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Assessing and Monitoring the Impacts of Genetically modified plants on Agro-ecosystems

D10.5 Integrated Pest Management: A cost-benefit analysis of IPM options for maize and potato in Europe

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Introduction

Within AMIGA, IPM-oriented field trials were conducted with two crops, maize and potato, during 3 growing seasons. For maize the trials were carried out in Slovakia, Spain, and Sweden, with additional trials in Denmark and Romania. Potato trials with cisgenic potato were conducted in the Netherlands and in Ireland, with supplementary trials in Finland and in Romania.

Basically, three treatment options were compared for maize:

A. Conventional maize with current regional (conventional) management;

B. Conventional maize with best regionally available IPM solutions (action thresholds, BC, mechanical weeding, etc); and

C. GM maize (Bt Mon810 or triple stack) with associated regional IPM strategies.

Additionally, in Spain herbicide-IPM was included to evaluate and compare the effect of conventional and innovative weed management practices on weeds and insects. This included:

A. Conventional herbicide treatment, i.e. the standard treatment conducted by farmers according to the regional practices for maize production

B. IPM1 system evaluated reduction in the herbicide treatments, and also in the doses of the herbicides employed for weed control.

C. IPM2 system introduced glyphosate treatments. The treatments were inter-row in order to mimic the use of GM tolerant maize. IPM2 included a pre-emergence application of the lowest registered rate of a commonly used residual herbicide, followed with a post-emergence application of glyphosate.

D. IPM3 included two glyphosate applications. IPM2 and IPM3 with Conventional maize mimicked the use of herbicide tolerant variety, while IPM2 and IPM3 with Bt maize mimicked the use of a stacked (Bt + glyphosate) tolerant variety.

The IPM Control strategies for potato compared three IPM options for potato late blight (PLB) control. All other necessary sprays and treatments e.g. against aphids, weeds, alternaria etc, were applied when necessary, and always to the whole experiment. IPM options for PLB control included:

1. No spraying against potato late blight. This results in a short season for the susceptible genotype Desiree. Plots were desiccated when severity passed a pre-determined threshold e.g. 1% severity or 10% severity, depending on local regulations and sensitivities (neighbors).
2. Current practice e.g. weekly application of preventive fungicides for late blight control.
3. IPM 2.0 control strategy, low fungicide input, designed to “save the R-gen(s) and the environment”.

Details, and outcomes from these experiments are reported in WP8 Deliverables.

Ideally, for a cost-benefit analysis a range of crop management parameters and output (yield) would have been collected, and an appropriate economic tool (e.g., DEXiPM, Pelzer et al. 2012) would have been used. It became clear very soon, however, that the quality of the data obtainable from the spatially small-scale trials in AMIGA would not allow such comparisons to be credibly made; therefore this Deliverable focuses on the broader cost-benefit issues, concepts and methodologies, and utilizes only tentative data and insights from the AMIGA field trials for the conclusions.

Economic framework analyzing benefits and costs of alternative pest control strategies

Economic benefits and costs of pest control strategies can be assessed at different levels. Assessment of benefits and costs of different control strategies at farm level allow to identify under what conditions one or the other control strategy might be profitable for farmers. The economic assessment at farm level will be discussed in the next section.

Profitability of one control at farm level does not necessarily imply that at aggregate level net benefits will be positive. The control strategy that would generate the highest profit at farm level might result in external costs and/or benefits that a farmer may not consider but need to be added when aggregating benefits and costs over time and space. The framework for a benefit costs assessment at aggregate level will be discussed after the next section.

Theoretical Framework Assessing Farm Level Benefits and Costs of Pest Control Strategies

The appropriate model specification for the productivity assessment of damage control inputs such as synthetic pesticides, insect-resistant crops, or biological control agents is subject of lively debate in agricultural economics. Damage control inputs do not directly increase yield, but rather, increase the share of potential output that is realized by reducing damage. Consequently, the effectiveness of these damage control inputs depends on the level of damage agents (e.g., pest pressure). Thus, productivity assessment of these inputs is not as straightforward as that of direct (yield increasing) inputs such as labor or capital.

The treatment of damage agents presents an additional challenge. As Norwood and Marra (2003) show, the absence of pest pressure information results in an underestimation of marginal pesticide productivity. However, if information about the pest pressure is available, it is unclear how these data should be modeled in the estimation of the damage control function, to allow the productivity of damage control inputs to depend on the level of pest pressure.

A rather straightforward economic threshold model that is less data demanding to assess the use of certain control methods, similar to that of Mumford and Norton (1984), is as follows:

$$P{*}D{*}K{*}\theta \text{ (benefit of control)} = C \text{ (cost of control)}, \qquad (1)$$

where P = price of crop (e.g. maize per ton); D = the loss in yields in comparison to the potential yield/ha per unit of pest pressure (such as e.g. larvae per stem), excluding any insurance value; K = the reduction in pest attack achieved by a strategy; = the level of pest attack, and C = the cost of applying a control measure per hectare. The economic threshold, or cost-benefit ratio, is thus:

$$\theta = \frac{C}{P * D * K} \qquad (2)$$

Equation 1 can also be expressed as:

$$P * D * K * \theta - C > 0 \qquad (3)$$

This is a rather simple approximation of optimal control levels. More complex models that consider uncertainties about control efficacies as well as the pest pressure show lower economic benefits of control.

Lichtenberg and Zilberman (1986) were the first to discuss the special nature of damage control inputs, and to account for this characteristic using a built-in damage control function in the production function framework, now a standard approach in applications (see e.g. Babcock, Lichtenberg, and Zilberman 1992; Carrasco-Tauber and Moffit 1992; Oude Lansink and Carpentier 2001), especially in the productivity assessment of Bt-crops (Pemsl et al. 2008; Kuosmanen et al. 2006; Qaim 2003; Thirtle et al. 2003; Huang et al. 2002).

Another important question in the productivity assessment of damage control agents concerns the specification of the functional form of the production function. Results are often sensitive to the specification of functional form in the sense that different specifications yield contradictory marginal value products for damage control inputs (Carrasco-Tauber and Moffit 1992; Fox and Weersink 1995). Resorting to nonparametric frontier estimation methods (e.g. Färe, Grosskopf, and Lovell 1994) that do not require parametric specification of the production function can resolve the specification problem. The key advantage of these methods is that they do not impose strong prior assumptions. However, the nonparametric approach has disadvantages, which might explain its limited diffusion to damage control function estimation. In particular, the nonparametric approach generally requires a large data set, and the techniques for statistical inference are less developed (see e.g. Simar and Wilson 2000). Perhaps most importantly, the lack of algebraic relationship between the variables can make it difficult to apply the estimation results in economic analyses.

While these methods allow to derive information about the optimal level of pest control provided sufficient data are available for a certain control strategy, one has to be careful comparing different control strategies. What might be good for one farmer might not be good for another farmer. Heterogeneity among farms and farmers caused by differences in farm and farmer characteristics are reasons for relative differences in profitability of different pest control strategies. Further, successful new pest control strategies might not only increase yield by reducing pest damage but also by increasing the use of other factor inputs such as fertilizer due to the yield risk reducing effect (e.g. Barrows et al., 2014). Another complicating factor is that control strategies within a cropping season may change depending on pest pressure and micro climatic conditions (Mbah et al., 2010).

For a profitability analysis at farm level not only input and output prices and quantities and the damage control function play a role but also non-pecuniary benefits such as having less to think about pest control. This has been reported for herbicide tolerant crops and has become a relevant factor for farmer adoption (Mara et al. 2004).

Assessing Environmental Benefits and Costs and Overall Welfare Effects of Pest Control Strategies

Concerns about the introduction of new and available pest control strategies have been driven by two major issues: impact on human and animal health and impact on the environment (see e.g. European Council for the Environment, 1999). As a response to these concerns a number of rules and regulations have been implemented to govern the approval process of pest control strategies. The implementation of rules and regulations are not costless. Costs arise to administer the rules and regulations, companies face additional costs to comply with, and in addition causing a delay in introduction resulting in foregone benefits. These additional costs have to be justified by the benefits generated by the rules and regulations implemented. Beforehand it is not obvious if this will always be the case. Companies will only have an interest to introduce a new product if a market for the new product exists. A potential market will exist if the new product is better than what is already available. If users expect this to be the case they will adopt the new product and have the chance to increase their net benefits. In this case society will benefit as well as more goods can be produced with the same amount of resources or the same amount of goods with less resources. In the case of pest control strategies, producing and consuming food products derived from agricultural crops may have negative impacts on human health and/or the environment. If these negative impacts on the one hand have not been included in the net-benefit assessment at user level, they might warrant restricting or even ban the use of some pest control strategies to reduce negative impacts. On the other hand, if those impacts have been included and there are positive net-gains additional constraints on use or a ban might not be justified from a cost-benefit perspective. Hence, it is not immediately obvious, if the introduction of a new pest control strategy just because its use has a negative impact on the environment warrants additional use restrictions or even a ban. As every kind of agricultural production has an impact on the environment, also the different pest control strategies will have. But it might be the case that the impact of one pest control strategy on the environment is less than the impact of the one it replaces.

It is clear that externalities bear additional costs, and views on measuring the costs and appropriate responses differ. These views, however, reach the same conclusion: the mere existence of externalities per se does not justify a ban.

The precautionary principle

A general discussion fails to differentiate between different types of external costs. A concern about environmental impacts is that they may be irreversible and/or catastrophic - one of the reasons why the precautionary principle has been mentioned in many regulation on e.g. GMOs (such as the Cartagena Protocol) or regulations on release within the European Union (EC, 2001).

There are diverse interpretations of the precautionary principle; the most widely held is the prospect that harmful effects of a new technology take precedence over the prospect of beneficial effects. As harmful effects are potentially catastrophic, and this possibility cannot be excluded, and “the infinite costs of a possible catastrophic outcome necessarily outweigh even the slightest probability of its occurrence” (van den Belt, 2003, p. 1123), the result would be a ban of new pest control strategies and all other new technologies, including nanotechnology and cellular telephones. Many people would disagree with this view, and this line of reasoning is logically inconsistent.

In the context of new pest control strategy approval, catastrophic negative and positive effects cannot be excluded: this interpretation of the precautionary principle is unhelpful. Van den Belt (2003) recommends comparing the benefits and costs of possible errors as a guideline for approval, which corresponds with recommendations by leading economists who state: “… regulate until the incremental benefits from regulation are just off-set by the incremental costs. In practice, however, the problem is much more difficult, in large part because of inherent problems in measuring marginal benefits and costs.” (Arrow, et al. 1996, p.221).

A method of addressing potential environmental impacts in line with the precautionary principle, and in particular considering uncertainties and irreversible damages, is by performing an extended benefit-cost-analysis suggested, amongst others, by Wesseler, et al. (2007). They propose modeling the uncertainty of future net benefits using a stochastic process. The economic literature suggests if a policy includes irreversible costs, the net-benefits arising from the policy have to be larger than otherwise. The additional net-benefits needed to compensate for irreversible costs are calculated by using real-option models. Wesseler, et al. (2007) suggest using this modeling approach and apply this to the case of the approval of GMOs. Because irreversible costs of GMOs are difficult to quantify, irreversible costs that are acceptable considering the net-benefits of GM crop cultivation should be calculated – a threshold value they call the maximal incremental social tolerable irreversible cost (MISTIC), as depicted in Table 1 for Bt corn in Europe.

MISTIC is a threshold which stipulates the maximum irreversible cost an individual or society is willing to accept due to the introduction of a certain technology or innovation (Wesseler at el., 2007). While actual social incremental irreversible cost of technology is denoted as IT, MISTIC is denoted as I* which is:

$$I^* = \frac{W_T}{\frac{\beta}{\beta - 1}} + R_T \qquad (4)$$

Where W_T is the social incremental reversible benefits (SIRB); $\frac{\beta}{\beta -1}$ a factor capturing uncertainty and irreversibility effects; and R_T the social incremental irreversible benefit (SIIB) from time T to infinity. It then follows that:

$$I_T < I^* \tag{5}$$

In other words I_T should not be less than I^* for the technology to be registered and approved.

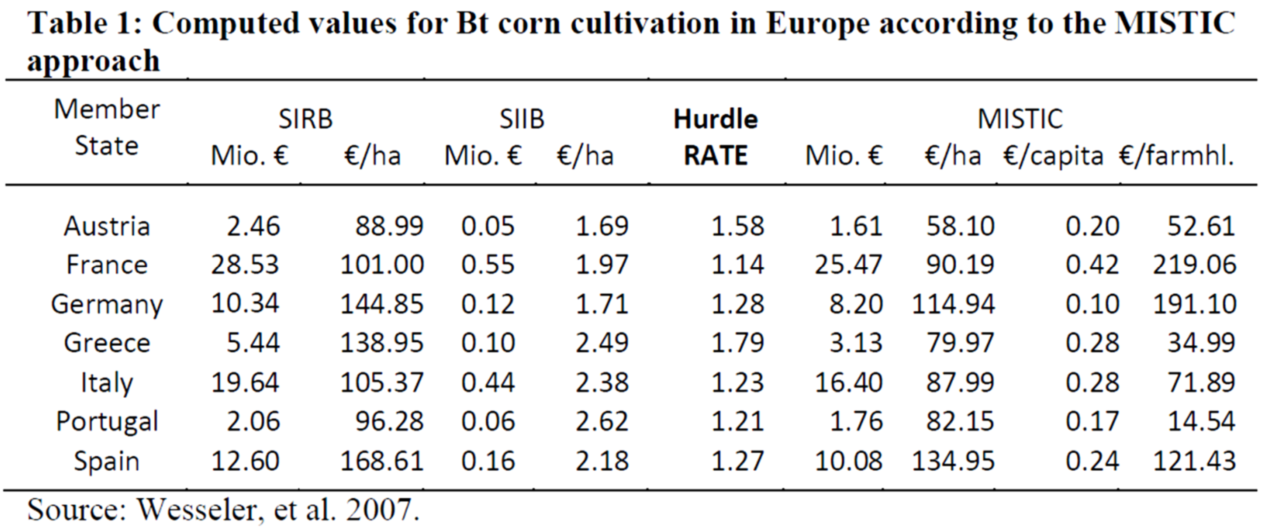


Table 1: Computed values for Bt corn cultivation in Europe according to the MISTIC approach

Member State	SIRB		SIIB		**Hurdle**	MISTIC			
	Mio. €	€/ha	Mio. €	€/ha	**RATE**	Mio. €	€/ha	€/capita	€/farmhl.
Austria	2.46	88.99	0.05	1.69	1.58	1.61	58.10	0.20	52.61
France	28.53	101.00	0.55	1.97	1.14	25.47	90.19	0.42	219.06
Germany	10.34	144.85	0.12	1.71	1.28	8.20	114.94	0.10	191.10
Greece	5.44	138.95	0.10	2.49	1.79	3.13	79.97	0.28	34.99
Italy	19.64	105.37	0.44	2.38	1.23	16.40	87.99	0.28	71.89
Portugal	2.06	96.28	0.06	2.62	1.21	1.76	82.15	0.17	14.54
Spain	12.60	168.61	0.16	2.18	1.27	10.08	134.95	0.24	121.43

Source: Wesseler, et al. 2007.

Note: Social incremental reversible net-benefit = SIRB,
Social incremental irreversible benefit = SIIB,
Maximal incremental social tolerable irreversible cost = MISTIC

The total and per hectare reversible benefits for Bt corn production for seven selected EU member states are tabulated in columns one and two, respectively. France's results show an annual social incremental reversible net-benefit (SIRB) of 28.53 Mio. € (101€ per hectare). Columns three and four show the social incremental irreversible benefits (SIIB) arising from reduced greenhouse gas (GHG) emissions and savings in pesticide use to be 55000€ per year and 0.55€ per hectare, respectively, for France. The hurdle rate captures uncertainty and irreversibility effects, and is 1.14 for France, which implies the sum of SIRB and SIIB has to be 14 per cent greater than the irreversible costs to justify an immediate introduction. Dividing the sum of SIRB and SIIB by the hurdle rate provides the maximum incremental social tolerable irreversible cost, being 25.47 Mio. € for France. If the annual irreversible damage to the environment of cultivating Bt corn in France is greater than 25.47 Mio. €, Bt corn should not be introduced, and vice versa. The three final columns indicate MISTICs per hectare; capita; and maize growing farm. It is striking how low the annual MISTIC per capita is, for e.g. 0.42€ per capita for France, which can be interpreted as follows: if the average capita in France is willing to pay more than 0.42€ per year for avoiding Bt corn cultivation, the introduction should be postponed.

The example illustrates the application for a new GE crop. The methodology can be applied to other pest control strategies as well and the example illustrates the application of the methodology and in particular the kind of information required for the application. But there is one problem with the line of reasoning presented. The problem with this line of interpretation is: if technologies that benefit a small group of society - in this case, corn farmers - are calculated on a per capita level, low numbers are inevitable. The relevant question would be to ask if there is evidence that annual environmental damage would reach, in the above case for France, 25.47 Mio. €.

Costs and benefits of pest control methods using synthetic pesticides and Bt-maize

Bt maize

First generation Bt-transgenic maize grown in the U.S. and Canada from the mid-1990s reduced European corn borers population due to its ability to produce Cry3Bb1 protein from the bacterium Bacillus thuringiensis. Additionally, a number of innovative transgenic crops have being developed during the last decades e.g. Diabrotica-active Bt-maize (Hellmich et al., 2008; Benbrook, 2012; Devos et al., 2012). In 2009 an estimated 14 million farmers from more than 25 countries commercially grew genetically modified (GM) crops, with GM insect-resistant and herbicide-tolerant crops accounting for more than 99 per cent of the global GM crop (Carpenter, 2010). A number of authors argue for the continued usage of Bt-maize and other Bt-crops, emphasizing the positive aspects of pest control and improved yields (Qaim, 2009; Carpenter, 2010; Kang et al., 2013). Environmental and economic benefits of Bt crops has been stressed by several author (Qiam et al. 2008; Zilberman et al. 2004; Wesseler and Smart 2013). Pest resistance has become an issue as resistance to Bt-toxins by target pests have been reported in cotton cultivation in the US and India as well as for Bt-Maize in the US (Gassmann et al., 2009; Gassmann et al., 2012; Tabashnik et al. 2008)

The economic benefits of Bt-maize come primarily from yield increases and decreases in insecticide use, which may vary depending on the level of infestations of a respective pest, price of premium seeds, etc. The value of protection offered by Bt-maize does not exceed its costs in most cases, as the use of chemicals is difficult due to timing of application (Fernandez-Cornejo and Li, 2005). Therefore Bt-maize is an adequate substitute for insecticide. Fernandez-Cornejo and Li (2005) identified the average difference in yield between adopters and non-adopters of Bt maize to be between 0.4 and 1.1 tons per hectare (7.1 and 18.2 bushels per acre). If U.S. farmers in 2000 had adopted between 30 and 100 per cent of Bt maize, it could have led to total benefits of between US$138 million and $402 million, of which $231 million in that same year would have accrued to farmers, with $58 million of the $231 million attributed to reduced usage of pesticides (Alston et al. 2002). This is in line with estimates from Qaim (2009) who identified welfare gains from Bt-maize in the U.S and Europe, estimating that Bt-maize in the U.S. would have produced a surplus of $334 million, of which $167 and $103.5 million would have gone to producers and farmers, respectively, while consumer surplus would have been minimal. In Europe (Spain) a welfare gain of €2.2 million was shared between farmers (60 per cent) and producers (40 per cent) in 2003 (Qaim, 2009; Hurley et al., 2006; Demont & Tollens (2004)). This is in line with Demont and Tollens's (2004) estimate of welfare gains of €15.5 million for Spain between 1998 and 2004, two-thirds of which were received by farmers and the remaining by seed companies. The cost-benefit ratio of WCR Bt-maize has been reported to range from 0.25 to 0.26 (Hurley et al., 2006). The economic impact of a farm-level adoption of GM crops estimated by Brookes and Barfoot (2009) in 2007 was substantial, as the net economic benefit which accrued to farms adopting GM would have been $10.1 billion and $44.1 billion for the 12-year period analyzed. Gianessi and Carpenter (1999) calculated that the value of the average net benefits of Bt-maize, when used to control the Eastern corn borer (economic damage similar to WCR) in 1997, a year of high infestation, was at a plus of $18.43/acre while the low infestation in 1998 gave way to a loss of $1.81/acre for that year. This estimate is in line with that of Marra et al. (2012) who calculated a surplus of $18.43/acre to farmers if the non-Bt cultivated area (refuge) would have been reduced from 20 to 5 per cent. Gianessi and Carpenter (1999) stated that total net benefits from Bt-maize went from a gain of US$72 million in 1997 to a loss of $26 million in 1998 due to pest infestation and low maize prices.

Integrated Pest Management (IPM) according to Rewa (2002) ideally combines biological and cultural control measures with limited pesticide use to keep pest populations below economically damaging levels, prevent future pest problems, and minimize the harmful effects of pesticides on humans and natural resources. Some of the benefits of biological control methods (apart from the substantial reductions in pesticides and limited residues, which lowers risks of exposure to producers and suppliers) include host specificity, low-resistance, and yield potential (Bale et al., 2008; Bailey et al., 2010; Khetan, 2001). In the EU biological control using natural enemies and crop protection products of natural origin (GNOs) is also seen as a means of achieving the directive for sustainable use of pesticides by 2014 (PAN E, 2007). The market for biological control in Almeria, Spain, alone is valued at €30 million, outperforming the total European market (Pilkington et al., 2010). The success story of biological control methods, which entirely replaced the use of pesticides in the control of thrips in Spain, is rather encouraging, with the ‘‘ecosystem service’’ provided estimated at ca. US$400 billion per year (van Lenteren, 2011).

There are certain costs or risks (uncertainty) associated with biological control method, as no level of host specificity testing can ensure zero risk to non-target organisms (Strand and Obrycki, 1996). According to these authors it is unlikely ever to have comprehensive knowledge of the biology of insect predators and parasitoids because of extremely high species diversity. Studies so far provide little evidence that introduced natural enemies are likely to disrupt native communities via indirect effects and competition. Therefore the scientific community needs to come to a consensus about how large this risk is and how it is to be measured relative to the monetary and environmental costs of managing pests by alternative means (Strand and Obrycki, 1996).

Pesticide reductions and low residue

In the U.S. use of biological control method against weevil reduced pesticide use alfalfa by 95 per cent from 1968 to 1983 saving farmer yearly insecticide and application cost of US$122 million (USDA, 2011).This complies with van Lenteren’s (2011) estimates which value pesticide use reduction from biological control at 90 per cent. Substantial reduction in pesticide use in the U.S. for the period under consideration (1964 – 1993) was only prevalent in two periods late 60s and early 80s. This reduction in chemical use, similar to that of Europe, may be linked to the inefficacy of chemical agents as well as a shift to biological control (U.S. Congress, 1995; van Lenteren, 2011). Biological control in outdoor horticulture is thus fast becoming the standard of pest control (Brown, 2008). introducing predatory bug (Orius laevigatus) (3 – 4 individual /m2) and predatory mite (Amblyseius swirskii) 100/m2) as biological control for Western flower thrips (Frankliniella occidentalis) and greenhouse whiteflies (Bemisia tabaci) in sweet pepper in Spain led to a 94 % drop in spanish sweet pepper pesticide reduce level sold in Germany (Knapp et al., 2008). The number of pepper samples which tested positive for chemical residue fell from 33 per cent to 0.4 per cent after the shift to biological control method in 2008 in Spain (Gonzalez et al., 2008). In 2007, a biological control program implemented in New Jersey for the Mexican bean beetle avoided ca. US$1.2 million in pesticide costs and eliminated the need to apply nearly 60,800 pounds of pesticide; soybean farmers in New Jersey have not had to use pesticides to control the Mexican bean beetle in 28 years (NJDA, 2007).

Host specificity

The impact of host specificity in biological control may be twofold: it determines efficacy and influences the commercialization potential of biocontrol methods (Brodeur 2012; Gaugler et al. 1989). Nearly 30 entomopathogenic nematodes species from the families Steinernematidae and Heterorhabditidae have preferred individual hosts including a variety of caterpillars, cutworms, crown borers, grubs, corn root worm, cranefly, thrips, fungus gnat, and other insects, respectively, while entomopathogenic nematode effects on non-target insects have been negligible, thus they are perceived as exceptionally safe (Miles et al., 2012). In the laboratory, a substantial number of EPNs infect a variety of insects due to optimal conditions. Several strains of Entomopathogenic fungi, e.g. Beauveria bassiana are more specific (and more efficacious) than others (no strict host specificity) and therefore can be used as a broad spectrum insecticide against several insect pests (Uma Devi et al., 2008).

Low-resistance

The evolutionary stability through strong persistence of the host – pest interactions makes biological control not only an alternative to chemical control but also an indicator for low resistance levels (Holt and Hochberg, 1997). These interactions, however, vary on a case-by-case basis and due to a number of factors ranging from biological to social characteristics may affect resistance development (Bailey et al., 2010). Available studies on host resistance in classical biological control, while emphasizing the need for more research, state that the current resistance level of diverse pests is rather minimal (Bailey et al., 2010; Thomas and Waage, 1996; Narayanan, 2004).

Yield potential

Agricultural pests are directly responsible for yield losses through feeding or indirectly by aiding infection through their activities (Oerke, 2005). Farmers in the state of New Jersey lose US$290 million annually from direct crop loss or damage caused by agricultural pests or the costs to control those pests (NJDA, 2007). Natural enemies that complement one another and act together to suppress pests can benefit primary producers by increasing yield (Denno et al., 2008). However, multiple release of natural enemy may be risky and lead to antagonistic interactions like competition or intraguild predation which weakens control and may lead to non-target effects (Pearson and Callaway, 2005; Denno et al., 2008). A meta-analysis of 35 published studies have shown that EPNs can reduce populations of their insect hosts by adversely affecting host fecundity and survival with an indirect positive effect on plants (Denno et al., 2008). These analyses also indicate that EPNs effects benefit both natural and agricultural systems, citing the example of Steinernema feltiae which was effectively used to reduce the populations of cabbage root flies Delia radicum and D. floralis, resulting in a two- to three-fold increase in cauliflower yield (Denno et al., 2008). This complies with studies which have shown that under certain climatic conditions, application of Steinernema carpocapsae Weiser can control weevil adults Listronotus oregonensis (LeConte) (Coleoptera: Curculionidae) in carrots and reduce damage by 59 per thus increasing yield in organic farming (Belair and Boivin, 1995). Some authors however pointed out that reduction in plant damage does not always translate into increased crop yield (Denno et al., 2008).

Additional Cost

The risk associated with biological control is the effect which arises from the interaction with non-target organisms which can be through direct or indirect attack (for instance, through ecological replacement and food-web interaction) (Pearson and Callaway, 2003; Delfosse, 2005).

High host specificity and efficacy regulates the population of BCAs and reduce the risk they may pose to non-target organisms (Pearson and Callaway, 2005). However, efforts to quantify and analyze the risk pose by agriculture biotechnology have been very challenging and difficult due to uncertainties regarding benefits, future output, microclimate and input prices and irreversible effect on human and non-target, biodiversity and administrative cost (Demont et al. 2004). The decision to either release or reject introduction of BCAs is therefore also subjected irreversibly and uncertainty (Delfosse, 2005; Wesseler at el., 2007). Irreversible effect in biological control methods such as testing of the hazard they pose to diverse non-target organisms is not only widely documented but has led to their registration and release (Delfosse, 2005) Biological control is refers to as the “white hat” of applied ecology; for instance, of the over 350 BCAs in weed management, only eight cases of non-target attacks were reported in the last 130 years (Delfosse, 2005). The uncertain costs and benefits associated with investing in BCAs is more complex, biological control method should however be instantaneously undertaken if benefits exceed the costs by a certain amount called the quasi-option value (Demont et al. 2004).Nevertheless, in addressing the cost of biological control under uncertainty, the minimum incremental social tolerable irreversible costs (MISTIC) is an appropriate estimating tool.

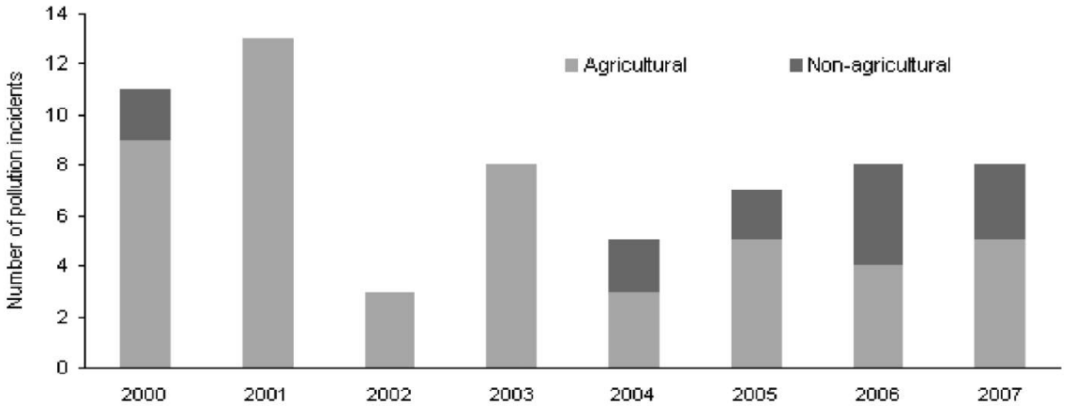
Economic Analysis

The benefit : cost ratios of biological control method of arthropod pests may exceed 145:1 while economic benefits from successful biological control programs are underestimated as profits continue to accrue annually following the reduction of a pest below economic threshold (Hoddle, 2003). Conservative estimation of benefit: costs ratio of biological control are estimated at 2.5 – 20: 1. This compares well with the benefit: cost ratios for the control of weeds. The benefit: cost ratio of the introduction of 1000 crown weevil Mogulones larvatus to control the weed salvation jane Echium plantagineum in Australia was estimated at 47:1 with a discounted net present value (NPV) from the period 1972 to 2050 of ca. US$916 million and an internal rate of return above 19% (Nordblom et al., 2001). The introduction fungus Colletotrichum gloeosporioides to control the weed Miconia calvescens in Hawaii over a 50-year horizon is expected to result in a positive NPV ranging between US$12.8 million and $36.1 million (Chock et al., 2010). Other examples of cost-benefit analyses of biological control efforts of diverse pests in Southern Africa point to a positive NPV as well (Chock et al., 2010). According to Simberloff and Stiling (1996) cost-benefit analyses of biological control are becoming exceedingly difficult to assess over time because it is challenging to assign values to the loss of species or ecosystem functions.

It is important to point out that the cost estimates used in most cost-benefit analyses, including the ones above, are mostly limited to fix and variable costs. Hence, they may not take into account other variables such as irreversibility and option value. However, this may be viewed as a basis for an economic analysis, given the complexity of biological control methods.

Health hazards of pesticides

35 per cent of all pesticides sold in Europe (fungicides, herbicides and insecticides) can be linked to health hazards such as carcinogenic, endocrine disruptor, reproductive and developmental toxicity and acute toxicity (Damalas and Eleftherohorinos, 2011). Thus the use of certain types of plant protection measures, e.g. chemicals for the control of WCR and wireworms, produces negative external effects. Figure 1 provides an overview of pollution incidents caused by the use synthetic pesticides in the UK (Ashbridge, 2011).



Source: Ashbridge, 2011

Figure 1. Serious pesticide pollution incidents 1999-2007.

External cost variable which includes health costs, contaminations, loss of natural enemies, cost of pesticide resistance, honeybee and pollination losses, crop losses, fishery losses, bird losses, groundwater contamination are associated with pesticide use (Waibel et al. 1998; Pimentel, 2005). For maize farmers in Brazil the costs of acute poisoning or health impact alone may represents 8% of the benefits of pesticide use if certain risk factors avoided or 85% of the benefits of pesticide use for a 10 year period when risk factor are considered. The total damage (including external cost) of pesticides within the EU is valued at between €230 billion and €240 billion euro depending on the discount rate (Fantke, 2012). The cost-benefit ratio of chemical pesticides use in agriculture was estimated at 0.68 and 0.3, respectively (Waibel et al. 1998; Pimentel, 2005).

Biological control, health and the environment

Benefit-cost analysis and risk assessment of biological control methods are vital to improve societal perception and depict potential benefits (Delfosse, 2005). This study looks at secondary sources that have been able to monetize the risk variables of chemical control. The average cost of pesticide to human health was about US$18 billion which was deemed rather conservative given that estimates could be higher (Fantke, 2012; Sexton et al., 2007; Radcliff, 2010; Soaresa and de Souza, 2009; Sanborn, 2012). The incidents of death in domestic animals and birds due to pesticides, although relatively well-documented, is yet to be adequately estimated; however this study reverts to Pimental (2005) which evaluates both costs at US$2.4 billion, which is a rather conservative calculation. The impact of pesticides on non-target organisms which contributes to their decline in populations, thus resulting in further loss in ecosystem services, is valued at about US$8 billion. Resistance development of pests has been valued at about US$10 billion (Aktar et al., 2009; Sexton et al., 2007). The loss of bees, and ultimately pollination, ranges from US$3 billion in fruits and $190 billion to $350 billion for all other agricultural produce (Gallai et al., 2009; Losey and Vaughan, 2006). Pesticide residues in food are estimated on average to cost US$169 million (Jungbluth, 1996; Praneetvatakul et al., 2013; Fantke P, 2012). The use of pesticides may lead to crop losses valued at US$1.4 billion. The value of the losses of fish to pesticide activity was estimated by Pimentel (1998) as “above US$56 million. The aggregated costs of government regulations range between US$34 billion and US$39 billion (Harrington, 2006). Table xx summarizes a rather broad or loose range of social costs due to the application of pesticides.

Table xx. Monetization of risk variable of synthetic pesticide use

Variables	**Cost (USD)**	**Sources**
Public health	18 billion	Fantke 2012; Sexton et al, 2007; Radcliff 2010; Soaresa and de Souza, 2009; Sanborn 2012
Domestic animal deaths and contaminations	30 million	Pimentel 2005
Loss of natural enemies (beneficial organisms)	8 billion	Aktar et al. 2009
Pesticide resistance	10 billion	Sexton et al. 2007
Honeybee and pollination losses	96.5 billion	Gallai et al 2009; Losey and Vaughan 2006
Residue in food	169 million	Jungbluth 1996; Praneetvatakul et al. 2013; Fantke P, 2012
Crop losses	1.4 billion	Evans 1993
Fishery losses	56 million	Pimentel 1998
Bird losses	2.1 billion	Khan et al. 2003; Pimentel 2005
Groundwater contamination	1.8 billion	Evans 1993
Government regulations	34 -39 billion	Harrington, W 2006

The inclusion of environmental effects in the economic analyses of biological control methods proves to be a rather difficult task. This is in part due to the difficulty in identifying and evaluating the costs, while benefits have estimation deficits. The fact remains that there are benefits traceable to biological control of pests; however, external or social costs of this control strategy should not exceed benefits. It then follows that control benefits should be greater than external cost. But many environmental effects as well as issues related to pest control such as pest resistance happen over time and requires a multi period analysis.

The case of IPM options for GM maize and potato in Europe

The framework for the analysis consists of the following information:

Evaluation of Management system and inputs required

Comparison between GM and conventional practices; comments-columns refer to the situation in GM crop

Variable to be considered	GM maize (IR, HT)	Cisgenic potato (DurPh)
necessary management practices	simplified weed control: two treatments instead of three; no large differences in insecticide applications	much simplified fungicide application: about two treatments instead of 10-15; no difference in other treatments, but increased costs of monitoring for resistance durability
necessary plant protection products, fertilizers & other inputs	reduced amount of herbicides (by about 30%); no difference in other inputs	fungicide inputs reduced by about 80-90%; no difference in other inputs
crop growth and vegetation period	no difference	no difference
stress tolerance of crop	no difference	no difference
durability of resistances	glyphosate resistance likely to evolve due to need to rely on one compound only	IPM strategy to replace resistance constructs before resistance is lost, leading to durable resistance; at least greatly prolonged durability
aptitude of crop to be integrated in a crop rotation	no difference	no difference
yield	yield benefits only under intense weed or pest pressure; AMIGA results indicate no yield benefit in HT trials, and a slight yield penalty in IR trials	no clear difference between GM and full fungicide program; conventional resistant cultivars (Opera, Voyager) yielded less than the susceptible cv Desiree, and fungicide treated potato yielded less than untreated cv without late blight pressure
management flexibility (=convenience for farmer) (e.g. number and timing of	increased flexibility for herbicide treatments; no other differences	increased convenience for farmer due to greatly reduced need for fungicide treatments;

management practices; coincidence with labour peaks; planning and organization; stress associated with severe crop diseases etc.).		impacts and labour needs for monitoring resistance development unclear (in any case offsetting some of the convenience achieved)

Evaluation of environmental goods and services

Variable to be considered	GM maize (IR, HT)	Cisgenic potato (DurPh)
Biodiversity: effects of the crop and its management system, and of the gene product(s): • on native flora; • on non-target arthropods; • on native wildlife, with special emphasis on extinction of species and changes in population size.	Reduced biodiversity of flora within the fields due to efficient weed management; little impacts on non-target arthropods other than via reduced resources (weeds) as host plants and nectar, pollen for pollinators; reduced wildlife due to fewer food resources	Likely benefits to non-target organisms, due to reduced fungicide sprayings; AMIGA results indicate slight increases in the number of arthropods caught in pitfall traps
Water • quantitative water use of crop and management system; • water balance in relation to soil structure; • pollution of water through the use of fertilizers, plant protection products or gene product(s)	No differences except possible differences due to changes in active ingredients for weed control (and associated residue and leaching effects and patterns)	No differences other than resulting from lower use of fungicides – likely less possibility to pollution of water
Soil • soil erosion; soil cover over entire rotation; • soil compaction: use of machinery; • fate of fertilizers, plant protection products and gene product(s) in soil, and toxicity to soil organisms	Reduced use of machinery and the possibility for adoption of minimum-till systems should benefit soil structure; possibility of lower toxicity to soil organisms if less toxic, and post-emergence herbicides only, are used	Reduced use of machinery and of fungicides should improve soil properties and cause less disturbance to soil organisms
Air & climate: air pollution, with special emphasis on greenhouse gases: • use of machinery; • spraying of pesticides; • evaporation of ammonia (e.g. from manure)	Improvements to be expected: less machinery use, lower amount of pesticides used	Improvements to be expected: less machinery use, lower amount of pesticides used
Energy balance: energy balance of agricultural system, and type of energy source (renewable / non-renewable) • energy needed for machinery and for input manufacture	Possibly slightly lower energy needs (machinery; manufacturing of pesticides)	Distinctively lower energy needs (machinery; manufacturing of pesticides)

(kind & quantity);		
Landscape: changes of visual aspects of the traditional, regional agricultural landscape. • diversity of crops (rotation); • new crops; • field & farm size; • natural habitats (hedges etc.); • novel management practices with relevance for visual aspects	No difference obvious at the landscape level	No difference obvious at the landscape level

Evaluation of social factors

Non-pecuniary social effects, such as:

Variable to be considered	**GM maize (IR, HT)**	**Cisgenic potato (DurPh)**
employment (including seasonal aspects)	No obvious differences	No obvious differences, except for less work involved in spray operations
job quality	Improved, if more flexibility is involved	Improved, as more flexibility is involved with less frequent spray operations
requirements for education, information, vocational and continuing training	Altered training requirements, including need to train for IPM techniques and aspects	Altered training requirements, including need to train for IPM techniques and aspects
effects on health, safety and dignity of farm family and labourers (e.g. in relation to pesticide spraying)	Slightly improved due to fewer spray operations	Significantly improved due to much fewer spray operations
social and economic protection of the farm family and labourers; social well-being	No difference (unless growing GM crops is a social hazard and unacceptable to some segments of the society)	No difference (unless growing GM crops is a social hazard and unacceptable to some segments of the society)

Evaluation of economic factors

Economic impacts to be assessed are

Variable to be considered	**GM maize (IR, HT)**	**Cisgenic potato (DurPh)**
operating costs (inputs, labour, economics of scale etc.)	Slightly reduced	Reduced
administrative costs on business	No data; probably no difference	No data; probably no difference
conduct of farm business	No data; probably no difference	No data; probably no difference
competitiveness (income,	No data; probably no	Considerable savings in crop

profitability, viability)	difference (but in some cases GM products have had lower producer prices than conventional	protection costs, probably at about 300 €/ha (De Wolf and van der Klooster 2006), may significantly improve the profitability of growing
property rights on land (tenure)	No data; probably no difference	No data; probably no difference
impact on investment and access to finance	No data; probably no difference	No data; probably no difference
consequences for specific regions and/or sectors	No data; probably no difference	No data; probably no difference
specialisation and diversification	No data; probably no difference	No data; probably no difference
eligibility for policy support	No data; probably no difference	No data; probably no difference

Conclusion

The continued reliance on chemical pesticide as the main approach in controlling agricultural pests and diseases, and the consequent negative impacts on maize and potato production systems, reduces benefits accruable to producers and the society.

The AMIGA case studies, GM-maize and cisgenic potato, offer significant benefits both to the grower and to the society, in terms of decreased pesticide use and increased flexibility in farm operations. The likely benefits appear much greater for cisgenic, blight resistant potato, than for GM maize. The growing system for neither of the case study crops, however, does not appear to provide immediate improvements in the broader adoption of integrated pest (or crop) management [e.g., such as discussed in Deliverable 8.1]. Further attention to comprehensive IPM for the whole cropping system, needs to be paid in future research projects.

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