



Research on biopesticides at INRA, France

Marc Bardin, Philippe C. Nicot

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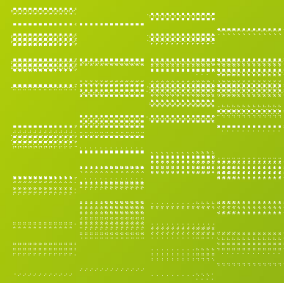
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INRA
SCIENCE & IMPACT

Research on Biopesticides at INRA, France

Marc BARDIN and Philippe NICOT
Plant Pathology
INRA PACA – Avignon - France

Biopesticides

US (www.epa.gov/pesticides/biopesticides)

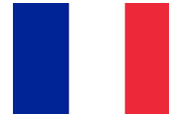
- naturally occurring **substances** (biochemical pesticides),
- **microorganisms** (microbial pesticides),
- **pesticidal substances produced by plants** containing added genetic material (plant-incorporated protectants) or PIPs

EU

- No formal definition of biopesticides exists at the European level
- Regulation (EC) No. 1107/2009 = natural substances + micro-organisms

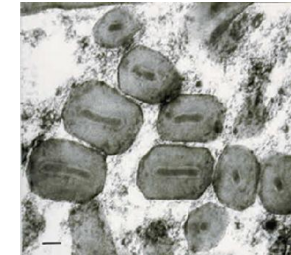
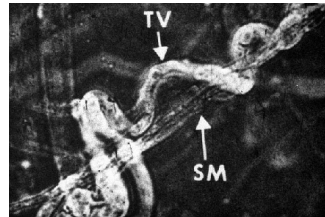
(Villaverde et al. 2014. Pest Manag Sci. 70: 2–5)

'Biocontrôle'

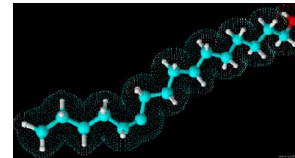


Biocontrol

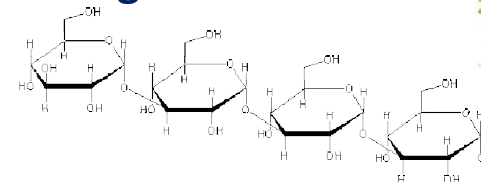
- Microorganisms : fungi, oomycetes, bacteria, virus



- Chemical mediators : pheromones



- Natural substances of mineral, plant or animal origin



Biocontrol

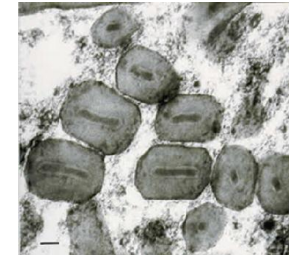
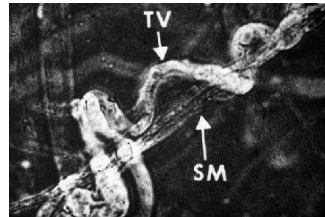
- Macroorganisms: vertebrates, invertebrates, nematodes, etc.



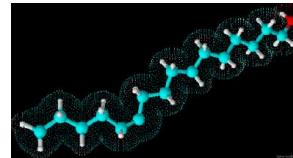
Biopesticides

Biopesticides

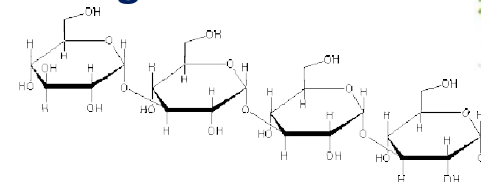
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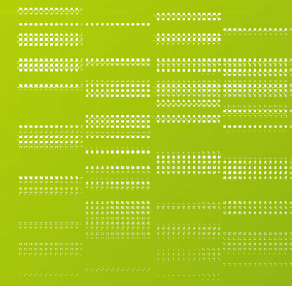


- Natural substances of mineral, plant or animal origin



- Macroorganisms: vertebrates, invertebrates, nematodes, etc.



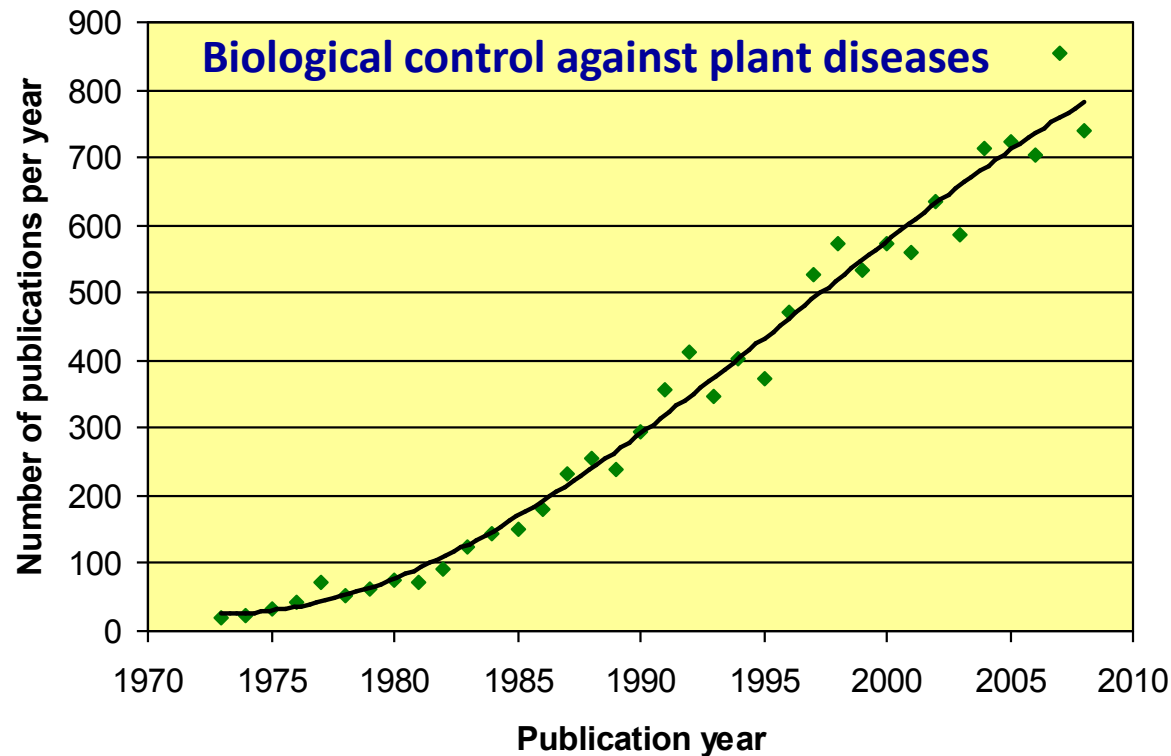


01

Biopesticides: research and development

Biopesticides

→ Much research on biopesticides

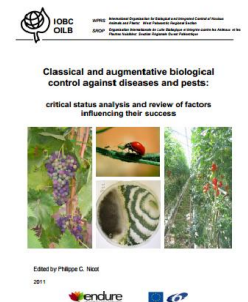


> 13000 pub (1965-2016)
Web of Science (22/04/2016)



Nicot et al, 2011

http://www.iobc-wprs.org/pub/biological_control_against_diseases_and_pests_2011.pdf



Biopesticide 2016 – London 28/04/2016

Biopesticides

- ➔ Much research on biopesticides
- ➔ Significant number of biopesticides shown to be efficient in laboratory conditions

- **157 species of microorganisms** described as effective against five major airborne plant diseases, *Botrytis*, powdery mildew, rusts, downy mildews (+ *Phytophthora infestans*) and Brown rot
- **29 fungal/oomycetes species** and **18 bacterial species**: significant effect in the field to control one of the 5 major diseases

➔ **Many resources in labs !**



Nicot et al, 2011

http://www.iobc-wprs.org/pub/biological_control_against_diseases_and_pests_2011.pdf



Biopesticide 2016 – London 28/04/2016

Biopesticides

- ➔ Much research on biopesticides
 - ➔ Significant number of biopesticides shown to be efficient in laboratory conditions
 - ➔ Still few products registered for use
- **44 microorganisms** commercially developed in the world :
25 fungi/oomycetes + 14 bacteria/actinomycetes + 5 virus
- against plant pathogens

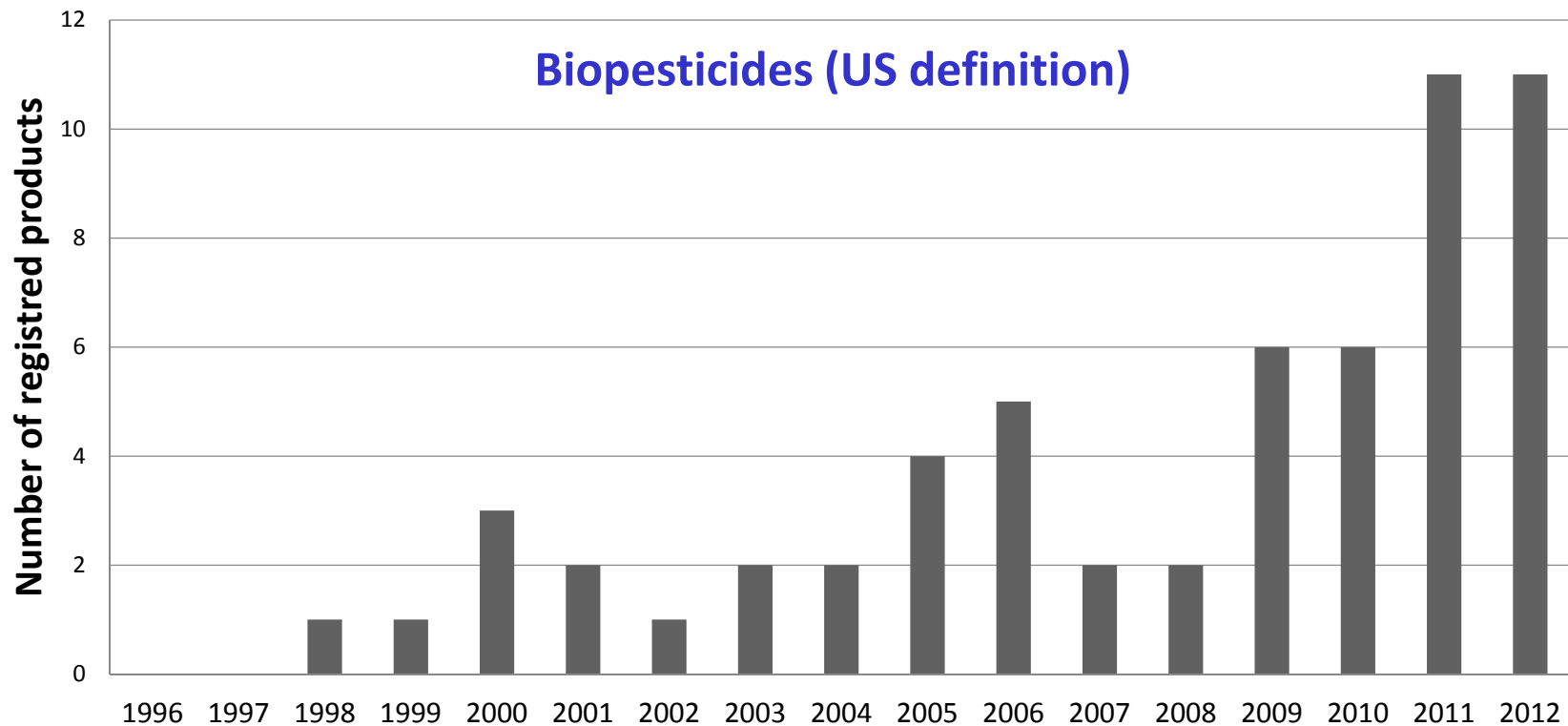


Gwynn, 2014. *Manual of Biocontrol agents*

Biopesticides

- ➔ Much research on biopesticides
- ➔ Significant number of biopesticides shown to be efficient in laboratory conditions
- ➔ Still few products registered for use

U.S. Environmental Protection Agency (<http://www.epa.gov/>)



Biopesticides

- ➔ Much research on biopesticides
- ➔ Significant number of biopesticides shown to be efficient in laboratory conditions
- ➔ Still few products registered for use

microbial strains included under Regulation 1107/2009 : listed in EU Pesticide Database

<http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=homepage&language=EN/>

Status on 26/4/2016

24 microbial strains against pathogens

14 fungi/oomycetes + 8 bacteria/actinomycetes + 2 virus



PLANTS

EU Pesticides database

Status on 26/4/2016

<i>Coniothyrium minitans</i>	2004	18	AT BE CZ DE DK EL ES FR HU IE IT LU NL PL PT SE SK UK
<i>Pseudomonas chlororaphis</i>	2004	14	AT BE DE DK ES FI FR IT LT LU NL PT SE UK
<i>Ampelomyces quisqualis</i>	2005	12	BE CY DE DK EL ES FR IT LU NL SI SK
<i>Gliocladium catenulatum</i>	2005	13	AT BE CY DE DK EE ES FI FR IE NL SE UK
<i>Bacillus subtilis</i> QST 713	2007	17	AT BE CY DE DK EL ES FI FR IE IT LU NL PL PT SI UK (+ CZ SE)
<i>Phlebiopsis gigantea</i>	2009	9	DK EE FI FR LT LV PL SE UK
<i>Pythium oligandrum</i>	2009	4	CZ FR HU PL SK (+ AT UK)
<i>Streptomyces sp.</i> K61	2009	13	BE CY EE ES FI FR HU IT LT LV NL SE UK (+ AT UK)
<i>Trichoderma aspellerum</i> (3)	2009	4	DE EL ES FR IT (+ PT)
<i>T. atroviride</i> IMI 206040 + T11	2009	2	IT SE
<i>T. gamsii</i> ICC080	2009	5	DE EL ES FR IT (+ PT)
<i>T. harzianum</i> T22 + ITEM 908	2009	7	BE DK FR NL SE SK UK (+ IE)
<i>T. polysporum</i> IMI 206039	2009	1	SE?
<i>Verticillium albo-atrum</i>	2009	1	NL SE (+ UK)

24 microbial strains against pathogens

14 fungi/oomycetes + 8 bacteria/actinomycetes + 2 virus



PLANTS

EU Pesticides database

Status on 26/4/2016

<i>Candida oleophila</i> strain O	2013	1	UK (+ AT HU NL)
<i>Trichoderma aspellerum</i> T34	2013	1	UK
<i>T. atroviride</i> I-1237	2013	1	FR
Zucchini Yellow Mosaik Virus, weak strain	2013	1	FR
<i>Aureobasidium pullulans</i> (2)	2014	12	AT BE DE EL HU IT NL PL PT SI SK PL
<i>Bacillus pumilus</i> QST 2808	2014	2	FR
<i>Pseudomonas sp.</i> DSMZ 13134	2014	3	AT NL SE (+ CZ IE)
<i>Bacillus amyloliquefaciens</i>	2015	1	IT
Pepino Mosaic Virus CH2 1906	2015	1	BE (+ AT CZ NL)
<i>Streptomyces lydicus</i>	2015	?	?

9 additional microbial strains with "pending" status against pathogens

Status on 26/4/2016

<i>Bacillus amyloliquefaciens</i> ^{AH2}	pending
<i>B. amyloliquefaciens</i> ^{MBI 600}	pending
<i>B. amyloliquefaciens</i> ^{FZB24}	pending
<i>B. subtilis</i> ^{IAB/BS03}	pending
<i>Fusarium sp.</i> ^{L13}	pending
<i>Pseudozyma flocculosa</i> (dossier soumis en 2002 !)	pending
<i>Saccharomyces cerevisiae</i> ^{LAS02}	pending
Mild Pepino Mosaic Virus ^{VC 1}	pending
Mild Pepino Mosaic Virus ^{VX 1}	pending

Biopesticides

- ➔ Much research on biopesticides
- ➔ Significant number of biopesticides shown to be efficient in laboratory conditions
- ➔ Still few products registered for use

microbial strains included under Regulation 1107/2009 : listed in EU Pesticide Database

<http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=homepage&language=EN/>

Status on 26/4/2016

- 24 against **pathogens** (+ 9 with "pending" status)
- 13 against **insects** (+5)
- 2 against **nematodes** (+1)

Biopesticides

- ➔ Much research on biopesticides
- ➔ Significant number of biopesticides shown to be efficient in laboratory conditions
- ➔ Still few products registered for use


In France (<https://ephy.anses.fr/>)

14 microorganisms: 8 fungi, 5 bacteria, 1 virus
4 plant extracts

against plant pathogens

Example of products registered in France (<https://ephy.anses.fr/>, 25/04/2016)

Microorganisms



Bacillus thuringiensis, *Helicoverpa armigera*
nucleopolyhedrovirus
(herbivorous caterpillars, coleoptera)
Lecanicillium muscarium, *Paecilomyces fumosoroseus*
(whitefly)
Bacillus firmus
(nematodes)
Trichoderma harzianum
(biofungicide/soil treatment)
Bacillus subtilis
(bacteria + *Botrytis cinerea*/elicitor)
Gliocladium catenulatum
(*Didymella*, *Botrytis*, *Sclerotinia*, damping off)
Ampelomyces quisqualis
(powdery mildew)



Bacillus thuringiensis
(phytophagous Coleoptera)



Pseudomonas chlororaphis
(biofungicide/seed treatment)

Natural substances

Orange oil
(whiteflies)
Spinosad
(herbivorous caterpillars, thrips)
Potassium hydrogen carbonate
(powdery mildew)

Spinosad
(phytophagous Coleoptera)
Paraffin oils
(virus)
Spearmint oil
(antigerminative)

Laminarin
(powdery mildew, Septoria/elicitor)

Biopesticides

- Much research on biopesticides
- Significant number of biopesticides shown to be efficient in laboratory conditions
- Still few products registered for use

→ Considerable scientific and industrial investments still necessary for the development and commercialization of products.



02

National Action Plan « Ecophyto »

National Action Plan "Ecophyto"

→ Ambitious policy for the reduction of pesticide use in France

Biocontrol Roadmap (april 2011)

12 measures proposed by the Ministry of Agriculture
(covering 4 priorities)

1. Encourage farmers to use biocontrol for the protection of their crops,
2. Innovate for the development of new safe and effective methods,
3. Promote the marketing of biocontrol products,
4. Better inform and follow the development of their use.



→ framework agreement established and signed by the Ministry of Agriculture, the Ministry of Ecology and by 21 stakeholders



National Action Plan "Ecophyto"

➔ Ambitious policy of reduction of pesticide use in France



➔ Stimulate scientific research for the development of innovative biocontrol tools for agriculture, including biopesticides.

= Funding of scientific projects, fostering collaboration between academia and the biopesticide industry

Biocontrol: a strong challenge for Ecophyto

➔ **Forum on biocontrol** (Paris, april 2014)
under the aegis of Ministry of Agriculture

4 conferences

- Inventory of the biocontrol industry
- Introducing regulations for biocontrol products
- Actions taken under the Plan Ecophyto
- Perspectives of biocontrol in the future Law

4 workshops

1. **Specific needs for research and development** and training tools necessary on biocontrol products
2. Valorisation and support to SMEs for innovation, development and export of biocontrol products
3. Biocontrol solutions for Overseas
4. How to tackle the problem of non-agricultural areas?



<http://agriculture.gouv.fr/mardi-22-avril-forum-biocontrôle-la-cite-des-sciences-et-de-lindustrie>





03

Research for the development of biocontrol

Biocontrol: significant research needs

- ➔ Identification and prioritization of research needs (consultation)
- ➔ Call for research projects: "PSPE2 - contribute to the development of biocontrol" (January 2014)

Four main issues:

 LIBERTÉ • ÉGALITÉ • FRATERNITÉ RÉPUBLIQUE FRANÇAISE MINISTÈRE DE L'AGRICULTURE DE L'AGROALIMENTAIRE ET DE LA FORÊT	Appel à projets de recherche « Pour et Sur le Plan Ecophyto » PSPE 2 - Edition 2014 : Contribuer à l'essor du biocontrôle	 ÉCOPHYTO RÉDUIRE ET AMÉLIORER L'UTILISATION DES PHYTOS
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1. Facilitate and encourage the **use** of biocontrol by farmers .
2. Evaluate and improve the **reliability** of the biocontrol products to control pests and characterize their side effects.
3. Develop **integrated pest management strategies** promoting the contribution of biocontrol.
4. Expand the **range of methods and products available** to provide biocontrol solutions to a greater variety of uses.

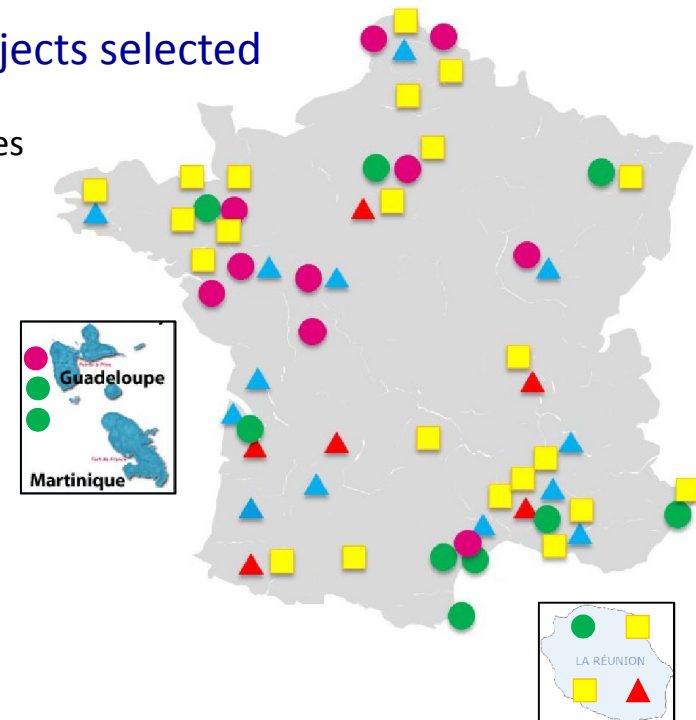
Call for research projects: "PSPE2 - contribute to the development of biocontrol"

→ Strong mobilization of the research and development communities

- 72 letters of intent received in response to the call for proposals
- great potential of R & D at the national level
- diverse partnerships

Research Unit participating in the 19 projects selected

- 10 ▲ Technical and interprofessional institutes
- 13 ▲ Regional experimental stations
- 22 ■ Private companies
- 18 ● Research Institutes (INRA, CIRAD)
- 12 ● Universities, higher education in Agronomy

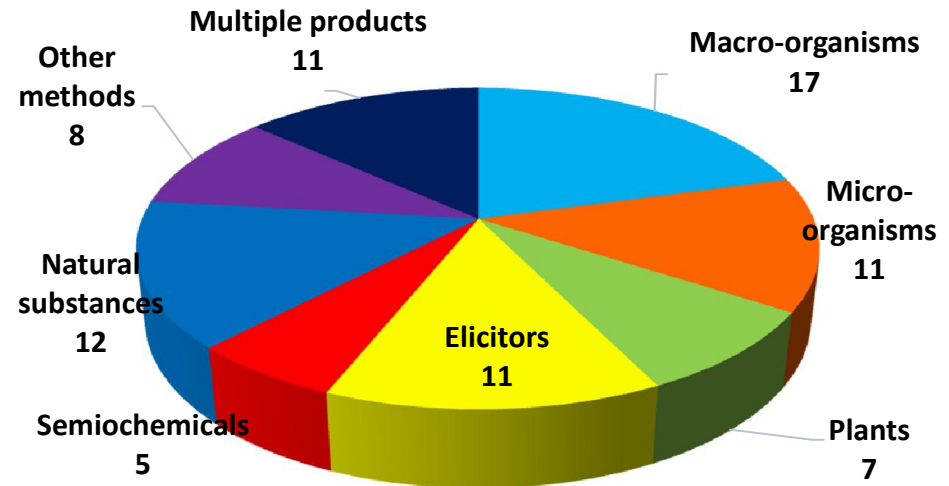


- 10 of 19 projects combine public research, R&D institutes and private companies

Call for research projects: "PSPE2 - contribute to the development of biocontrol"

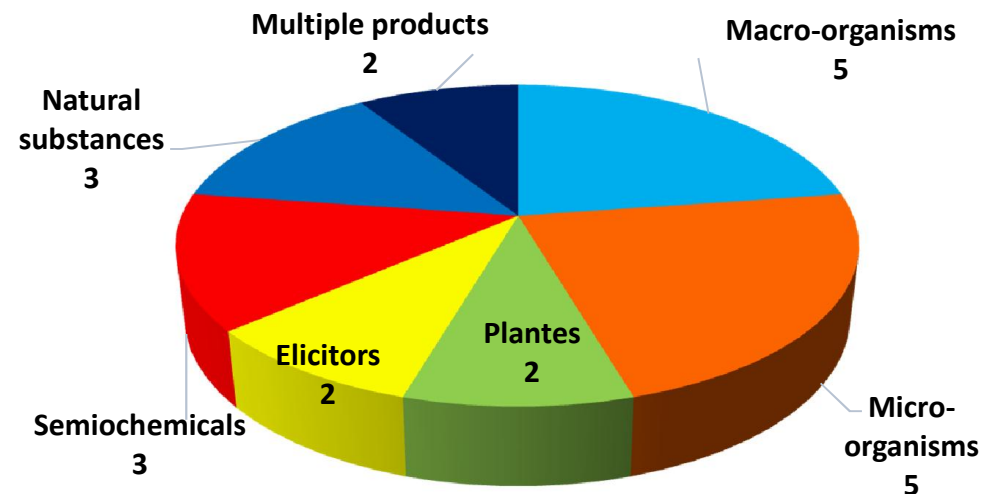
→ Wide range of biocontrol methods present in the projects

Letters of intent



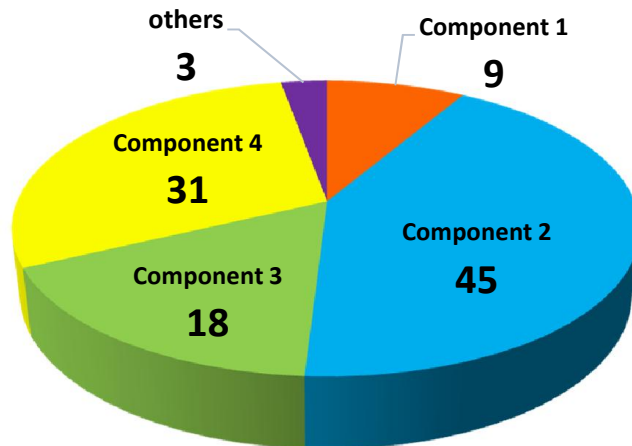
Selected projects

diversity of expertise available
at the national level



Call for research projects: "PSPE2 - contribute to the development of biocontrol"

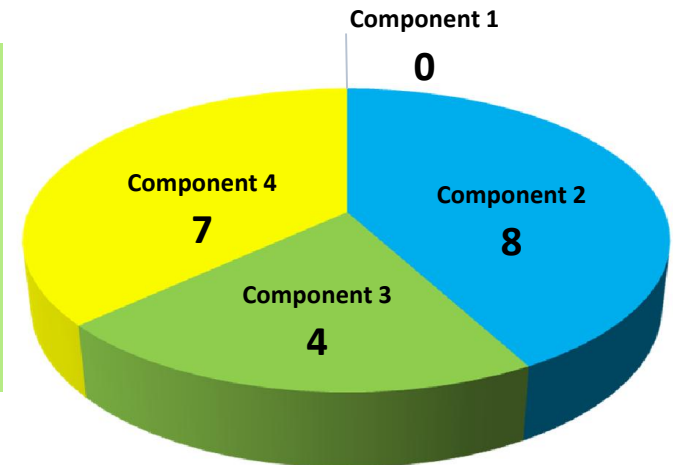
Letters of intent



Component of the call

1. Facilitate and encourage use
2. Evaluate and improve reliability
3. Develop integrated pest management strategies
4. Expand the range of methods and products available

Selected projects



➔ interest in the development of new biocontrol tools (Component 4)

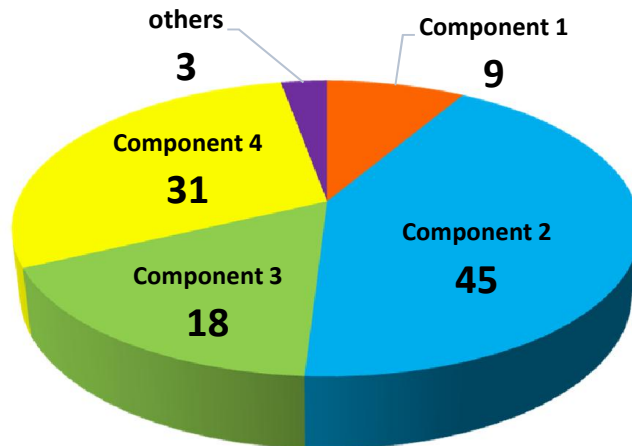
➔ potential innovations available for farmers at medium to long term

➔ interest in the evaluation and improvement of the reliability of biocontrol methods (Component 2 – involvement of technical institutes)

➔ potential practical solutions in the shorter term
(existing biocontrol methods or imminent development)

Call for research projects: "PSPE2 - contribute to the development of biocontrol"

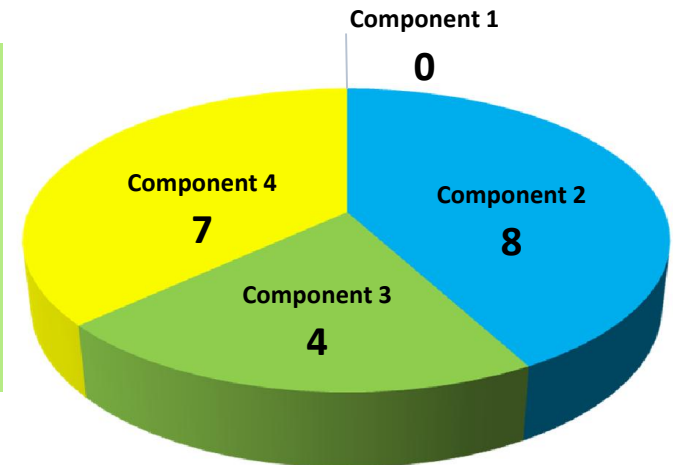
Letters of intent



Component of the call

1. Facilitate and encourage use
2. Evaluate and improve reliability
3. Develop integrated pest management strategies
4. Expand the range of methods and products available

Selected projects



➔ Some weaknesses revealed by this call

1. Some aspects little or not considered

- Component 1: not the main focus of research projects aimed at removing obstacles - rather limited to demonstration proposals
- Component 3: insufficiently addressed

Call for research projects: "PSPE2 - contribute to the development of biocontrol"

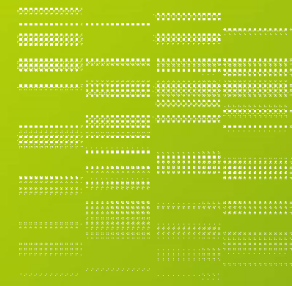
→ Some weaknesses revealed by this call

1. Some aspects little or not considered

2. A bias in the objects of study in relation to the priorities of Ecophyto

- The crops that use the largest amount of pesticides (viticulture, arboriculture) only account for 1/3 of letters of intent and selected projects
- Fungal diseases and weeds are targeted by less than 1/3 of letters of intent and selected projects

→ necessity to interact more directly with private companies
public-private consortium on biocontrol



04

Consolidate the French biocontrol industry

Public-private consortium on biocontrol



- ➔ Priorities of the "Agriculture-Innovation 2015" plan
(announced 20 February 2015, Minister for Education, Minister for Agriculture)



- ➔ Coordinate actors in biological control with the dual objective of:
- offering farmers alternatives to plant health products,
 - consolidating the French biocontrol industry.
- ➔ **Objective:** at the horizon of 2020, increase the share of biocontrol to 15% of the French crop protection market (5% at present), and multiply four-fold the jobs offered by this industry

Public-private consortium on biocontrol



Partners in the consortium include:

- Research actors: **INRA** (National Institute for Agricultural Research) and CIRAD (Agricultural Research for Development)
- Research and Development actors: ACTA (Network for Innovative Research in Agriculture)
- Ministry for Agriculture, the Food Industry and Forestry/Directorate General for Food (MAAF)
- Professional association: IBMA France (International Biocontrol Manufacturers' Association - France)
- 8 Industrial companies

➔ Result in call for research projects combining public research, R&D institutes and private companies



05

French Research and development network

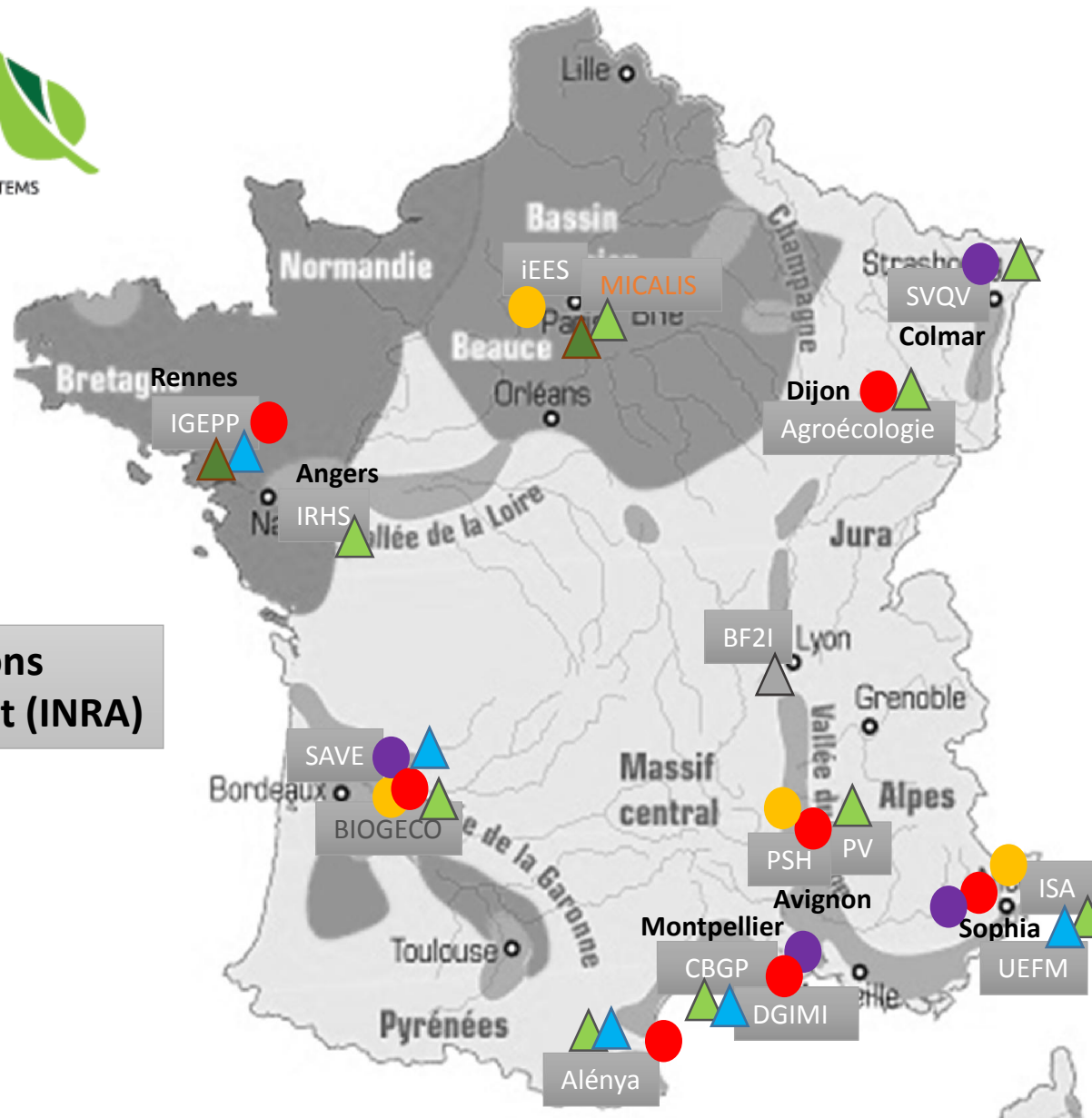
French Research and development network

Ecological Management of Bioagressors in Agroecosystems (INRA, 2013)

- Inventory of actors and research
 - INRA teams



French Research and development network



Crops

- Vegetables
- Fruits
- Vineyard

Biocontrol

- ▲ Macro
- ▲ Micro
- ▲ Pheromones
- ▲ Nat. Subst.

**~80 persons
15 research unit (INRA)**

French Research and development network

Ecological Management of Bioagressors in Agroecosystems (INRA, 2013)



- Inventory of actors and research

- INRA teams
- Researchers from other institutes and from universities
+ existing or potential collaborations
- Industrial partners + existing or potential collaborations

=> directory (web interface)

<https://www6.inra.fr/emba>

- Scientific animation and prospective

- thematic meetings: overview of research
- exchange meetings with the profession (industry, technical institutes)
=> inventory of needs
- Synthesis + proposals by working groups

French Research and development network

Two other networks involved in biopesticides research

Induced Resistance network (INDRES, INRA 2011)

- Platform for academic exchanges
(public research laboratories: INRA, CNRS, Universities)

Integrated French network promoting plants protection by induced resistance

- Understand, develop and promote the enhancement of plant resistance by elicitor treatments
- Interactions between academic research – applied research organization – regional experimental stations



<http://elicitra.org/>

French Research and development network

Various aspects of biopesticides research:

- develop new products,
- understand the determinants of their efficacy,
- acquire knowledge on their mode of action,
- anticipate their potential failure and carefully manage their use once they become commercially available

French Research and development network

→ Some 'success stories'

AntiBot®



→ Potential for interdisciplinary approach
important for IPM



06

Develop international collaborations

International collaborations

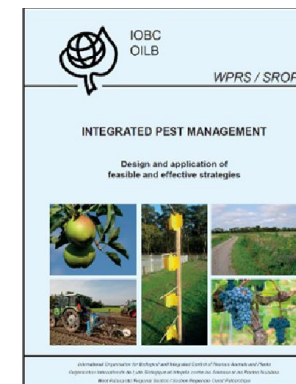
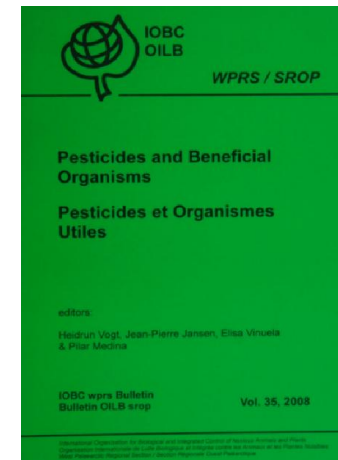
- ➔ Concerted actions and collaborations expected at an international level
- ➔ R & D biocontrol community very active and highly structured by IOBC-wprs and European networks coordinated by INRA

IOBC

(International Organisation for Biological and integrated Control)

- 20 working groups
- 5 commissions
- 10 meetings per year
- 12 Bulletins IOBC-WPRS per year
- Peer reviewed scientific journal
- Books and leaflets

www.iobc-wprs.org

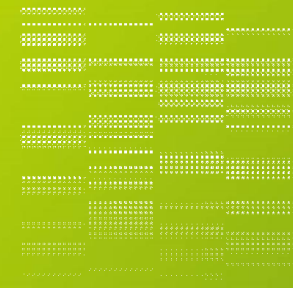


International collaborations

- ➔ R & D community very active and highly structured by IOBC and European networks coordinated by INRA
- ➔ Concerted actions and collaborations expected
- ➔ Participation in research projects funded by Europe (H2020)

Examples of IPM projects





07

Conclusion - Perspectives

Conclusion

- Many aspects of research developed
- Many researchers involved in different aspects of biocontrol in France
- Development of research networks
- Interactions consolidated between public research and private actors (in progress)

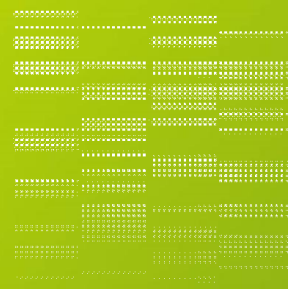
Perspectives

➔ need for more interactions between:

- scientific fields (including the socio-economics)
- “applied” research and “academic” research
- INRA research teams and private partners (industry + institutes and agricultural sectors)

➔ challenges and needs for innovation

- develop new biopesticides: lack of products, some aspects little or not developed (eg bioherbicides)
- stabilize their efficacy in the field
 - Strategies of screening
 - Formulation and application techniques
 - Knowledge of the modes of action
 - Are biopesticides likely to be more durable than chemicals ?
- IPM strategies: workshops on the integration of biocontrol
 - ➔ development of Decision Support System
- socio-economics aspects



Thank you