# The Effects of Agricultural Practices on Biodiversity

The wide range of plant and animal species that live on the planet – referred to as biodiversity – is now being threatened by intensive agriculture. A growing human population, however, also entails growing needs, which, in turn, requires current agricultural practices to maximize the use of available land while minimizing damage to the environment and biodiversity.

Genetically modified (GM) crops bring much promise as much as they carry many questions. Are they safe? Will they be able to answer for humankind's most pressing agricultural needs?

Following is a condensed version of a review written by Ammann (2004), entitled "The Impact of Agricultural Biotechnology on Biodiversity," which may be downloaded in full at http://www.botanischergarten.ch/Biotech-Biodiv/Report-Biodiv-Biotech12.pdf. In his review, Ammann attempts to answer the questions raised on genetically modified organisms and their effects on the environment.

***Biodiversity and its distribution***

Biodiversity refers to diversity in a gene, species, community, or ecosystem. It comprises all living beings, from the most primitive forms of viruses to the most sophisticated and highly evolved animals and plants.

At its lowest level, biodiversity can depend on the sequences of genes in living organisms. Genes are composed of stretches of DNA, and these sequences, along with the proteins encoded by the genes, are almost identical to their counterparts in other species. Thus, they are said to be highly conserved across species, and such commonalities (or even differences) are referred to as genetic diversity. The importance of genetic diversity is noted in the combination of genes within an organism (the genome), the variability in the proteins or traits (phenotype) that they produce, and their resilience and survival under selection.

A species could broadly be defined as a collection of populations that may differ genetically from one another to a greater or lesser degree, but whose individuals are able to mate and produce offspring. Species are the most useful units for biodiversity research, and species diversity is the most useful indicator of biodiversity. Today, about 1.75 million species have been described and named, but the majority remains unknown.

The highest level of organization is the ecosystem, which may be classified into natural ecosystems, composed of native organisms; semi-natural ecosystems, in which human activity is limited and the ecosystem is subject to some level of low intensity human disturbance; and "managed ecosystems", where human control is fully exercised, and where management takes on 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. Ecosystem diversity is likewise the highest organization by which biodiversity may be measured.

Biological diversity has emerged in the past decade as a key area of concern for sustainable development. It 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. Generally, it is assumed that higher biodiversity results in higher productivity for biomass

In the tropics, where the climate is warmer, wetter, and less seasonal, biodiversity is richer, compared to temperate and polar regions. Latin America, the Caribbean, Asia and the Pacific together host 80% of the ecological mega-diversity of the world. Consequently, biodiversity is, to a large degree, influenced by man, as changes in agrobiological management will influence biodiversity in such countries overall.

## ***Threats to global biodiversity***

Loss of biodiversity is occurring 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. According to the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA, 2003), habitat loss is the greatest, most serious of all threats to biodiversity. Habitat loss due to the expansion of human activities, including urbanization and the increase in cultivated land surfaces, is identified as a main threat to 85% of all species described in the IUCN Red List (IUCN, 2000).

The introduction of non-native species and genetic stock is a major threat to biodiversity. There are thousands of new and foreign genes introduced with trees, shrubs, herbs, microbes, and higher and lower animals each year (Sukopp & Sukopp, 1993). Many of these new species survive and, after many years of adaptation, become invasive (Starfinger et al., 1998).

Genetic diversity among agricultural crops has also declined rapidly due to the introduction of new commercial varieties. Reported losses of over 80% of varieties in species such as apple, maize, tomato, wheat and cabbage have occurred worldwide (UNEP World Conservation Monitoring Centre, 2003

Agriculture and other development activities have led to an overall decline of approximately 2% in the world's forests and woodlands, between 1980 and 1990. In the developing regions, natural forest cover declined by 8% (UNEP, 1997). Agricultural practices also influence terrestrial and aquatic biodiversity within and around agricultural fields (Tilman, 1999; Tilman et al., 2002). Fertilizers, pest control chemicals, tillage and even crop rotation have an impact on the biodiversity of agricultural ecosystems (Beringer, 2000; Ross et al., 2002).

## ***Agricultural Practices***

World food production almost doubled in the thirty-five years from 1961-1996 (Tilman, 1999; Tilman et al., 2002), with only a 1.1 fold increase in cultivated lands. This was made possible due to the use of fertilizers and pest control compounds, implementation of specific agricultural practices, shifts to higher yielding varieties, and adoption of new technologies.

Despite these advances, the productivity of crop plants is still challenged by abiotic and biotic stresses. Abiotic stresses include nutrient deficiencies, water challenges, temperature extremes, and soil acidity, alkalinity, and salinity. Biotic stresses include weeds, insects, and plant pathogens such as fungi, viruses, and bacteria. Weeds cause 10-13% loss in terms of world food supply, insects 13-16%, and pathogens 12-13%. Without pesticides or other pest control measures, it has been estimated that the losses would increase to 70%, with an economic loss of $400 billion USD per year (Oerke & Dehne, 1997).

Two common pest control practices include crop rotation and tillage. Crop rotation, or using one field to plant different crops from one harvest to the next, is an effective practice, since some pests rely on specific crops as host. A study in Canada indicates a decrease in nitrate fertilizer requirement and 22% higher wheat yield after 8 years in the second rotation cycle under no tillage conditions, as compared to conventional tillage (Soon & Clayton, 2002).

Tillage practices, on the other hand, can cause soil erosion, reduce soil quality, and disrupt biodiversity. The introduction of herbicides, or of herbicide-tolerant crops, can reduce the dependence of farmers on tillage. In the US, 80% of growers are making fewer tillage passes and 75% are leaving more crop residue (Cotton Council, 2003). Under no-tillage crop production, the soil remains relatively undisturbed and plant litter decomposes at the soil surface, much like in natural soil ecosystems.

## ***Genetically Modified (GM) Crops***

One method to both study plants in greater detail as well as to produce new varieties of plants is through the use of its genetic material, or DNA. For instance, in taxonomy and conservation, scientists may use molecular markers to identify species, in the same way that forensic medicine is used to identify criminals. In seed banks and conservation projects, genetic fingerprints are used to establish the origin of a seed or the relatedness of one plant variety to another.

A plant's genetic material may also be beneficial for breeding new varieties. Using conventional methods, plant varieties with desirable traits (such as resistance to an infectious plant disease, or to herbicide treatment) can be crossed, and, by analyzing a few cells of the newly sprouted plant, one can predict some of the expected properties of the progeny by looking at the presence or absence of certain genes.

Modern methods involve directly manipulating the plant's genetic material, thus allowing scientists greater control over the plants produced. In a process called genetic engineering, a gene is transferred from one organism to another, so that the recipient produces a protein normally made only in the donor. The recipient of the new gene is called a Genetically Modified Organism (GMO), and crops produced by such a process are commonly called GM Crops.

GM Crops have been available on the market for some time. Clive James from ISAAA compiled information on the total number of hectares per country planted with GM crops (Table 1). Other countries not included in the list are South Africa, India, Spain, Mexico, Indonesia, Honduras, Australia, Romania, Uruguay, Bulgaria, Colombia, Germany, and the Philippines, all of which planted less than 1 million hectares of GM crops in 2003.

**Table 1. Global status of biotech crops in 2003 (James, 2004)**

| Country | Hectares (million) |
|---|---|
| USA | 42.8 |
| Argentina | 13.9 |
| Canada | 4.4 |
| Brazil | 3.0 |
| China | 2.8 |

Table 2 presents the total hectares planted in 2003 per GM crop. Herbicide tolerance has consistently been the dominant trait, followed by insect resistance. In 2003, herbicide tolerance was deployed in soybean, corn, cotton, and canola, and occupied 73%, or 44.2 million hectares of the global 67.7 million hectares. Herbicide tolerant soybean was the single biggest trait/crop with 41.4 million hectares.

Insect protected crops were offered in maize and cotton, and covered 12.2 million hectares of the global transgenic area in 2003. Bt maize covered 7.7 million of those hectares. Stacked gene combinations, with both herbicide tolerance and insect protected traits in the same product, were offered in both cotton and maize, and occupied 5.8 million hectares in 2003. A small amount of squash and papaya with virus resistance was also grown in 2003.

**Table 2. GM Crops grown globally in 2003**

| Crops | Hectares (million) |
|---|---|
| Soybean | 41.4 |
| Maize | 15.5 |
| Cotton | 7.2 |
| Canola | 3.6 |

There are hundreds of crops and traits still being tested in laboratory and field experiments. (Agbios Database, 2003).

## ***The Impact of Agricultural Practices on Biodiversity***

Modern agricultural practices, including tillage and the intensive use of conventional insecticides, have been broadly linked to declines in biodiversity in agro-ecosystems.

The very act of putting land to agricultural use limits gene flow among populations and fragments habitats available to any particular species. Where individuals of an animal species are unable to move through agricultural fields, populations will become more isolated, further reducing effective population sizes and threatening the viability of these populations. (Hanski, 2002)

Tillage leads to frequent disturbances of the agricultural landscape, increases energy loss from agricultural fields, and increases problems of soil erosion and run-off from agricultural fields. When (Witmer et al., 2003) studied corn, soybean, and wheat cropping systems in the Mid- Atlantic region of the United States, they found that ground dwelling and foliage-dwelling beneficial arthropods were least abundant, and pests were most abundant, in the simplest, most intensively managed continuous corn system. This suggests that shifts toward conservation tillage and no-till will benefit agricultural biodiversity.

The intensive use of conventional insecticides generally reduces diversity through direct toxic effects. Many of the widely used classes of conventional insecticides, including organophosphates and pyrethroids, have been shown to adversely affect a broad range of non-target species, including species of economic importance. Local extinctions are common where these insecticides are frequently used. Such insecticides have been shown to eliminate important predator and parasitoid species from agricultural systems. (Pimentel et al., 1993)

To lessen the need for both methods would require plants which are tolerant to herbicides, or which contain their own protective mechanisms – both of which have now been achieved through genetic modification. Pesticide resistance is managed by insertion of the Bt (*Bacillus thuringiensis*) toxin gene, which is normally produced by a soil bacterium. Unlike the bacterium, which produces the toxin in a precursor form, Bt corn contains an inserted truncated cry1Ab gene that encodes the active toxin. The toxins do not appear to have any consistent effects on organisms in soil (earthworms, nematodes, protozoa, bacteria, fungi) or on microorganisms *in vitro* (Koskella, 2002; Saxena et al., 1999; Saxena & Stotzky, 2001).

## ***The Impact of GM Crops on Biodiversity***

The use of herbicide tolerant or self-protecting Bt GM crops can positively impact agricultural species biodiversity, as these crops allow the management of weeds and insect pests in a more specific way than chemical herbicides and pesticides. In particular, the adoption of insect resistant Bt crops, expressing highly specific Bt proteins, represents an opportunity to replace broad-spectrum insecticide use. Large numbers of field studies have been conducted to compare fields of Bt crops and conventional crops in terms of species abundance. Species diversity in Bt cornfields (Lozzia et al., 1999; Lozzia, 1999; Dively & Rose, 2002) did not significantly differ with that in untreated, conventional cornfields. The same is true with Bt cotton fields (Fitt & Wilson, 2003; Naranjo & Ellsworth, 2002; Naranjo et al., 2002; Xia et al., 1999). However, the target pests and their specific parasites were significantly less in Bt crop fields compared to conventional fields. Studies have also shown that in conventional fields that are sprayed with pesticides, many non-target species are adversely impacted (Candolfi et al., 2003; Candolfi et al., 2004; Dively & Rose, 2002; Fitt & Wilson, 2003; Head et al., 2001; Naranjo et al., 2002; Xia et al., 1999).

In addition, herbicide tolerant crops permit greater flexibility in herbicide application practices, particularly the timing of applications. Herbicide tolerant crops can also encourage herbicide application practices that benefit wildlife. For example, studies on herbicide tolerant sugar beet in the UK and Denmark have shown that leaving weeds untreated in the agricultural field for a longer period allows arthropod populations to increase to higher levels than are seen in conventional fields, without affecting crop yield (Dewar et al., 2002).

GM crops can replace agricultural practices that would otherwise depress and disrupt species biodiversity, and can encourage or complement other practices that enhance biodiversity, such as the selective use of mixed cropping (Zhu et al., 2000a; Zhu et al., 2000b) or organic or integrated farm management strategies. There is basically no scientifically plausible reason to keep GM crop and organic/integrated farmer practices strictly apart.

With the introduction of GM crops, concern has been expressed that overall genetic diversity within crop species will decrease because breeding programs will concentrate on a smaller population of high value cultivars. However, genetic uniformity among cotton (Bowman et al., 2003) and soybean varieties (Sneller, 2003) has not changed significantly with the introduction of transgenic crops.

## ***Conclusions***

Habitat loss and fragmentation due to modern intensive farming represent the greatest threats to natural genetic diversity. Practices that increase the productivity of existing agricultural lands will help to limit these effects (UNDP, 2001). Biotechnology can be a valuable tool for introducing GM crops, which produce higher yield, increase the productivity of agricultural lands, and lessen the need for herbicides and pesticides, thereby preserving biodiversity. The introduction of GM crops varieties does not represent any greater risk to crop genetic diversity than the breeding programs associated with conventional agriculture.

## ***References***

The full list of references to the review by Ammann can be found on the latter pages of the review itself, which may be downloaded in full at http://www.botanischergarten.ch/Biotech-Biodiv/Report-Biodiv-Biotech12.pdf. The report is structured with contents and an index, list of figures, and contains numerous direct links to the Internet. Listed below are those mentioned in this document.

**Benton, T.G., Bryant, D.M., Cole, L., & Crick, H.Q.P. (2002)**
Linking agricultural practices to insect and bird populations: a historical study over three decades. Journal of Applied Ecology, 39, 673-687

**Beringer, J.E. (2000)**
Releasing genetically modified organisms: will any harm outweigh any advantage? Journal of Applied Ecology, 37, 207-214

**Boutin, C. & Jobin, B (1998)**
Intensity of agriculture practices and effects on adjacent habitats. Ecological Applications, 8, 544-557

**Bowman, D.T., May, O.L., & Creech, J.B. (2003)**
Genetic uniformity of the US upland cotton crop since the introduction of transgenic cottons. Crop Science, 43, 515-518

**Candolfi, M., Brown, K., Reber, B., & Schmidli, H. (2003)**
A faunistic approach to assess potential side-effects of genetically modified Bt-corn on non-target arthropods under field conditions, Biocontrol Science and Technology, in press

**Candolfi, M., Brown, K., Grimm, C., Reber, B., & Schmidli, H. (2003)**
A faunistic approach to assess potential side-effects of genetically modified Bt-corn on non-target arthropods under field conditions, Biocontrol Science and Technology, 14, 129-170

**CBD (1992)**
Convention on Biological Diversity, accessed: 2003, United Nations

**Cotton Council (2003)**
National Cotton Council of America, accessed: 2003, Cotton Council

**Dewar, A., May, M., & Woiwod IP. Lisa A. Haylock, G.T.C., Beulah H. Garner, Richard J. Sands, Aiming Qi and John D. Pidgeon (2002)**
A novel approach to the use of genetically modified herbicide tolerant crops for environmental benefit. Proceedings of the Royal Society UK, Febr. 11. 2002

**Dively, G.P. & Rose, R. (2002)**
Effects of Bt transgenic and conventional insecticide control on the non-target invertebrate community in sweet corn, Amherst, MA. U.S. Forest Service, In Proceedings of the First International Symposium of Biological Control of Arthropods

**Donald, P.F., Evans, A.D., Muirhead, L.B., Buckingham, D.L., Kirby, W.B., & Schmitt, S.I.A. (2002a)**
Survival rates, causes of failure and productivity of Skylark Aluda arvensis nests on lowland farmland. Ibis, 144, 652-664

**Donald, P.F., Pisano, G., Rayment, M.D., & pain, D.J. (2002b)**
The Common Agriculture Policy, EU enlargement and the conservation of Europe's farmland birds. Agriculture Ecosystems & Environment, 89, 167-182

**Duelli, P., Obrist, M.K., & Schmatz, D.R. (1999)**
Biodiversity evaluation in agricultural landscapes: above-ground insects. Agriculture Ecosystems & Environment, 74, 33-64

**Fitt, G. & Wilson, L. (2003)**
Non-Target Effects of Bt Cotton: A Case Study from Australia, Canberra CSIRO Entomology, Biotechnology of Bacillus thuringiensis and Its Environmental impact (eds R. Akhurst, C. Beard & P.A.E. Hughes)

**Gianessi, L., C, S., Sankula, S., & Carpenter, J. (2002)**
Plant Biotehcnology: Current and Potential Impact for Improving Pest Management in US Agriculture, An Analysis of 40 Case Studies, accessed: 2003

**Head, G., Brown, C.R., Groth, M.E., & Duan, J.J. (2001)**
Cry1Ab protein levels in phytophagaous insects feeding on transgenic corn: implications for secondary exposure risk assessment. Entomologia Experiments Et Applicata, 99, 37-45

**Lozzia, G., Furlanis, C., manachini, B., & Rigamonti, I. (1999)**
Effects of Bt corn on Rhodopalosiphum padi (Rhynchota Aphidiae) and its predator Chrysoperla carnea Stephen (Neuroptera Chrysopidae). Boll. Zool. Agr. Bachic. Ser. II, 31, 37-58

**Lozzia, G.C. (1999)**
Biodiversity and structure of ground beetle assemblages (Coleopterae, Carabidae) in Bt corn and its effect on non target insects. Boll. Zool. Agr. Bachic. Ser. II, 31, 37-58

**Naranjo, S.E. & Ellsworth, P.C. (2002)**
Arthropod communities and transgenic cotton in the Western United States: Implications for biological control., Amherst MA, USA U.S Forest Service, First International Symposium of Biological Control Arthropods

**Naranjo, S.E., Ellsworth, P.C., Chu, C.C., & Henneberry, T.J. (2002)**
Conservation of predatory arthropods in cotton: Role of action thresholds for Bemisia tabaci (Homoptera: Aleyrodidae). Journal of Economic Entomology, 95, 682-691

**Oerke, E.C. (2002)**
Global crop production and the efficacy of crop protection – Current situation and future trends. European Journal of Plant Pathology, 103, 203-215

**Ross, K.A., Fox, B.J., & Fox, M.D. (2002)**
Changes to plant species richness in forest fragments: fragment age, disturbance and fire history may be as important as area. J. Biogeography, 29, 749-765

**SBBTTA (2003)**
Subsidiary Body on Scientific Technical and Technological Advice: Introduction, accessed: 2003, Convention of the Biological Diversity

**Soon, Y.K. & Clayton, G.W. (2002)**
Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can. J. Soil Sci., 82, 165-172

**Starfinger, U., Edwards, K., Kowarik, I., & Williamson, M. (1998)**
Plant Invasions, Ecology and Human Response Backhuys, Leiden, 362

**Sukopp, H. & Sukopp, U. (1993)**
Ecological Long-term Effects of Cultigens Becoming Feral and Naturalization of Nonnative Species. Experientia, 49, 210-218

**Tilman, D. (1999)**
Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the United States of America, 96, 5995-6000

**Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., & Polasky, S. (2002)**
Agricultural sustainability and intensive production practices. Nature, 418, 671-677

**UNEP (1997)**
Global State of the Environment Report, Executive Summary

**UNEP World Conservation Monitoring Centre (2003)**
Conservation Databases, accessed: 2003

**Xia, J., Cui, J., Ma, L., Dong, S., & Cu, X. (1999)**
The role of transgenic cotton in integratede pest management. Acta Gossypii Sinica, 11, 57-64