summary:

impact of agricultural biotechnology on biodiversity

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Abstract

This overview concentrates on the impact of agricultural biotechnology on biodiversity. In order to understand this kind of impact, we also need to better understand biodiversity in terms of its fundamental components (genes and taxa), the interrelatedness of these components (ecology), their importance for human life and life in general, and the overall factors that threaten biodiversity. Within the tropics, Biodiversity is still concentrated in unmanaged habitats. In temperate zones, particularly in the European Union, almost 50% of the landscape is agricultural, and agricultural lands contain a significant portion of the biodiversity in these zones. The greatest threats to biodiversity are

destruction and deterioration of habitats, particularly in tropical developing countries, and introductions of exotic species. Maintaining biodiversity requires addressing these threats.

Many of the factors affecting biodiversity are related directly or indirectly to the needs of agricultural production, and it is important to consider how these impacts could be mitigated. Increasing human population and limited arable land have demanded increased agricultural productivity leading to more intensive agricultural practices on a global basis. In response, higher yielding crop varieties have been coupled with increased inputs in the form of fertilizers, irrigation, and pesticides and more intensive practices such as greater tillage of soil and fewer crop rotations and fallows. More recently, technological advances have led to the development of genetically modified (GM) crops with insect resistance and herbicide tolerance that have a demonstrated potential to enhance productivity and reduce environmentally harmful effects at the same time. These technologies have been broadly adopted in some farming systems, replacing broad-spectrum insecticides in some systems and facilitating reductions in tillage in others. This summary report is the result of an extensive screening of pertinent literature of over 3000 references. The author has not found a single document which would give scientific proof of permanent and specific negative impact of agricultural biotechnology under commercial field conditions.

This short version is based on an extensive report on the same subject, containing lots of active links, which can be downloaded at:

http://www.botanischergarten.ch/Biotech-Biodiv/Report-Biodiv-Biotech12.pdf

Impact of traditional agriculture on biodiversity

Farms have become more specialized and efficient, especially in recent decades. [1] analyzed changes in agriculture and biodiversity in Britain since the 1940s. They found a consistent reduction in landscape diversity, as reflected in a 65% decline in the number of farms.

Modern agricultural practices have been broadly linked to declines in biodiversity in agro-ecosystems. This has been found to be true for a wide variety of taxonomic groups, geographic regions and spatial scales. More specifically, various researchers have found significant correlations between reductions in biodiversity and agricultural intensification [2]. Similarly, analysis of 30 years of monitoring records demonstrated that arthropod populations are lowest where agriculture is the most intensive [3]; [4, 5].

These effects of agricultural intensification undoubtedly reflect a large number of factors which are addressed individually in the following sections, including the cropping pattern, the frequency of tillage, the amount and nature of fertilizers used, and the amount and nature of pesticides applied (particularly insecticides and herbicides). However, it should be kept in mind that all of these factors are interrelated to a greater or lesser degree and often the combination causes negative synergies [6] . There is no doubt that many human, social and cultural factors have to be taken into account, but nevertheless, in all cultures the practice is uncontested that habitat conversion is acceptable to provide for our own needs more food and settlement. [7] emphasize in a review, that the kinds of potential impacts of GM crops fall into the classes familiar from the cultivation of non-GM crops (invasiveness, weediness, toxicity or biodiversity. It is likely, however, that the novelty of some of the products of GM crop improvement will present new challenges and also new opportunities to manage particular crops in creative ways. But in order to get a clear picture, all risk assessment should be done under realistic field conditions and in comparison with the risks of traditional agriculture – it is deplorable that many risk assessment studies do not follow these simple rules.

In an agricultural context, a rapid decline in species, varieties and genetic diversity has been brought about by the success of new commercial varieties. Reported losses of over 80% of varieties in species such as apple, maize, tomato, wheat and cabbage have occurred worldwide [8]. Studies in population genetics raised concern over genetic erosion and the recognition of the importance of plant genetic material in the development of new varieties led to the establishment in the 1970’s of the International Plant Genetic Resources Institute in Rome [9, 10] and increased efforts to collect germplasm for *ex-situ* collections. The strong decrease in the number of butterfly species in Flanders (north Belgium) in the 20th century is illustrated by [11] using data from a national butterfly mapping scheme. Nineteen of the 64 indigenous species went extinct and half of the remaining species are threatened at present. Flanders is shown to be the region with the highest number of extinct butterflies in Europe. More intensive agriculture practices and expansion of house and road building increased the extinction rate more than eightfold in the second half of the 20th century.

Terrestrial but also aquatic biodiversity within and around agricultural fields, as discussed in Chapter 3, has also been strongly influenced by agricultural practices. [12, 13] Fertilisers, pest control chemicals, tillage and even crop rotation have been shown to profoundly impact the richness and diversity of agricultural ecosystems. [14, 15]. Habitat fragmentation may have a more adverse effect in combination with disturbance.

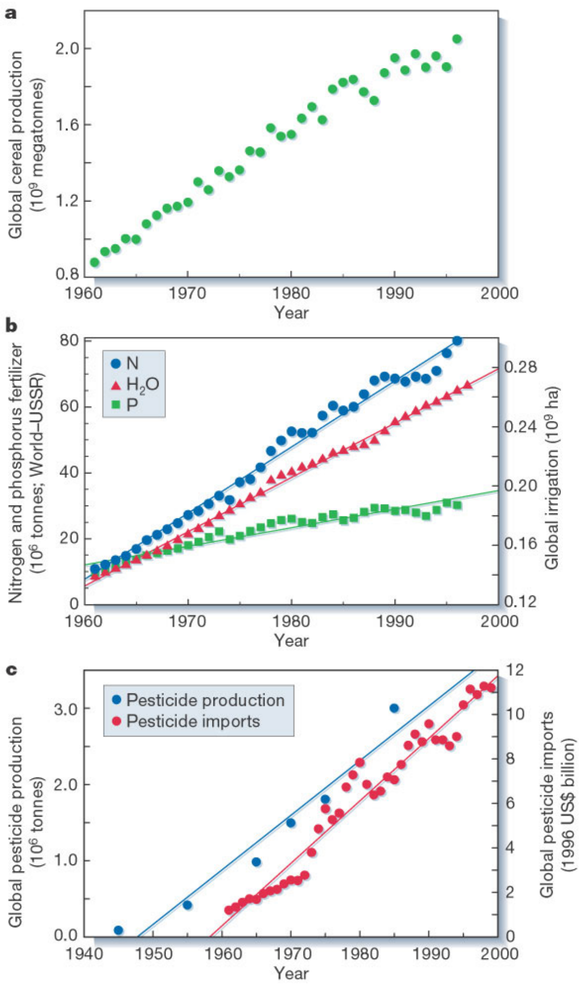

Figure 1 Agricultural trends over the past 40 years. a, Total global cereal production; b, total global use of nitrogen and phosphorus fertilizer (except former USSR not included) and area of global irrigated land; and c, total global pesticide production[3] and global pesticide imports (summed across all countries). Parts b and c modified from [16] [13]

Intensive tillage and frequent crop rotation, both targeting an unwelcome buildup of weeds and pests, lead to frequent disturbances of the agricultural landscape, increases energy loss from agricultural fields, and increases problems of soil erosion and run-off from agricultural fields. All of these factors adversely affect the quality of agricultural habitats, with significant consequences for agricultural biodiversity. When [17] studied corn, soybean and wheat cropping systems in the Mid- Atlantic region of the United States, they found that ground-dwelling and foliage-dwelling beneficial arthropods were least abundant, and pests were most abundant, in the simplest, most intensively managed continuous corn system.

The threats to biodiversity through traditional agriculture have been aggravated by the fact that recently, a slight decline in land converted into arable and permanent cropland becomes reality as shown in fig. 1:

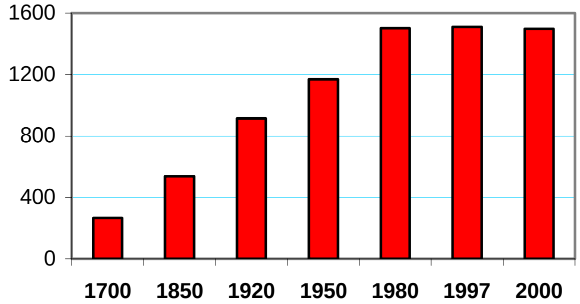

Figure 2: Land converted to arable and permanent cropland, in a time axis from 1700 to now, in million hectares [18]

Impact of Agricultural Biotechnology on Biodiversity

It is a frequent error to assume that agricultural biodiversity will automatically worsen the impact of agricultural practices on biodiversity – on the contrary: Combined with ecologically sound management and proper stewardship, GM crops have proven to enhance on the long term environmental impacts of modern agriculture. Here a summary of the arguments:

Impact of GM crops on biodiversity: two examples

1. Geneflow

Outcrossing transgenes are often not adversely affecting the wild species. This is because those new wild transgenic relatives are normally associated with decreased fitness genes, which they have received with the transgene, – consequently they will be soon selected out of the recipient population. [19]. However, if fitness is for some reason greatly increased through outcrossing effects and weedy characteristics of the wild relative could be enhanced. Such an effect could cause indirect negative effects on natural plant communities and the animals dependent upon them. At least with currently commercialized GM crops, no significant impact on the wild species is expected because the traits involved should not affect the fitness of individuals of the wild species [20]. The long-term experiment with four GM crops in England and a given set of transgenes suggest that competitiveness of the wild relatives outside the field prevents survival of the GM crops after a few years: [21-23].

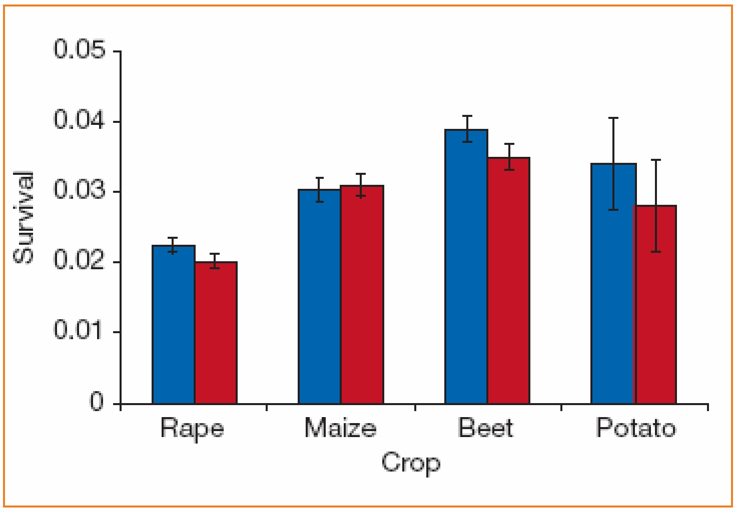

Fig. 3: The performance of conventional (blue) and transgenic (red) crops in natural habitats. Survival is the fraction of seeds sown (or tubers planted in the case of potato) that produce mature plants at the end of the first growing season. Error bars, 1 s.e. Data are averaged over habitats and replicates within habitat. In no case did populations of either conventional or transgenic plants increase, and transgenic plants never persisted significantly longer than conventional plants. All populations of maize, rape and sugar beet were extinct at all sites within 4 years of sowing. Potato still survives at one site, 10 years after planting, but the survivors are all conventional. [23]

Theoretically, scenarios can be described with incidences of outcrossing Bt genes with wild Helianthus producing 50% more seeds [24], but what then about Helianthus cultivars with even more seed production ? In field experiments wild Helianthus having received through outcrossing transgenic resistance to white mold did also did not demonstrate higher competitiveness [25], [26]. GM crops that are phenotypically similar to conventionally bred organisms and do not establish free-living populations can be regulated with more ease, since many crops have been improved using genes for disease resistance by crossing them with sexually compatible relatives — and if their relatives lack these genes, the same goal can be met by genetic engineering using genes from viruses, bacteria, plants or other organisms. [27]. These few examples demonstrate that assessing risk related to gene flow should always be based on case by case studies. It should also be noted, that gene flow measurement based on short term molecular analysis has its flaws, since the data can vary dramatically from season to season and place to place [28]. A method revealing long term results on gene flow from crops to wild relatives is based on plant collection statistics [29, 30].
Mitigation of gene flow is possible, first of all we can make use of the decades old experience of the seed producers: Keeping well known distances between the fields. Also it should be noted that oilseed rape traits with high erucic acid

content for industrial purpose is (as non-transgenic trait) in the fields and obviously did not pose any problems in segregation (USDA-Standard for oilseed grain: below 2% of erucic acid).

2. Non-target Insects in GM crop fields

The use of GM crops can positively impact agricultural species biodiversity if those GM crops allow the management of weeds and insect pests in a more specific way than chemical herbicides and pesticides. In particular, the adoption of insect resistant Bt crops, expressing highly specific Bt proteins, represents an opportunity to replace broad-spectrum insecticide use. The insecticidal proteins expressed in Bt crops such as Bt maize and Bt cotton are so narrow in their toxic activity that they have little or no impact against non-target organisms. Furthermore, the toxins are expressed within the plant tissues, minimizing the exposure of animals that do not feed on the crop plants. As a consequence, considering the large number of field studies that have been conducted, few or no differences have been seen with respect to community structure or individual species abundances where fields of Bt crops have been compared to conventional crops that have not been treated with insecticides. Where they have been calculated, indices of species diversity and community structure have not differed significantly for Bt corn fields compared to untreated conventional corn fields (e.g., [31-35] or for Bt cotton fields compared to conventional cotton fields [36-39]. The only species that have been observed to be significantly and consistently less abundant in fields of Bt crops relative to fields of conventional crops are the target pests and their specific parasites. It was Rachel Carson herself who named Bt proteins as a possible way out of the pesticide crisis which she described in her famous ‘The Silent Spring’, and one can only wonder what she would have said about the Bt toxin instead of being sprayed in large, but rapidly decomposing quantities, built genetically into the corn borer infested crops [40].

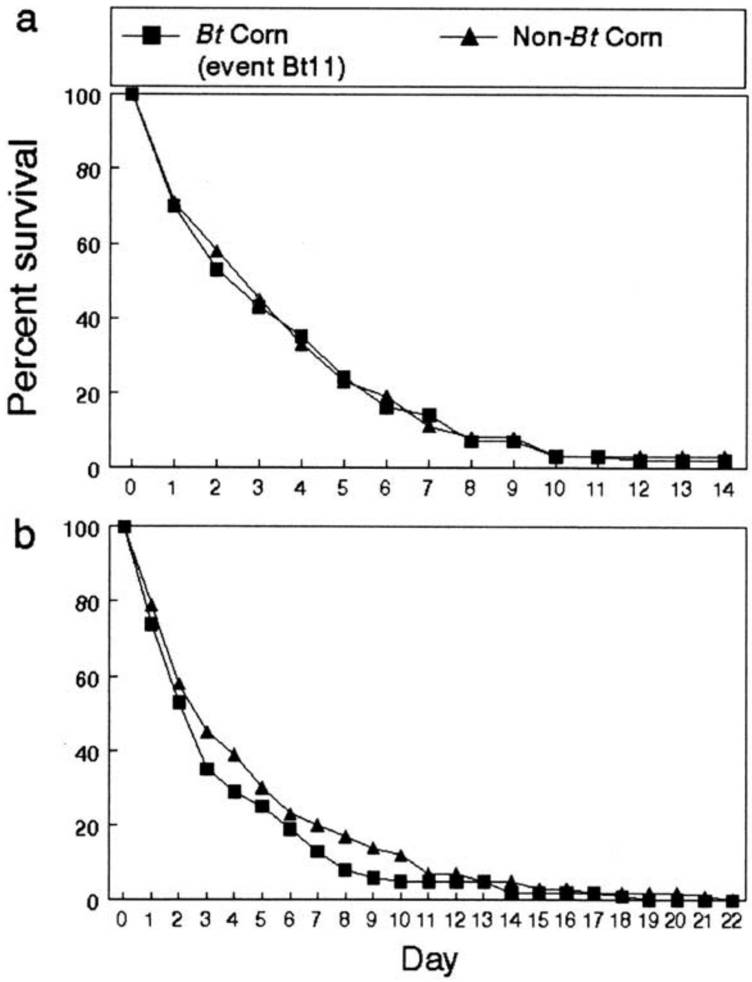

Figure 4. Survival curves for monarch larvae placed in and near *Bt* and non-*Bt* corn fields. (*a*) Iowa. (*b*) New York. The survival curves of larvae pooled over the three Bt corn sites were not significantly different from those in non-Bt (Fig. 13a). In New York, trends in survivorship were also statistically the same for cohorts of larvae feeding for 22 days on milkweeds in Bt and non-Bt fields (Fig. 13b). [41]

Benefits of GM crops related to biodiversity

At first sight and mindful of the recent English farm scale experiments [42], GM crops are always related to negative effects on biodiversity, but it is not that simple as critics of the farm scale experiments reveal: [43]. The fate of biodiversity depends heavily on the herbicide management and varies from crop to crop. Fighting off weeds within the harvested crop is a necessity, and it is done with less labour and energy input with broad band herbicides in combination with herbicide tolerant crops – consequently, farmers will be encouraged to follow up strategies to enhance off-field biodiversity of the margins with a clear beneficial effect [44].

There are clearcut biodiversity benefits shown in a field trial with Bt potatoes: [45]:

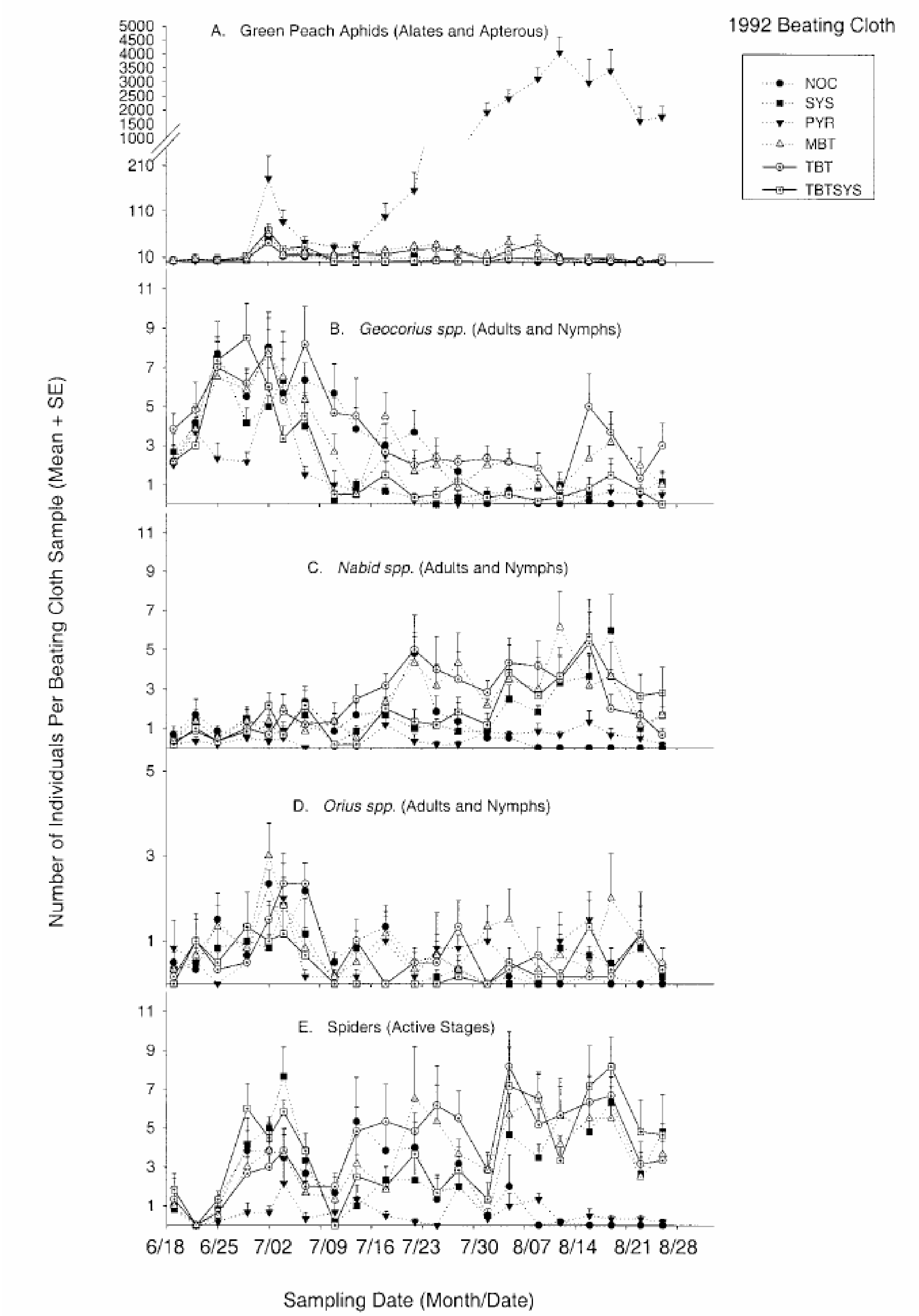

Fig. 4: Population dynamics of green peach aphids and major predators in different treatment plots sampled with beating cloths in 1992
field trial. Treatment description: NOC = conventional potato with no control measures; SYS = conventional potato with systemic insecticide treatments;

PYR = conventional potato with pyrethroid treatments; MBT = conventional potato with microbial Bt sprays; TBT = transgenic Bt potato alone; TBTSYS = transgenic Bt potato with systemic insecticide treatments. [45]

Also, it has been shown that no-tillage strategies are easier put in place with herbicide tolerant crops and show considerable positive effects on the soil biodiversity [46-50]

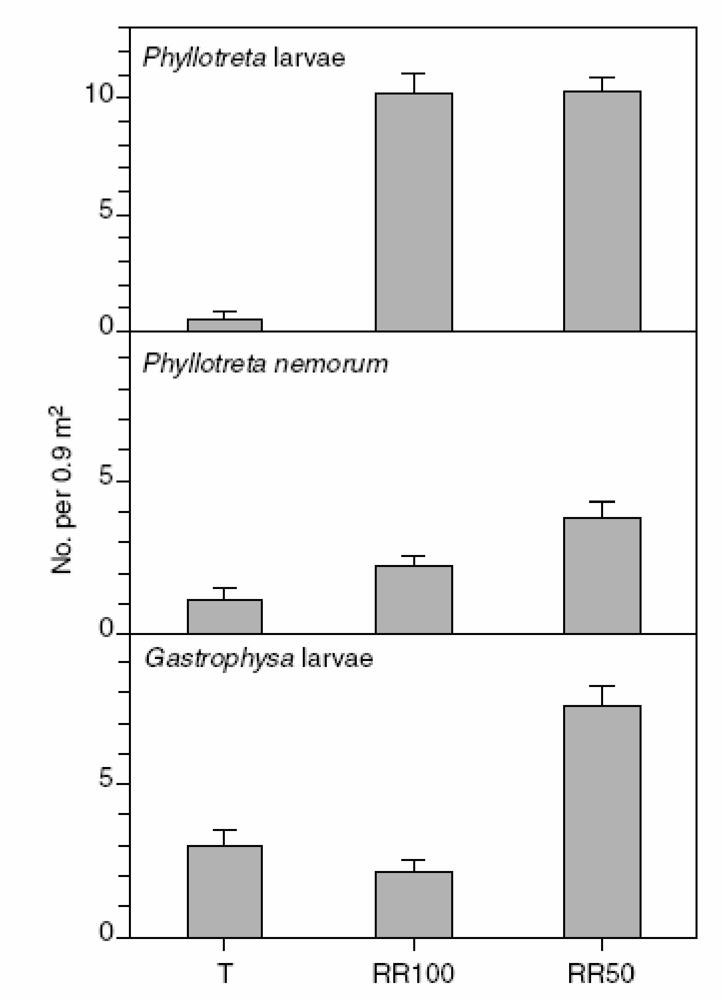

Figure 5: Density of *Gastrophysa polygoni* larvae, flea beetle larvae and *Phyllotreta nemorum* in the traditional (T) fodder beet plot, RR100 plot and RR50 plot at Skejby. Bars indicate standard error of means. [49]

Many other accounts and prospects of benefits have been described by [51] on animals and manure, [7, 52-58] on environmental aspects in general. It is clear, that the reduction of pesticide use and the shift from environmentally problematic herbicides to degradable and environmentally more benign herbicides will on the long term also have beneficial impact on biodiversity. Reports such as [59] stating that GM crops have a negative balance in pesticide use (i.e. require in average more pesticides and herbicides) are based on selective use of statistics: It is the lower environmental toxicity related to GM crop growing which decides over the fate of biodiversity. [60]

Conclusions of the Report as a Whole:

Habitat loss and fragmentation represent the greatest threats to natural genetic diversity. Practices that increase the productivity of existing agricultural lands will help to limit these effects. [61]. GM crops can be useful in this respect. Preservation of the genetic diversity present in crop species is an important need being addressed by various public and private programs. In this respect, biotechnology can be a valuable tool for introducing novel genes or valuable genes from old cultivars. Furthermore, the development and introduction of GM crop varieties does not represent any greater risk to crop genetic diversity than the breeding programs associated with conventional agriculture. The view, early published by the [62], that "GM crops offer more precision in lab and field testing than conventional ones" has not been disproven to date.

The study concentrates on the impact of agricultural biotechnology on biodiversity, but in several chapters of the full paper it becomes clear that biotechnology with its doubtless great potential can only play part of the game, since an optimal work with GM crops depends heavily on management and stewardship, on strategies adapted to crop and local ecology. Consequently, we need in future to dig into many other agricultural strategies to produce more and better food. Designing the best future solutions for food production certainly needs open minds and there is no doubt that we also should learn from traditional agriculture and recent trends like integrated and organic farming.

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