Biodiversity and the debate on GM crops

Can GM crops help to enhance biodiversity?

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1. The Issue
Genetically engineered crops are often taken automatically for the main reason of biodiversity loss.

There are numerous false claims of this kind, such as Vandana Shiva gives in her frequent world tours: Shiva, V., Emani, A., & Jafri, A.H. (1999)

“In such a situation, the introduction of genetically engineered (GE) seeds becomes worrisome. In absence of any such regulation, the costlier GE seeds will offer no guarantee for whether they perform well or not. This will lead to complete erosion of the agricultural biodiversity and adversely affect the socio-economic status of the farmers. This will be further aggravated since GE seeds will be patented, and corporations will treat information about them as proprietary.”

And another citation from Greenpeace Great Britain, downloaded from their website November 12, 2009

“The introduction of genetically modified (GM) food and crops has been a disaster. The science of taking genes from one species and inserting them into another was supposed to be a giant leap forward, but instead they pose a serious threat to biodiversity and our own health. In addition, the real reason for their development has not been to end world hunger but to increase the stranglehold multinational biotech companies already have on food production.”

The contrary is true, GM crops can help reduce the application of herbicides which are problematic for the environment, and a plethora of hard data proofs that non-target insects often survive quite well in Bt maize fields, whereas in non-GM crop fields, often the non-target organisms suffer from massive spraying of chemicals problematic to the environment and life. Another set of hard facts has been generated from the no-tillage culture of herbicide tolerant soybeans, where it is proven that soil fertility is greatly enhanced.

2. Summary
The need for biodiversity on all levels is made clear: Biodiversity provides a source of significant economic, aesthetic, health and cultural benefits (3.). Relationshhips between biodiversity and ecosystems is given in a table (3.1.) and a new concept of sustainability with more emphasis on development and progress is given (3.2.)

Types of biodiversity are often used without clear definition: genetic biodiversity - species diversity and ecosystem diversity are all part of biodiversity (4.).

A short chapter on global distribution on biodiversity closes the general part (5).

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The loss of biodiversity has one main reason: habitat destruction through urbanization, land use and agriculture (6.1.). Another threat to indigenous biodiversity is invasive species and species migration due to human activities (6.2.). Biodiversity is a kind of biological insurance for ecosystem processes (6.3.).

In chapter 7 crop biodiversity gets a closer look: the genome of transgenic crops is not basically different from non-transgenic crops (7.1.). Strikingly enough, the ancestral crop species chosen by the first farmers have lived in monodominant stands (7.2.). Agricultural biodiversity is characterized through high dynamics of all processes (7.3 and 7.4).

Chapter 8 deals with a series of proposals on how to enhance agricultural biodiversity through (landscape) management (8.1.), mixed cropping (8.2.), enhancing crop diversity through fostering orphan crops (8.3.) varietal mixture of genes and seeds of the same crop (8.4.), allow indirectly more diversity of non-target insects with the use of pest resistant transgenic crops and by reducing pesticide use and through no-tillage (8.5.), push-and-pull technologies (8.6.), better plant breeding (8.7), enhancing natural resistance with biotechnology (8.8.).

In an interlude chapter 9 on the activities of the protest industry and opponent scientists it is explained why the obvious success of GM crops is not really making progress in Europe.

In chapter 10, two case studies on GM crops are given with some detail on how those crops with widespread commercialization are helping efficiently to regain biodiversity in regions with intensive and industrial agriculture: Herbicide tolerant crops (10.1.) and pest tolerant Bt crops (10.2.)

In a final chapter 11, the health benefits of Bt maize are documented: transgenic Bt maize has much lower mycotoxin levels than non-transgenic maize.

3. The needs for biodiversity – the general case

Biological diversity (often contracted to biodiversity) has emerged in the past decade as a key area of concern for sustainable development (see 3.2), but crop biodiversity, the subject of this text, is rarely considered. The author’s contribution to the discussion of crop biodiversity in this chapter should be considered as part of the general case for biodiversity. Biodiversity provides a source of significant economic, aesthetic, health and cultural benefits. It is assumed that the well-being and prosperity of earth’s ecological balance as well as human society directly depend on the extent and status of biological diversity (Table 1). Biodiversity plays a crucial role in all the major biogeochemical cycles of the planet. Plant and animal diversity ensures a constant and varied source of food, medicine and raw material of all sorts for human populations. Biodiversity in agriculture represents a variety of food supply choice for balanced human nutrition and a critical source of genetic material allowing the development of new and improved crop varieties. In addition to these direct-use benefits, there are enormous other less tangible benefits to be derived from natural ecosystems and their components. These include the values attached to the persistence, locally or globally, of natural landscapes and wildlife, values, which increase as such landscapes and wildlife become scarce.
Biological diversity may refer to diversity in a gene, species, community of species, or ecosystem, or even more broadly to encompass the earth as a whole. Biodiversity comprises all living beings, from the most primitive forms of viruses to the most sophisticated and highly evolved animals and plants. According to the 1992 International Convention on Biological Diversity, biodiversity means “the variability among living organisms from all sources including, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part” (CBD, 1992). It is important not to overlook the various scale-dependent perspectives of biodiversity, as this can lead to many misunderstandings in the debate about biosafety. It is not a simple task to evaluate the needs for biodiversity, especially to quantify the agro ecosystem biodiversity vs. total biodiversity (Purvis & Hector, 2000; Tilman, 2000).

One example may be sufficient to illustrate the difficulties: Biodiversity is indispensable to sustainable structures of ecosystems. But sustainability has many facet’s, among others also the need to feed and to organize proper health care for the poor. This last task is of utmost importance and has to be balanced against biodiversity per se, such as in the now classic case of the misled total ban on DDT, which caused hundreds of thousands of malaria deaths in Africa in recent years, the case is summarized in many publications, here a small selection: (Attaran & Maharaj, 2000; Attaran et al., 2000; Curtis, 2002; Curtis & Lines, 2000; Horton, 2000; Roberts et al., 2000; Smith, 2000; Taverne, 1999; Tren & Bate, 2001; WHO, 2005)

### 3.1. Relationship between biodiversity and ecological parameters

The relationships between biodiversity and ecological parameters, linking the value of biodiversity to human activities are partially summarized in Table 1.

**Table 1 Primary goods and services provided by ecosystems**

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Goods</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agro ecosystems</td>
<td>Food crops</td>
<td>Maintain limited watershed functions (infiltration, flow control, partial soil protection)</td>
</tr>
<tr>
<td></td>
<td>Fiber crops</td>
<td>Provide habitat for birds, pollinators, soil organisms important to agriculture</td>
</tr>
<tr>
<td></td>
<td>Crop genetic resources</td>
<td>Build soil organic matter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sequester atmospheric carbon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide employment</td>
</tr>
<tr>
<td>Forest ecosystems</td>
<td>Timber</td>
<td>Reduce air-pollutants, emit oxygen</td>
</tr>
<tr>
<td></td>
<td>Fuel wood</td>
<td>Cycle nutrients</td>
</tr>
<tr>
<td></td>
<td>Drinking and irrigation water</td>
<td>Maintain array of water shed functions (infiltration, purification, flow control, soil stabilization)</td>
</tr>
<tr>
<td></td>
<td>Fodder</td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td>Non-timber products (vines,</td>
<td>Sequester atmospheric carbon</td>
</tr>
<tr>
<td></td>
<td>bamboos, leaves, etc.)</td>
<td>Generate soil</td>
</tr>
<tr>
<td></td>
<td>Food (honey, mushrooms,</td>
<td>Provide employment</td>
</tr>
<tr>
<td></td>
<td>fruit, and other edible</td>
<td>Provide human and wildlife habitat</td>
</tr>
<tr>
<td></td>
<td>plants; game)</td>
<td>Contribute aesthetic beauty and provide recreation</td>
</tr>
<tr>
<td></td>
<td>Genetic resources</td>
<td></td>
</tr>
<tr>
<td>Freshwater</td>
<td>Drinking and irrigation water</td>
<td>Buffer water flow (control timing and volume)</td>
</tr>
<tr>
<td>ecosystems</td>
<td>Fish</td>
<td>Dilute and carry away wastes</td>
</tr>
<tr>
<td></td>
<td>Hydroelectricity</td>
<td>Cycle nutrients</td>
</tr>
<tr>
<td></td>
<td>Genetic resources</td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sequester atmospheric carbon</td>
</tr>
</tbody>
</table>
### 3.2. A new concept of sustainability

With this introduction, the following sustainability scheme can easily be understood: The left column is really the most important one when it comes to necessities of mankind. But in order to reach sustainability in agriculture, we must adopt progressive and innovative management strategies, it will be necessary to combine the most efficient and sustainable agriculture production systems. Details can be seen in the fig. 1. It should be made clear that agriculture needs to become highly competitive, innovative and there is an urgent need to produce more food on a smaller surface. But all efforts will be in vain, if we do not succeed to make substantial progress in the fields of socio-economics and technology.

Unfortunately, the concept of sustainability is often seen in combination with an extremely defensive concept of the precautionary “principle” – which actually has to be called correctly the precautionary approach (Böschen, 2009), it is often abused as a defence against the introduction of GM crops.

If we want to aim at a more sustainable world, it needs more than the usual defensive means advocated.

<table>
<thead>
<tr>
<th>Grassland ecosystems</th>
<th>Livestock (food, game, hides, fiber)</th>
<th>Maintain array of watershed functions (infiltration, purification, flow control, soil stabilization)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drinking and irrigation water</td>
<td>Cycle nutrients</td>
</tr>
<tr>
<td></td>
<td>Genetic resources</td>
<td>Reduce air-pollutants, emit oxygen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Generate soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sequester atmospheric carbon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide human and wildlife habitat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide employment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contribute aesthetic beauty and provide recreation</td>
</tr>
<tr>
<td>Coastal and marine ecosystems</td>
<td>Fish and shellfish</td>
<td>Moderate storm impacts (mangroves; barrier islands)</td>
</tr>
<tr>
<td></td>
<td>Fishmeal (animal feed)</td>
<td>Provide wildlife (marine and terrestrial) habitat</td>
</tr>
<tr>
<td></td>
<td>Seaweeds (for food and industrial use)</td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td>Salt</td>
<td>Dilute and treat wastes</td>
</tr>
<tr>
<td></td>
<td>Genetic resources</td>
<td>Sequester atmospheric carbon</td>
</tr>
<tr>
<td></td>
<td>Petroleum, minerals</td>
<td>Provide harbors and transportation routes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide human and wildlife habitat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide employment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contribute aesthetic beauty and provide recreation</td>
</tr>
<tr>
<td>Desert ecosystems</td>
<td>Limited grazing, hunting</td>
<td>Sequester atmospheric carbon</td>
</tr>
<tr>
<td></td>
<td>Limited fuelwood</td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td>Genetic resources</td>
<td>Provide human and wildlife habitat</td>
</tr>
<tr>
<td></td>
<td>Petroleum, minerals</td>
<td>Provide employment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contribute aesthetic beauty and provide recreation</td>
</tr>
<tr>
<td>Urban ecosystems</td>
<td>space</td>
<td>Provide housing and employment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide transportation routes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contribute aesthetic beauty and provide recreation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contribute aesthetic beauty and provide recreation</td>
</tr>
</tbody>
</table>
Sustainable development has been defined in many ways, but the most frequently quoted definition is from *Our Common Future*, also known as the Brundtland Report (UN-Report-Common-Future, 1987):

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

the concept of needs, in particular the essential needs of the world’s poor, to which overriding priority should be given; and

the idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs”

Sustainability is usually understood as a definition with a rather defensive spirit, but if one reads it in its original content, then the words envision uncompromisingly the way forward – asking not only for conservation, but also for development and management of patterns of production and consumption.

The declaration of the OECD, authored by Yokoi (Yokoi, 2000) catalogues a range of concrete measures and rules in order to achieve a more sustainable agriculture. It is remarkable, that the proposed indicators do not distinguish between farming with or without transgenic crops.

The scheme in Figure 1 meets those needs and asks for an intransigent view into the future. The three column model has been chosen with care, and as one can see:

3.2.1. The most important column to the left is agriculture.

It demands “to foster renewable resources, knowledge based agriculture (Trewavas, 2008) and includes some additions (Swaminathan, 2001) (Ammann, 2007b, 2008d). The rather provocative word “Organic Precision Biotechnology Agriculture” is now coined, a shorter one might be “organotransgenic” Agriculture, but the most elegant “orgenic” (Gressel, 2009) is unfortunately already lost to other purposes. By no means does this suggest to include the mistakes of organic farming or exaggerated industrialization of production; those mistakes in organic farming are dealt with properly in my previous article in New Biotechnology (Ammann, 2008d), as there are (1) the low yield, documented in many long term monitoring experiments and the eco-imperialist attitude towards farmers of the developing world (Paarlberg, 2000, 2009; Paarlberg, 2001; Paarlberg, 2002) and (2) the propaganda-like slogans of better food quality, contradicted by numerous scientific analysis, to name just one major meta study: On the positive side is some pioneering work in developing recycling loops in agriculture (Albihn, 2001; Ernst, 2002; Granstedt, 2000a, b; Kirchmann et al., 2005; Korn, 1996; Srivastava et al., 2004) and also in better landscape management: (Belfrage et al., 2005; Boutin et al., 2008; Clemetsen & van Laar, 2000a; Filser et al., 2002; Hadjigeorgiou et al., 2005; Hendriks et al., 2000; Holst, 2001; Jan Stobbelaar & van Mansvelt, 2000; Kuiper, 2000; MacNaeldhe & Culleton, 2000; Norton et al., 2009; Potts et al., 2001; Rossi & Nota, 2000; Schellhorn et al., 2008; Skar et al., 2008; Stobbelaar et al., 2000). To balance local production against global trade will not be easy, since the equilibrium between the demands and perils of pressure to produce for global trading and local food production must be found. The economic basis should be important, but local social networking and life need to be taken into account as well. The mistakes on the side of industrial agriculture have been already anticipated by one of the creators of the green revolution: Swaminathan (Swaminathan, 1968) published early warnings on unwelcome developments related to the Green Revolution:
“The initiation of exploitive agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture, and without first building up a proper scientific and training base to sustain it, may only lead us, in the long run, into an era of agricultural disaster rather than one of agricultural prosperity.”

After the unique success of the Green Revolution, detrimental effects (upsurge of pest insects, growing insect resistance against widely used pesticides and negative effects on the soil fertility and a rising number of herbicide resistant weeds), Swaminathan called for an Evergreen Revolution in 2006 (Kesavan & Swaminathan, 2006; Swaminathan, 2006): higher productivity in perpetuity needs a new emphasis on better infrastructure, crop rotation, sustainable management of natural resources and progressive enhancement of soil fertility and overall biodiversity, goals which can only be achieved in a new combination of traditional and high technology knowledge. Logically, detrimental effects like upcoming resistance of pests, upcoming resistant weeds and a replacement of old, successfully reduced pest insects by new resistant species (moving into a huge ecological niche) are problems of broadly adopted new high tech crops. But these are also old problems known from conventional and traditional agriculture since ages, the only difference is that correction with new technological means (modern breeding, conservation tillage etc.) will be easier and quicker. A comprehensive overview on how sustainability could be organized, is offered by (Reed et al., 2006): The good thing about this scheme is that it is open ended and conceived as a learning process, thus having the near automatic capability of adaptation to local needs.

![Fig. 1 Adaptive learning process for sustainability indicator development and application, from (Reed et al., 2006).](image-url)
On a more theoretical level, but in a comparable process spirit (Phillis & Andriantiatsaholiniaina, 2001) have chosen the approach over fuzzy logic, followed by a recent publication within the same framework: (Phillis et al., 2010), giving a truly holistic picture including corporate structures.

“Many people believe that our society is at the crossroads today because of societal and environmental problems of scales ranging from the local to the global. Such problems as global warming, species extinction, overpopulation, poverty, drought, to name but a few, raise questions about the degree of sustainability of our society. To answer sustainability questions, one has to know the meaning of the concept and possess mechanisms to measure it. In this paper, we examine a number of approaches in the literature that do just that. Our focus is on analytical quantitative approaches. Since no universally accepted definition and measuring techniques exist, different approaches lead to different assessments. Despite such shortcomings, rough ideas and estimates about the sustainability of countries or regions can be obtained. One common characteristic of the models herein is their hierarchical nature that provides sustainability assessments for countries in a holistic way. Such models fall in the category of system of systems. Some of these models can be used to assess corporate sustainability.” From (Phillis et al., 2010)

3.2.2. Middle column: Socio Ethics:
It is of utmost importance to reach greater equity in the whole food production system, especially in these difficult times of the credit crunch 2009. It will be imperative to reduce the huge agricultural subsidies paid to the farmers in the developed world, which needs to be clearly labeled as protectionism and which therefore needs to be seriously questioned. Access to global markets is important, but should not hamper local food production and social structures in the developing world. The myth that developing countries are in the tight grip of multinationals can be debunked with some statistically underpinned publications: (Aerni et al., 2009; Atkinson, 2003; Beachy, 2003; Chrispeels, 2000; Cohen, 2005; Cohen & Galinat, 1984; Cohen & Paarlberg, 2004; Dhlamini et al., 2005). A new creative capitalism – a novel discussion which would have been totally utopic before the global economic crisis in 2008 – needs our attention. It will be a demanding process to reconcile traditional knowledge with modern science; the IP system is often seriously underestimated in its positive effects, but it is up to now completely unilateral - no wonder - since it has been created by the developed world. In the IP handbook of (Krattiger, 2007), accessible over the internet, there are numerous contributions offering innovative solutions to reconcile this contrast; the author also contributed and offered some solutions (Ammann, 2006). This contribution made it clear that we need a big boost in breeding science, but also a new focus on emerging fields in science: biomimetics (formerly bionics) could be a promising area of research, where high technology equipment is certainly helpful, but not indispensable, and agriculture needs new research goals for new production lines (Gressel, 2007) including up to now underutilized crops. Biomimetics needs to be considered with a broad perspective, here just the example of hygroscopic mechanisms occurring abundantly in the plant kingdom and in insects. But the functional details, sometimes working for 200 years beyond the organismal death, need clarification; maybe in some future days we will be able to use the adiabatic moisture differences of our daily climate fluctuations to produce power – as soon as we start to understand the still basically unknown mechanisms in numerous hygroscopical organs – these thoughts will soon be part of a new research project. Published literature on the subject: (Bhushan & Jung, 2010; Johnson et al., 2009; Luz & Mano, 2009; Reed et al., 2009; Zabler et al., 2010)
3.2.3. Right column on Evolution:
The most audacious third column questions our view of evolution in the biological and in the general sense of the word. Evolution deplorably still contains – often not conscious – some elements of creationism (Mayr, 1991) – and this not only with opponents of gene splicing. It will be important to emancipate these views and make clear, that for many years we have taken human evolution into our own hands through modern medicine, and we need to deal with the problems and prospects of a new evolutionary view. Modern breeding has the potential to enlighten the population, if done in an ethically acceptable way and if communicated properly. The tasks will grow over the next decades, and in many fields of science we are already now heavily dependent on calculation power; therefore, let’s make sure that mathematical algorithms can be translated into useful artificial intelligence in the service of mankind. We need the help of all new and emerging technologies (of course regulated in a sensible way) in order to enhance food production and the livelihood of mankind. The statement “only one planet” is at the same time a reminder to precaution, but appeals also to our responsibility to take evolution as a whole into our own hands. This can only be achieved if we have a close and conscious look at the cultural side of human evolution as a whole with all its consequences for ourselves. This will be another string of thoughts in a next feature on ‘Darwin and beyond’, the development of the evolutionary theory after Darwin on all levels, from the molecules to culture, it will need historical and philosophical scrutiny, going far beyond the usual disputes on technologies. (Azzone, 2008; Mesoudi & Danielson, 2008).

Fig. 2 A new concept of a sustainable world, in AGRICULTURE based on renewable natural resources, knowledge based agriculture and organic precision biotech-agriculture, in SOCIO-ECONOMICS based on equity, global dialogue, reconciliation of traditional knowledge with science, reduction of agricultural subsidies and creative capitalism, in TECHNOLOGIES in (Ammann, 2009c).
3.3. Crop biodiversity has not been reduced in the twentieth century according to a new meta analysis

According to (van de Wouw et al., 2010) the agricultural crop biodiversity trends are not as negative as common sense would suggest: Although there was a significant reduction of crop biodiversity of 6% in the 1960s compared to 1950, the data indicate that after the 1960s the trend was positively reversed.


In recent years, an increasing number of papers has been published on the genetic diversity trends in crop cultivars released in the last century using a variety of molecular techniques. No clear general trends in diversity have emerged from these studies. Meta analytical techniques, using a study weight adapted for use with diversity indices, were applied to analyze these studies. In the meta analysis, 44 published papers were used, addressing diversity trends in released crop varieties in the twentieth century for eight different field crops, wheat being the most represented. The meta analysis demonstrated that overall in the long run no substantial reduction in the regional diversity of crop varieties released by plant breeders has taken place. A significant reduction of 6% in diversity in the 1960s as compared with the diversity in the 1950s was observed. Indications are that after the 1960s and 1970s breeders have been able to again increase the diversity in released varieties. Thus, a gradual narrowing of the genetic base of the varieties released by breeders could not be observed. Separate analyses for wheat and the group of other field crops and separate analyses on the basis of regions all showed similar trends in diversity (van de Wouw et al., 2010).
3.4. Biodiversity is better served by conventional agriculture compared to organic production

According to


“There is increasing recognition that ecosystems and their services need to be managed in the face of environmental change. However, there is little consensus as to the optimum scale for management. This is particularly acute in the agricultural environment given the level of public investment in agri-environment schemes (AES). Using a novel multiscale hierarchical sampling design, we assess the effect of land use at multiple spatial scales (from location-within-field to regions) on farmland biodiversity. We show that on-farm biodiversity components depend on farming practices (organic vs. conventional) at farm and landscape scales, but this strongly interacts with fine- and coarse-scale variables. Different taxa respond to agricultural practice at different spatial scales and often at multiple spatial scales. Hence, AES need to target multiple spatial scales to maximize effectiveness. Novel policy levers may be needed to encourage multiple land managers within a landscape to adopt schemes that create landscape-level benefits.”

Fig. 4 Farmland biodiversity components in relation to landscape-scale management (C: coldspot vs. H: hotspot), farm management (Con: conventional vs. Org: organic), location-within-field (centre vs. edge vs. margin) and crop type (arable vs. grass fields). Mean species density ± SEM of (a) forb plant species per transect and survey, n = 3456; geometric mean number of individuals ± SEM of: (b) epigeal arthropods per sampling station and survey, n = 5139; (c) butterflies per transect and survey, n = 856; (d) hoverflies; (e) bumblebees; and (f) solitary bees per sampling station and survey, n = 4354, respectively. From (Gabriel et al., 2010)

From the discussion: Plant species density was much higher in organic fields than in conventional ones (although differences were much lower for margins), and there were additional landscape-level effects but mainly in organic fields. The absence of a landscape effect in conventional cereal fields is due to farmers using more chemicals to suppress weeds within hotspots. Similarly, epigeal arthropods,
butterflies (and bumblebees in arable fields) were more abundant in organic farms and hotspots. In contrast, adult hoverflies (Syrphidae) were more common on conventional farms, especially in hotspots, despite their larvae being more common in organic fields. Farmland bird diversity was also higher on conventional farms (except generalist species and corvidae). In general, the conclusions did not fit the common views of clear benefits of organic farming related to biodiversity. In a Times article, Ben Webster, the editor on environment, concluded:

“Birds such as the skylark and lapwing are less likely to be found in organic fields than on conventional farms, according to a study that contradicts claims that organic agriculture is much better for wildlife. It concludes that organic farms produce less than half as much food per hectare as ordinary farms and that the small benefits for certain species from avoiding pesticides and artificial fertilizers are far outweighed by the need to make land more productive to feed a growing population. The research, by the University of Leeds, is another blow to the organic industry, which is already struggling because of falling sales and a report from the Food Standards Agency that found that organic food was no healthier than ordinary produce. In organic fields than on conventional farms, according to a study that contradicts claims that organic agriculture is much better for wildlife. It concludes that organic farms produce less than half as much food per hectare as ordinary farms and that the small benefits for certain species from avoiding pesticides and artificial fertilizers are far outweighed by the need to make land more productive to feed a growing population.”

4. Types of Biodiversity

4.1. Towards a general theory of biodiversity

(Pachepsky et al., 2001) show in a thoughtful publication, that there are still many unknowns in the equations modeling biodiversity. They present a framework for studying the dynamics of communities which generalizes the prevailing species-based approach to one based on individuals that are characterized by their physiological traits. The observed form of the abundance distribution and its dependence on richness and disturbance are reproduced, and can be understood in terms of the trade-off between time to reproduction and fecundity. This is more or less confirmed by (Banavar & Maritan, 2009) with the following caveat: A lesson from these calculations is that just because a theory fits the data, it does not necessarily imply that the assumptions underlying the theory are correct.

Whereas Pachepsky et al. emphasize the importance of individual organisms over species, (Levine & HilleRisLambers, 2009) come to the conclusion, that niches play an important role in maintaining biodiversity, together with strong evidence, that species differences have a critical role in stabilizing species diversity. Ecological niches also have been seriously underestimated when calculating with models the impact of climate change on biodiversity:

4.2. Genetic diversity

In many instances genetic sequences, the basic building blocks of life, encoding functions and proteins are almost identical (highly conserved) across all species. The small un-conserved differences are important, as they often encode the ability to adapt to specific environments. Still, the greatest importance of genetic diversity is probably in the combination of genes within an organism (the genome), the variability in phenotype produced, conferring resilience and survival under selection. Thus, it is widely accepted that natural ecosystems should be managed in a manner that protects the untapped

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2 http://www.ask-force.org/web/Organic/Webster-Study-Spikes-organic-Times-201005.PDF
resources of genes within the organisms needed to preserve the resilience of the ecosystem. Much work remains to be done to both characterize genetic diversity and understand how best to protect, preserve, and make wise use of genetic biodiversity (Batista et al., 2008; Baum et al., 2007; Cattivelli et al., 2008; Mallory & Vaucheret, 2006; Mattick, 2004; Raikhel & Minorsky, 2001; Witcombe et al., 2008).

The number of metabolites found in one species exceeds the number of genes involved in their biosynthesis. The concept of one gene - one mRNA - one protein - one product needs modification. There are many more proteins than genes in cells because of post-transcriptional modification. This can partially explain the multitude of living organisms that differ in only a small portion of their genes. It also explains why the number of genes found in the few organisms sequenced is considerably lower than anticipated.

### 4.3. Species diversity

For most practical purposes measuring species biodiversity is the most useful indicator of biodiversity, even though there is no single definition of what is a species. Nevertheless, a species is broadly understood to be a collection of populations that may differ genetically from one another to some extent degree, but whose members are usually able to mate and produce fertile offspring. These genetic differences manifest themselves as differences in morphology, physiology, behaviour and life histories; in other words, genetic characteristics affect expressed characteristics (phenotype). Today, about 1.75 million species have been described and named but the majority remains unknown. The global total might be ten times greater, most being undescribed microorganisms and insects (May, 1990).

### 4.4. Ecosystem diversity

At its highest level of organization, biodiversity is characterized as ecosystem diversity, which can be classified in the following three categories:

**Natural ecosystems**, i.e. ecosystems free of human activities. These are composed of what has been broadly defined as "Native Biodiversity". It is a matter of debate whether any truly natural ecosystem exists today, as human activity has influenced most regions on earth. It is unclear why so many ecologists seem to classify humans as being "unnatural".

**Semi-natural ecosystems** in which human activity is limited. These are important ecosystems that are subject to some level of low intensity human disturbance. These areas are typically adjacent to managed ecosystems.

**Managed ecosystems** are the third broad classification of ecosystems. Such systems can be managed by humans to varying degrees of intensity from the most intensive, conventional agriculture and urbanized areas, to less intensive systems including some forms of agriculture in emerging economies or sustainably harvested forests.

Beyond simple models of how ecosystems appear to operate, we remain largely ignorant of how ecosystems function, how they might interact with each other, and which ecosystems are critical to the
services most vital to life on earth. For example, the forests have a role in water management that is crucial to urban drinking water supply, flood management and even shipping.

Because we know so little about the ecosystems that provide our life-support, we should be cautious and work to preserve the broadest possible range of ecosystems, with the broadest range of species having the greatest spectrum of genetic diversity within the ecosystems. Nevertheless, we know enough about the threat to, and the value of, the main ecosystems to set priorities in conservation and better management. We have not yet learnt enough about the threat to crop biodiversity, other than to construct gene banks, which can only serve as an ultimate ratio – we should not indulge into the illusion that large seed banks could really help to preserve crop biodiversity. The only sustainable way to preserve a high crop diversity, i.e. also as many landraces as possible, is to actively cultivate and breed them further on. This has been clearly demonstrated by the studies of Berthaud and Bellon (Bellon & Berthaud, 2004, 2006; Bellon et al., 2003; Berthaud, 2001) Even here we have much to learn, as the vast majority of the deposits in gene banks are varieties and landraces of the four major crops. The theory behind patterns of general biodiversity related to ecological factors such as productivity is rapidly evolving, but many phenomena are still enigmatic and far from understood (Schlapfer et al., 2005; Tilman et al., 2005), as for example why habitats with a high biodiversity are more robust towards invasive alien species.

5. The global distribution of biodiversity

Biodiversity is not distributed evenly over the planet. Species richness is highest in warmer, wetter, topographically varied, less seasonal and lower elevation areas. There are far more species in total per unit area in temperate regions than in polar ones, and far more again in the tropics than in temperate regions. Latin-America, the Caribbean, the tropical parts of Asia and the Pacific all together host eighty percent of the ecological mega-diversity of the world. An analysis of global biodiversity on a strictly metric basis demonstrates that besides the important rain forest areas there are other hotspots of biodiversity, related to tropical dry forests for example (Kier et al., 2005; Kuper et al., 2004; Lughadha et al., 2005).

Within each region, every specific type of ecosystem will support its own unique suite of species, with their diverse genotypes and phenotypes. In numerical terms, global species diversity is concentrated in tropical rain forests and tropical dry forests. Amazon basin rainforests can contain up to nearly three hundred different tree species per hectare and supports the richest (often frugivorous) fish fauna known, with more than 2500 species in the waterways. The sub-montane tropical forests in tropical Asia and South America are considered to be the richest per unit area in animal species in the world. (Vareschi, 1980).
Fig. 5 Global biodiversity value: a map showing the distribution of some of the most highly valued terrestrial biodiversity world-wide (mammals, reptiles, amphibians and seed plants), using family-level data for equal-area grid cells, with red for high biodiversity and blue for low biodiversity (Williams et al., 2003)
6. Loss of biodiversity

6.1. Species loss will increase

(Pimm & Raven, 2000) come to the following conclusion: **Unless there is immediate action to salvage the remaining unprotected hotspot areas, the species losses will more than double.** There is, however, a glimmer of light in this gloomy picture. High densities of small-ranged species make many species vulnerable to extinction. But equally this pattern allows both minds and budgets to be concentrated on the prevention of nature’s untimely end. According to Myers et al., these areas constitute only a little more than one million square kilometers. Protecting them is necessary, but not sufficient. Unless the large remaining areas of humid tropical forests are also protected, extinctions of those species that are still wide-ranging should exceed those in the hotspots within a few decades (see Box 1).”

![Box 1: Extinctions in tropical forests, 2000–2100](image)

“Applying the species–area relationship to the individual hotspots gives the prediction that 18% of all their species will eventually become extinct if all of the remaining habitats within hotspots were quickly protected (curve c in Box 1). Assuming that the higher-than-average rate of habitat loss in these hotspots continues for another decade until only the areas currently protected remain (curve b in Box 1), these hotspots would eventually lose about 40% of all their species. All of these projections ignore other effects on biodiversity, such as the possibly adverse impact of global warming, and the introduction of alien species, which is a well-documented cause of extinction of native species.
6.2. Agriculture as the major factor of biodiversity loss

Biodiversity is being lost in many parts of the globe, often at a rapid pace. It can be measured by loss of individual species, groups of species or decreases in numbers of individual organisms. In a given location, the loss will often reflect the degradation or destruction of a whole ecosystem. The unchecked rapid growth of any species can have dramatic effects on biodiversity. This is true of weeds, elephants but especially humans, who being at the top of the chain can control the rate of proliferation of other species, as well as their own, when they put their mind to it.

Habitat loss due to the expansion of human urbanisation and the increase in cultivated land surfaces is identified as a main threat to eighty five percent of all species described as being close to extinction. The shift from natural habitats towards agricultural land paralleled population growth, often thoroughly and irreversibly changing habitats and landscapes, especially in the developed world. Many from the developed world are trying to prevent such changes from happening in developing nations, to the consternation of many of inhabitants of the developing world who consider this to be eco-imperialism, promulgated by those unable to correct their own mistakes. A clear decline of biodiversity due to agricultural intensification is documented by (Robinson & Sutherland, 2002) for the post-war period in Great Britain.

Today, more than half of the human population lives in urban areas, a figure predicted to increase to sixty percent by 2020 when Europe, and the Americas will have more than eighty percent of their population living in urban zones. Five thousand years ago, the amount of agricultural land in the world is believed to have been negligible. Now, arable and permanent cropland covers approximately one and a half billion hectares of land, with some 3.5 billion hectares of additional land classed as permanent pasture. The sum represents approximately 38% of total available land surface of thirteen billion ha according to FAO statistics.

Habitat loss is of particular importance in tropical regions of high biological diversity where at the same time food security and poverty alleviation are key priorities. The advance of the agricultural frontier has led to an overall decline in the world’s forests. While the area of forest in industrialised regions remained fairly unchanged, natural forest cover declined by 8% in developing regions. It is ironical that the most bio-diverse regions are also those of greatest poverty, highest population growth and greatest dependence upon local natural resources. (Lee & Jetz, 2008)
Although poverty and the growing global population are often targeted as responsible for much of the degradation of the world's resources, other factors—such as the inefficient use of resources (including those of others), waste generation, pollution from industry, and wasteful consumption patterns—are equally driving us towards an environmental precipice. Fig. 4 indicates the relative importance of environmental issues within and across regions (UNEP, 1997).

Fig. 7 Regional Concerns: Relative Importance Given to Environmental Issues by Regions: Although poverty and the growing global population are often targeted as responsible for much of the degradation of the world’s resources, other factors—such as the inefficient use of resources (including those of others), waste generation, pollution from industry, and wasteful consumption patterns—are equally driving us towards an environmental precipice. Fig. 4 indicates the relative importance of environmental issues within and across regions (UNEP, 1997).

Fig. 8 Regional environmental trends in habitat loss (UNEP, 1997) reflects trends for the same issues, without depicting the rate of changes in these trends. In many instances, although trends are increasing, the rate of increase over the years has slowed down or was less than the rate of increase in economic growth previously experienced by countries with comparable economic growth. This suggests that several countries are making the transition to a more sustainable environment at a lower level of economic development than industrial countries typically did over the last 50 years. From (UNEP, 1997).
Changing priority concerns. As nations develop, different sets of environmental concerns assume priority. Initially, prominence is given to issues associated with poverty alleviation and food security and development—namely, natural resource management to control land degradation, provide an adequate water supply, and protect forests from overexploitation and coastal zones from irreversible degradation. Attention to issues associated with increasing industrialization then follows. Such problems include uncontrolled urbanization and infrastructure development, energy and transport expansion, the increased use of chemicals, and waste production. More affluent societies focus on individual and global health and well-being, the intensity of resource use, heavy reliance on chemicals, and the impact of climate change and ozone destruction, as well as remaining vigilant on the long-term protection needs of natural resources. Figure 3 illustrates the observed progression on environmental priority issues. From (UNEP, 1997)

The full complexity of factors influencing habitat and species loss is still heavily researched and progress can be expected in the next few years. Two examples may suffice to demonstrate on how intricate the dynamics of habitat and species loss is working: (Field et al., 2009; Kerr & Deguisé, 2004). There is no doubt, that the situation is bleak, and action is needed, action which realistically will be built on difficult decisions on priorities.
(Sole & Montoya, 2006) demonstrate the dynamics of ecological network meltdown due to habitat loss:

“Theory suggests that the response of communities to habitat loss depends on both species characteristics and the extent to which species interact. Larger bodied and rare species are usually the first losers in most ecosystems around the world (Purvis & Hector, 2000; Woodroffe & Ginsberg, 1998). Similarly, food web theory predicts that habitat loss and fragmentation reduces population densities of top predators, and therefore species of higher trophic levels are more frequently lost than species from lower levels, see (Petchey et al., 2004) for a review. In a related context, the consequences of species loss are highly mediated by the position of such species within the interaction network (Dunne et al., 2002; Pimm, 1993; Pimm et al., 1995; Sole & Montoya, 2001). The disappearance of preys attacked by numerous specialized predators, for example, have larger consequences than the loss of preys with fewer specialized predators.”

Fig. 10 Estimated loss and gain of plant species from 2000 to 2005. It is interesting to see that in highly disturbed regions as Europe, SE-Asia and North America the number of species has even augmented, but no doubt: always on the cost of the indigenous flora. [http://maps.grida.no/go/graphic/estimated-loss-of-plant-species-2000-2005](http://maps.grida.no/go/graphic/estimated-loss-of-plant-species-2000-2005)
Fig. 11 Number of species in each trophic level for different values of habitat destroyed. Here two different probabilities of colonization by plants are used: Here two different probabilities of colonization by plants are used: \( p = 0.15 \), straight lines (numbers in the figure). See text for details. Other parameters: \( C = 0.28 \) (including competitive interactions among plants). from (Sole & Montoya, 2006).

Still, more needs to be known about the dynamics of habitat loss (Memmott et al., 2006): Habitat destruction is a collective term for a variety of environmental troubles, each of which may have different effects on food web structure and, given that they often act concomitantly, may also interact with each other in unpredictable ways. While a frequent outcome of habitat destruction is species loss, whether the different types of habitat destruction lead to different patterns of species loss remains largely unknown.

6.3. Impact of agriculture can also help biodiversity
A case study for high-altitude rice in Nepal by (Joshi & Witcombe, 2003) has demonstrated, that participatory rice breeding can also result in a positive impact on rice landrace diversity. With the exception of two villages, the varietal richness among adopting farmers was either static or increased, and there was an overall increase in allelic diversity. However, this positive picture could change with an unconsiderate introduction of modern traits.
6.4. Are GM crops responsible for a higher loss of biodiversity?

In a report (Ammann, 2004a) and a summaries published later (Ammann, 2005) it is stated extensively and clearly with lots of literature references, that biodiversity is not hampered by the cultivation of GM crops per se, on the contrary, Bt crops for instance need less pesticide sprays and consequently, non-target insect populations are considerably better off in Bt maize (Bitzer et al., 2005; Candolfi et al., 2004; Hails, 2005; Hector et al., 2007; Kalushkov et al., 2009; Lozza, 1999; Robinson & Sutherland, 2002; Symondson et al., 2006; Trewavas, 2001) and in cotton fields (Cattaneo et al., 2006): Their results indicate that impacts of agricultural intensification can be reduced when replacement of broad-spectrum insecticides by narrow-spectrum Bt crops does not reduce control of pests not affected by Bt crops. Regarding herbicide tolerant crops which allow for a nearly 100% change towards no-tillage management, which results in clearly higher soil fertility: (Christoffoleti et al., 2008; Locke et al., 2008; Norsworthy, 2008; Wang et al., 2008). Four major meta studies have proven that biotechnology crops can help to enhance biodiversity as a whole: (Duan et al., 2008; Marvier et al., 2007; Naranjo, 2009; Wolfenbarger et al., 2008). For details and discussions see chapter 10 with the two case studies of Bt crops and herbicide tolerant crops.

6.5. Introduced species, another threat to biodiversity

Unplanned or poorly planned introduction of non-native (“exotic” or “alien”) species and genetic stocks is a major threat to terrestrial and aquatic biodiversity worldwide. There are hundreds if not thousands of new and foreign genes introduced with trees, shrubs, herbs, microbes and higher and lower animals each year (Kowarik, 2005; Sukopp & Sukopp, 1993). Many of those organisms sometimes barely survive and can, after years and even many decades of adaptation, begin to be invasive. In the case of exotic tree species in Central Europe, the average lag time has been calculated to about 150 years (Kowarik, 2005). This might be misconstrued as increasing biodiversity, but the final effect is sometimes the opposite – even though (Landolt, 1994) has enumerated after years of inventory work for the town of Zurich some 2000 higher plant species, a majority of which inhabit disturbed and ruderal habitats. Still, in natural biota the introduced species often displace native species such that many native species become extinct or severely limited, such cases are known to be very serious in tropical islands (Ammann, 1997; Fowler et al., 2000). An important share of alien species originates from agricultural weeds and as a result of constant traffic with commercial seeds and plant materials such as cotton.

Freshwater habitats worldwide are amongst the most modified by humans, especially in temperate regions. In most areas, introduction of non-native species is the most or second most important activity affecting inland aquatic areas, with significant and often irreversible impacts on biodiversity and ecosystem function. A classic example is the extinction of half to two thirds of the indigenous fish population in Lake Victoria after the introduction of the Nile perch Lates niloticus, a top predator (Schofield & Chapman, 1999). Several species of free-floating aquatic plants able to spread by vegetative growth have dispersed widely over the globe and become major pests. Water hyacinth (Eichhornia crassipes) is a notable example in tropical waters as is Anarchis canadensis = Elodea canadensis in temperate waters of the Northern Hemisphere.
6.6. Biodiversity as a ‘biological insurance’ against ecosystem disturbance

Biodiversity should still act as biological insurance for ecosystem processes, except when mean trophic interaction strength increases strongly with diversity (Thebault & Loreau, 2005). The conclusion, which needs to be tested against field studies, is that in tropical environments with a natural high biodiversity the interactions between potentially invasive hybrids of transgenic crops and their wild relatives should be buffered through the complexity of the surrounding ecosystems. This view is also confirmed by the results of Davis (Davis, 2003). Taken together, theory and data suggest that compared to intertrophic interaction and habitat loss, competition from introduced species is not likely to be a common cause of extinctions in long-term resident species at global, meta-community and even most community levels.

There is a widespread view that centers of crop origin should not be touched by modern breeding because these biodiversity treasures are so fragile that these centers should stay free of modern breeding. This is an erroneous opinion, based on the fact that regions of high biodiversity are particularly susceptible to invasive processes, which is wrong. On the contrary, there are studies showing that a high biodiversity means more stability against invasive species, as well as against genetic introgression (Morris et al., 1994; Tilman et al., 2005; Whitham et al., 1999). The introduction of new predators and pathogens has caused well-documented extinctions of long-term resident species, particularly in spatially restricted environments such as islands and lakes. One of the (in)famous cases of an extinction of an endemic rare moth is documented from Hawaii, it has been caused by a failed attempt of biological control (Henneman & Memmott, 2001; Howarth, 1991). However, there are surprisingly few instances of extinctions of resident species that can be attributed to competition from new species. This suggests either that competition-driven extinctions take longer to occur than those caused by predation or that biological invasions are much more likely to threaten species through inter-trophic than through intra-trophic interactions (Davis, 2003). This also fits well with agricultural experience, which builds on much faster ecological processes combined with “exotic” crops which often lack important instruments for rapid spreading.

There is more evidence, that biological invasions, and thus also transgenic hybrids of wild relatives of GMOs with a potentially higher fitness, are depending on a multitude of factors, some now with recent research stepwise identified:

(Von Holle & Simberloff, 2005) established the first experimental study to demonstrate the primacy of propagule pressure as a determinant of habitat invisibility in comparison with other candidate controlling factors. There is more evidence documented that vegetation structure and diversity has influence on invasion dynamics on various vegetation types (Von Holle et al., 2003; Von Holle & Simberloff, 2004; Weltzin et al., 2003).

In a later paper (Fridley et al., 2007) the same author group makes even clearer statements:

“Given a particular location that is susceptible to recurrent exotic invasion, native species richness can contribute to invasion resistance by means of neighborhood interactions and should be maintained or restored.”

See also the caption of the figure from (Fridley et al., 2007) where a similar statement is included.
Fig. 12 Conceptualized diagram of the invasion paradox. Fine-grained studies, many of which are experimental, often suggest negative correlations between native and exotic species richness but are highly variable. Nearly all broader-grain observational studies indicate positive native–exotic richness correlations. Likely exceptions are comparisons between temperate and tropical biomes, where preliminary data suggest that biodiversity hotspots have very few exotic species. From (Fridley et al., 2007).

The much more dynamic picture on agricultural fields fits well with farming experience, which builds on much faster ecological processes. It is a widespread error of many ecologists not to take into account the ephemeral ecological situation of agricultural plant communities (Ammann et al., 2004).

Also according to (Thebault & Loreau, 2005) biodiversity should still act as biological insurance for ecosystem processes, except when mean trophic interaction strength increases strongly with diversity. The conclusion – which needs to be tested against field studies, is that in tropical environments with a natural high biodiversity the interactions between potentially invasive hybrids of transgenic crops and their wild relatives should be buffered through the complexity of the surrounding ecosystems.

This view is also confirmed by (Davis, 2003): Taken together, theory and data suggest that, compared to intertrophic interaction and habitat loss, competition from introduced species is not likely to be a common cause of extinctions in long-term resident species at global, metacommunity and even most community levels. It should also be clear that the simple introduction of transgenes to the wild populations or any kind of preservable landrace would not cause any harm to biodiversity, except if the
introduced transgene is changing the population structure due to some considerable change in the competitiveness of the species or race receiving the transgene. With this caveat it is simply antibiotech propaganda if one claims that the introgression with transgenes has *per se and automatically* something to do with a reduction of biodiversity. On the contrary, GMO crops often can – wisely used, be the source of betterment of biodiversity (Ammann, 2005).

Useful for our thesis produced here is the paper of (Morris et al., 1994). The authors indeed found that 4-8 m of in width may actually increase seed contamination over what would be expected if the intervening ground were instead planted entirely with a trap crop.

Finally, it should also be made clear that the threat of landraces is not only caused by environmental and biological agents, but is often the cause of vanishing traditional knowledge (Gupta et al., 2003).

(Harlan, 1975) was among the first to state that landraces have come to rely on cultivation for their survival, active breeding and conscious selection are at the heart of landrace definition, although not all researchers share this view: (Hawkes, 1983) states that the adaptation of the landraces to the environment is the result of selection ‘largely of an unconscious nature’. An excellent review about definitions and classifications of landraces is given by (Zeven, 1998), see also (Zeven, 1999, 2000, 2002). An excellent early, but still valid comment and table summing up advantages and disadvantages of ex-situ and in-situ conservation of landraces is given by (Hawkes, 1991):

“No doubt other factors might be considered in addition to those mentioned in Table I. However, the fact that in-situ and ex-situ methods both possess advantages and disadvantages renders it imperative to scrutinize each with great care. The general conclusions reached up to now are that each method is complimentary to the other, rather than antagonistic. However, the problems continue to confront us, namely, that whereas ex-situ storage methods have been established satisfactorily for at least two decades (Frankel & Hawkes, 1975) and are those in common use for "orthodox" seeds, those for in-situ conservation are only just beginning to be formulated. This is particularly worrying when we need to decide on conservation strategies for "recalcitrant" species – those whose seeds have no dormancy period and cannot thus be stored under the reduced temperature and humidity that have proved so satisfactory for orthodox species (Roberts, 1975). It is quite clear that much more thought and research initiatives need to be applied to the problem of in-situ conservation. The International Board for Plant Genetic Resources, IBPGR (1985) developed a provisional list of species for ecogeographical surveying and in-situ conservation for fruit trees, forages and a number of other crops, and pointed out the need for "sufficiently large and diverse" populations so as to sustain the levels of allelic frequencies in conserved populations. The publication called for further research, setting out at the same time a number of useful parameters for genetic conservation. However, the publication is understandably reticent on hard data involved in setting up reserves, for the simple reason that hard data do not yet exist.”

Still, it seems that we do not know yet enough to make out of the above thesis a theory which holds up to all scrutiny, as (Ives & Carpenter, 2007) develop with convincing details and an impressive survey of the existing literature on biodiversity stability and ecosystems. Their final remarks are rather inconclusive and call for a case by case perspective:

“Finally, a finding common to many empirical studies is that the presence of one or a handful of species, rather than the overall diversity of an ecosystem, is often the determinant of stability against different perturbations. We suspect that, depending on the types of stability and perturbation, different species may play key roles.

Predicting which species, however, is unlikely to be aided by general theory or surveys of empirical studies; each ecosystem might have to be studied on a case-by-case basis. In the face of this uncertainty and our ignorance of what the future might bring, the safest policy is to preserve as much diversity as possible.”
6.7. On centers of biodiversity and centers of crop diversity

Centers of biodiversity are still a controversial matter as was shown by (Barthlott et al., 2007) with the example of various African biodiversity patterns published over decades.

![Maps of plant species richness patterns in Africa](image.png)

Fig. 13 Historical evolution of maps displaying plant species richness patterns in Africa. Apart from the map of (Wulff, 1935) which indicates the total species richness of the displayed areas, the maps show species richness per standard area of 10,000 km². All maps are inventory-based and to a varying degree rely on expert-opinion. The same legend of ten classes as displayed was applied to all maps, from (Barthlott et al., 2007)
Fig. 14 The original eight centers of crop diversity according to Vavilov, N.I. (Hawkes, 1983; Hawkes, 1990, 1991, 1999; Hawkes & Harris, 1990; Vavilov, 1987; Vavilov, 1940; Williams, 1990)

Also the definition of centers of crop biodiversity is still debated. Harlan (Harlan, 1971), in deviation of the classic Vavilov centers (Hawkes, 1983; Hawkes, 1990, 1991, 1999; Hawkes & Harris, 1990; Vavilov, 1926, 1951; Vavilov, 1987, 2009), proposed a theory that agriculture originated independently in three different areas and that, in each case, there was a system composed of a center of origin and a noncenter, in which activities of domestication were dispersed over a span of five to ten-thousand kilometers. One system was in the Near East (the Fertile Crescent) with a noncenter in Africa; another center includes a north Chinese center and a noncenter in Southeast Asia and the south Pacific, with the third system including a Central American center and a South American noncenter. He suggests that the centers and the noncenters interacted with each other.

The centers of diversity which Vavilov described were not discrete but overlapped for a number of crops, as regions which have concentrations of variation assessed in terms of recognizable botanical varieties and races. But he also included a complex of properties which include physiological and ecotype characters (Williams, 1990). This is why the concept of the biodiversity centers underwent later many amendments and enlargements, which resulted among others in the map of (Zeven, 1998; Zeven & Zhukovsky, 1975).
Harlan proposes the theory that agriculture originated independently in three different areas and that, in each case, there was a system composed of a center of origin and a noncenter, in which activities of domestication were dispersed over a span of 5000 to 10000 kilometers. One system includes a definable Near East center and a noncenter in Africa; another center includes a North Chinese center and a noncenter in Southeast Asia and the South Pacific; the third system includes a Mesoamerican center and a South American noncenter. There are suggestions that, in each case, the center and the noncenter interact with each other. **Crops did not necessarily originate in the centers of their highest diversity (or in any conventional concept of the term), nor did agriculture necessarily develop in a geographical centre.**
7. The case of agro-biodiversity, old and new insights

In many publications about agro-biodiversity it is hardly questioned whether biodiversity per se is a good thing. It is just assumed that we need to strive for as much biodiversity as possible, sometimes on the cost of simple production rules. This is why the following subchapters will try to produce a fresh and more pragmatic look at biodiversity in agriculture. It is scientifically and agronomically not acceptable to ask for more biodiversity related to non-crop species within the production field; this is why the British Farm Scale Experiments ask basically the wrong questions: (Chassy et al., 2003).

7.1. On the genomic processing level, genetically engineered crops are not basically different from conventionally bred crops.

Generally, it should be emphasized, that there is no need to stress too much the difference between transgenic and non-transgenic crops: It has been confirmed by many authors, that Werner Arbers insight has proven to be correct (Arber, 2000, 2002, 2003, 2004; Arber, 2009):

“Site-directed mutagenesis usually affects only a few nucleotides. Still another genetic variation sometimes produced by genetic engineering is the reshuffling of genomic sequences, e.g. if a given open reading frame is brought under a different signal for expression control or if a gene is knocked out. All such changes have little chance to change in fundamental ways, the properties of the organism. In addition, it should be remembered that the methods of molecular genetics themselves enable the researchers anytime to verify whether the effective genomic alterations correspond to their intentions, and to explore the phenotypic changes due to the alterations. This forms part of the experimental procedures of any research seriously carried out.

Interestingly, naturally occurring molecular evolution, i.e. the spontaneous generation of genetic variants has been seen to follow exactly the same three strategies as those used in genetic engineering. These three strategies are:
- small local changes in the nucleotide sequences,
- internal reshuffling of genomic DNA segments, and
- acquisition of usually rather small segments of DNA from another type of organism by horizontal gene transfer.

“However, there is a principal difference between the procedures of genetic engineering and those serving in nature for biological evolution. While the genetic engineer pre-reflects his alteration and verifies its results, nature places its genetic variations more randomly and largely independent of an identified goal. Under natural conditions, it is the pressure of natural selection which eventually determines, together with the available diversity of genetic variants, the direction taken by evolution. It is interesting to note that natural selection also plays its decisive role in genetic engineering, since indeed not all pre-reflected sequence alterations withstand the power of natural selection. Many investigators have experienced the effect of this natural force which does not allow functional disharmony in a mutated organism.”

This view has been lately confirmed for a baseline comparison of transgenic and non-transgenic crops by (Batista et al., 2008; Baudo et al., 2006; Shewry et al., 2007). For more details see p. 28ff and the ASK-FORCE contribution on this topic: http://www.efb-central.org/index.php/forums/viewthread/58/

(Van Bueren et al., 2003) try to explain on the molecular level, why organic farming cannot accept genetic engineering with a number of arguments:

Following (Verhoog et al., 2003), they state that the naturalness of organic agriculture not only to the avoidance of inorganic, chemical inputs and to the application of other agroecological principles, but also implies integrity. Their definition of intrinsic integrity of plant genomes:

“The general appreciation for working in consonance with natural systems in organic farming extends itself to the regard with which members of the movement view individual species and organisms. Species, and the organisms belonging to them, are regarded as having an intrinsic integrity. This integrity exists aside from the practical value of the species to humanity and it can be enhanced or degraded by management and breeding measures. This kind of integrity can only be assessed from a biocentric perspective (see below). Organic agriculture assigns an ethical value to this integrity, and encourages propagation, breeding, and production systems that protect or enhance it.”

And further on:

“From a biocentric perspective, organic agriculture acknowledges the intrinsic value and therefore the different levels of integrity of plants as described above. The consequence of acknowledging the intrinsic value of plants and respecting their integrity in organic agriculture implies that the breeder takes the integrity of plants into account in his choices of breeding and propagation techniques. It implies that one not merely evaluates the result and consequences of an intervention, but in the first place questions whether the intervention itself affects the integrity of plants. From the above described itself affects the integrity of plants.”

From the above described levels of the nature of plants and its characteristics, a number of criteria, characteristics, and principles for organic plant breeding and propagation techniques are listed by the authors for exclusion: All breeding methods using chemicals or radiation, such as cholchicinizing or gamma radiation induced mutants, all methods not allowing a full live cycle of the plant, all methods manipulating the genome of the organisms etc.

Unfortunately, the authors completely miss the point that the structure and assembly of DNA has been changed heavily over the decades and centuries of conventional breeding. Modern wheat in all variants and traits used today – also by organic farmers – are a product of processes, where the intrinsic value of the genomic naturalness has been completely ignored and any imaginable change has been successfully integrated, from adding chromosome fragments to integrating foreign genomes and accepting radiation
mutation in the case of Triticum durum over a long period of time, also chromosome inversions, translocations are well documented in most major crops. The reality is, whether we accept it for any kind of definition, that most of the principles advocated by (Van Bueren & Struik, 2004, 2005; Van Bueren et al., 2002; Van Bueren et al., 2003; Verhoog et al., 2003) are clearly violated by almost all existing modern crop traits and cannot be redone, unless you could theoretically go back to the ancestral traits (which have in most cases of the major crops not survived the centuries of classical breeding efforts). So, in reality, the principle of the ‘intrinsic values of the plant genome’ is a fiction and not science based, and to be clear: purely politically motivated as a very doubtful marketing argument.

The whole concept of violation of the intrinsic naturalness of the genome by inserting alien genes from other species across the natural species barrier is also falsified by the occurrence of a naturally transgenic grass: See the case discussed by (Ghatnekar et al., 2006) in chapter 6.2 paragraph 2). Have also a look at David Tribes blog with an impressive list of natural transgenic crops and organisms: http://gmopundit2.blogspot.com/2006/05/collected-links-and-summaries-on.html

It is also questionable to stress the overcoming of natural hybridization barriers by genetic engineering, since this has been done by traditional breeding methods in former decades: Here the example of Somatic hybridising (i.e. non-sexual fusion of two somatic cells). The advantage of this method is that by the fusion of cells with different numbers of chromosomes (for instance different species of Solanum) fertile products of the crossing can be obtained at once because diploid cells are being somatically fused. Polyploid plants are obtained containing all the chromosomes of both parents instead of the usual half set of chromosomes from each. For this, cells are required whose cell walls have been digested away by means of enzymes and are only enclosed by a membrane, (these are then called protoplasts). With the loss of their cell walls, protoplasts have also lost their typical shape and are spherical like egg cells. This mixture of cells to be fused is then exposed to electric pulses. In order to get from the cell mixture the ‘right’ product of the fusion (since fusion of two cells from similar plants can also occur) one different selectable character in each of the original plants is necessary. Only cells that survive this double selection are genuine products of fusion. (The easiest way to achieve such selectable markers is by genetic engineering, for instance by incorporating antibiotic resistance into the original plants.)

Protoplast fusion has been investigated and applied to potatoes, for instance. In the EU regulations concerning the deliberate release of genetically modified organisms into the environment somatic hybrids are not considered as GMO’s and do not require authorization. The most recent draft of the EU organic regulations in which the introduction of GMO’s in organic cultivation is forbidden, follows the above definition. (Karutz, 1999; Koop et al., 1996). Somatic hybrids have been experimentally achieved in hundreds of cases, the publication list in the Web of Science reveals over 3500 references.

This basic insight of a molecular biologist has been confirmed by analysis of modern breeding processes and their real products in crops, as an example here a comparison on the genomic level between transgenic and non-transgenic wheat traits done by Shewry et al.: (Shewry et al., 2006):

“Whereas conventional plant breeding involves the selection of novel combinations of many thousands of genes, transgenesis allows the production of lines which differ from the parental lines in the expression of only single or small numbers of genes. Consequently it should in principle be easier to predict the effects of transgenes than to unravel the multiple differences which exist between new, conventionally-produced cultivars and their parents. Nevertheless, there is considerable concern expressed by consumers and regulatory authorities that the insertion of transgenes may result in unpredictable effects on the expression of
endogenous genes which could lead to the accumulation of allergens or toxins. This is because the sites of transgene insertion are not known and transgenic plants produced using biolistics systems may contain multiple and rearranged transgene copies (up to 15 in wheat) inserted at several loci which vary in location between lines (Barcelo et al., 2001; Rooke et al., 2003).

Similarly, this apparently random insertion has led to the suggestion that the expression of transgenes may be less stable than that of endogenous genes between individual plants, between generations and between growth environments. Although there is evidence that the expression of transgenes introduced by biolistic transformation is prone to silencing in a small proportion of wheat (Anand et al., 2003; Howarth et al., 2005), many recent reviews including, (Altpeter et al., 2005; Jones, 2005; Kohli et al., 2003; Sahrawat et al., 2003) demonstrate the utility of biolistics transformation (and other methods such as direct insertion of DNA fragments as a basis for stable genetic manipulation.”

(Baker et al., 2006; Barcelo et al., 2001) are confirming the above statements – they could be extended to other methods of transformation like direct insertion of DNA fragments (Paszkowski et al., 1984) and with some questions about the long term stability also to the agrobacterium mediated transformations (Maghuly et al., 2007). But what is really interesting us here is published and documented by (Baudo et al., 2006): Overall, genome disturbances in traditional breeding in comparable cases are measured to be greater than in transformation.

“Detailed global gene expression profiles have been obtained for a series of transgenic and conventionally bred wheat lines expressing additional genes encoding HMW (high molecular weight) subunits of glutenin, a group of endosperm-specific seed storage proteins known to determine dough strength and therefore bread-making quality. Differences in endosperm and leaf transcriptome profiles between untransformed and derived transgenic lines were consistently extremely small, when analyzing plants containing either transgenes only, or also marker genes. Differences observed in gene expression in the endosperm between conventionally bred material were much larger in comparison to differences between transgenic and untransformed lines exhibiting the same complements of gluten subunits. These results suggest that the presence of the transgenes did not significantly alter gene expression and that, at this level of investigation, transgenic plants could be considered substantially equivalent to untransformed parental lines.”

Further confirmings are coming from recent publications like (Batista et al., 2008; Shewry et al., 2007), they all come to the conclusion, that at least certain transgenic crops show demonstrably less transcriptomic disturbances than their non-transgenic counterparts.

(Miller & Conko, 2004) raise in a justified way doubts about the commonly used concept of transgenesis. In the light of pre-recombinant DNA produced in great variety by conventional breeding with thousands of foreign genes.

“In these examples of prerecombinant-DNA genetic improvement, breeders and food producers possess little knowledge of the exact genetic changes that produced the useful trait, information about what other changes have occurred concomitantly in the plant or data on the transfer of newly incorporated genes into animals, humans or microorganisms. Consider, for example, the relatively new man-made wheat ‘species’ Triticum agropyrotriticum, which resulted from the wide-cross combination of the genomes of bread wheat and a wild grass sometimes called quackgrass or couchgrass (Banks et al., 1993; Sinigovets, 1987) T. agropyrotriticum, which possesses all the chromosomes of wheat as well as the entire genome of the quackgrass, was independently produced for both animal feed and human food in the former Soviet Union, Canada, the United States, France, Germany and China.”

See also the ASK-FORCE contributions on the web by K. Ammann 2009 ³ and ⁴ on the same subject.


The consequences are, that organic farming – using the argument of artificial DNA breeding disturbance, should decide for the transgenic crops in many cases. Another consequence is that transgenic crops of the first generation should never have been subjected to regulation purely based on the processes involved, rather it would have been wise to have in each case a close look at the products. In the case of the Golden Rice this has serious ethical consequences, because each year lost to unreasonable and unscientific regulation causes the death of hundreds of thousands of deaths due to severe deficiency in vitamin A, especially among the children of developing countries of South Eastern Asia. In Europe this kind of unscientific regulatory basis hinders the development of transgenic crop breeding for the benefit of a more ecological production. And on top of this the organic farming industry does not shy away from false and often hypocrite propaganda against genetically engineered crops for the sake of marketing their own products. For a broader view on “organotransgenics” as a whole see (Ammann, 2008b; Ammann, 2009c; Ammann & van Montagu, 2009).

7.2. Nature’s fields: ancient wild crop relatives grew often in monodominant stands
Species and genetic diversity within any agricultural field will inevitably be more limited than in a natural or semi-natural ecosystem. Surprisingly enough, many of the crops growing in farming systems all over the world have traits of ancestral parents which lived originally in natural monocultures (Wood & Lenne, 2001). This is after all most probably the reason why our ancestral farmers chose those major crops. There are many examples of natural monocultures, such as the classic stands of Kelp, *Macrocystis pyrifer*, already analyzed by Darwin (Darwin, 1845), and more relevant to agriculture, it has now been recognized by agro-ecologists that simple, monodominant vegetation exists throughout nature in a wide variety of circumstances. Indeed, (Fedoroff & Cohen, 1999) reporting (Janzen, 1998, 1999) use the term ‘natural monocultures’ in analogy with crops. Such monodominant stands may be extensive. As one example out of many, Harlan recorded that for the blue grama grass (*Bouteloua gracilis*): ‘stands are often continuous and cover many thousands of square kilometers of the high plains of central USA.’ It is of utmost importance for the sustainability of agriculture to determine how these extensive, monodominant and natural grassland communities persist and when and if we might expect their collapse. More examples are given in Wood & Lenne 1999 (Wood & Lenne, 1999), here we cite a few more cases. Wild species: *Picea abies, Spartina townsendii, Pteridium aquilinum,* various species of Bamboos, *Arundinaria ssp,* (Gagnon & Platt, 2008). Also the related *Phragmites communis* grow in large monodominant stands, which contain large clones. They renew after some decades over seeds (just like the large tropical Bamboos do in amazingly regular periods), this causes local temporary breakdowns of the populations. Still other ancestral cultivars are cited extensively (Wood & Lenne, 2001). *Sorghum*, the wild variety *verticilliflorum* is the widest distributed feral complex of the genus, with a broad climatic plasticity, extending almost continuously east of 20° east longitude from the South African coast to 10° north latitude. It overlaps along its northern and northwestern borders with variety *aethiopicum* and var. *arundinaceum,* again hybridizing extensively. It grows over extensive areas of tall grass savannah in the Sudan (Wood & Lenne, 2001). Typically enough, (Ayana et al., 2000) found a remarkably narrow genetic basis for the variety *verticilliflorum* in their analysis. Wild rice: *Oryza coarctata* is reported in Bengal as growing in simple, oligodiverse pioneer stands of temporarily flooded riverbanks (Prain, 1903); Harlan
ascribed _Oryza_ (Harlan, 1989) to monodominant populations and illustrated harvests from dense stands of wild rice in Africa (_Oryza barthii_, the progenitor of the African cultivated rice, _Oryza glaberrima_). _Oryza barthii_ was harvested wild on a massive scale and was a local staple crop across Africa from the southern Sudan to the Atlantic. Grain yields of wild rice stands in Africa and Asia could exceed 0.6 tonnes per hectare — an indication of the stand density of wild rice (Evans, 1998).

Botanists and plant collectors have repeatedly and emphatically noted the existence of dense stands of wild relatives of wheat (Wood & Lenné, 2001). For example, in the Near East, massive stands of wild wheats cover many square kilometers (Harlan, 1992). Wild einkorn (_Triticum monococcum subsp. boeoticum_) in particular tends to form dense stands, and when harvested, its yields per square meter often match those of cultivated wheats under traditional management (Hillmann, 1996). Wild Einkorn occurs in massive stands as high as 2000 meters altitude in south-eastern Turkey and Iran (Harlan & Zohary, 1966). Wild emmer (_Triticum turgidum subsp. dicoccoides_) grows in massive stands in the northeast of Israel, as an annual component of the steppe-like herbaceous vegetation and in the deciduous oak park forest belt of the Near East (Nevo, 1998). Wild wheat was also recorded to grow in Turkey and Syria in natural, rather pure stands with a density of 300/ m² (Anderson, 1998).

### 7.3. Extreme plant population dynamics of agricultural systems

Agricultural ecosystems can be dynamic in terms of species diversity over time due to management practices. This is often not understood by ecologists who involve themselves in biosafety issues related to transgenics. They still think in ecosystem categories close (or seemingly close) to nature. Biodiversity in agricultural settings can be considered to be important at a country level in areas where the proportion of land allocated to agriculture is high: Ammann in (Wolfenbarger et al., 2004). This is the case in continental Europe for example, where 45% of the land is dedicated to arable and permanent crops or permanent pasture. In the UK, this figure is even higher, at 70%. Consequently, biodiversity has been heavily influenced by man for centuries, and changes in agrobiological management will influence biodiversity in such countries overall. Innovative thinking about how to enhance biodiversity in general, coupled with bold action, is critical in dealing with the loss of biodiversity.

Consequently, biodiversity has been heavily influenced by humans for centuries, and changes in agrobiological management will influence biodiversity in such countries overall. Innovative thinking about how to enhance biodiversity in general coupled with bold action is critical in dealing with the loss of biodiversity. High potential to enhance biodiversity considerably can be seen on the level of regional landscapes, as is proposed by (Dollaker, 2006; Dollaker & Rhodes, 2007), and with the help of remote sensing methods it should be possible to plan for a much better biodiversity management in agriculture (Mucher et al., 2000).

### 7.4. Agrobiodiversity and the food web of insects also show extreme population dynamics

In a recent and notable paper Macfayden et al. 2009 (Macfadyen et al., 2009), were able to show in extensive field studies, focusing on the food web and its ecosystem services, instead of using traditional biodiversity descriptors, that things are a bit more complex than expected: Although organic farms
support greater levels of biodiversity on all three trophic levels, as shown in meta studies (Bengtsson et al., 2005; Hole et al., 2005), these systems provide greater levels of natural pest control and therefore also provide greater resistance towards the invasion of alien herbivores since more parasitoids are attacking herbivores. However they also predict (Macfadyen et al., 2009), as a consequence of higher species richness, a lower connectance and therefore a lower robustness of organic farms to species loss (Lafferty et al., 2008).

It is amazing to see that there are entomologists who wonder about the slightest detail in insect population shifts and food-webs in order to satisfy their strive to find negative effects of transgenic crops on non-target insects, they often forget some basics about experimentation. This has recently happened again with a paper from lab entomologists (Lovei et al., 2009), which has been refuted justifiably on multiple grounds by an important consortium (Shelton et al., 2009), here only one important reason mentioned: Feeding experiments have been done in the past (Hilbeck et al., 1998a; Hilbeck et al., 1998b) with low quality prey, but when you use healthy prey, the lacewings have a proven extremely high tolerance for the Bt proteins (Dutton et al., 2002; Romeis et al., 2004). Given here as a typical controversy on experimental details, some of the main influences are completely forgotten: Just imagine the mass extinction effects which happen with certitude, if you change the cropping system, often from year to year? Interestingly enough, there is literature on the detrimental effects of crop rotation against pest insects (Landis et al., 2000), but it’s difficult to find field work data on non-target insects related to crop rotation.

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### 7.5. The case of organic farming

It is often assumed, that organic farming is automatically helping agrobiodiversity. But is it not that simple. A comparison to conventional farming in Switzerland over 21 years has revealed positive effects of organic farming: (Mader et al., 2000; Mader et al., 2002a; Widmer et al., 2006). Soil fertility, including mycorrhiza data can be related positively to organic farming.

Fact is, that biodiversity depends on many elements, such as landscape, management etc. It is therefore no surprise that biodiversity levels in a comparison between organic and conventional farming show a mixed picture, as demonstrated by (Gabriel et al., 2010).
The authors of the study conclude:

"Conservation management needs to target multiple spatial scales. To date, schemes have been focused on relatively fine scales, because the land is managed at these scales. However, our results suggest that, for maximum effect, there is a need to manage at a spatial scale beyond the farm. The challenge will be to find policy levers to encourage multiple farmers within a landscape to adopt such schemes in concert, thereby creating landscape-level benefits. Our results also have implications beyond agricultural..."
On the other hand, yield is still on the negative side in organic farming, as the same DOC 21-year tests in Switzerland have revealed:

![Graph showing yield of winter wheat, potatoes, and grass-clover in the farming systems of the DOK trial.](image)

*Fig. 18 Yield of winter wheat, potatoes, and grass-clover in the farming systems of the DOK trial. Values are means of six years for winter wheat and grass-clover and three years for potatoes per crop rotation period. Bars represent least significant differences (P, 0.05). From (Mader et al., 2002b)*

The conclusions of the author of this study is tending towards making peace between the various parties of farming management: In order to get out the best possible solutions, always adapted to local conditions, should be an optimal mixture from organic to industrial farming including all methods of modern technology, from better community and landscape structure analysis over enhanced recycling methods to conservation tilling and – last but not least, include modern breeding methods. The author can imagine that some of the transgenic crops (mainly insect resistance and stress resistance events)
should be included into ecological and even organic farming. (Ammann, 2008b; Ammann, 2009c; Ammann & van Montagu, 2009)

8. Selected proposals for improving high technology agriculture related to biodiversity

8.1. Biodiversity and the management of agricultural landscapes
High potential to enhance biodiversity considerably can be seen on the level of regional landscapes (Dollaker, 2006; Dollaker & Rhodes, 2007), and with the help of remote sensing methods it should be possible to plan for much better biodiversity management in agriculture (Mucher et al., 2000). This is also a good point for organic farming in marginal regions like the Norwegian Sognefjord. An analysis has shown the positive influence of small scale organic farming in this region (Clemetsen & van Laar, 2000b). Some of the more important papers demonstrate the intensive research activities on the relationship between landscapes and biodiversity (Belfrage et al., 2005; Boutin et al., 2008; Clemetsen & van Laar, 2000a; Filser et al., 2002; Hendriks et al., 2000; Jan Stobberlaar & van Mansvelt, 2000; Kuiper, 2000; MacNaeidhe & Culleton, 2000; Norton et al., 2009; Rossi & Nota, 2000; Schellhorn et al., 2008; Stobberlaar et al., 2000). (Bawa et al., 2007; Brush & Perales, 2007; Bryan et al., 2007; Harrop, 2007; Heywood et al., 2007; Jackson et al., 2007a; Jackson et al., 2007b; Pascual & Perrings, 2007) all advocate the many ingenious agricultural systems that have shaped novel, resilient landscapes for centuries and in so doing have also sustained high levels of biodiversity. These authors of a special volume for Diversitas also criticize intensification of agriculture with the sole target of enhancing production, and want to go back to traditional management. Unfortunately, traditional agricultural systems are no more compatible with the today’s demand for higher yield and economic incentives. It is therefore essential, to search for innovative combinations of landscape management focusing on biodiversity and modern agriculture. Organotransgenic strategies have been analyzed in detail and combinations are possible (Ammann, 2008b; Ammann, 2009c; Ammann & van Montagu, 2009). A bibliography, containing a total of over 300 papers dealing with the impact of ecological agriculture on landscapes and vice versa can be found in (Ammann, 2009a). There is a lot of potential in restructuring landscape in regions with a high yielding industrial agricultural production. In a thoughtful multivariate scheme Benton et al. (Benton et al., 2003) show the highly complex interactions between farmland activities and the diversity of bird species:
Now that many of the biodiversity myths related to agriculture are clarified, it is becoming obvious, that one of the priorities in fostering biodiversity in agriculture, is to take better care of the landscape structure, and this is where high tech agriculture can learn from organic and integrated farming. But there are also other ways and means to cope up with the demand of enhancing biodiversity in high tech agriculture.

### 8.2. More biodiversity through mixed cropping

Mixed cropping systems have been proposed for a variety of agricultural management systems. The bibliography coming from the Web of Science reach nearly 300 items and many papers offer a wide variety of options. There is no reason, why modern cropping system with industrial automation could not cope up with some specific mixed cropping systems. Mixed cropping offers advantages in pest management and soil fertility (Wolfe, 2000; Zhu et al., 2000; Zhu et al., 2003), but also is subject to limitations, such as the fight against the maize stem borer (Songa et al., 2007), still, under low pest pressure a system of maize-bean intercropping in Ethiopia seems to be successful (Belay et al., 2009).
A recent publication confirmed the positive effects: A combination of enhanced AMF (Arbuscular Mycorrhizal Fungi), EF (Earth Worm data), and mixed cropping increased the yield, mycorrhizal colonization rate, SMB (soil microbial biomass), and nitrogen uptake of the clover plants, confirming the positive effects of diversity on an agro-ecosystem (Zarea et al., 2009). Positive results are also reported from Pakistan: A pot experiment was conducted to study the effect of mixed cropping of wheat and chickpea on their growth and nodulation in chickpea (Gill et al., 2009). But there are also limits to mixed cropping provided you mix crops within the same field without any separation. (Paulsen, 2007) worked on such intricate mixtures with peas, wheat, lupins, false flax and demonstrated serious problems with reduced yield, those systems need further development.

8.3. On the wish list: more crop diversity, foster orphan crop species.
Another important aspect has been covered by the recently published book of Gressel (Gressel, 2007) with an interesting theme: a proactive review on orphan crops, their present day deficiencies (the ‘glass ceiling’ and how biotechnology methods could greatly enhance them, so that they could be commercialized in a more competitive way in future. It is especially fascinating to see how the author blends modern molecular biology with a deep insight into agriculture and its forgotten crops. This is an important boundary line, where organic/ecological farming can meet with modern biotechnology and create considerable synergy. Even within crops with a seemingly low reputation like the herbicide tolerant soybeans regarding diversity, trends are positive, as a report from Iowa shows (Tylka, 2002): Recently there are over 700 nematode resistant soybean traits registered, the majority of them herbicide tolerant.

8.4. Varietal mixture of genes and seeds
Also on a micro scale of seed production, biodiversity could play a new role. Precision Biotechnology could also mean a combination of resistance genes, done either through gene stacking (Gressel et al., 2007; Lozovaya et al., 2007; Taverniers et al., 2008) or by taking up the idea of artificial gene clusters (Thomson et al., 2002). This has been the accepted strategy up to now.

But this goal of introducing more biodiversity in the fields could be achieved in a much simpler way. Other than complex gene-stacking it would be easier to create a seed mix in which each seed contains a single resistance, and the appropriate mixture could be adapted to the local pest situation. This would considerably lower selection pressure (Ammann, 1999) and would create a situation, which comes closer to nature, where we encounter many genomes within a square mile and dozens of different resistance genes. Varietal mixtures have been proposed by several authors (Gold et al., 1989, 1990; Murphy et al., 2007; Smithson & Lenne, 1996).

8.5. More biodiversity in the food web including non-target insects by reducing pesticide use with transgenic crops and other strategies
If we refrain from heavy pesticide use, beneficial insects will come back – as they do in Bt maize fields, (Candolfi et al., 2004; Marvier et al., 2007; Naranjo, 2009; Wolfenbarger et al., 2008) and adapt to GMO’s. More comments on biodiversity and the advantageous use of biotechnology in agriculture are published in the reviews by (Ammann, 2004a, 2005, 2007a, 2008a, 2009b; Ammann et al., 2005).
Much has been written on agricultural biodiversity; foremost the book of Wood & Lenne (Wood & Lenne, 1999) should be mentioned here, a refreshing mix of modern agriculture and independent views on biodiversity. Each chapter, written by some of the best experts in the field, deserves to be taken up in the future debate on agriculture and biodiversity. The chapter on traditional management written by (Thurston et al., 1999) provides a very enlightening summary. Of course those management details have to be carefully selected for modern agriculture and where necessary also to be adapted. As a catalogue of ideas the tables in this article serve well.

There are also comparative data available on long term development, with organic and conventional agriculture. The results show positive trends towards more biodiversity, when conventional farms are converted into organic farms, but the influence of local management habits and also a changing landscape are very important (Taylor & Morecroft, 2009) and high technology farming could again learn.

See the final chapter on case studies for more details.

8.6. Push- and pull strategy for reducing pest damage in maize fields.
The ‘push–pull’ or ‘stimulo-deterrent diversionary’ strategy is established by exploiting semiochemicals to repel insect pests from the crop (‘push’) and to attract them into trap crops like Desmodium spp. which can at the same time produce with bacterial nodules a nitrogen fertilizer effect. (Hassanali et al., 2008). Results of this field trial demonstrate higher maize yield when applying the push- and pull strategy, when compared with conventional maize cultures in Africa. It would be more interesting and convincing to see a field trial with a comparison to Bt maize.

8.7. Plant breeding revisited

8.7.1 New biotechnology approaches in plant breeding

In an early paper, Britt et al. give an overview on many molecular possibilities which will develop for new breeding successes (Britt & May, 2003), they address the current status of plant gene targeting and what is known about the associated plant DNA repair mechanisms. One of the greatest hurdle that plant biologists face in assigning gene function and in crop improvement is the lack of efficient and robust technologies to generate gene replacements or targeted gene knockouts. It seems to be clear that transgenesis will remain a solid technology for breeding, but new approaches will appear – as science is always open for progress and new breakthroughs. There are many new biotechnologies enhancing the speed of achieving targeted breeding successes such as (Wittenberg et al., 2005) with the high throughput marker finding technology, only a few can be mentioned here:

8.7.1.1. Cis- and Intragenic approaches

A new technology has now proven to be a successful strategy: As Romments describe it, cisgenetics is a welcome way of combining the benefits of traditional breeding with modern biotechnology. It is an
understandable enthusiasm of the first researchers using this technology to emphasize the positive sides by also comparing to transgenesis as an ‘old-fashioned’ method with its problems. But things are certainly not so easy: In chapter 7.1. it is made clear that on the genomic level, particularly on the level of molecular processes, there is no difference between transgenic and non-transgenic crops (supported by an important body of scientific literature), and this is certainly also true to cisgenic and intragenic varieties. This is why it is questionable and based on false grounds to make claims that those new methods in transformation would be safer, as Giddings has made it clear in his letter (Giddings, 2006), and his arguments against the the views of (Schouten & Jacobsen, 2007; Schouten et al., 2006a; Schouten et al., 2006b) and later publications (Conner et al., 2007; Jacobsen & Nataraja, 2008; Jacobsen & Schouten, 2007) could have been targeted as well: they try to demonstrate that the new cisgenics and intragenics are safer than transgenics, which is not based on any facts, rather it is based on accepting without scientific scrutiny the negative public perception on transgenic crops. It is also wrong to use without clarification the term “alien genes” in view of confirmed and widely accepted universality of DNA and genomic structures.

However, there is nothing to say against the application of such new methods per se, as (Jacobsen & Nataraja, 2008; Jacobsen & Schouten, 2007) can demonstrate:

“The classical methods of alien gene transfer by traditional breeding yielded fruitful results. However, modern varieties demand a growing number of combined traits, for which pre-breeding methods with wild species are often needed. Introgression and translocation breeding require time consuming backcrosses and simultaneous selection steps to overcome linkage drag. Breeding of crops using the traditional sources of genetic variation by cisgenesis can speed up the whole process dramatically, along with usage of existing promising varieties. This is specifically the case with complex (allo)polyploids and with heterozygous, vegetative propagated crops. Therefore, we believe that cisgenesis is the basis of the second/ever green revolution needed in traditional plant breeding. For this goal to be achieved, exemption of the GM-regulation of cisgenes is needed.”

8.7.1.3. Reverse screening methods: tilling and eco-tilling
Two rather independent publications (Parry et al., 2009; Rigola et al., 2009) with largely incongruent literature lists promote a new technology of finding useful genes within the genome of the crops involved: They both promote powerful reverse genetic strategies that allow the detection of induced point mutations in individuals of the mutagenized populations can address the major challenge of linking sequence information to the biological function of genes and can also identify novel variation for plant breeding (Parry et al., 2009). (Rigola et al., 2009) develop reverse genetics approaches which rely on the detection of sequence alterations in target genes to identify allelic variants among mutant or natural populations. Current (pre-) screening methods such as tilling and eco-tilling are based on the detection of single base mismatches in heteroduplexes using endonucleases such as CEL 1. However, there are drawbacks in the use of endonucleases due to their relatively poor cleavage efficiency and exonuclease activity. Moreover, prescreening methods do not reveal information about the nature of sequence changes and their possible impact on gene function. (Rigola et al., 2009) present a KeyPointTM technology, a high-throughput mutation/polymorphism discovery technique based on massive parallel sequencing of target genes amplified from mutant or natural populations. Thus KeyPoint combines multidimensional pooling of large numbers of individual DNA samples and the use of sample identification tags (“sample barcoding”) with next-generation sequencing technology. (Rigola et al., 2009) can demonstrate first successes in tomato breeding by identifying two mutants in the tomato elf4E gene based on screening more than 3000 M2 families in a single GS FLX sequencing run, and discovery of six haplotypes of tomato elf4E gene by re-sequencing three amplicons in a subset of 92 tomato lines from the EU-SOL core collection. This technology will prove to be useful and does not need for its own breakthrough to refer to a scientifically unjustified critique of transgenesis. Whether the new
technology will replace the transgenic ‘Amflora potato’ has still to be proven by further scrutinizing of the results of the equivalent trait (Davies et al., 2008).

8.7.1.4. Zinc finger targeted insertion of transgenes
Plant breeding has gone through dynamic developments, from marker assisted breeding to transgenesis with steadily improved methods to the latest development of the Zink finger enzyme assisted targeted insertion of transgenes in complex organisms (Cai et al., 2009; Shukla et al., 2009; Townsend et al., 2009). The development is so rapid, that it is necessary here to make some additional remarks related to the paragraph in the first of the articles dealing with the topic of organo-transgenesis (Ammann, 2008b):

According to the descriptions of the new technology, it will be even more difficult for the breeders of new organic crops to refuse Zink finger transgenesis, since it is very likely that the transcriptomic disturbances will be even smaller in future – compared to the clumsy and tedious methods of conventional breeding.

8.7.1.5. Synthetic biology
In some 150 laboratories, synthetic biology is intensively researched, and it seems clear that the future will bring here some unexpected revolutions: A new field, synthetic biology, is emerging on the basis of these experiments (Benner, 2004), where chemistry mimics biological processes as complicated as Darwinian evolution. According to (Tian et al., 2009) the emerging field of synthetic biology is generating insatiable demands for synthetic genes, which far exceed existing gene synthesis capabilities. Tian et al. claim that technologies and trends potentially will lead to breakthroughs in the development of accurate, low-cost and high-throughput gene synthesis technology - the capability of generating unlimited supplies of DNA molecules of any sequence or size will transform biomedical and any biotechnology research in the near future. And, according to (Benner et al., 1998), already in 1998 the redesigning of nucleic acids has been judged in an optimistic way, this was confirmed in an important Nature review in 2005 (Benner & Sismour, 2005).

The real breakthrough came with the synthesis of an organism including its reproduction, achieved after years of research and a firm belief in success, typical for the senior author of the mega-project still continuing: (Gibson et al., 2008a; Gibson et al., 2008b; Gibson et al., 2010; Rusch et al., 2007).

A pragmatic view of a new regulatory scheme answering to the new biosafety tasks of synthetic biology is proposed by (Bugl et al., 2007):
Fig. 170 Our framework calls for the immediate and systematic implementation of a tiered DNA synthesis order screening process. To promote and establish accountability, individuals who place orders for DNA synthesis would be required to identify themselves, their home organization and all relevant biosafety information. Next, individual companies would use validated software tools to check synthesis orders against a set of select agents or sequences to help ensure regulatory compliance and flag synthesis orders for further review. Finally, DNA synthesis and synthetic biology companies would work together through the ICPS, and interface with appropriate government agencies (worldwide), to rapidly and continually improve the underlying technologies used to screen orders and identify potentially dangerous sequences, as well as develop a clearly defined process to report behavior that falls outside of agreed-upon guidelines. ICPS, International Consortium for Polynucleotide Synthesis. From (Bugl et al., 2007)

This kind of new regulatory approach will be necessary in order to avoid unnecessary hindering of research progress in synthetic biology, a demand supported with other innovative suggestions for interactive procedures (Maurer et al., 2006). Another balanced view (Serrano, 2007) demonstrates also the new risks arising from synthetic organisms and the accidental (or purposeful) release in the environment. As always, the ethical awareness and behavior has to be developed further, agreeing with (Edmond & Mercer, 2009) not in a way which gives forfeit power to social sciences. What we really need is a new interfacultary, interdisciplinary or even better transdisciplinary discursive scheme as proposed in chapters 5.2 and 5.3. of Ask-Force blog on the debate strategy (Ammann, 2010).

It should be a warning, what happened some 35 years ago in the US National Institute of Health with the words of Henry I. Miller 5:

“Thirty-five years ago, the US National Institutes of Health adopted overly riskaverse guidelines for research using recombinant DNA, or “genetic engineering,” techniques. Those guidelines, based on what has proved to be an idiosyncratic and largely invalid

set of assumptions, sent a powerful message that scientists and the federal government were taking seriously speculative, exaggerated risk scenarios – a message that has afflicted the technology's development worldwide ever since.”

8.7.2. Improvement of conventional breeding
For sure there is also value in the development of conventional breeding methodologies for organic (and non-organic) crops. It is obvious, that also high technology breeding of new crops can learn from the newly developed organic breeding strategies:

In a recent and comprehensive paper, a consortium lead by Wolfe (Wolfe et al., 2008) give an account on breeding crops for organic farming. Many of the characteristics required in new varieties are common to both conventional and organic agriculture, but there are also a number of breeding targets, mostly of complex nature, that must have a higher priority in organic farming. Characters that are important for the farming system and the crop rotation, weed competition and adaptation to arbuscular mycorrhizas for instance have a higher priority. To rationalize the long enduring selection process, it is necessary to focus on simultaneous selection processes such as weed competition, nutrient uptake and disease/pest resistance. It seems, that the trend to ban any kind of in vitro breeding technology is unfortunately growing and therefore it is anticipated, that banning even marker assisted breeding will deprive the organic community from modern and very efficient tools to achieve the genomic breeding goals. This way, the slowdown process cannot be stopped, it will be very difficult to reach the urgent need of better yield, and the difficulties will grow with the need to cope with a considerably higher diversity of environmental factors, which does not favour centralized breeding.

The real force of breeding for organic crops comes from the strong link to social structures, as promoted by a variety of breeding programs, such as the ones on Sorghum in Western Africa by researchers from Wageningen (Slingerland et al., 2003; Slingerland et al., 2006), explicitly enforcing participative working strategies including traditional knowledge. These thoughts and strategies could well also be taken up by breeding programs using unrestrained all modern DNA related manipulation methods.

8.8. New ways of using biotechnology for enhancing natural resistance
With the pioneering work of Métraux, Boller and Turlings in the mid eighties and early nineties (Metraux & Boller, 1986; Metraux et al., 1990; Turlings et al., 1989) the Systemic Acquired Resistance got some interest: They found that salicylic acid was functioning as internal signal for triggering systemic acquired resistance (Dangl & Jones, 2001; Metraux et al., 2002). There is potential for such strategies for fighting off pests by employing mechanisms close to nature.

In 1996, a maize (E)-beta-caryophyllene synthase has been discovered (Jackson, 1996) implicated in indirect defense responses against herbivores. This defense substance is no more expressed in most American maize varieties, but there is a possibility to restore the defense by genetic engineering (Degenhardt et al., 2009; Kollner et al., 2008; Rostas & Turlings, 2008) – another promising pathway in modern breeding.
8.9. Final remarks on the improvement list related to biodiversity

This cannot be the place to give a comprehensive list of possible improvements which are compatible with high technology agriculture. This would fill dozens of pages and could also well be the intellectual engine for a long term research program – and it is rewarding to see that major organizations are active in this field, such as CGIAR, IFPRI etc., including some leading universities such as Cornell, Wageningen, Hohenheim, Davis etc. etc. Rather, the reader is referred to some books having been written with the purpose to improve agricultural biodiversity – most of the chapters cited below do not envisage improving high technology agriculture per se, rather most of the authors see themselves in opposition to it. In the eyes of the author this is at least questionable, and it would be much more fruitful to find opportunities for collaboration and create synergy.

There are a number of books, reports and numerous peer reviewed journal articles which deal with all aspects of ecological agriculture. The authors come with proposals on how to enhance sustainability, how to preserve biodiversity and what can be done so that traditional knowledge with all its treasures does not vanish. There are a majority of authors who really do not lose the focus of the developing world and its dramatic problems, but they avoid topics like modern breeding etc. (Altieri & Nicholls, 2004; Altieri, 2002; Scherr & McNeely, 2007; Thurston, 1991). Scherr et al. and in particular also Wood & Lenne (Wood & Lenne, 1999) offer highly interesting chapters on the science and practice of ecoagriculture. It is impressive for the reader to learn about various schemes of integrated farming systems, and some are really integrative and especially strong on the side of analyzing social dynamics, history and economy, topics sometimes forgotten by conservationists and certainly by proponents of high technology agriculture. On the other hand it is striking to see, with a few notable exceptions, that modern breeding technology and in most cases also high technology management methods like remote sensing, GIS supported systems are often only briefly mentioned. In Scherr & McNeely (Scherr & McNeely, 2007) even a meticulous search does not reveal a single sentence on genetically engineered crops, the otherwise extensive keyword index does not contain such words. On the other hand, it is rewarding to see in the same book a treatment on remote sensing (Dushku et al., 2007), stating that this is an important instrument in the landscape planning of ecoagriculture (GIS-based decision support).

Nevertheless, the scarcity of such treatments provokes the serious question about bias against modern agricultural technology. The same can be said from the IAASTD report. In a rebuttal to a letter to Science (Mitchell, 2008) attacking the views of Fedoroff (Fedoroff, 2008), the author (Ammann, 2008c) commented about the IAASDD report (IAASTD http://www.agassessment.org/ 2007):

“Mitchell referred to the IAASTD report to degrade the importance of transgenic crops, but this report does not meet scientific review standards and comes to questionable negative conclusions about biotechnology in agriculture. “Information [about GM crops] can be anecdotal and contradictory, and uncertainty on benefits and harms is unavoidable.” Such biased judgment ignores thousands of high quality science papers; it is not surprising that most renowned experts left the IAASTD panel before the final report was published”.

The good thing about all those cited publications on ecoagriculture is to see with an open mind, that transgenic crops and all high technology practices, even the first generation transgenic crops, could very well fit into ecoagriculture and, vice versa, that ecoagricultural strategies could very well be introduced into high tech agriculture. The possible positive role of biotechnology related to ecology and conservation has been stated as early as 1996 (Bull, 1996). It is fact which has been repetitiously stated
with solid justification: The present day transgenic crops commercialized are not inherently scale dependent, which means, they can, with some adaptation in the management, very well be integrated in small scale farming – which has been shown with success in India and China with Bt cotton (Gruere Guillaume P. et al., 2008; Herring, 2008; Vitale et al., 2008).

9. Interlude: the role of fundamentalist activists and scientists with a strong anti-GMO agenda in the dispute about GM crops

New technologies always cause in the introductory phase some concern, even anxiety among the population. Some nice examples from past technology introduction phases are summarized in “Hystories” (Showalter, 1997), the present situation is probably best analyzed by (Taverne, 2005b) and his latest book on the “March of Unreason” (Taverne, 2005a). It is also devastating to see, that development of modern breeding is hindered dramatically in Africa (Paarlberg, 2000), and it is one of the perpetuating myths that the multinational companies are taking over in developing countries – on the contrary, it’s the public research which is dominant to 85% according to FAO statistics (Dhlamini et al., 2005) and (Cohen, 2005). The statistics of ISAAA show that the trend in developing countries is very positive http://www.isaaa.org/resources/publications/briefs/37/executivesummary/default.html

Contrary to this constant positive trend in the development and spread of GM crops there is a widespread activity existing of various kinds of anti-GMO activists, here just a very few typical examples:

There are four main lines of resistance working frantically to reverse these positive trends:

- Scientists who publish questionable or simply flawed papers, based usually on lab protocols which do not fit to international standards, such as Irina Ermakova’s rat experiments (Marshall, 2007), for more details go to the ASK-FORCE of PRRI: http://pubresreq.org/index.php?option=com_smf&Itemid=27&topic=13.0

- Activist websites like the ones of Greenpeace, producing lots of scaremonger material such as the hoax of the 1600 dead sheep in India which allegedly have eaten leaves of Bt cotton and died afterwards, a story which has been perpetuated on the websites, despite scientific evidence that the sheep died from infections. Full details on the ASK-FORCE blog of the European Federation of Biotechnology http://www.efb-central.org/index.php/forums/viewthread/13/

- Lay people like Jeffrey Smith, a long time ardent member of the Maharishi cult and fanatic anti-GMO author: He publicly claimed there were 500 studies proving that yogic flying and transcendental meditation cut crime and increased IQ. His latest book is proof of the contrary: scare stories in a professional layout, with very little verifiable facts but written in a brilliant style in the mode: Throw plenty of dirt and some will be sure to stick. (Smith, 2007). An excellent documentation of many of those myths against GM crops has recently been published by Peggy Lemaux (Lemaux, 2008), getting some excellent science into the debate.
The most problematic publications stem from scientists who filter facts, give a one-sided picture by omitting crucial data, but per se come with reproducible results and manage to get them published in peer reviewed journals, a typical example comes from a member of GENOEK from Tromsoe in Norway, a group pretending to have a holistic view in contrast to most pro-GMO scientists, but actually just do the exact contrary: Ann Myhre published a paper demonstrating that the 35S promoter so often used to enhance transgene expression, shows some activity in cultures of human cells. This is – per se – a scary story, but in her paper (Myhre et al., 2006) she and her co-authors carefully avoid to tell the reader that the very same promoter is eaten daily in quantities by those who relish vegetables of Brassicaceae. More details see in the ASK-FORCE text on the critical review of (Dona & Arvanitoyannis, 2009) under http://www.pubresreg.org/index.php?option=com_content&task=view&id=70

10. Two case studies on the impact of transgenic crops on biodiversity and health

The two case studies are just samples of an intensive biosafety research with thousands of peer reviewed publications, and the positive results from it are well documented. Worldwide, there has not been a single incident of negative, permanent impact of GM crops, published in a peer reviewed journal, which caused real problems in environment and food.

10.1. The case of herbicide tolerant crops, Application of Conservation Tillage easier with herbicide tolerant crops

The soil in a given geographical area has played an important role in determining agricultural practices since the time of the origin of agriculture in the Fertile Crescent of the Middle East. Soil is a precious and finite resource. Soil composition, texture, nutrient levels, acidity, alkalinity and salinity are all determinants of productivity. Agricultural practices can lead to soil degradation and the loss in the ability of a soil to produce crops. Examples of soil degradation include erosion, salinization, nutrient loss and biological deterioration. It has been estimated that 67% of the world’s agricultural soils have been degraded (World Resources Institute, 2000).

It may also be worth noting that soil fertility is a renewable resource and soil fertility can often be restored within several years of careful crop management.

In many parts of the developed and the developing world tillage of soil is still an essential tool for the control of weeds.

Unfortunately, tillage practices can lead to soil degradation by causing erosion, reducing soil quality and harming biological diversity. Tillage systems can be classified according to how much crop residue is left on the soil surface (Fawcett et al., 1994; Fawcett & Towery, 2002; Trewavas, 2001; Trewawas, 2003). Conservation tillage is defined as “any tillage and planting system that covers more than 30% of the soil surface with crop residue, after planting, to reduce soil erosion by water” (Fawcett & Towery, 2002). The value of reducing tillage was long recognized but the level of weed control a farmer required was viewed as a deterrent for adopting conservation tillage. Once effective herbicides were introduced in the latter half of the 20th century, farmers were able to reduce their dependence on tillage. The development of crop varieties tolerant to herbicides has
provided new tools and practices for controlling weeds and has accelerated the adoption of conservation tillage practices and accelerated the adoption of “no-till” practices (Fawcett & Towery, 2002). Herbicide tolerant cotton has been rapidly adopted since its introduction in (Fawcett et al., 1994). In the US, 80% of growers are making fewer tillage passes and 75% are leaving more crop residue (Cotton Council, 2003). In a farmer survey, seventy-one percent of the growers responded that herbicide tolerant cotton had the greatest impact on soil fertility related to the adoption of reduced tillage or no-till practices (Cotton Council, 2003). In soybean, the growers of glyphosate tolerant soybean plant higher percentage of their acreage using no-till or reduced tillage practices than growers of conventional soybeans (American Soybean Association, 2001). Fifty-eight percent of glyphosate-tolerant soybean adopters reported making fewer tillage passes versus five years ago compared to only 20% of non-glyphosate tolerant soybean users (American Soybean Association, 2001). Fifty-four percent of growers cited the introduction of glyphosate tolerant soybeans as the factor which had the greatest impact toward the adoption of reduced tillage or no-till (American Soybean Association, 2001). Today, the scientific literature on “no-tillage” and “conservation tillage” has grown on more than 6500 references, a selection of some 1200 references from the last three years are given in the following link: http://www.ask-force.ch/web/Tillage/Bibliography-No-conservation-Tillage-2006-20080626.pdf

Several important reviews have been published in recent months, the all tell a positive story regarding the overall impact of herbicide tolerant crops and the impact on the agricultural environment:

Here just a few examples and statement:

(Bonny, 2008): In a comprehensive review Bonny describes the unprecedented success of the introduction of transgenic Soybean in the United States.

It is worthwhile to show one of the graphs about the statistics of glyphosate use, thus correcting some of the legends spread by opponents, sometimes coming in seemingly sturdy statistics like those of (Benbrook, 2004) stating that the herbicide and pesticide use has grown ever since the introduction of transgenic crops. But a closer, more differentiated look reveals this to be an “urban legend”: (Carpenter & Gianessi, 2000).
Fig. 21 Main herbicides used on total soybean acreage, 1990-2006 (as % of soybean surface treated by each herbicide) (From USDA NASS, 1991-2007). With the development of glyphosate-tolerant soybean, this herbicide is used far more extensively. Indeed, it replaces the herbicides used previously; the Figure shows only a few of the latter. From (Bonny, 2008):

“A comparison of transgenic versus conventional soybean reveals that transgenic glyphosate-tolerant soybean allows both the simplification of weed control and greater work flexibility. Cropping transgenic soybean also fits well with conservation tillage. Transgenic soybean has an economic margin similar to conventional soybean, despite a higher seed cost. The next section describes the evolution of the use of herbicides with transgenic soybean, and some issues linked to the rapid increase in the use of glyphosate. At the beginning a smaller amount of herbicides was used, but this amount increased from 2002, though not steadily. Nonetheless, the environmental and toxicological impacts of pesticides do not only depend on the amounts applied. They also depend on the conditions of use and the levels of toxicity and ecotoxicity. The levels of ecotoxicity seem to have somewhat decreased. The success of transgenic soybeans for farmers has led to a higher use of glyphosate as a replacement for other herbicides, which has in turn led to a decline in its effectiveness. However, the issue here is not only genetic engineering in itself, but rather the management and governance of this innovation.”

(Cerdeira et al., 2007) also emphasize the benefits, despite some green propaganda from Brazil and Argentina, but point also to some potential problems with the evolution of glyphosate resistant weeds:

“Transgenic glyphosate-resistant soybeans (GRS) have been commercialized and grown extensively in the Western Hemisphere, including Brazil. Worldwide, several studies have shown that previous and potential effects of glyphosate on contamination of soil, water, and air are minimal, compared to those caused by the herbicides that they replace when GRS are adopted. In the USA and Argentina, the advent of glyphosate-resistant soybeans resulted in a significant shift to reduced- and no-tillage practices, thereby significantly reducing environmental degradation by agriculture. Similar shifts in tillage practiced with GRS might be expected in Brazil. Transgenes encoding glyphosate resistance in soybeans are highly unlikely to be a risk to wild plant species in Brazil. Soybean is almost completely self-pollinated and is a non-native species in Brazil, without wild relatives, making introgression of transgenes from GRS virtually impossible. Probably the highest agricultural risk in adopting GRS in Brazil is related to weed resistance. Weed species in GRS fields have shifted in Brazil to those that can more successfully withstand glyphosate or to those that avoid the time of its application. These include Chamaesycye hirta (erva-de-Santa-Luzia), Commelina benghalensis (trapoeraba), Spermacoce latifolia (erva-quente), Richardia brasiliensis (poaia-branca), and Ipomoea spp. (corda-de-viola). Four weed species, Conyza bonariensis, Conyza canadensis (buva), Lolium multiflorum (azevem), and Euphorbia heterophylla (amendoim bravo), have evolved resistance to glyphosate in GRS in Brazil and have great potential to become problems.”

These findings are also published in an earlier study with a worldwide scope looking at the herbicide tolerant crops of the Western Hemisphere by some of the same authors (Cerdeira & Duke, 2006) with the same outcome as above. A summary on glyphosate tolerant crops is also published in (Ammann, 2004b; Ammann, 2005).

More pertinent review papers on soil erosion and other agronomic parameters have been published in relationship with the new agricultural management of herbicide tolerant weeds:

(Anderson, 2007; Bernoux et al., 2006; Beyer et al., 2006; Bolliger et al., 2006; Causarano et al., 2006; Chauhan et al., 2006; Etchevers et al., 2006; Gulvik, 2007; Knapen et al., 2007; Knowler & Bradshaw, 2007; Peigne et al., 2007; Raper & Bergtold, 2007; Thomas et al., 2007; Thompson et al., 2008; Wang et al., 2006).

10.2. The Case of Impact of Bt maize on non-target organisms
In a study on environmental impact of Bt-maize on the environment, a book project of now 350 pages, the author also has included a commentary chapter for over 180 scientific studies dealing with non-
target organism which could be harmed by the cultivation of Bt maize. Observing strictly the baseline comparison with non-Bt maize cultivation, it can be said that there is not a single publication pointing to detrimental effects of Bt maize compared to other maize traits. Four meta studies have been published recently with more or less stringent selection of data published in scientific journals, and all those meta analysis do not show any sign of regulatory problems. (Chen et al., 2008; Duan et al., 2008; Marvier et al., 2007; Wolfenbarger et al., 2008)

(Wolfenbarger et al., 2008) is singled out here since it is the best meta-analysis existing so far, the selection criteria are clearly defined on all levels and based on a carefully filtered dataset, actually a subset of the database published by (Marvier et al., 2007) on the net under www.sciencemag.org/cgi/content/full/316/5830/1475/DC1

In total, the database used contained 2981 observations from 131 experiments reported in 47 published field studies on cotton, maize and potato. Maize has been studied in the following two comparison categories (including also data on potato and cotton).

- The first set of studies contrasted Bt with non-Bt plots, neither of which received any additional insecticide treatments. This comparison addresses the hypothesis that the toxins in the Bt plant directly or indirectly affect arthropod abundance. It also can be viewed as a comparison between the Bt crop and its associated unsprayed refuge (Gould, 2000).
- The second set of studies contrasted unsprayed Bt fields with non-Bt plots that received insecticides. This comparison tests the hypothesis that arthropod abundance is influenced by the method used to control the pest(s) targeted by the Bt crop. (The third set of studies contrasted fields of Bt-crops and non-Bt-crops both treated with insecticides, a category which did not occur in the here included studies of maize.)

Great care was taken to eliminate redundant taxonomic units and multiple development stages of the same species, with a preference of the least mobile development stage, also the datasets are all derived from the same season.

In contrast to the following study by (Marvier et al., 2007) the statistical analysis was not done with the original taxonomic units, rather the authors decided to use an additional descriptor, six ‘functional guilds’ (herbivore, omnivore, predator, parasitoid, detritivores, or mixed). More details can be read in the original publication, as a whole, database robustness and sensitivity of the datasets have been thoroughly discussed and careful decisions have been made in order to get maximum quality of the meta-analysis.

"In maize, analyses revealed a large reduction of parasitoids in Bt fields. This effect stemmed from the lepidopteran-specific maize hybrids, and examining the 116 observations showed that most were conducted on Macrocentrus grandii, a specialist parasitoid of the Bt-target, Ostrinia nubilalis. There was no significant effect on other parasitoids, but M. grandii abundance was severely reduced by Bt maize. Higher numbers of the generalist predator, Coleomegilla maculata, were associated with Bt maize but numbers of other common predatory genera (Orius, Geocoris, Hippodamia, Chrysoperla, were similar in Bt and non-Bt maize."

The conclusion is rather simple: Bt maize is better for the environment, and in almost all field studies the non-target insects, including a whole range of butterflies have a better survival chance than in non-Bt crop fields.
Fig. 22 The effect of Bt crops on non-target functional guilds compared to unsprayed, non-Bt control fields. Bars denote the 95% confidence intervals, asterisks denote significant heterogeneity in the observed effect sizes among the comparisons (*, 0.05, **, 0.01, ***, 0.001), and Arabic numbers indicate the number of observations included for each functional group.
doi:10.1371/journal.pone.0002118.g001. Fig. 1 from (Wolfenbarger et al., 2008)
Fig. 23 The effect of Bt crops on non-target functional guilds compared to insecticide-treated, non-Bt control fields. Bars denote the 95% confidence intervals, asterisks denote significant heterogeneity in the observed effect sizes among the studies (*,0.05, **,0.01, ***,0.001), and Arabic numbers indicate the number of observations included for each functional group. doi:10.1371/journal.pone.0002118.g002. Fig. 2 from (Wolfenbarger et al., 2008)

"In maize, the abundance of predators and members of the mixed functional guild were higher in Bt maize compared to insecticide-sprayed controls (Fig. 2b). Significant heterogeneity occurred in predators, indicating variation in the effects of Bt maize on this guild. For example, we detected no significant effect sizes for the common predator genera Coleomegilla, Hippodamia or Chrysoperla, but the predator Orius spp. and the parasitoid Macrocentrus were more abundant in Bt maize than in non-Bt maize plots treated with insecticides. Partitioning by taxonomic groupings or the target toxin (Lepidoptera versus Coleoptera) did not reduce heterogeneity within predators. However, insecticides differentially affected predator populations. Specifically, application of the pyrethroid insecticides lambda-cyhalothrin, cyfluthrin, and bifenthrin in non-Bt control fields resulted in comparatively fewer predators within these treated control plots. Omitting studies involving these pyrethroids revealed a much smaller and homogeneous effect size. Predator abundance in Bt fields was still significantly higher compared with insecticide-treated plots, but the difference was less marked without the pyrethroids (Fig. 3). Compared to the subset of controls using pyrethroids, Bt maize was particularly favorable to Orius spp."
Fig. 24 Effects of Bt maize vs. control fields treated with a pyrethroid insecticide on predatory arthropods. Bars denote the 95% confidence intervals, asterisks denote significant heterogeneity in the observed effect sizes among the studies (*, 0.05, **, 0.01, ***, 0.001), and Arabic numbers indicate the number of observations included for each functional group. doi:10.1371/journal.pone.0002118.g003. Fig. 3 from (Wolfenbarger et al., 2008)

“Bt-maize favored non-target herbivore populations relative to insecticide-treated controls, but there was also significant heterogeneity, some of which was explained by taxonomy. Aphididae were more abundant in insecticide sprayed fields and Cicadellidae occurred in higher abundance in the Bt maize. In contrast to patterns associated with predators and detritivores, type of insecticide did not explain the heterogeneity in herbivore responses. The pyrethroid-treated controls accounted for 85% of the herbivore records. Individual pyrethroids had variable effects on this group, and none yielded strong effects on the herbivores.

An underlying factor associated with the heterogeneity of the herbivore guild remained unidentified, but many possible factors were eliminated (e.g., Cry protein target, Cry protein, event, plot size, study duration, pesticide class, mechanism of pesticide delivery, sample method, and sample frequency).

An underlying factor associated with the heterogeneity of the herbivore guild remained unidentified, but many possible factors were eliminated.”
Fig. 25  Effect of Bt crops vs. insecticide-treated, non-Bt control fields on soil-inhabiting predators and detritivores. Bars denote the 95% confidence intervals, asterisks denote significant heterogeneity in the observed effect sizes among the studies (*, 0.05, **, 0.01, ***, 0.001), and Arabic numbers indicate the number of observations included for each functional group. doi:10.1371/journal.pone.0002118.g004. Fig. 4 from (Wolfenbarger et al., 2008)

“The “mixed” functional group was more abundant in Bt maize (E = 0.1860.14, n= 103) compared with non-Bt maize treated with insecticides. The majority of this functional group is comprised of carabids (n= 33), nitidulids (n= 26), and mites (n =23). For potatoes, the abundance of predators (E = 0.6960.30, n =38), but not herbivores, was significantly higher in the Bt crop (Fig 2c). Responses within each functional group were variable but sample sizes were too low to further partition this significant heterogeneity.

Predator-non target herbivore ratio analyses
No significant change in predator-prey ratios was detected in cotton or potato; in maize there was a significantly higher predator-prey ratio in Bt maize plots than in the insecticide controls (E = 0.6360.42, n= 15). Significant heterogeneity for the predator: prey response existed in all three crops, but again sample sizes were too small to explore the cause of this variability.

Predator-detritivore analyzes.
The higher abundance of detritivores in sprayed non-Bt maize appeared to be driven primarily by two families of Collembola with a high proportion of surface-active species (Entomobryidae: E=20.2460.15, n= 97; Sminthuridae: E=20.2860.23, n= 43, Fig 4). Three other families, Isotomidae, Hypogastruridae, and Onychiuridae, with more sub-surface species, were similar in Bt and non-Bt fields. We would expect surface-active collembolans to be more vulnerable to surface-active predators, and we detected a significantly lower abundance in one predator of Collembola (Carabidae: E= 0.2360.22, n= 43) but not in another (Staphylinidae: E=20.2160.23, n = 39, Fig 4). The other two detritivore families occupy different niches than Collembola and responded differently to insecticide treatments. The abundance of Japygidae (Diplura) was unchanged (E =20.1160.35, n= 9), but that for Lathridiidae (Coleoptera) was higher in Bt maize (E =0.7660.70, n =6), suggesting a direct negative effect of insecticides on this latter group. Lathridiid beetles, although being surface-active humusfeeders, are larger and more motile than Collembola and thus may be less vulnerable to predators and more vulnerable to insecticides.”
As a whole, the study of Wolfenbarger et al. et al. did not reveal any negative effects, confirming for a large amount of data and publications the environmental benefits of the Bt maize tested.

11. Biodiversity data in GM crops other than Bt resistance and Herbicide tolerance

Although one has to see that most commercialized GM crops are related to Bt resistance and herbicide tolerance, there are field data existing for not yet commercialized crops showing likewise positive results, a few examples of transgenic wheat are presented here:

In a study by (von Burg et al., 2011), hypothesizing that GM wheat could influence the quantitative food web of aphids, the results suggest that the effects are negligible and the potential effect on non-target insects is limited:

“In this study, (von Burg et al., 2011) looked at transgenic disease-resistant wheat (Triticum aestivum) and its effect on aphid–parasitoid food webs. They hypothesized that the GM of the wheat lines directly or indirectly affect aphids and that these effects cascade up to change the structure of the associated food webs. Over 2 years, they studied different experimental wheat lines under semi-field conditions. They constructed quantitative food webs to compare their properties on GM lines with the properties on corresponding non-transgenic controls. They found significant effects of the different wheat lines on insect community structure up to the fourth trophic level. However, the observed effects were inconsistent between study years and the variation between wheat varieties was as big as between GM plants and their controls. This suggests that the impact of our powdery mildew-resistant GM wheat plants on food web structure may be negligible and potential ecological effects on non-target insects limited.” (von Burg et al., 2011)

In a previous detailed laboratory study (von Burg et al., 2010) emphasized that studies of plant–insect interactions and their ecology are important to understand how these interactions shape insect herbivore communities. The use of transgenic plants opens up a whole range of new research questions, which are not necessarily questions about potential environmental risks of the novel plants (Raybould, 2010). In this study they wanted to find out if and how transgenic powdery mildew-resistant wheat affects the non-target aphid M. dirhodum and whether there are aphid clone x wheat lines (G x E) interactions. The research group could not detect any major effects of the transformed wheat line on a range of life-history parameters in this detailed laboratory study. This suggests that the genetic transformation did not alter the quality of the wheat plants as hosts for the aphid M. dirhodum.

In another study within the same research project (see www.wheat-cluster.ch) came to interesting conclusions, which might be related to epigenetic effects: Abstract:

“Background:
The introduction of transgenes into plants may cause unintended phenotypic effects which could have an impact on the plant itself and the environment. Little is published in the scientific literature about the interrelation of environmental factors and possible unintended effects in genetically modified (GM) plants.

Methods and Findings:
We studied transgenic bread wheat Triticum aestivum lines expressing the wheat Pm3b gene against the fungus powdery mildew Blumeria graminis f.sp. tritici. Four independent offspring pairs, each consisting of a GM line and its corresponding non-GM control line, were grown under different soil nutrient conditions and with and without fungicide treatment in the glasshouse. Furthermore, we performed a field experiment with a similar design to validate our glasshouse results. The transgene increased
the resistance to powdery mildew in all environments. However, GM plants reacted sensitive to fungicide spraying in the glasshouse. Without fungicide treatment, in the glasshouse GM lines had increased vegetative biomass and seed number and a twofold yield compared with control lines. In the field these results were reversed. Fertilization generally increased GM/control differences in the glasshouse but not in the field. Two of four GM lines showed up to 56% yield reduction and a 40-fold increase of infection with ergot disease Claviceps purpurea compared with their control lines in the field experiment; one GM line was very similar to its control.

Conclusions:

Our results demonstrate that, depending on the insertion event, a particular transgene can have large effects on the entire phenotype of a plant and that these effects can sometimes be reversed when plants are moved from the glasshouse to the field. However, it remains unclear which mechanisms underlie these effects and how they may affect concepts in molecular plant breeding and plant evolutionary ecology.” (Zeller et al., 2010)

Comment: It is normal, that breeding effects, whether with traditional methods or molecular methods, show differences in reproduction, greenhouse and field performance, this is known by professional breeders and is usually subject to careful selection processes. It is also normal, that many of those effects are unknown in their origin, and the rule is that molecular breeding yields more clarity than conventional methods (Muurinen et al., 2006).

12. Bt corn has less cancer causing mycotoxins than conventional corn

Bt corn is definitely healthier: Many publications have demonstrated that Bt maize has less mycotoxins with their bad reputation of cancerogeneity.

In a worldwide review, (Placinta et al., 1999) summarized the situation on mycotoxins in animal feed (including a comprehensive list of literature).

“Three classes of Fusarium mycotoxins may be considered to be of particular importance in animal health and productivity. Within the trichothecene group, deoxynivalenol (DON) is widely associated with feed rejection in pigs, while T-2 toxin can precipitate reproductive disturbances in sows. Another group comprising zearalenone (ZEN) and its derivatives is endowed with oestrogenic properties. The third category includes the fumonisins which have been linked with specific toxicity syndromes such as equine leukoencephalomalacia (ELEM) and porcine pulmonary oedema.”

It is important to know that storage conditions are heavily influencing the fumonisin content of the maize cobs, as was shown by (Fandohan et al., 2003; Gressel et al., 2004; Olakojo & Akinlosotu, 2004) in Africa: the storage conditions are often poor and foster fungal infection dramatically, also due to post-harvest weevils.

It seems logical to fight fumonisin producing fungi with fungicides, but this is obviously not an easy task according to (D’Mello et al., 1998; D’Mello et al., 2001; D’Mello et al., 1999). There are no feasible solutions ready – except the ones offered by the Bt crops. Also the use of fungicide sprays does not really bring considerable remedy. It is interesting to note that D’Mello deems most promising to develop Fusarium resistant crops, in order to avoid the clearly detrimental effects of pigs reacting on high fumonisin levels in feed.
Many studies in epidemiological human medicine have proven the clear pathogenicity of fumonisins: Here the important critical review of many pertinent papers: (Marasas et al., 2004). They found and cite numerous studies which demonstrate that fumonisins are potential risk factors for neural tube defects, craniofacial anomalies, and other birth defects arising from neural crest cells because of their apparent interference with folate utilization.

13. Some closing words:
Agriculture is in the centre of this text, and rightly so, since we have the urgent task to feed a billion hungry people, and there is no time for sterile sophisticated bickering on whether some hypothetical negative effects could emerge decades from now, since by then, hundreds of millions of people will die from hunger and diseases. The case of the golden rice is symbolic for the situation of mankind: we can develop it as fast as we can, unhampered by over-regulation – or we may tolerate hundreds of thousands of children dying every year from pro-vitamin A deficiency. It is no coincidence that this article closes with some references essential for the Golden Rice debate (Depee et al., 1995; Humphrey et al., 1998; Humphrey et al., 1992; Mayer et al., 2008; Miller, 2009; Potrykus, 2003; Stein et al., 2008). Actually the solution would be extremely simple and its unconditional support would honor all institutions of the United Nations, including the Convention of Biodiversity which has created the Cartagena Protocol on Biosafety.

Human beings should be part of any risk assessment in technology: this is a request with enormous ethical implications.

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