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Comparison of benefits/risks between different groups of plant protection products

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1. several REBECA workshops during 2006-2007, in particular WS6 (Porvoo, Finland, D25)
2. literature reviews

Document Abstract

This document briefly reviews discussions concerning documented and suspected risks from biological control agents (BCAs), as well as risks from other plant protection products/methods (PPP). Finally, a cost-benefit assessment of plant protection methods is given, including a comparative assessment of their benefits and risks. The conclusion from this study is that the replacement of chemical pesticide treatments by biological controls would bring immense socio-economic benefits to the society: the benefits from controlling the pests would still accrue, but the negative externalities would disappear.

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Introduction

A farmer's choice of the pest management method is influenced by many factors. Sometimes there is not even a choice: if a crop is grown on a contract, the contractor often determines how the crop is to be treated. In Europe this is an increasing trend, with large wholesale chains specifying more and more precisely the quality standards for the products which they agree to buy. If the farmer has a choice, at least the following factors will affect how pests ultimately will be managed:

- pest pressure at the time when crop is susceptible, and damage potential
- direct expense of control (e.g., price of pesticide treatment/ha)
- indirect expenses (e.g., equipment, fuel)
- time constraints (e.g., is there time to carry out treatments at the right time)
- compatibility of pest control method with other farm operations (e.g., weed and disease control)
- knowledge of factors affecting efficacy of treatment
- expected efficacy of control treatments
- expected change in crop value as a result of pest management
- expected development of market value of the commodity (including price elasticity)
- overall economics of pest management

Several computer and internet-based decision support systems have emerged to assist farmers in making choices particularly regarding the timing and need of pesticide treatments; these seldom, however, take into consideration alternative pest management options. At the farm level, the over-riding factor in deciding which pest management method to use, is the net economic benefit from the pest management operation (Mumford & Norton, 1984), combined with perceived reliability of the method (avoidance of crop failure, sometimes leading to 'insurance' treatments). Although in theory numerous control alternatives exist (such as host plant resistance, cultural control methods, etc.), the considerations as listed above currently usually lead to straightforward applications of chemical pesticides, where the fine-tuning comes from choosing the active ingredient, when and how to apply it, and how many treatments are necessary. Overall, it has been estimated that using pesticides results in improved crop revenues in the USA at the rate of about four dollars for each dollar invested (Pimentel et al., 1997); similar data have been presented for German agriculture (Waibel et al., 1998). For the UK, benefits at the farm level from pesticide use vary greatly, being in commercial apple production about ten times greater than the cost (Webster & Bowles, 1996), but in wheat production hardly matching them (Webster et al., 1999). Similarly in Finnish cereal production the private costs of pesticide treatments are barely recovered by the increase in crop value; indeed, in many cases negative balance is obtained (Kurppa, 1990).

At the farm level, short-term private benefits dictate which method of pest control will be used. Biological control cannot seriously as yet compete with chemical control in most crops, either because suitable methods have not been worked out, control agents are not available, or because farmers do not consider that they provide reliable enough control at an acceptable level. A notable exception is the greenhouse

industry, where on vegetables in particular biological control is the rule rather than exception. Under the relatively simple, controlled conditions existing in a greenhouse, biological control has proven to be also economically superior to other forms of pest management, and therefore has gained overwhelming farmer acceptance and level of adoption in particular in Western Europe.

Pest management decisions do not only provide private benefits and costs to the farmer, but also affect the society at large. Benefits arise from improved farm economies and increased output of agricultural products, affecting welfare of the farming sector. Negative impacts on the society are mainly related to changes in pesticide usage, which involves at least two major categories of externalities. Firstly, human health can be affected by pesticide use. Particular groups at risk include those who apply pesticides, bystanders, and the consumers of food containing pesticide residues (Bowles & Webster, 1995). Secondly, natural ecosystems may also be at risk, through effects on non-target organisms, and subsequently on other members of the ecosystem via the food chain. Indirect effects of pesticides may reduce the biodiversity and resilience of the ecosystem. Valuing these externalities is a difficult and complicated task.

Compilation of documented and suspected risks from BCAs

This section is a summary review of outcomes of a series of REBECA workshops in 2006. Outcomes for these workshops have been summarised for REBECA by Jeff Bale (a), Hermann Strasser (b), and Bernhard Speiser (c), and the details of the identified risks are presented in their corresponding workshop reports.

- (a) Invertebrate Biological Control Agents (Macrobiales)
Wageningen, The Netherlands, April 4-6 2006
- (b) Risk Assessment Macrobiales
Innsbruck, Austria, 12. – 13. April 2006
- (c) Review of potential risks of botanicals and semiochemicals
Brussels, Belgium, 13 – 14 June 2006

MACROBIALS

Overall conclusions for macrobiales:

- risks to human health are very low
- main risks are to the environment (these may be perceived rather than real for many species)
- need to separate 'true risks' from 'perceived risks', and then identify those risks that needed to be 'regulated'

Human and animal health

Risks to humans considered to be remote, and limited to allergic reactions among production personnell and bites and stings. Personnel in production is most likely to be exposed, and can introduce protection measures to minimize the risks.

Plant and crop damage and development to nuisance

Few reports of crop damage (e.g. *Macrolophus caliginosus* on tomato), and of contamination of crop products (e.g. *Harmonia axyridis* in grapes). The latter can also be a nuisance when entering into houses.

Environment

The most important risk of biological control with invertebrates, real or perceived, is to the environment. A range of possible outcomes include:

- establishment in a new country,
- parasitism or predation of non-target species,
- competition or displacement of native species,
- perturbation of ecosystem functions (e.g. pollination),
- introduction of contaminating agents (pathogens, hyperparasites),
- interbreeding with native species

The occurrence of such events, or extensive crop damage, would undermine the reputation of biological control.

MICROBIALS

In some cases BCAs are considered a risk because they belong to species, which has been identified as a human pathogen. However, it is often possible to distinguish between BCAs and clinical isolates with the help of modern molecular methods. These data can often indicate a phylogenetic separation of the BCAs from clinical isolates of the same species and sometimes even make possible the description of new species.

BOTANICALS AND SEMIOCHEMICALS

Concerning botanicals BPPP the risks associated with their use may vary between very low and very high. Risks should therefore be assessed case-by-case. The discrimination of low risk substances from other substances should be the result of an assessment. Semiochemical-BPPP have low inherent toxicity and are expected to present a low risk. They modify behaviour of the pest species rather than killing them, they are more target specific than conventional insecticides, and are used at concentrations close to those in nature.

CONCLUSION

BPPP until now have proven to be extraordinarily safe from all points of view. It should be noted, however, that the assessments and experiences of risks from BPPP (or identification of hazards) are mainly limited to currently available, well known products, or organisms close to market, or those that have been researched for a long time as serious candidates for commercialisation. The discussion on risks might achieve other dimensions if there would be no regulations at all, or if the regulations would be significantly more relaxed than what we currently have. Attempts to commercialise organisms which currently stand no chance would likely take place. These include e.g. pathogens which are closer to vertebrate pathogens than those currently in use or in development (e.g., entomopox viruses). The question needs to be posed whether a less stringent regulatory system would allow the use of these products (even unrestricted use), and at what risk? There is also a different approach to risk in 'western' societies, and in 'developing countries'.

Review of risks from chemical PPP

The risks from chemical PPP (external costs) include: productivity loss (crops, animals), pollution costs (water, soil, air), environmental costs (biodiversity, wildlife), human health costs (acute, chronic), information costs (regulation, monitoring), dependency (resistance, loss of beneficials), and equity issues (failure of polluter pay principle). Assessments of the external costs of chemical pesticides from several countries around the world show interestingly that the external costs sometimes greatly exceed the purchase value of pesticides, and also that many of these assessments are incomplete in the sense that not all of the important externalities have been included. For example in Germany over 50% of the estimated external costs arise from ground water contamination – which has not been included in some other assessments. In the USA the biggest monetary value for externalities has been placed to bird losses – and that was not considered at all in the assessments for Germany or for Thailand. It is thus clear that too little studies have been carried out in this area. Case studies on external costs of pesticides should be added, previous studies should be repeated, and meta analysis of external costs should be carried out. Similarly, meta analysis of the economics of using BCA should be carried out for comparison (Waibel, 2007).

Pimentel and co-workers have analysed the environmental and socio-economic costs of pesticide use in the USA (summarised by Pimentel & Greiner, 1997). They calculate that these costs amount in the US to about \$8.3 billion every year (roughly \$30 per person per year). This clearly exceeds the purchase value of all pesticides, which is about \$6.5 billion per year. Thus the real costs of applying pesticides is more than double of that what is paid by farmers, and could be viewed as society subsidies to support this form of pest management. In the estimates by Pimentel & Greiner (1997) the highest cost from pesticide usage was calculated to arise from bird losses (\$2.1 bn/a), followed by costs of groundwater contamination (\$1.8 bn/a), costs of pesticide resistance (\$1.4 bn/a), and public health impacts (\$0.93 billion/a). These authors conclude that if it would be possible to measure the full environmental and social costs of pesticide usage, the total cost would still be significantly greater than their estimate of \$8.3 billion/year in the USA.

In the following section a specific attention is paid to human health risks from pesticides, because of its fundamental importance, and because this aspect is one of the critical differences between CPPP and BPPP.

Human health risks

Many negative health effects of pesticides are only known partly because of scarce research and poor and inconsistent record of health effects. Endocrine disrupting pesticides are likely to add to the exposure of mankind of a big pool of potential disrupting (with unknown combination effects) which could (or already have) change the quality of life of generation by introducing morphological changes and affecting

reproduction. The example of vinclozolin (Anway, 2005) capable of inheritable changes shows the potential of negative effects.

Worker exposure

Only few independent studies on workers' health have been carried out at the European level. In the late 1990s, the European Federation of Agricultural (EFA) workers carried out a survey of pesticide poisoning among its two million members (Pesticide News, 1997). The results showed that at least one person in five considers that they have been made ill or poisoned, or adversely affected by pesticides.

Among those poisoned, 53% informed their employer, but only 27% informed the competent authority. In 46% of cases, poisoning involved medical intervention, either a consultation or visit to a hospital. Symptoms most often reported by pesticide users included: headaches (67%); skin irritation (39%); stomach pains (33%); vomiting (30%); eye irritation (25%); diarrhoea (15%). Some reported more than one symptom. Other symptoms occurred in 10% of cases: notably symptoms linked with the nervous systems such as fatigue, difficulty in concentration, difficulty in muscle control and co-ordination of movement; and the respiratory system. Besides poisoning, workers frequently exposed to pesticides are known to develop several diseases, including cancer, chronic fatigue and respiratory diseases.

For the US, public health impacts of pesticide use are estimated by Pimentel et al. (1992) to cost \$787 million each year. These impacts arise from human pesticide poisonings and illnesses, and include costs of hospitalization, outpatient treatment, lost work time, treatment of pesticide induced cancers, and fatalities. Deaths of domestic animals (particularly cats and dogs) and contamination of meat, milk and eggs cost at least an additional \$30 million annually.

The International Labour Office (ILO) recognises that workers in developing countries are at especially high risk due to inadequate education, training and safety systems. About 5000 fatal pesticide poisonings per year are estimated to occur globally, with some 500 000 less severe cases of poisoning. But even in developed countries such as EU countries agriculture ranks consistently among the most hazardous industries. In Italy, for example, although agriculture production employs 9.7% of the workforce it is responsible for 28.7% of accidents. Exposure to pesticides and agrochemicals constitutes one of the major risks faced by farm workers, accounting in some countries for as much as 14% of all occupational injuries in the agricultural sector and 10% of all fatal injuries.

Residents and bystander exposure

A report by the UK Royal Commission on Environmental Report (RCEP 2005) finds that *'Based on the conclusions from our visits and our understanding of the biological mechanisms with which pesticides interact, it is plausible that there could be a link between residents and bystander pesticide exposure and chronic ill health. We find that we are not able to rule out this possibility. We recommend that a more precautionary approach is taken with passive exposure to pesticides.'* Residents and

bystander exposure has not been rigorously evaluated under field conditions, and apparently has been chronically under evaluated.

In utero exposure

Mothers' exposure during pregnancy can also cause birth defects. Mothers can be exposed directly through food, occupational use, gardening and household use, the house being exposed near sprayed fields, and indirectly through partner's professional or amateur use. An extensive literature review divided scientific studies according to their findings in terms of implications for the progeny (Wattiez, 2005). Exposure to pesticides is linked to central nervous system defects, cardiovascular defects, oral cleft, eye anomalies, urogenital defects, limb defects, intrauterine growth retardation and neurodevelopment impairments.

Children's exposure

A study from the World Health Organization (WHO) and European Environment Agency (EEA) addressed the environmental impacts on children's health (WHO/EEA, 2002). The section on pesticides points out that fetuses, infants and children can be more vulnerable to pesticides, both quantitatively and occasionally qualitatively, than adults, because their bodies are still developing. Fetuses, infants and children are highly vulnerable to critical windows of exposure, and their systems for protecting the body from toxic chemicals are still immature. They are also more exposed because of childhood patterns of behavior and specific diet.

The core tests to determine the safety of pesticides currently in use within and outside the EU, including for new EU pesticide authorizations, do not fully assess the hazards posed by specific pesticides to infants and children. Moreover, current risk assessment methodology does not specifically consider these effects on infants and children nor the wide range of exposure patterns that exist within this population. Consequently, variations in dietary and environmental exposure to pesticides (aggregated exposure) and health risks related to age and particular sensitivity are not addressed when establishing ADIs (average daily intake), ArfDs (average reference doses) and MRLs (maximum residue limits).

Possible health effects include immunological effects, endocrine disrupting effects, neurotoxicological disorders and cancer. Susceptibility of this vulnerable group to delayed functional toxicity -- as a result of exposure to apparently sub-toxic doses of pesticides during a critical window -- may not become manifest until adulthood.

Cost-benefit assessments of plant protection

Chemical PPP

Only a few cost-benefit assessments concerning the use of chemical PPP have been carried out. Even those have used different assessment and valuation methods, have included many important aspects only partially or not at all, and have often ignored costs and benefits at different levels of society (e.g., private vs. public benefits and costs). Also, important aspects of long-term negative impacts are largely unknown (such as endocrine disrupting effects of persistent agents, or their breakdown products, and the synergistic effects of mixes of synthetic chemicals which in some cases are known to amplify the effects by several orders of magnitude).

Examples of some assessments that have been performed are summarised in the following Tables:

Benefit-Cost Ratio of pesticides in German agriculture (old federal states)
Source: Waibel und Fleischer 1998.

	Bill. DM
Costs	
Total costs per year	1.941
Pesticide costs	1.100
Application costs	0.589
External costs	0.252
Benefit	2.836
Benefit-cost ratio: 1.47	

Type of costs	External costs [Mill US\$ per annum]		
	Thailand	Germany	USA
Public health	0.6	13.6	787
Domestic animals and fish	---	---	54
Loss of beneficial organisms	2.4	5.9	520
Residues in Food	209.0	---	---
Pesticide resistance	---	---	1400
Production loss	---	1.2	1062
Bird losses	---	1.2	1062
Groundwater contamination	---	75.3	1800
Government regulation and research	16.8	52.2	200
Total	228.9	148.2	7923
Value of pesticides	247	647.1	4100
Ratio	0.93	0.23	1.93

As can be seen from the Tables (above), many studies exclude several components that are known to affect the outcome of these calculations, and as a consequence arrive at widely varying results. The most complete assessment (USA) arrives at a ratio of almost 2, meaning that the external costs of pesticides (still incomplete in this assessment) are almost two times higher than the purchase value of these pesticides.

Further studies have been carried out on the economic costs and benefits of alternative pesticide usage scenarios in the UK by Webster and his co-workers for wheat and apple production (e.g., Bowles & Webster 1995, Webster & Bowles 1996, Webster et al. 1999). The ratio between private and society benefits in their example on UK wheat production is illustrative: for every £1 gained by farmers in private benefits in a move from conventional to integrated farming (with reduction in pesticide usage), there would be £6 worth of benefits to society. The authors conclude from this that the government may have a role in the promotion of reduced pesticide strategies.

Estimates of private benefits and costs of chemical pesticides usually have arrived at a benefit-cost ratio of about 4:1 (Pimentel, 1997). If we consider that the external costs of chemical PPP are conservatively estimated to be double of their purchase value, this yields as the overall economic benefit:cost ratio for chemical PPP about 4:3 [private benefits = 4; purchase cost + external costs = 3]. Considering that the overall costs of pesticides are still underestimated, it is difficult to conclude that the use of chemical PPP is a meaningful economic activity.

Biological Plant Protection Products (BPPP)

Numerous cost-benefit analyses have been carried out concerning biological plant protection products (e.g., Cullen and Whitten 1995, Greathead 1995, Törmälä 1995, De Groote 1997, Lubulwa and McMeniman 1998, Gutierrez et al. 1999, Perkins and Garcia 1999, Collier and Van Steenwyk 2004). These show that overall for BPPP the benefits outweigh the costs typically at a ratio between 30:1 and 40:1. It should be noted that in the case of BPPP the costs consist practically only of the private costs to the grower (or operator), because external costs are largely absent. In the case of inundative biological control the ratio for the grower (private benefits vs. costs) often is comparable to that for chemical PPP, but for the society the ratio is much more favourable. Biological control methods are not known to pose any health hazards to the application personnel, nor to the consumers because there are no toxic residues on the products. Negative impacts on the environment from biological control treatments usually do not exist (van Lenteren et al., 2003; 2006; Hokkanen & Hajek, 2003), nor any other of the socio-economic costs similar to those associated with the use of chemical pesticides (see Pimentel & Greiner, 1997).

In conclusion, the replacement of chemical pesticide treatments by biological controls would bring immense socio-economic benefits to the society: the benefits from controlling the pests would still accrue, but the negative externalities would disappear.

Comparative assessment of benefits and risks of plant protection methods

To our knowledge, no detailed comparative studies have been published concerning the benefits and risks (costs) of the various plant protection methods. Methods for carrying out and quantifying risk assessments for BPPP were developed within the EU-funded project ERBIC (see e.g. Hokkanen and Hajek 2003; van Lenteren et al. 2003, 2006). These have later been refined and adopted for comparative assessments by Laengle and Strasser (2008), who compared the risks for several BPPP with risks from some conventional chemical PPP (CPPP) (see Table below). These assessments take into consideration the definition of risk as the product of the likelihood of occurrence by the magnitude of effect ($R=L*M$). Important factors to be assessed include the potential for impacts outside the treated target area (dispersal), the range of non-target organisms (NTOs) potentially affected (host range), the direct effects on these NTOs, and potential indirect effects. For further details of the methodology see van Lenteren et al. (2003) and Laengle and Strasser (2008).

Risk scores and calculated risk index for selected pest control products (Laengle & Strasser 2008)

Active Ingredient	Persistence factor	Dispersal factor		Host Range		Direct Effect		Indirect Effects		Vertebrate effects	Risk Index
		Distance	Quantity	Species	Taxonomic level	Likelihood	Magnitude	Likelihood	Magnitude		
<i>Bacillus thuringiensis</i> (spray)	2	2	3	4	4	3	2	2	3	1	280
<i>Beauveria brongniartii</i> (soil)	1	3	1	2	1	1	1	1	1	1	16
<i>Beauveria bassiana</i> (spray)	1	3	3	4	4	3	2	2	2	1	260
<i>Beauveria bassiana</i> (soil)	1	3	1	4	4	3	2	1	2	1	96
<i>Coniothyrium minitans</i> (soil)	1	1	3	1	1	1	1	2	2	1	24

<i>Metarhizium anisopliae</i> (soil)	1	3	1	4	4	3	2	1	2	1	96
<i>Metarhizium anisopliae</i> (spray)	1	3	3	4	4	3	2	1	2	1	240
<i>Pantoea. agglomerans</i> (spray)	1	3	2	3	3	2	1	1	1	2	98
<i>Pseudomonas fluorescens</i> (spray)	1	2	3	3	3	2	1	1	1	1.5	91
<i>Trichoderma harzianum</i> (soil)	2	1	1	3	3	3	2	2	2	1	95
Chlorpyrifos (spray)	3	5	4	5	5	5	5	5	3	2	2610
Benomyl (spray)	4	2	3	5	5	5	4	5	3	2	1760
Methyl bromide (fumigation)	5	5	5	5	5	5	3	3	3	2	3200
Streptomycin	3	3	3	5	5	3	3	5	3	1	882
Atrazine	5	5	4	5	5	5	5	3	3	???	1530
DDT (spray)	5	5	4	5	5	5	5	5	4	2	4275
Phorate (granular)	3	5	3	5	5	5	5	3	3	2	2016

Comparison of risk indexes arising from such assessments show that typically CPPP produce risk indexes ten to twenty (but up to several hundred) times higher than BPPP. This is consistent with the conclusion from the earlier economic cost-benefit assessments (earlier section of this document).

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