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WORKING MATERIAL

CONSULTANTS GROUP MEETING ON

Improvement of Codling Moth SIT to Facilitate Expansion of Field Application

VIENNA, AUSTRIA

16 - 20 OCTOBER 2000

CONTENTS

I. Executive Summary

SIT currently has only limited application in Lepidoptera control. Prospects for improvement of the technique however are good, and the species with the best immediate prospect is the codling moth (*Cydia pomonella*).

Codling moth is the key pest of most apple and pear orchards in the world and the cause of intensive insecticide use during the whole fruiting season. As a result of increasing development of insecticide resistance in codling moth, the banning of essential insecticides, as well as public concerns about the environment and food safety, the Subprogramme continues to receive enquiries from a number of countries as to the applicability of SIT as a suppression method for this species.

SIT is currently used as part of areawide codling moth control in British Columbia, Canada and in the border area with Washington State, USA. The SIT can be integrated with a number of other techniques, including mating disruption as in the trial in Washington State. The Canadian programme is co-funded by growers, local and national government. The programme is proving effective at controlling the moth in an environmental friendly way. Currently the programme is only financially attractive with government subsidy although in view of the replacement of insecticide use with SIT, growers will be able to access the rapidly growing and very lucrative market for organic fruit.

A new CRP is proposed with the objective of improving the efficiency of all stages of the SIT for codling moth. This will cover reducing the cost of production, product and process quality control, genetic sexing, strain compatibility and field monitoring among others.

II. Background

a) The Problem

Codling moth (*Cydia pomonella*) is the key pest of most apple and pear orchards in the world (see World Pome Fruit Production Statistics in Annex 3). It is the cause of intensive insecticide use during the whole fruiting season. As a result of increasing development of insecticide resistance in codling moth, lowering of acceptable residue levels and even the banning of essential insecticides, as well as public concerns about the environment and food safety, the Sub-programme continues to receive enquiries from a number of countries as to the applicability of SIT for this species.

A codling moth SIT programme was initiated in British Columbia, Canada in 1994, co-funded by growers, property owners in the community, the provincial government and the federal government. A mass-rearing facility was built which now produces 15 million moths per week. After several years of operation, and in spite to some initial failures, most growers in the SIT programme area now report no damage and no longer have to spray against the codling moth. Where the management of other insect pests during the fruiting period can be achieved using biological control methods, the produced fruit can be classed as 'insecticide-free fruit' and probably obtain a better-than-normal return in the marketplace. Even the creation of a pest-free area is feasible if so desired, with the establishment of quarantine measures to prevent the reintroduction of the pest.

At present the SIT approach to codling moth management may still require a subsidy from the community at large and higher levels of government to keep the cost to growers within reason.

The resulting relatively low cost to growers is competitive with insecticide cost and areawide pheromone mating disruption, another promising areawide technology. There is a great potential for the application of codling moth SIT, both for suppression or for eradication purposes, since there are a number of promising research areas that can advance SIT's applicability and cost-efficiency:

a) development of a genetic sexing strain;
b) use of F_1 sterility during part of the fruiting season;
c) use of diapause induction for stockpiling and for the development of new release strategies;
d) use of virus resistant strains;
e) use of transgenesis to introduce genetic markers;
f) combining the SIT with other control tactics, e.g. pheromone mating disruption, release of parasitoids, insecticide (including IGR) treatments and tree banding;
g) aerial chilled-moth release systems and the competitiveness of the released moths;
h) benefits from releasing only sterile males instead of both sexes;
i) development of a trap to catch female moths, and
j) development of a method to assess the percent sterile matings in the field between wild females and sterile males.

b) Explanation of SIT

Since the 1950's it is known that insect pests can be controlled or eradicated through a "birth control" method based on genetic manipulation know as autocidal pest control or the Sterile Insect Technique (SIT). It involves the colonization and mass rearing of the target pest species, sterilization through the use of gamma radiation and releasing them into the field on a sustained basis and in sufficient numbers to achieve appropriate sterile to wild insect over flooding ratios. Here the sterile males find and mate with fertile females, transferring sterile sperm. No offspring results, thereby causing a reduction in the natural pest population. The validity of this method has been demonstrated for many insect pests, including moths, screwworms, tsetse and fruit flies.

c) Need for Nuclear Technology

Sterilization is accomplished by exposing insects to a specific dose of gamma radiation emitted by radioisotopes (Cobalt-60 or Caesium-137). No other methods are available or appropriate to achieve sterilization. Chemosterilants carry a high risk of environmental contamination and pose serious health concerns. Linear accelerators have not shown sufficient applicability and reliability in consistently achieving the desired level of sterility.

Nuclear technology has not only a comparative advantage in sterilizing mass reared insects, but is, at present, the only technology available for this purpose. As every single insect used in SIT activities must to be sterilized, irradiation is a central and indispensable part of the total process.

d) Integration of Nuclear and Non-Nuclear Techniques

SIT is not a stand-alone technology. To be effective it should be integrated in a package together with non-nuclear techniques, including economics, public education, quarantines, sanitation, and biological, cultural and chemical controls, etc.

Central to the application of SIT, within an integrated approach, is the areawide concept in which the total population of the pest in an area or region is managed. Present insecticide use can best be described as an uncoordinated attack by individual farmers on a small segment of the pest population. Insects move, often over considerable distances. Therefore such uncoordinated field-by-field action is only a temporary control measure. As long as the farmer's neighbours do not join in the efforts, the pest insects will re-invade his fields requiring regular insecticide applications to protect his crops. However, when growers of a given area or region organize themselves into farmer associations to apply an areawide control program against the total population of the pest, much less insecticide inputs will be required and the control achieved will be more effective.

e) Attributes of SIT

SIT has special attributes which make it a unique insect pest management tool:

> species specificity: unlike non-selective insecticide-based control, SIT represents a biologically-based tool for pest control in view of the species specificity involved. The induced sterility is directed exclusively at the target species, thereby controlling only the pest populations. Furthermore, unlike biological controls where many cases of adverse impact on non-target organisms have been reported, no such case is known for radiation induced sterility and related genetic pest control methods.
>
> inverse density-dependence: unlike most control methods, SIT has the unique attribute of increased efficiency with decreasing target population density. SIT is the only environment-friendly technology available to eradicate insect pests if applied consistently on an areawide basis: the sterile males have the ability to find the last wild females in the whole area.
>
> compatibility for integration: SIT is compatible with other pest control methods, and can therefore be effectively integrated with other methods including biological methods, such as parasitoids, predators and insect pathogens. In this way, totally biological systems for managing some of the world's most important insect pests can be made available.

f) Applications of SIT

Considerable advances in the development of SIT have resulted in major applications of this technology against tephritid fruit flies of economic importance. Similar advances are possible for codling moth control. There are four major roles SIT application can play:

> Control: To avoid heavy fruit losses caused by codling moth, intensive insecticide treatments are routinely required to produce worm-free fruit. The resulting damage to non-target beneficial organisms, disruption of biologically based controls of other orchard pests, residues on fruit and general contamination of the environment, are driving the need for more environment-friendly methods such as SIT to control codling moth.
>
> As a result of its species-specificity, SIT can be effectively used to replace insecticides for control of insect pests. Pilot tests have demonstrated the effectiveness of SIT to control codling moth, and economic analyses have shown that SIT applied as part of an integrated approach could be competitive with conventional methods. Routine use of sterile insects for control will allow the future commercialization of SIT.
>
> Also, SIT for pre-harvest control, applied as part of a systems approach in combination with a post-harvest treatment, can be used to create internationally recognized pest free

or low prevalence areas to overcome these trade barriers to agricultural produce. Irradiation is an effective and innocuous post-harvest treatment for commercial fruit which is often affected by other treatments. Food irradiation can guarantee quarantine security of importing countries and it is increasingly accepted internationally.

Eradication: As a result of its inverse density dependence, SIT used on an area-wide basis and with adequate quarantine support, has been shown to eradicate fruit fly pests successfully in Chile, Mexico, parts of Patagonia, and urban areas of the USA. SIT should also be able to achieve eradication in codling moth.

Barrier and Prevention: To protect pest-free fruit production areas that are contiguous to infested areas, SIT can also be used as a biological barrier to maintain the pest-free status of the free areas. SIT can also be applied in a preventive form over pest-free areas with high risk of invasion to avoid the establishment of the pest species.

III. Objectives of the Meeting:

This consultants' group meeting was convened to review the constraints and progress made to date in Lepidoptera SIT and to determine if the Subprogramme should focus its efforts in Lepidoptera SIT on codling moth or another species. Once this decision was complete they were asked whether a CRP would make a significant contribution to advancing the applicability of SIT to codling moth and result in direct support to the IAEA's Technical Co-operation Programme and eventually benefit end-users in Member States. If their decision was affirmative, the consultants were requested to determine the specific focus of the R&D to be carried out and help to formulate the objectives of the CRP. In view of the favourable review by these consultants (see below and annexes) a new CRP on "Improvement of Codling Moth SIT to Facilitate Expansion of Field Application" is proposed to start in 2002.

IV. Justification for selection of codling moth for SIT programmes

Nineteen species of Lepidoptera were considered for the possible use of the Sterile Insect Technique (SIT) for suppression and/or eradication (see Annex 4). The criteria that each species was evaluated against included the following: global importance, key pest status, economic importance, mass rearing history, radiation biology, migration behaviour, potential for reinfestation, grower support, host range, national/international support, and the presence of monitoring tools. Each criterion was rated from zero to four, zero being the worst situation and four being the best.

The five species that had the highest ratings were selected for closer examination based on the types of control that could act in tandem with SIT. These were: mating disruption, biocontrol, chemical control, and biotechnologies. The five species that had the highest ratings were 1) codling moth, 2) grape berry moth complex, 3) pink boll worm, 3) Oriental fruit moth, and 5) diamondback moth.

Codling moth (CM) remained the highest rated species also after the control aspects were factored in. We consider that the codling moth is the best candidate for SIT suppression and/or eradication of the lepidopterous species examined. Two area-wide programmes for CM already have been implemented successfully in the USA and Canada using mating disruption and SIT combined with other control technologies.

The grape berry moth complex involves two sympatric species that occur together so if SIT were to be used sterile releases would need to be conducted simultaneously for both species. This would affect the cost of the programme significantly.

The pink boll worm is an important global species. Transgenic cotton has effectively controlled certain cotton pests in some parts of the world. Pink boll worm certainly could be eliminated by integrating SIT and transgenic cotton in the very near future. However, this species also is able to migrate long distances which may pose a serious threat of reinfestation.

Oriental fruit moth usually occurs along with peach twig borer and/or false codling moth. Unless mating disruption becomes available for these species, their presence would require a spray programme that would be in direct competition with the SIT technology.

The diamondback moth is found throughout the world attacking a wide range of food crops. Biological control seems to work well in certain climates. F1 sterility is very complimentary to the biological control and these technologies together could provide an effective and environment-friendly pest management.

V. Conclusions

1. Codling moth is a key pest of several important crops in some seventy countries.
2. Current control of codling moth relies heavily on chemical spraying, however, new legislation is reducing acceptable residue levels or even banning essential insecticides.
3. In areas where hard chemicals have been replaced with other control techniques problems of resistance and inadequate control are starting to appear.
4. The SIT for Codling Moth is effective when applied on an areawide basis and can be integrated with several other control techniques.
5. Codling moth presents the most favourable combination of factors for the further development of SIT.
6. Areas for improvement of codling moth SIT include cost of rearing, process and product quality control, sexing, genetics and monitoring.
7. A Co-ordinated Research Project to address these issues is worthwhile and justified.

An outline for a possible CRP is attached at Annex 5.

VI. Annexes

Annex 1 Participants

Mr. Erich Dickler
Biologische Bundesanstalt
Institut für Obstkrankheiten
D-6901 Dossenheim über Heidelberg
Germany
Tel: +49 6221 868 05 00
Fax: +49 6221 868 05 15
E-Mail: BBA.Dossenheim@t-online.de

Dr. Marcos Gerding
Estación Experimental
Quilamapo Casilla 426
Chillan
Chile
Tel: 0056042211177
Fax: 0056042217852
E-Mail: mgerding@quilamapu.inia.cl

Dr. Frantisek Marec
Institute of Entomology
Czech Academy of Sciences
Branisovska 31
CS-37005 Ceske Budejovice
Czech Republic
Tel: 00420387775250
Fax: 004203843625
E-Mail: marec@entu.cas.cz

Dr. Howard Thistlewood
Sterile Insect Release Programme
P.O.BOX 1080
Osoyoos
BC
Canada
Tel: 0016044952555
Fax: 0016044956439
E-Mail: hthistle@bctree.com or oksir@vip.net

Mr. Graham Thwaite
Special Entomologist
Orange Agricultural Inst.
Forest Road
Orange NSW 2800
Australia
Tel.: 0061263913821
Fax: 0061263913899
E-Mail: graham.thwaite@agric.nsw.gov.au

Mr. Tom Blomefield
ARC-Fruit, Vine and Wine Research Institute
P.O.BOX Private Bag X5013
7599 Stellenbosch
South Africa
Tel.: 0027218093460
Fax: 0027218093400
E-Mail: brian@infruit.agric.za

Dr. Fritz Polesny
Federal Office and Research Centre for Agriculture
Institute of Phytomedicine
Spargelfeldstr. 191
P.O.BOX 400
A-1226 Vienna
Austria
Tel.: 00431732162002
Fax: 00431732162108
E-Mail: fpolesny@bfl.at

Dr. James Carpenter
USDA/ARS
P.O. Box 748
Tifton GA 31793-0748
Tel: 00 1 912 387 2348
Fax: 00 1 912 388 2321
E-mail: jcarpent@tifton.cpes.peachnet.edu

Dr. Ken Bloem
USDA/APHIS
429 Medowridge
Tallahasee FL 32312
Tel: 00 1 850 894 2662
Fax: 00 1 850 894 2083
E-mail: ksbloem@nettally.com

Dr. Carrol Calkins
USDA/ARS/PWA
5230 Konnowac Pass Road
Wapato WA 98951-9651
USA
Tel: 00 1 509 454 6570
Fax: 00 1 509 454 5646
E-mail: ccalkins@yarl.gov

Mr. Adalecio Kovaleski
Empresa Brasileira de Pesquia Agropecuária
EMBRAPA
Caixa Postal 1513
CEP 95.200-000
Vacaria RS
BRAZIL
Tel: 005432317125
Fax: 00542311100
E-Mail: adalecio@cnpuv.embrapa.br

FAO/IAEA STAFF

Arnold Dyck

Walther Enkerlin

Jorge Hendrichs

Andrew Parker

Alan Robinson

Annex 2 Agenda

CONSULTANTS' GROUP MEETING ON

Improvement of Codling Moth SIT to Facilitate Expansion of Field Application

16-20 October 2000
Vienna International Centre, IAEA- Building A, Room 2210

Agenda

Monday, 16 October ***INTRODUCTION AND PRESENTATIONS***

09:00	Introduction and Welcome	*J. Hendrichs*
09:15	The Insect Pest Control Sub-Programme	*J. Hendrichs*
10:00	Administrative matters	*A. Parker*
10:15	*Break*	
10:45	Lepidoptera activities within ICPS	*A. Parker*
11:30	Entomology Laboratory Activities	*A. Robinson*
12:15	*Lunch*	
14:00	Review of current R & D on Lepidoptera SIT	*J. Carpenter*
14:45	The SIR Program, Osoyoos, BC; Current status, problems and R & D needs	*H. Thistlewood*
15:30	*Break*	
15:45	Review of the areawide codling moth control program in the western USA; problems and R & D needs	*C. Calkins*
16:30	Review of codling moth and parasitoid rearing and suggestions for research	*K. Bloem*
17:15	*Cocktails*	

End of day one

Tuesday, 17 October ***PRESENTATIONS***

.

09:00	Review of genetics R & D related to Lepidoptera SIT	*F. Marec*
09:45	Review of codling moth control and ongoing R & D in Australia	*G. Thwaite*
10:30	*Break*	
11:00	Review of codling moth control and ongoing R & D in Austria	*F. Polesny*
11:45	Review of codling moth control and ongoing R & D in Chile	*M. Gerding*
12:30	*Lunch*	
13:30	Review of codling moth control and ongoing R & D in Brazil	*A. Kovaleski*
14:15	Review of codling moth control and ongoing R & D in South Africa	*T. Blomefield*
15:00	Review of codling moth control and ongoing R & D in Germany	*E. Dickler*
15:45	*Break*	
16:15	Outline of key topics for discussion on Wednesday	

End of Day two

Wednesday, 18 October ***GENERAL DISCUSSION ON THE CO-ORDINATED RESEARCH PROJECT (CRP)***

Discussions on Key Topics
09:00 Background situation analysis
09:50 Overall objectives
10:40 *Break*
11:10 Specific Research Objectives
11:50 Expected Research Outputs
12:30 *Lunch*
14:00 Discussion of the logical framework
15:30 *Break*
16:00 Continuation
17:00 *End of day three*

Heurigen Evening

Thursday, 19 October ***DRAFTING OF THE CRP***

09:00 Drafting of the CRP
12:00 *Lunch*
14:00 Drafting of the CRP
16:30 Wrap-up
17:00 *End of day four*

Friday, 20 October
09:00 Final draft
13:00 *Lunch*
15:00 Presentation of Conclusions and Recommendations
16:00 Closing
End of meeting

Annex 3 World-wide Pome fruit production

WORLD POME FRUIT PRODUCTION 1998							
		Apples		Pears		Quince	
		Ha	Tonne	Ha	Tonne	Ha	Tonne
	World Total	7,042,518	57,149,645	1,863,121	15,247,810	43,583	330,260
1	Afghanistan	2,350	17,500	320	2,300		
2	Albania	2,300	11,500	1,000	2,400	200	700
3	Algeria	12,870	75,385	10,420	60,132	500	2,072
4	Argentina	45,327	1,033,520	22,258	537,458	2,950	24,000
5	Armenia	20,000	56,000	3,000	15,600		
6	Australia	19,760	308,856	7,460	153,000	15	270
7	Austria	11,259	416,489	3,000	132,394	113	600
8	Azerbaijan	46,000	248,000	3,800	18,000		
9	Belarus	66,000	133,000	4,000	9,000	1,000	2,000
10	Belgium-Luxembourg	9,606	420,730	5,070	152,660	150	900
11	Bhutan	2,500	5,500				
12	Bolivia	1,460	8,880	755	4,077	550	3,500
13	Bosnia and Herzegovina	4,300	18,000	2,900	6,400		
14	Brazil	26,209	787,414	2,200	16,000	1,400	4,500
15	Bulgaria	14,751	129,145	901	20,237	300	4,000
16	Canada	26,940	496,186	1,637	17,381		
17	Chile	31,200	1,000,000	16,500	320,000		
18	China	3,800,900	19,490,501	1,258,700	7,390,384	4,800	30,000
19	Croatia	6,700	72,361	1,900	11,556	113	600
20	Cyprus	1,200	11,000	150	1,500	13	80
21	Czech Republic	30,600	283,148	5,280	24,668		
22	Denmark	1,550	64,000	400	6,300		
23	Ecuador	4,749	25,080	2,381	13,604		
24	Egypt	22,560	388,461	4,022	41,391		32
25	Estonia	7,790	8,728				
26	Finland	452	10,500				
27	France	78,000	2,208,966	14,000	260,300	148	2,119
28	Georgia	51,500	92,599	5,500	37,268		
29	Germany	90,000	2,296,200	33,000	429,300		
30	Greece	13,700	358,090	9,765	70,694	855	5,500
31	Grenada	120	520				
32	Guatemala	2,900	27,000				
33	Honduras	35	150				
34	Hungary	33,700	481,987	7,600	36,317	450	2,300
35	India	227,680	1,320,590	22,500	135,000		
36	Iran, Islamic Rep of	141,822	1,943,627	17,940	187,281	4,500	29,000
37	Iraq	9,500	86,000	620	3,100	330	2,100
38	Ireland	500	9,700				
39	Israel	4,300	102,910	1,300	24,400		
40	Italy	63,786	2,115,470	43,955	931,015	80	700

WORLD POME FRUIT PRODUCTION 1998

		Apples		Pears		Quince	
		Ha	Tonne	Ha	Tonne	Ha	Tonne
41	Japan	45,500	879,100	18,800	409,700		
42	Jordan	4,576	38,527	715	2,833	30	150
43	Kazakhstan	41,000	36,000	4,400	8,000		
44	Kenya		100	35	200		
45	Korea, Dem People's Rep	68,000	630,000	12,600	120,000		
46	Korea, Republic of	34,692	459,010	24,612	259,770		
47	Kyrgyzstan	18,000	73,765				
48	Latvia	7,000	13,700				
49	Lebanon	15,448	118,970	3,273	63,824	980	18,500
50	Libyan Arab Jamahiriya	3,700	45,000	140	1,150		
51	Lithuania	27,300	100,000	1,500	10,000		
52	Macedonia, The Fmr Yug Rp	5,573	61,675	879	9,263	94	963
53	Madagascar	4,100	6,500	900	1,600		
54	Malta	30	300				
55	Mexico	58,740	370,244	5,175	25,691	1,200	7,500
56	Moldova, Republic of	90,969	485,000	2,165	6,637	100	550
57	Morocco	26,100	284,800	3,500	31,100	2,800	29,500
58	Netherlands	14,700	518,000	6,000	141,000		
59	New Zealand	12,050	500,500	1,900	41,000	65	850
60	Norway	2,079	47,656	267	3,266		
61	Pakistan	45,000	600,000	2,800	36,000		
62	Paraguay	80	600	25	180		
63	Peru	12,712	126,805	594	2,974	540	3,700
64	Poland	165,000	1,687,226	18,300	82,661		
65	Portugal	24,269	165,404	13,402	120,033	200	1,800
66	Romania	79,499	364,619	6,483	64,464	1,000	5,000
67	Russian Federation	415,000	1,330,000	16,500	48,000	1,600	4,300
68	Réunion	20	120				
69	Saint Vincent/Grenadines	160	635	57	230		
70	Slovakia	2,886	83,464	560	12,022		
71	Slovenia	15,000	104,134	2,000	10,604	15	50
72	South Africa	22,000	576,264	12,000	251,975	50	289
73	Spain	50,000	719,000	41,000	599,800	1,100	10,000
74	Sweden	6,550	65,000	1,200	15,500		
75	Switzerland	11,000	494,870	3,200	141,380	125	800
76	Syrian Arab Republic	27,000	362,000	2,900	19,000	650	6,900
77	Tajikistan	34,000	82,000				
78	Tunisia	26,000	82,500	12,500	53,900	320	4,500
79	Turkey	106,600	2,500,000	37,700	415,000	11,500	100,000
80	Turkmenistan	10,000	18,500				
81	Ukraine	250,000	568,000	40,000	149,000		
82	United Kingdom	13,300	183,600	2,500	26,300		
83	United States of America	189,230	5,165,000	26,780	866,500		

WORLD POME FRUIT PRODUCTION 1998							
		Apples		Pears		Quince	
		Ha	**Tonne**	**Ha**	**Tonne**	**Ha**	**Tonne**
84	Uruguay	2,800	57,570	2,400	19,922	950	7,500
85	Uzbekistan	90,000	380,000	6,000	32,000		
86	Yemen	339	1,994	95	175	110	456
87	Yugoslavia, Fed Rep of	27,000	192,000	12,900	73,719	1,800	12,579
88	Zambia				70		
89	Zimbabwe	640	5,800	130	250		

Source: FAOSTAT database, reported area and production figures for 1998

Annex 4 Ranking of factors influencing the suitability of SIT for controlling a species.

	Global importance	Key pest	Economic importance	Mass rearing	Radiation biology	Migration	Potential for Reinfestation	Grower buy-in	Host range	National/ International support	Monitoring tools	Total	Rank	Mating disruption	Biocontrol	Chemical control	Biotechnologies	Others	Control Options Total
Codling moth	4	4	4	4	4	4	1	3	4	3	4	39	***1***	2	2	3	0	1	8
Grape berry moths	4	4	4	2	2	4	4	3	4	3	4	38	***2***	3	3	4	0	0	10
Pink bollworm	3	4	4	4	3	1	1	3	4	2	4	33	***3***	1	1	4	4	0	10
Oriental fruit moth	4	4	4	3	3	4	0	3	1	3	4	33	***3***	3	2	3	0	0	8
DBM	4	3	4	2	3	2	1	2	3	2	4	30	***5***	1	3	2	0	0	6
Sugar cane borer	3	4	2	2	2	2	2	3	4	3	2	29	6	0	3	1	0	0	
Angoumois grain moth	4	2	2	4	2	2	0	3	3	3	4	29	6	0	0	3	0	0	
Carob moth	2	4	3	2	2	3	2	3	4	2	1	28	8	0	1	0	0	0	
Peach twig borer	4	3	2	0	1	4	0	2	4	3	4	27	9	3	0	3	0	0	
Pine shoot moth	2	4	3	0	1	1	2	3	4	2	4	26	10	0	3	3	0	0	
False codling moth	3	4	4	3	2	0	0	3	1	2	4	26	10	1	3	2	0	0	
Gypsy moth	3	3	2	3	3	1	0	1	2	3	4	25	12	0	3	2	0	0	
Helicoverpa spp.	4	3	4	3	4	0	0	1	0	2	4	25	12	0	2	3	4	0	
Carposina niponensis	1	4	4	0	1	4	1	2	4	1	2	24	14	0	3	3	0	0	
Spodoptera	4	2	3	3	4	0	0	1	0	2	4	23	15	0	3	3	3	0	
Asian corn borer	1	3	3	3	3	0	0	1	3	2	4	23	15	0	1	2	1	0	
Cactus moth	1	4	3	2	1	4	3	2	1	1	1	23	15	0	2	1	0	0	
Asian gypsy moth	2	2	3	2	1	0	0	1	2	3	3	19	18	0	0	2	0	0	
Chestnut leaf miner	2	1	2	0	1	0	0	1	4	2	4	17	19	0	1	3	0	0	

Annex 5 CRP outline

1. Title of CRP:

Improvement of Codling Moth SIT to Facilitate Expansion of Field Application (Project D.4.01, Activity 4)

2. Background Situation Analysis (Rationale/Problem Definition)

The Problem

Codling moth (*Cydia pomonella* (L.), CM) is the key pest in most pome fruit (apple, pear and quince) and some walnut orchards in the temperate regions of all major continents (Barnes, M. M., 1991; CAB International, 1995). The damage inflicted on fruit can be considerable with up to 80% of apples and up to 60% of pears infested on neglected apple and pear trees. This high infestation rate is related to the oviposition behaviour of female moths, which lay eggs singly and at random on leaves, fruits and twigs of the host tree (Wood, 1965). Feeding by the larvae on walnut creates holes in the hulls and shells that can allow fungi to enter and infect the kernels. Some fungi produce toxins that at high levels are a food safety concern (Stelljes, 2001). Fruit growing areas free of this moth are at a considerable advantage, being able to market high quality, low insecticide fruit (Woods & Hardie, 1997).

In 1999 world pome fruit production was some 74 million metric tonnes from 7.2 million ha, and walnut production 1.2 million tonnes from 500,000 ha. International trade in pome fruits and fruit products was more than 8 million tonnes, valued at $4,600 million, and for walnuts 150 thousand tonnes valued at $360 million (FAOSTAT database). Uncontrolled losses run at up to 80% in apples, and even with additional control measures 4 - 5 conventional cover sprays of an organophosphate insecticide are required to keep damage to an acceptable level. In the southern USA direct costs of conventional insecticide sprays plus residual fruit damage are estimated at about 3.5% of crop value (Horton, Dutcher & Ellis, 1997), but indirect cost due to loss of natural enemies and pollinators, insecticide residues and environmental contamination are estimated to be up to 6 times this level.

An extensive review of the older literature on CM is available in Butt (1975).

Current Control Methods

Control of this pest has relied mostly on the intensive use of organophosphate (OP) and other broad spectrum insecticides applied throughout the growing season. Although the development of temperature dependent models, the use of efficient pheromone traps and the visual inspection of foliage has decreased the number of insecticide spraying cycles to 4 or 5 in each growing season (Trimble and Solymar, 1997), the almost exclusive use of insecticides has led to the development of resistance and cross-resistance to most traditionally used organophosphorous and pyrethroid insecticides (Varela *et al.*, 1993; Knight *et al.*, 1994; Giliomee and Riedl, 1998) and even to the insect growth regulators (IGRs) in Europe (Sauphanor *et al.*, 1998; Charmillot *et al.*, 1999; Espuna, 2000). The application of these insecticides has in addition resulted in the disruption of natural controls of the secondary pest complex e.g. the use of insecticides to control CM has dramatically reduced the density of predators and parasitoids of the pear psylla (*Psylla pyricola* Foerster) and chemicals to control the pear psylla turned out to be toxic for an important predator of spider mites (Moffit and Westigard, 1984). It has been estimated that the direct costs of OP application in orchards to suppress CM populations in the early 1980's were ca. US$ 60/ha/year, but the indirect costs attributable to their negative effects on non-target insects and beneficial species amounted to US$ 450/ha/year (Gut *et al.*, 1981)

In addition, the reduction of acceptable residue levels for some insecticides and the withdrawal and banning of a number of other essential insecticides because of increasing environmental and human health concerns has placed severe constraints on the ability of growers to implement effective resistance management programmes and to place their pome production on international markets. As a result, growers have been looking to new technologies to keep CM populations below economic levels. These technologies include the use of selective synthetic IGRs (Westigard, 1979), mating disruption used alone (Moffit and Westigard, 1984) or integrated with cultural practices (post-harvest fruit removal, tree banding to catch over wintering larvae) (Judd *et al*., 1997), "attract and kill" (Trematerra *et al*, 1999; Charmillot *et al.*, 2000), and biological control agents such as the use of the CM granulosis virus (CpGV) (Jacques *et al.*, 1981). Although these technologies have proven effective under certain conditions and reduced reliance on hard chemicals, they are primarily effective only when population pressure is low and in many areas do not provide consistent control. This is particularly true in areas where there is a close rural-urban interface and any application of chemical controls is viewed negatively. The efficacy of mating disruption for instance seems to be density dependent, and hence, a poor crop protector under high population densities leading to recommendations to use mating disruption only in orchards where CM had not yet established (Trimble, 1995). The application of mating disruption remains in addition more expensive per hectare than using traditional insecticides (Williamson *et al*., 1996). In some European countries, the increased use of IGRs in fruit trees has also resulted in the development of resistance to IGRs (Charmillot, 2000). Therefore, additional non-chemical control options are urgently needed.

The Sterile Insect Technique and Inherited Sterility in Lepidoptera

Since the 1950's it is known that insect pests can be controlled or eradicated through a "birth control" method based on genetic manipulation know as autocidal pest control or the Sterile Insect Technique (SIT). It involves the colonization and mass rearing of the target pest species, sterilization through the use of gamma radiation and releasing them into the field on a sustained basis and in sufficient numbers to achieve appropriate sterile to wild insect overflooding ratios. Here the sterile males find and mate with fertile females, transferring the genetically modified sperm. No offspring results, thereby causing a reduction in the natural pest population. The validity of this method has been demonstrated for many insect pests, including moths, screwworms, tsetse and fruit flies.

One of the reasons for the paucity of sterility programmes against Lepidoptera is the fact that many species have been found to be highly radio-resistant and, as such, the amount of radiation required to fully sterilize them also negatively impacts their competitiveness and field performance. However, this radio-tolerance is caused by chromosomal morphologies that allow radiation induced inherited sterility (IS or F_1 sterility) effects to occur when lepidopterans are exposed to substerilizing doses of radiation. In the application of IS, the dose of ionizing radiation is lowered so that insects are only partially sterile, or the dose is adjusted so that females are completely sterile and males are partially sterile (LaChance, 1985). The radiation-induced deleterious effects are inherited for one or more generations. Because the dose of radiation is lowered, partially sterile insects are generally more competitive than fully sterile insects (North, 1975). As such, releasing partially sterile insects offers greater suppressive potential that using fully sterile insects.

Inherited or F_1 sterility (IS) was first documented by Proverbs and Newton (1962) during the course of his studies on the CM, and since then has been found in many lepidopteran species of economic importance (LaChance, 1985). Knipling (1970) explored the theory of IS for control of lepidopteran pests and it's genetic basis was reviewed by LaChance (1985). Using mathematical models, Knipling (1970) suggested that when releasing partially sterile insects, the sterile to wild overflooding ratio could be as low as ¼ of what is normally required for fully sterile insects. In addition, because the infusion of IS (in the parental generation) results in F_1 progeny with varying degrees of sterility (LaChance, 1985; North, 1975; Proverbs & Newton, 1962), the field application of this control method allows for the production of sterile insects in the field (Carpenter, 1993).

Both full sterility (SIT) and partial or inherited sterility (IS) have been used for CM, and throughout this CRP Proposal references to SIT should be taken to include IS and vice versa, unless the context precludes this.

Development of SIT for CM

The initial development of the SIT for CM control was conducted almost simultaneously in Canada and Europe (Charmillot *et al.*, 1976a, b), but the work in Europe concentrated more on the development of IS (Charmillot *et al.*, 1973; Charmillot, 1977). The work in Europe was not followed up, but a pilot programme to control the CM with sterile males was conducted from 1976 to 1978 in 500 ha of apples and pear orchards in the Similkameen valley of British Columbia (Proverbs *et al.*, 1982). The native CM population was suppressed with chemicals and this was followed by the release of 1 million sterile moths every week. Sterile moths were released at densities of 23,600 to 36,500/ha for each growing season exceeding the desired sterile:wild moth ratio's of 40:1. Eradication was achieved in some localised areas and fruit damage exceeded the economic threshold (0.5%) in only 1.1%, 3.1% and 0% of the treated orchards in 1976 (n=86), 1977 (n=193) and 1978 (n=157), respectively. The field programme was considered a success but the cost of the control programme by the release of sterile insects remained too high (Can. $225/ha/yr vs. Can $95 for chemical control) (Proverbs *et al.*, 1982).

Following on from this trial the first operational CM SIT programme in the world was initiated in 8,000 ha of apple and pear trees located in mostly commercial orchards in the Okanagan region of British Columbia, Canada in 1992 (Dyck *et al.*,1993). This programme is co-funded by growers, property owners in the community, the provincial government and the federal government. In combination with other techniques, the performance of the programme has been very good and by 2000 in control Zone 1 wild moth trap catches had declined to 20% of 1995 levels, orchards reporting no CM damage at all had risen to 98% from 42% and most dramatically sales of OP pesticides for CM control had declined to 10% of 1995 levels (V. A. Dyck, pers. comm.). However the programme remains not cost effective and continues to require State Government support for recurrent costs to supplement the levy on growers and property owners.

The history of technical advancements in SIT programmes for other species suggests there is great potential for the application of SIT for CM, and there are a number of promising research areas that can advance SIT's applicability and cost-efficiency in both developed and developing economies. Obvious areas for improvement are in the diet and rearing procedures, sexing strains, quality control (Bloem *et al.*, 1998), diapausing of larvae (Charmillot et at, 1976a, b), IS (Charmillot *et al.*, 1973; Charmillot, 1977; Bloem *et al.*, 1999a, b, 2001) and the combination of SIT with other technologies (for example parasitoids (Mannion *et al.*, 1994; Knipling 1966, 1999; Nguyen & Nguyen, 2001) and mating disruption). Other areas are in genetic comparisons between populations, and population phenology under different conditions.

3. Co-ordinated Research Projects on Lepidoptera species

Previous CRPs on Lepidoptera species

A first five-year CRP on lepidopteran insect pests (1987-1991), established following the recommendations of a group of external consultants, dealt primarily with aspects such as determining the effects of various radiation dose levels on the resulting sterility in the treated parents and their F_1 progeny in different Lepidoptera species. In addition, models were developed on the suppressive effects of IS on field populations, and some studies were conducted in laboratory or field cages to assess the impact of IS on pest suppression. The research results "Radiation Induced F_1 Sterility in Lepidoptera for Area-Wide Control" were published in 1993 in the IAEA Panel Proceedings Series (IAEA STI/PUB/929).

A second follow-up CRP on lepidopteran pests (1994-1998) built on the results of the first CRP and focused on addressing a more challenging phase, consisting of rearing key pest moths and evaluating their application for pest control purposes. The specific objective of the CRP was therefore to assess the potential of suppressing populations of caterpillar pests in the field by IS methods, i.e. by rearing and releasing irradiated moths and/or their progeny in combination with other biological control methods. The ultimate goal was to have alternative environment-friendly control methods available to be able to reduce the vast quantities of insecticide that are used in agriculture to combat Lepidoptera pests and that adversely affect the trade balance of developing countries because they must use hard currency to import them.

These Lepidoptera studies have covered a wide range of species, including *Helicoverpa armigera*, *Plutella xylostella*, *Spodoptera litura*, *Ephestia kuehniella*, *Ectomyelois ceratoniae*, *Spilosoma oblique*, *Spodoptera litura*, *Spodoptera frugiperda*, *Ostrinia furnacalis*, *Grapholita molesta*, *Pectinophora gossypiella* and *Diatraea saccharalis* in addition to CM. The results have been published in various refereed journals, including a block of five papers in the Florida Entomologist **84** (2001) and in an Agency TecDoc "Evaluation of population suppression by irradiated Lepidoptera and their progeny" (in press).

The two FAO/IAEA sponsored Lepidoptera CRPs have resulted in expanded research and implementation programmes on IS in combination with natural enemies. Such programmes are underway in Tunisia for suppression of the carob moth, *Ectomyelois ceratoniae*, and on the island of Mauritius for control of the diamondback moth, *Plutella xylostella.* IS programmes for other lepidopteran pest species also are being considered in other countries. The CRPs have also highlighted several areas that would benefit from further research and development to increase the economic viability of IS programmes. For a majority of Lepidoptera pests still considerable additional R&D, feasibility assessments and field evaluations will be required before implementation of operational projects is possible. Development of diets using locally available ingredients would reduce rearing costs, especially in locations with developing economies. Improvements in mass rearing are needed to take advantage of the economy of scale as evidenced in dipteran SIT programmes. Development of genetic sexing techniques, especially those that would eliminate females at the egg or early larval stage, would reduce rearing costs, would increase the efficiency of rearing, irradiation and release and would eliminate assortative mating of released moths in the field. Such R&D would even benefit the programmes that are in operation against the pink bollworm in California and the CM in British Columbia, Canada.

Recommendation for a new CRP

A Consultants Group Meeting convened in Vienna 16 – 20 October 2000 to review progress made and to assess research and development needs in the field of lepidopteran pest control. They examined the current status of knowledge and various biological, economic and regulatory issues for 19 key lepidopteran pests.

Their conclusions were:

1. Unlike the previous CRPs, which addressed the development of SIT/IS in Lepidoptera in general, a new CRP should focus on applied R & D for one major key moth pest in order to move application of SIT/IS for Lepidoptera forward.
2. Based on the selection criteria CM ranked top of the list of 19 species.
3. CM is a key pest of several important crops in some seventy countries.
4. Current control of CM relies heavily on chemical spraying, however, new legislation is reducing acceptable residue levels or even banning essential insecticides.
5. Even in areas where hard chemicals have been replaced with other control techniques problems of resistance and inadequate control are starting to appear.
6. The SIT for CM is effective when applied on an area-wide basis and can be integrated with several other control techniques.
7. CM presents the most favourable combination of factors for the further development of SIT/IS.
8. Areas for improvement of CM SIT include cost of rearing, process and product quality control, sexing, genetics, monitoring and integration with other techniques.
9. A Co-ordinated Research Project focused specifically on CM to address these issues is worthwhile and justified.

Beneficiaries

Achieving the objectives of the CRP would expand the use of SIT/IS for CM. As such, producers would have an additional CM control tactic compatible with IPM; consumers would have greater confidence in food safety; and the general public and the environment would be less threatened by exposure to pesticides.

4. Nuclear component

Sterilization is accomplished by exposing insects to a specific dose of gamma radiation emitted by radioisotopes (Cobalt 60 or Caesium 137). No other methods are available or appropriate to achieve sterilization. Chemosterilants carry a high risk for environmental contamination and pose serious health concerns. Linear accelerators have not shown sufficient applicability and reliability in consistently achieving the desired level of sterility.

Nuclear technology has not only a comparative advantage in sterilizing mass reared insects, but is, at present, the only technology available for this purpose. As every single insect used in SIT/IS activities must be sterilized, irradiation is a central and indispensable part of the total process.

5. Overall Objective of the CRP

To reduce insecticide use in agriculture and the rural-urban interface and to facilitate international trade in agricultural commodities by developing a cost-effective and environment-friendly alternative to pest management in pome fruit production.

6. Specific Research Objective (Purpose)

To improve CM SIT for application in orchard and urban areas internationally.

7. Expected Research Outputs (Results)

(Outputs are not ranked in any order of importance)

Improved cost-effectiveness of rearing, sterilization, release and distribution.
Research is required on improving existing rearing for CM and on different methods of mass rearing, including assessment of rearing into diapause; development of diets for use in different countries using locally available ingredients; control of microbial diseases; elements of radiation biology i.e. optimization of radiation dose (100-250 Gy), effects of dose on sperm transfer, ratio of eupyrene and apyrene sperm, optimal sterile: fertile ratio's (field cage tests); benefits of male only releases; improved methods of both aerial, ground and point source release; potential for international shipping of different life stages.

Standards for quality of moths and mating competitiveness.
Both production and product quality control tests and standards need to be developed to ensure the consistent production of high quality moths. These should address measures of:

a. diet and rearing conditions (e.g., diet pH and moisture content, and temperature, relative humidity and light/dark cycles in rearing rooms);
b. developmental parameters of laboratory colony (e.g., % egg hatch, pupal size and weight, adult eclosion, adult size and weight, sex ratio, female fecundity); and
c. field performance in comparison with wild moths (e.g., sperm and mating competitiveness of moths irradiated at 100-250 Gy, strain compatibility, survival and dispersal ability).

Better understanding of CM genetics for developing genetic sexing strains.
SIT or IS becomes more efficient when only males are released (Anisimov and Shvedov, 1996) but a suitable sexing technique is lacking for most Lepidoptera. The only genetic sexing strain available in Lepidoptera is a balanced lethal strain of *Ephestia kuehniella* Zeller (the Mediterranean flour moth) which produces males trans-heterozygous for 2 sex-linked recessive lethal mutations (Marec, 1990, 1991; Marec *et al.*, 1999). To initiate the assessment of the potential for developing sexing strains in CM the following areas will need to be investigated:

a. characterization of the genome of CM with currently available methods of cytogenetics and molecular genetics.
b. intensive searches of native and laboratory populations of CM, together with mutation experiments, in an attempt to isolate and/or identify morphological, biochemical or molecular markers, particularly those located on the sex chromosomes.

It is expected that isolated mutations together with a detailed analysis of sex chromosomes will bring new possibilities of genetic sexing.

Improved knowledge of populations and release strategies.

For SIT/IS to succeed against CM, released male moths should be capable of mating with females from all hosts and geographic regions. Research using population genetic techniques will be carried out to:

a. characterise and compare geographical and host strains of CM
b. verify compatibility of mass-reared strains with geographical and host strains.

Improvement of monitoring techniques.

In traditional traps, synthetic sex pheromones (Codlemone) have been used to attract male moths to traps and this has been the standard tool for monitoring CM populations in orchards. A disadvantage with this method is the lack of females in the samples, and hence, no information is available on the proportion of the native female population which has mated with a sterile moth i.e. the rate of induced sterility. Recently, new kairomones originating from pears have been discovered that seem to attract female CM to traps (Stelljes, 2001). Research should be conducted to assess the efficiency of traps baited with these new chemicals in the field and to identify additional potential attractants.

Problems associated with the use of sex pheromone baited traps require attention. Difficulties in detection of CM populations arise due to their clumped distribution and low densities. In addition, pheromone baited traps elicit a behavioural response by attracting male moths from long distances and so the trap catch does not necessarily reflect the local female density (Weissling and Knight, 1995). This makes interpretation of the trap catches difficult and could result in an overestimation of the real moth population density. These monitoring techniques need to be improved, especially if SIT is used in combination with mating disruption, where detection in sex pheromone traps will be difficult.

Research should be conducted to improve our knowledge of the dispersal and diapause behaviour of moths from a variety of terrains and situations.

Efforts will be initiated to develop standard protocols (e.g., for infestation level assessment, measuring release ratios, sampling non-commercial hosts).

Improved understanding of combinations of SIT with other techniques.

Research needs to be undertaken to determine how the use of SIT in combination with other techniques, such as mating disruption, attract and kill, parasitoids and CpGV, as well as physical and cultural methods of control, can best be used to manage CM. Control strategies based on multiple technologies will minimise the risk of the development of resistance and reduce the producers dependence on insecticides. An assessment of secondary pests is also required when implementing area-wide management programmes.

Suppression of CM in urban areas is a key step for area-wide population reduction or eradication campaigns, and minimises the possibility of dispersal to commercial orchards free of CM. SIT, or combinations with "attract and kill", mating disruption, parasitoids or granulosis virus, are all environmentally friendly technologies for urban areas.

Publication of research results.

8. Action Plan (Activities)

Activity 1. Form network of laboratories interested in CM SIT/IS and award Research Agreements and Research Contracts.

Activity 2. Organise 1st RCM to co-ordinate research areas and methods.

Activity 3. Organise 2nd RCM to review results and refine approaches.

Activity 4. Organise 3rd RCM to evaluate CM SIT.

Activity 5. Organise 4th and final RCM to collate all reports and synthesise results.

All pome fruit producing countries should be included and are possible candidates for a future CRP. A partial list of potential participating countries and support centres (marked *) includes:

Argentina	Chile	Russia
Armenia	China	Slovak Republic
Australia	Czech Republic	South Africa
Austria	France	Spain
Brazil	Germany	Sweden
Bulgaria	Italy	Switzerland
Canada*	Poland	Syria
		United States*

9. Inputs

8 Research Contracts

2 Technical contracts

4 Research Co-ordination meetings

5 Research Agreements,

No R & D is foreseen to be carried out on CM at the Agency's Laboratories at Seibersdorf.

10. Assumptions

- Continued interest of FAO and IAEA Member States in the development of environment friendly alternatives to CM control.
- Continued relevance of SIT/IS for cost effective CM control.
- Expansion of SIT/IS programmes for CM control.

11. Format for the Logical Framework

(Project No. D4.01, Activity 4)

Narrative Summary	Objective Verifiable Indicators	Means of Verification	Important Assumptions
Overall Objective: To improve IPM in pome fruit production.	N/A	N/A	Continued interest of Member States in the development of environment friendly alternatives to CM control
Specific Objective: To improve CM sterile insect technique (SIT) for application in orchard and urban areas internationally.			**(Specific to Overall Objective)** Continued relevance of SIT for economic CM control
Outputs:			
1. Improved cost-effectiveness of rearing, release and distribution.	1. Alternatives for rearing, release and distribution identified.	1. Report prepared on protocols for rearing, release and distribution.	1. Rearing and shipping is appropriate and workable in all laboratories of CRP.
2. Develop standards for quality of moths and mating competitiveness	2. Standard tests being used by participants.	2. Manuals prepared and results of tests distributed.	2. Development of standards is feasible and sufficient resources exist.
3. Better understanding of CM genetics for developing genetic sexing strains.	3. Genetic and/or molecular markers identified for sex chromosomes.	3. Progress reports.	3. CM genome is suitable for use of genetic approaches.
4. Improved knowledge of populations and release strategies.	4. Standard methods being used in diverse populations or habitats.	4. Progress reports and results of tests distributed.	4. Standard methods are appropriate at all sites of CRP.
5. Improvement of monitoring techniques.	5. Improved monitoring techniques	5. Progress reports.	5. Female specific attractants exist.
6. Improved understanding of combinations of SIT with other techniques.	6. Recommendations developed for SIT in combination with other techniques.	6. Progress reports.	6. SIT pilot tests or programmes are operational.
7. Publication of research results.	7. Reports published by collaborators.	7. Reports published and distributed.	7. Quality and quantity of data appropriate for publication.
Activities:			
1. Form network of laboratories interested in CM SIT	1. Research contracts and agreements awarded.		1. Suitable proposals submitted.
2. 1st RCM to co-ordinate research areas and methods	2. 1st RCM held		2. Rearing technologies are transferable.
3. 2nd RCM to review results and refine approaches	3. 2nd RCM held		3. Collaborators have access to irradiation technology.
4. 3rd RCM to evaluate CM SIT	4. 3rd RCM held		4. IAEA funding for CRP continues
5. Final RCM to collate all reports and synthesise results.	5. Final RCM held		5. Final reports are submitted by participants to Agency.

12. Brief Summary for the Agency's Bulletin

Codling moth (*Cydia pomonella*) is a key pest of pome fruits in more than 70 countries, and its control currently requires the use of large quantities of insecticide. However the development of resistance to insecticides, including several of the new generation of insect growth regulators, and ever lower insecticide residue limits to protect consumers are making codling moth control increasingly difficult. The objectives of this CRP are to improve the application of the sterile insect technique (SIT) and inherited sterility (IS) for codling moth control and its integration with other environmentally friendly control methods to expand its use in field control applications and reduce insecticide use.

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