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Insect-plant interactions, genetically modified crops and integrated pest management: what does the future hold?

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Insect-plant interactions, genetically modified crops and integrated pest management: what does the future hold?

The African Food Crisis

At the time of independence, most of sub-Saharan Africa was self-sufficient in food. In less than 40 years, the sub-continent went from being a net-exporter of basic food staples to reliance on imports and food aid (Djurfield *et al.*, 2006a,b).

In 1966-1970, for example, net exports averaged 1.3 million tons/year, three quarters of which were non-cereals. By the late 1970's, sub-Saharan Africa imported 4.4 million tons of staple food per year, a figure that had risen to 10 million tons per year by die mid-1980's (Djurfield, 2006). Cereal imports increased from 2.5 million tons per year in the mid-1960's to more than 15 million tons in 2000 and 2001. Since independence, agricultural output per capita remained stagnant and, in many places, declined. Africa is the only continent where cereal production per capita was less in 2001 than in 1961 (Fig. 1). Notwithstanding the seriousness of the situation, it should also be noted that after independence sub-Saharan Africa faced the highest rate of population growth over the last decades, but growth in food production did not follow this tendency (Djurfield, 2006).

The stagnating or decreasing per capita production of cereals in Africa over the last 40 years is in great contrast to the development in East and South-east Asia, where per capita production increased during this period (Fig. 1). Comparing the first and last 5-year annual averages during the entire period, 1961-2001, per capita output in Asia increased by 24% while it decreased by 13% in sub-Saharan Africa.

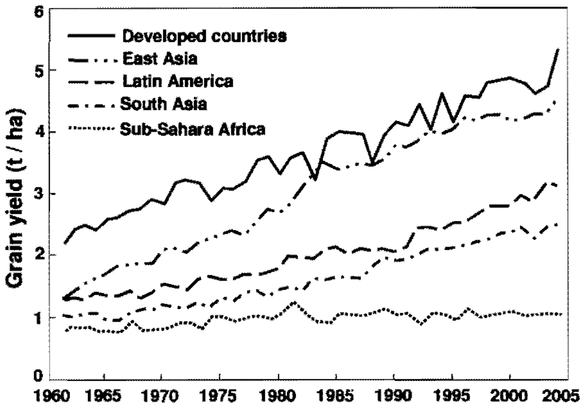

Figure 1. Per capita production of cereals in different regions of the world (Djurfield, 2006).

Insects contribute significantly to yield losses observed in all major food and fibre crops produced in the world (Table 1)(Oerke, 2006). In the case of maize, although yield potential increased over the last three decades yield losses due to biotic stresses remained largely the same.

Table 1. Estimates of actual crop losses due to weeds, animal pests, and diseases in world wide production of wheat, maize and cotton for the years 1964/65, 1988-90 and 2001 – 03 (from Oerke, 2006).

		Actual loss (%)			
Period	**Yield (kg/ha)**	**Weeds**	**Animal pests***	**Diseases**	**Total**
Wheat					
1964/65	1250	9.8	5.0	9.1	23.9
1988-90	2409	12.3	9.3	12.4	34.0
2001-03	2691	7.7	7.9	12.6	28.2
Maize					
1964/65	2010	13.0	12.4	9.4	34.8
1988-90	3467	13.1	14.5	10.8	38.3
2001-03	4380	10.5	9.6	11.2	31.2
Cotton					
1964/65	1029	4.5	11.0	9.1	24.6
1988-90	1583	11.8	15.4	10.5	37.7
2001-03	1702	8.6	12.3	7.9	28.8

* includes insect pests

The Green Revolution

Based on low crop yields indicating little or no increase in yields in Africa since the beginning of the Green Revolution (Djurfield *et al.*, 2006a), the question can be asked: Did Africa miss the Green Revolution? The poor adoption rates of new crop cultivars and very low use of fertilizers in Africa add to the relevance to the statement that the Green Revolution did not have any effect in Africa.

The Green Revolution is a much misunderstood and maligned process (Djurfield *et al.*, 2006b), so much slandered that the term itself may have grown largely worthless. Misplaced assumptions have marred the discussion of an African Green Revolution or the Green Revolution and the discussion easily turns into debate about transferability of technology. In Asia the Green Revolution had huge impact. Given the radically different agro-ecological conditions, the answer is given: Asian technologies, on the whole, are not transferable to Africa. Inter alia, this is because the potential for irrigation in sub-Saharan Africa is much lower that that in Asia, resulting in rice being a much less dominant crop in Africa. African Green Revolutions should build on another crop-mix and therefore also on other technologies. Such technologies do exist and have previously been researched in terms of pest management. *This aspect forms the crux of this presentation and will be addressed in detail later on.*

As is well-known, the Asian Green Revolution was based on break throughs in crop breeding, achieved, first for wheat in Mexico by a team led by Borlaug, and later for rice by the International Rice Research Institute (IRRI) in the Philippines, and even earlier in China (Djurfield, 2006).

Extensive agriculture

The above résumé gives at hand that intensification of (food) agriculture 'ought' to take place in contemporary sub-Saharan Africa. Most critics, however, seem convinced that it does not. Apparently, extensive agriculture dominates, as it seems always to have done. And, apart from some sporadic and short-lived outbursts, the Green Revolution is said 'never to have happened' here. Instead, it is commonly argued that yield growth has been of minor importance and that growth of agricultural production has been almost entirely based on extending the area under cultivation (Holmen, 2006). At the same time sub-Saharan Africa is deemed to have a 'vast agricultural potential (Holmen, 2006), which, apparently, is not being made use of.

Potential for agricultural intensification and a Green Revolution in sub-Saharan Africa

Several strategies have been proposed to realize a new 'Green Revolution' in Africa. The importance of pest management and other newly available technologies in attaining higher crop yields in Africa have been indicated by Gressel *et al.* (2004) and Van Huis and Meerman (1997), but these have not found their way to the farm-level. Insect pests contribute to poor crop production in the Southern African Development Community (SADC) region (Anonymous, 1997).

Pest management strategies that have found their way to farm-level include the "push-pull" system (Cook *et al.*, 2007) and, to a very small degree, genetically modified (GM) cotton and maize in South Africa (Gouse *et al.*, 2005; Gouse *et al.*, 2006; Kirsten & Gouse, 2003; Morse *et al.*, 2005). *The push-pull system as well as genetically modified crops form the basis of the rest of this document which discusses its role in integrated pest management as well as criticisms for and against GM crops.*

Integrated pest management

With reference to integrated pest management, Africa is rich in examples of localized successes (Gatsby, 2004; Khan *et al.*, 2000) and sometimes interesting questionable technologies (Van den Oever and Segeren, 1997). The latter authors reported the following interesting local strategy to control stem borers in maize: To control maize stem borers, women from the village gather at the field, take off their clothes and run through field naked, shouting insults at people; this event is followed by a meal.

The Push-pull system of pest management

A novel pest management strategy developed by Khan *et al.* (2000) is used to control the most important pests of maize (lepidopterous stem borers) as well as to improve soil and general crop health.

It is generally accepted that vegetative diversification in some crop systems can lead to lower pest populations and crop damage, thereby enhancing yields (Andow, 1991). Vandermeer (1989) proposed the 'disruptive crop' hypothesis to explain how vegetative diversity can affect herbivore populations, similar to Root's (1973) 'resource concentration' hypothesis. It stipulates that a second plant species disrupts the ability of an insect to effectively attack its preferred host either by some sort of confusion (physical or chemical) or due to frequent encounters with non-host plant species. Under this hypothesis, stimuli that either elicit or inhibit reactions can be used to disrupt behaviour of the insect pest. In practice, stimulant and deterrent chemicals have been used for this purpose (Foster & Harris 1997), either singly or in combination, with the latter yielding a complementary hypothesis, the 'stimulo-deterrent' ('push-pull') hypothesis (Khan *et al.*, 2000).

In an attempt to exploit the 'stimulo-deterrent' hypothesis, the International Centre of Insect Physiology and Ecology (ICIPE) (Kenya) and its partners have developed a habitat management strategy by use of selected gramineous and fodder plants that provide a diversionary strategy for maize stemborers. It involves use of repellent ('push') plants such as molasses grass, *Mellinis minutiflora* Beauv. and desmodium, *Desmodium uncinatum* (Jacq.), as intercrops between rows of the main crop (maize) and a trap crop ('pull') surrounding the plot ('push-pull' strategy). The latter comprise a number of wild hosts, including Napier grass, *Pennisetum purpureum* Schumach, which are considerably more attractive to gravid female stemborer moths than the main crop (Rebe *et al.*, 2004). Studies in western Kenya showed that intercropping maize with non-host *M. minutiflora* significantly decreased levels of infestation by *C. partellus* in the main crop (maize) and also increased its larval parasitism by *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) (Khan *et al.*, 1997). Use of sudan grass, *Sorghum* *vulgare sudanense* (Pers.), as a trap crop led to attraction of stemborers leading to lower pest populations in the main crop (Khan *et al.,* 1997). Similarly, use of *P. purpureum* as a trap crop and *D. uncinatum* as an intercrop in a 'push-pull' system resulted in a significantly lower maize stemborer population and damage than a maize monocrop system in the same region (Khan *et al.*, 1997, 2001).

While the push-pull system as well as many other cultural control strategies largely take care of a more complete livelihood in rural areas and contribute to sustainable livelihoods, GM crops are often in the cross fire that it does the opposite. The push-pull system is often advanced as the alternative to GM maize for the management of stem borers in Africa.

Genetically modified maize

Scientists recognize the benefits of GM crops but also note that releases into the environment could have adverse impacts under some circumstances and therefore urge continued science-based assessment of benefits and risks. In this discussion, reference is only made to Bt maize with insecticidal properties.

Advantages of Bt maize

GM crops have advantages but also disadvantages like any other pest management technology. The most important advantage of GM crops is the reduction in the use of insecticides. The reduction in the number of insecticide applications result in economic benefits to farmers (Cannon, 2000; Meeusen & Warren, 1989; Nottingham, 2002) and is also beneficial to the environment. Because of biodiversity loss and killing of many beneficial insects due to widespread application of broad-spectrum insecticides, one solution is to replace insecticides with a transgenic crop that is more target specific (Musser & Shelton, 2003). Target pest resurgence is an effect often observed after insecticide applications, which can have a substantial and deleterious impact on the natural enemy complex (Armenta *et al.*, 2003; Deedat, 1994; Eckert *et al.*, 2006).

The first and most important disadvantage that a GM crop may have is the non-target effect on the environment. Transgenic crops are not inherently dangerous; they only present problems where the new traits, or combinations of traits, made possible by modern gene technology produce unwanted effects in the environment. Different genetically engineered crops will present different problems depending on the new genes they contain, the characteristics of the parent crop, and the region (environment) in which they are grown (Rissler & Mellon, 2000). These findings open a whole new dimension on the unexpected impacts of transgenic crops on non-target organisms that play key and many times unknown roles in the ecosystem (Altieri, 2004).

Non-target effects of Bt maize

Ecological interactions are complex, and adverse environmental impacts can be felt along food chains and throughout ecosystems (Nottingham, 2002). Because the crops and genes are so numerous and varied, identifying and categorizing potential risks of transgenic crops remains a challenge (Rissler & Mellon, 2000). The push for "monoculture crop" uniformity will not only destroy the diversity of genetic resources, but also disrupt the biological complexity that underlies the sustainability of indigenous farming systems. There are many unanswered ecological questions regarding the impact of releasing transgenic plants and micro-organisms into the environment (Altieri, 2004).

There are three main concerns regarding the use of *Bt* maize: 1) using *Bt* maize may increase the target insects' resistance to the Cry proteins, 2) the transgenes may infect wild populations, and 3) there may be negative effects on non-target organisms (Obrycki *et al.*, 2001; Head *et al.*, 2002).

However, of the three main concerns regarding transgenic *Bt* crops, possibly the largest and the most investigated is the effect of *B. thuringiensis* Cry toxins on non-target organisms, but most studies have failed to prove any significant negative effects (Escher *et al.*, 2000; Bourget *et al.*, 2002;

Baumgarte & Tebbe, 2005; Romeis *et al.*, 2008), including studies involving earthworms (Saxena & Stotzky 2001, Clark & Coats 2006, Ahmad *et al.*, 2006).

Another potential disadvantage is that biotechnology is being pursued to repair the problems caused by previous agrochemical technologies. Based on the fact that more than 500 species of pests have already evolved resistance to conventional insecticides, surely pests can also evolve resistance to Bt toxins in transgenic crops (Altieri, 2004). This was confirmed by the first report of field resistance by the stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) to Bt maize in the Christiana region of South Africa (Van Rensburg, 2007).

Ecological risk should be assessed before GMOs are released into the environment. To say whether there are risks, ecologists need to make comparisons of scenarios with and without a GM crop, or before and after the introduction of a GM crop. This comparison with the existing situation is particularly important in agricultural ecosystems, as modern farming methods have already had a large impact on biodiversity. However, manipulation experiments of this type are few and far between. Most of the experiments of this type are laboratory-based or small-scale field studies where no ecological data has been collected. Nevertheless, owed to current research a larger picture is starting to emerge, from which a framework for assessing risk can be developed. Although the risks in many cases are relatively small, there is potential for a wide range of direct and indirect ecological effects that could result from release of GM crops. Identifying ecological risks at an early stage is therefore important (Nottingham, 2002).

Resistance to adoption of GM crops in Africa

Crops can be genetically engineered to improve appearance, taste, nutritional quality, drought tolerance as well as insect and disease resistance. GM crops are therefore often proposed as the solution to yield deficits.

In Africa, the use of GMO technology and its products is still in its infancy. South Africa is the only African country that is producing GM crops commercially. However, Egypt is approaching commercialization of four GM crops *i.e.* yellow and white maize, potatoes, squash and cotton. In Burkina Faso, Bt cotton is planted while talks on the release of Bt maize has been on going in Kenya since approximately 2003.

There is, however, growing debate about the potential value of GM crops in helping to achieve Africa's development and food security goals. The challenge facing policymakers is not only to understand what the technology can do, or has done elsewhere, but also to establish what opportunities it presents to Africa.

There are three critical issues: 1) whether or not genetically modified organisms offer a sustainable food security option, 2) what the implications are of transgenic technologies for biosafety as well as for human health, and 3) the extent of existing African capacity to undertake research, and effectively monitor and evaluate genetically modified products and their use.

However, achieving food security is about more than just fulfilling yield deficits. Food security is having sufficient physical, social and economic access to safe, nutritious and culturally acceptable food at the household level, without having to resort to emergency supplies. This demands either adequate food production or food imports. Agricultural choices are as much about food quantity as they are about nutritional needs, livelihoods, culture, poverty, trade and sustainable development. Genetic modification technology may be useful in addressing some of these aspects. However, the potential impact that such technologies may have is controversial. There is considerable uncertainty about the impact on human and environmental health, and also whether these products will provide a sustainable solution to food problems. The risks and benefits associated with GM technologies are difficult to quantify.

As financial resources for public sector research decreases, and the values that promote private sector development and interests become entrenched in global governance instruments, the growth and applications of GM technology seems certain. However, the potential role of GM crops in Africa in promoting food security and improved human well-being is far from clear, and it is uncertain how their adoption will impact on the sustainability of livelihoods and food production systems.

The ignorance with regard to GM crops and food as well as "frustration" is illustrated by the statement by the then president of Zambia, Mr Levy Mwanawasa, about Bt-maize (Fig. 2).

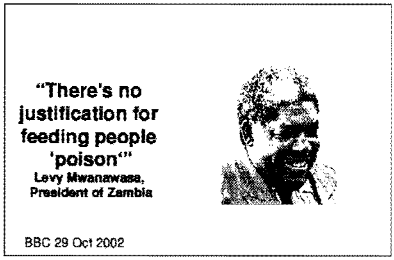

Figure 2. Statement by the president of Zambia on BBC radio.

The challenge for policymakers is how to respond to this uncertainty about the relative opportunities and threats posed by GM technologies: The dilemma is whether to adopt this new technology and face criticism for lack of precaution, or to request thorough study of potential risks and face criticism for failing to act promptly.

In South Africa, under the Genetically Modified Organisms Act of 1997, three transgenic crops – insect or herbicide resistant cotton and maize as well as herbicide tolerant soybean – have been approved for commercialization. GM crop plantings are expanding and in 2009 South Africa had approximately 1 million ha under GM crops. The area planted to GM crops is continuously increasing in white GM maize used for food and yellow GM maize used for feed. GM soybean planted in South Africa does not contain insecticidal proteins but has the characteristic of herbicide tolerance.

Research at North-West University on potential environmental impacts of GM crops

In order to address issues around potential positive or negative impacts of GM crops in South Africa and the rest of Africa a research focus on GM crops were developed in the Plant Protection research stream of the School of Environmental Sciences and Development at North West University. This research group, which consists mainly of post graduate students contributes significantly to generating information on effects of GM crops in the environment. This information plays an important role in risk assessments in South Africa.

For this reason, research regarding the possible direct and indirect effects of Bt maize on non-target organisms as well as target organisms (resistance development) are being studied in the Plant Protection research stream at North-West University (Figure 3). These include epigeal arthropods, termites as well as a wide range of non-target organisms. These are being studied as part of several PhD and MSc projects. Biodiversity assessments of arthropods on maize is an ongoing activity in this research group.

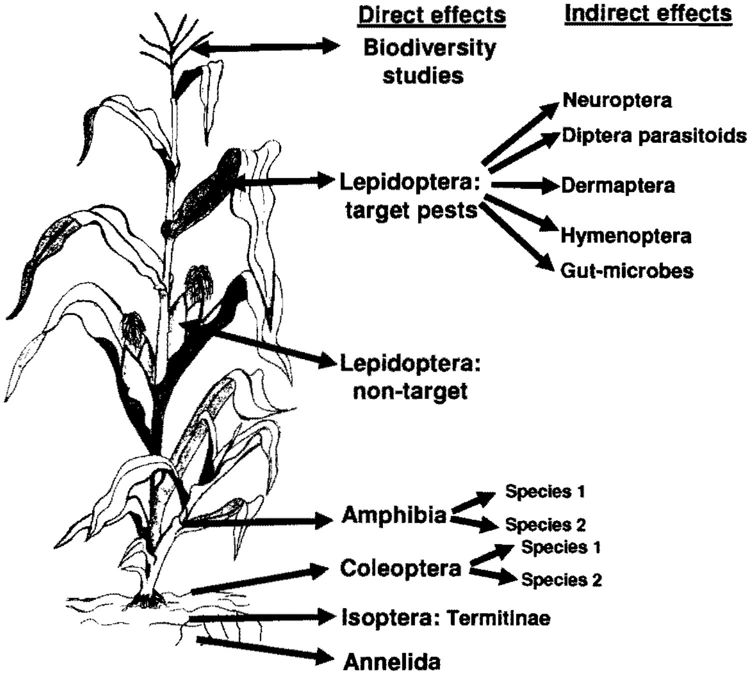

Figure 3. A graphical summary of organisms on which the possible direct and indirect effects of Bt maize are being studied at North-West University.

Importance of ecological risk assessments and monitoring

Risk assessment is a process by which risks are identified and in which the seriousness of these risks are characterized so that decisions can be made on whether or how to proceed with the technology (Hilbeck & Andow, 2004). As stated by McGeoch & Rhodes (2006) the protocols and guidelines for risk assessment of genetically modified crops in South Africa has yet to be developed.

The biodiversity of an agro-ecosystem is important because it influences ecological functions that are vital for crop production in sustainable agricultural systems and the surrounding environment. Each species assemblage in this ecosystem fulfils a variety of functions. These functions may be disturbed if changes occur within these assemblages. Guild arrangements can also be influenced and rearranged as a result of the elimination of a target pest. This changed guild structure can result in development of secondary pests. It is therefore essential to assess the potential environmental risk that the release of genetically modified organisms may hold, and also to study the effect it has on the species assemblages within that ecosystem (Van Wyk *et al.*, 2007).

The use of an ecological model to identify priority species for use in monitoring of GM crops instead of using pre-determined species as is often done when using an ecotoxicological model, has been advocated in case studies on both Bt cotton in Brazil (Hilbeck *et al.*, 2006) and Bt maize in Kenya (Hilbeck & Andow, 2004). In these case studies, as well as a South African study by Van Wyk *et al.* (2007) the authors indicated that local surveys in areas where the GM crop will be deployed should be done to identify which species should be monitored and/or used in studies on the effects of Bt crops on ecosystem health. This applies to any non-target organism, e.g. termites, Amphibia and earth worms.

Although positive as well as negative effects of GM crops have been discussed above, one important area of concern, aquatic ecosystems, is not receiving enough attention. The reason for this is most likely because it is a difficult environment to do research in and because it is "far removed" from the target environment of GM crops which is the cropping system.

The aquatic ecosystem

Several studies conducted in aquatic systems have found interesting and sometimes disturbing results.

A study by Rosi-Marshall *et al.* (2007) on Bt maize adjacent to headwater streams in the USA revealed interesting facts. They showed that maize pollen and detritus enter headwater streams and are subject to storage, consumption, and transport to downstream water bodies. Laboratory feeding trials showed that consumption of Bt maize byproducts reduced growth and increased mortality of non-target stream insects such as algae feeding Trichoptera. These stream insects are important prey for aquatic and riparian predators, and if these observations are an indication of a widespread phenomenon, planting of Bt crops could in future have unexpected effects on the aquatic ecosystem.

A study conducted in Sweden by Bohn *et al.* (2008) evaluated effects of Bt maize on survival, growth, and reproduction of the water flea *Daphnia magna*, a crustacean arthropod commonly used as a indicator species in ecotoxicological studies. In these studies *D. magna* were fed 100% ground maize in suspension, using either GM or isogenic unmodified (UM) maize. Individuals that fed on GM maize showed a significantly reduced fitness performance: The mortality was higher, a lower proportion of females reached sexual maturaty, and the overall egg production was lower compared to *D. magna* fed isogenic maize.

The potential flow of the transgene itself in an ecosystem was shown in a study by Douville *et al.* (2008). In the later study the contamination of cry1 and cry1Ab genes from *Bacillus thuringiensis* and transgenic maize in feral freshwater mussels collected from sites located in proximity to maize fields was studies. In addition, mussels were transplanted for two months to a site in a river upstream to an area subject to intensive maize farming. Mussels were significantly contaminated by both genes in their gills, digestive glands and gonads. In an attempt to explain the presence of the transgene in mussel tissues, heterotrophic bacteria were grown from surface water and sediment samples collected form the maize producing area. The transgene was found in several water samples and in one sediment sample. The study showed that the presence of the transgenic maize cry1Ab gene in mussels seems to be proceeded by ingestion of micro-organisms during feeding by these mussels.

Conclusion

The debate on whether GM crops will be the solution to the challenges provided by abiotic stresses will continue for many years to come. Scientific research have pointed out many advantages as well as potential disadvantages of planting GM crops. The latter refers to potential negative ecological impacts, especially in aquatic ecosystems.

The well known phrase, "*to Bt or not to Bt: that is the question*" adapted from that of borrowed from the famous English author, William Shakespeare, is often used in terms of Bt crops (Anonymous, 2009). The concern embedded in the above mentioned quotation describes the polarization experienced world-wide between pro- and anti-GM groups. The responsibility of scientists and research groups such as that at North-West University is to critically investigate and report on environment impacts of GM crops.

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