Smid, guest editor)

- Annual Review of Entomology (Vet, editorial board)
- Biochemical Systematics and Ecology (Dicke, editorial board).
- Biological Control: Theory and Application in Pest Management (van Lenteren, editorial board)
- British Ecological Society's Symposium Series (Vet, advisory editorial board)
- Chemoecology (Vet, associate editor)
- Ecological Entomology (Dicke, editorial board)
- Entomologia Experimentalis et Applicata (co-editor, van Loon).
- Entomological Bulletin Guido Grandi, University of Bologna (van Lenteren, editorial board)
- Evolutionary Ecology (de Jong, editorial board)
- European Journal of Entomology (de Jong, editorial board)
- Insect Science (Dicke, editorial board)
- International Journal of Pest Management (van Lenteren, editorial board).
- International Journal of Tropical Insect Science (van Huis, editorial board)
- IOBC bulletins (van Lenteren, editor).
- IPM practitioner (van Lenteren, editorial board).
- Journal of Chemical Ecology (Dicke, editorial board).
- Journal of Ethology (Dicke, advisory board).
- Journal of Insect Behaviour (van Lenteren, Vet, editorial board).
- Neotropical Entomology (van Lenteren, editorial board)

PROJECTS FUNDED EXTERNALLY

- **2000–2005** Functional biodiversity: strategic use of nectar and pollen sources to boost biological control. Funded by Robert Bosch Foundation.
- **2000-2005** Mode of action of sex modifying supernumerary chromosomes. Funded by NWO-ALW.
- **2000-2005** Identification of human volatiles as attractants for *Anopheles gambiae sensu stricto*. In collaboration with the Laboratory of Organic Chemistry, Wageningen University. Funded by Technology Foundation (STW).
- **2000-2005** Chemical ecology and management of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) Funded by IITA.
- **2000-2005** Host-plant selection in *Helicoverpa* moths. Collaborative project with Institute of Zoology, Chinese Academy of Sciences, Beijing, China. Funded by Koninklijke Nederlandse Akademie van Wetenschappen, KNAW)
- **2000–2005** Learning-related differences in olfactory information processing in two closely related parasitic wasps: phenotypic plasticity analysed from behaviour to neuron. Funded by NWO/ALW.
- **2000-2006** Convergence of Science: inclusive innovation technology processes for better integrated soil and crop management. (Funded by INREF and DGIS)
- **2001-2005** Evaluation of the biological control capacity of Eretmocerus spp for the control of whiteflies on Gerbera. Funded by the Ministry of Agriculture of the Islamic Republic of Iran.
- **2001-2005** Induced indirect plant defence and plant fitness: testing the "evolutionary enlistment" hypothesis. Funded by NWO/ALW.
- **2001-2005** Convergence of sciences: inclusive technology innovation processes for better integrated crop and soil management. Funded by International Research and Education Fund (INREF) and Directorate General of International Cooperation (DGIS) of the Netherlands' Ministry of Foreign Affairs.
- **2001-2006** Genomics approach to integration of host plant insect resistance and biological control. (Funded by Dutch and Chinese government.**)**
- **2001-2006** Cross-talk between signal-transduction pathways in induced defence of Arabidopsis against microbial pathogens and herbivorous insects. Funded by NWO/ALW.
- **2001-2007** Development of a method for breeding of cucumber for improved attraction of biological control agents. Funded by Technology Foundation (STW).
- **2002-2005** Learning-related differences in olfactory information processing in two closely related parasitic wasps; phenotypic plasticity analysed from behaviour to neuron. (Funded by NWO/ALW)
- **2002-2006** The contribution of landscape elements to natural pest control (Financed by Univ Bologna)
- **2003-2005** Phloem located resistance to the aphid *Aphis gossypii* in accession "TGR-1551". Funded by Director General de Universidades (Spanish Government).
- **2003-2006** EU-FIPSE Transatlantic Exchange Program in Higher education on Sustainable Crop Protection (SUSPROT) Funded by EU.
- **2003-2007** Temperature distribution in shallow water bodies: Influence of abiotic factors on the population dynamics of immature stages of African malaria vectors. Funded by WOTRO.
- **2004-2007** Molecular characterisation of mechanisms of *Solanum* resistance to *Myzus persicae* - Impact on PLRV transmission. Funded by Alβan-EU.
- **2004-2008** Linking variation in plant defence to higher level biodiversity. Experimental Plant Sciences, Strategic Funds. (collaboration between Entomology, NIOO and Plant Research International).

- **2004-2008** Spatio-temporal modelling of infochemicals in a food-web context. Funded by NWO-ALW (collaboration with Mathematical and Statistical Methods Group)
- **2004-2008** Ethnobotanicals for the control of *Ripicephalus appendiculatus*, the vector of East Coast Fever in East Africa. Funded by Wageningen University, IFS and ICIPE.
- **2004-2008** Effect of agro-ecological conditions and banana crop management of efficacy and persistance of Beauveria bassiana for control of the banana weevil in Uganda. Funded by Wageningen University, Rockefeller foundation and IITA.
- **2004-2008** Assessing the contribution of Farmer Field School approach to the management of cassava, soil and family health and its role in food security in Malawi. Funded by JICA.
- **2004-2008** Crop protection perspectives in Kazakhstan: shifting interfaces between farmer practice and agricultural research. Funded by WUR and Govt. of Kazakhstan.
- **2004-2008** Interactions among leafhopper vector populations, maize streak virus disease, agro-environments and soil fertility. Funded by WOTRO.
- **2004-2009** A molecular genetic approach to chemical ecology and community ecology. Funded by NWO-VICI.
- **2004-2009** Behavioural and ecological determinants of gene flow in African malaria vectors. Funded by NWO-VIDI.
- **2004-2009** Ecological and physiological functions of biogenic isoprenoids and their impact on the environment (ISONET). Funded by EU.
- **2005-2006** Behaviour, anatomy and sensory physiology of chemosensillae in parasitoids. (Financed by Univ Ancona)
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