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Genetic Engineering and Biotechnology for Food Security and for Climate Change Mitigation and Adaptation: Potential and Risks

by Jack A. Heinemann

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Third World Network

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Note

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Chapter 1

Introduction

Global food production is increasing faster than demand (IAASTD, 2009a). Aside from price spikes in 2008 and 2010-11, food prices have been at 100-year lows (Nellemann et al., 2009). Despite this, billions of people are malnourished and a billion are starving (Hoffmann, 2011; Khan and Hanjra, 2009).

Current agricultural practices, including the harvesting of natural resources such as ocean fisheries, are having enormous and unsustainable environmental impacts (Khan and Hanjra, 2009; Rivera-Ferre, 2008). And increased agricultural production is putting pressure on ever-shrinking ecosystem services (Daily et al., 1998; IAASTD, 2009a). These services are needed to maintain the productivity of land as well as fresh and salt water used to produce food (MEA, 2005; Tilman et al., 2002). The unfortunate feedback cycle is that as agriculture expands into ever more marginally productive ecosystems, its impact on climate change grows (Nellemann et al., 2009).

Hunger is a choice

The current failures to feed the world are not due to limitations of technology, but to social choices (Heinemann, 2009; IAASTD, 2009a; Kiers et al., 2008). Importantly, these choices undermine the availability of balanced diets in areas where hunger and malnutrition are endemic (Nord, 2009).

The cost of food and the environmental cost of food production could be dramatically reduced just by cutting food waste. According to Nellemann et al. (2009: 7), "[D]eveloping alternatives to the use of cereal in animal feed, such as by recycling waste and using fish discards, could sustain the energy demand for the entire projected population growth of over 3 billion people" by 2050. Some of this waste from farm to fork could be reduced by technological advances, as well as by cutting consumer rejection before and after purchase, but mostly it could be overcome by a change in social policy and attitudes, especially among consumers in developed countries who waste up to 10 times the amount of food wasted in developing countries (Gustavsson et al., 2011).

Demand for food alone is not the only cause of agriculture's growing footprint. Many countries, even those experiencing famine, rely on the export of food to generate income (Vandermeer and Pefecto, 2007). In recent decades, large-scale conversions of the agroecosystem in some countries have been correlated with an increase in food insecurity, motivated by the push to produce more export commodities at the expense of foods of higher nutritional value for domestic consumption (Pengue, 2005; and Table 1 below).

New or improved technologies could help feed the world (Heinemann, 2009; IAASTD, 2009a). Before considering which technological approaches are best for reducing the effects of climate change on agriculture and mitigating agriculture's contribution to factors causing climate change (such as greenhouse gases), it will be essential to determine which problems are best solved by technological tools and which can be solved by changes in the socio-economic and socio-political status quo. This will entail considering some painful questions about the causes of the problems. Conspicuously, few are likely to have been caused by a lack of technology (*Nature*, 2010).

Table 1. Changes in food security in Argentina							
Food supply for human consumption (per person/ day)	**1990-92**	**1995-97[a]**	**2000-02[b]**	**2005-07[c]**	**1990-92 to 1995-97 (%)[d]**	**1995-97 to 2000-02 (%)[d]**	**2000-02 to 2005-07 (%)[d]**
Dietary energy supply (kcal)	3010	3160	3140	3000	0.9	-0.1	-0.9
Total protein intake (grams)	95	100	99	94	1	-0.3	-0.9
Animal protein (grams)	61	64	63	62	0.9	-0.5	-0.3
Fat (grams)	106	113	110	108	1.2	-0.4	-0.5

Source: Based on data from FAOSTAT.

[a] Period of first introduction of commercial genetically modified (GM) plants; industry figures report 1.7 million hectares of GM crops were being cultivated in 1996 (*ISAAA Brief* No. 36).

[b] According to industry figures, during this period, 13.5 million hectares of GM crops were being cultivated (*ISAAA Brief* No. 36).

[c] According to industry figures, during this period 19.1 million hectares of GM crops were being cultivated (*ISAAA Brief* No. 37).

[d] Annual rate of change – not total change over the period.

Chapter 2

Choosing Among Technological Paths to Pro-Poor, Climate-Resilient Agriculture

The right technology delivered in the right way should be able to help reverse agriculture's adverse impact on climate change, and ultimately contribute to food security (Heinemann, 2009; Scialabba, 2007a). Otherwise, proposed technological solutions to these problems will not be sustainable, make their fair contribution to the Millennium Development Goals or help distribute the benefits more equitably among the peoples of the world. As concisely stated by the Director of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), "business as usual is not an option".[1] One form of "business as usual" is the highly damaging traditional agricultural practices. Damaging traditionalist approaches are due more to the neglect of farmers than to farmers preferring to use them. Poor and subsistence farmers are challenged by a lack of adequate extension and community support services that disseminate knowledge, affordable financing and access to markets for the sale of surplus production.

Another form of "business as usual" is the intensive use of external inputs in agriculture and, especially, support to massive monocultures, both of which are concentrated in developed countries and some rapidly industrializing developing countries. Unlike unsustainable traditional approaches, input-

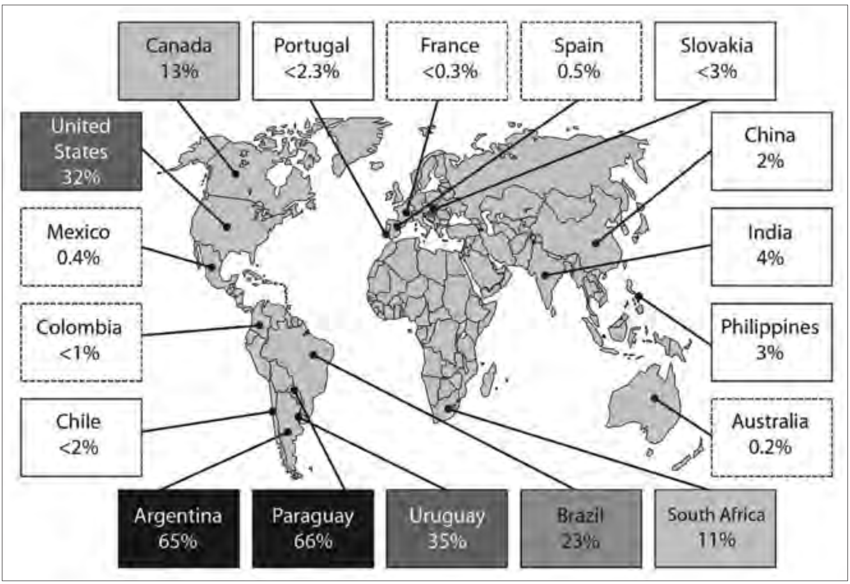
[1] See: www.agassessment.org/docs/NAE_press_release_final.doc.

intensive agriculture – loosely referred to as conventional or industrial agriculture – has been promoted by policy decisions. The policies and technologies associated with industrial agriculture involve a shift in innovation resources from public control to the private sector (IAASTD, 2009a; Spielman, 2007) as a result of the private sector investing more than the public sector in research and development. Private investment further leverages much of what remains of public investment through government policies that promote co-funding by the private sector, the pursuit of intellectual property (IP) by public sector institutions (e.g., universities and agriculture agencies) and public sector licensing of IP from the private sector (IAASTD, 2009b; Vanloqueren and Baret, 2009). Industrial agriculture also receives large public subsidies (direct and indirect) in developed economies, which stifle producers and markets in developing countries and further undermine the ability of poor and subsistence farmers to intensify production and reduce their environmental footprint (Kiers et al., 2008; Spielman, 2007). Furthermore, industrial agriculture has neither produced a sustainable, highly productive agroecosystem nor curbed agriculture's impact on climate change.

Of the many biotechnology options available for testing or implementing, perhaps the one that receives the most attention is genetic engineering (GE) for the production of genetically modified organisms (GMOs) – plants, animals and microbes (IAASTD, 2009b). As currently applied, GE has come to symbolize agricultural production systems that make intensive use of external inputs and promote monocultures (Rivera-Ferre, 2008). This is because of the types of commercialized GM products that are the most common (i.e., soybeans, maize, rapeseed and cotton), because of the particularly large agroecosystems that have adopted GM crops, mainly those in Argentina, Brazil, Canada, Paraguay, the United States and Uruguay (Figure 1), and because of the most common commercialized GM traits:

herbicide tolerance and insecticide production. Herbicide tolerance, in particular, lends itself to mechanized delivery of an inseparable co-technology, a chemical for weed management. This weed control strategy requires large tracts of monoculture to avoid herbicide drift onto neighbouring or other agricultural land. Finally, because of the relatively small number of countries that have adopted GM crops and the few companies that have

Figure 1. Degrees of commitment to GM agriculture (estimates for 2007)



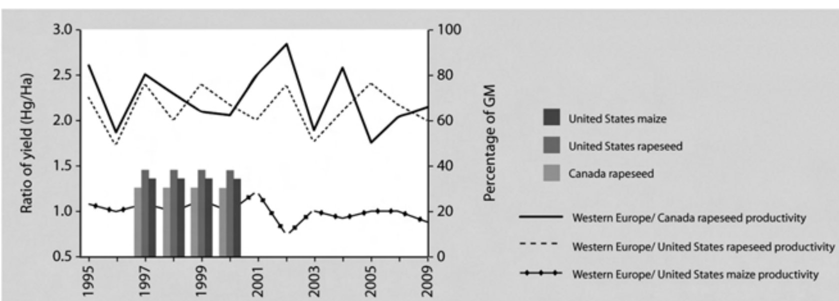
Source: Reproduced from Heinemann, 2009.

Only two countries in the world have converted the majority of their agricultural systems to GM cropping (black boxes). According to industry figures, Argentina and Paraguay are true “mega countries” of GM crops (James, 2007). The majority of the top 20 GM producing countries commit less than 1-5 per cent of their agricultural production to GM (white boxes with solid lines indicate above 1 per cent). Even the world’s largest producer, the United States, commits no more than about a third of its cropping capacity to GM (grey boxes for countries having more than 10 per cent).

commercialized it, individual country- and company-specific policies and business plans have had an important influence on the adoption of this biotechnology.

That some of the largest agricultural countries in the world have adopted GM versions of a few crops should not be taken as evidence that GE has delivered sustainably and reliably greater yields. Contrasting North American and Western European production of maize and rapeseed is instructive in this regard because they both have high-input, high-production agroecosystems. In Canada, for example, rapeseed (canola), and in the United States, maize, are almost exclusively produced from GM plants. Collectively, Western Europe has shunned the cultivation of GM maize and rapeseed (Figure 2). Yet maize yields are very similar in the two agroecosystems, and Western Europe's rapeseed yields are about double those of North America (Figure 2). This trend has not changed since the adoption of GM plants in North America.

Figure 2. Comparative yields in GM adopting and non-adopting agricultural systems, 1995–2009

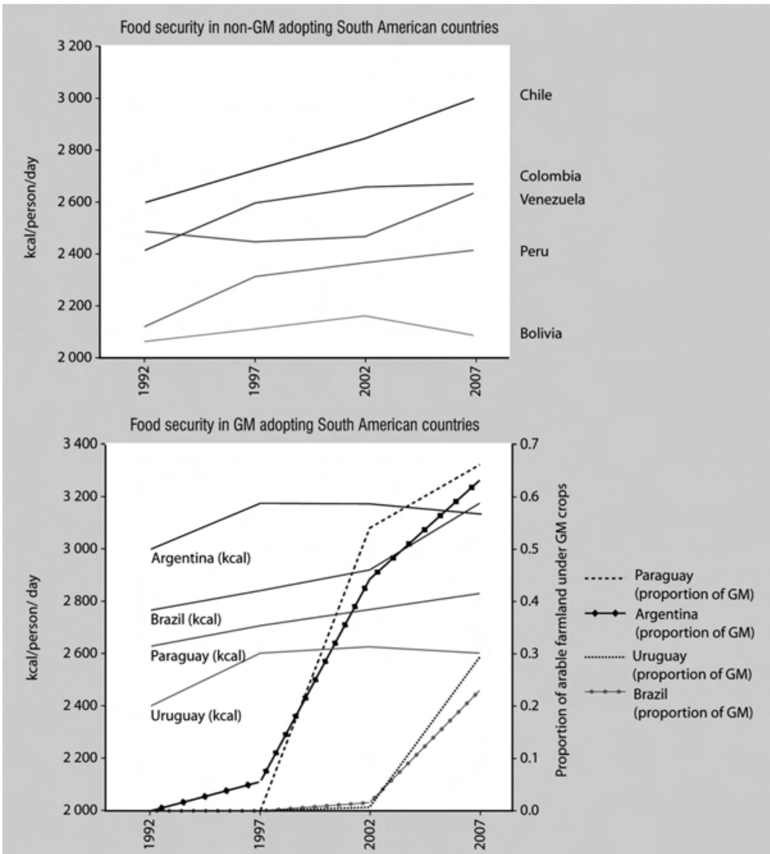


Source: FAOSTAT for ratio of yield; and GMO Compass for percentage of GM maize and rapesseed (accessed May 2011).

Note: Left axis is the ratio of yield in hectograms (Hg) per hectare (Ha) for two crops, rapeseed (top) and maize (bottom), and three producers, Western Europe, Canada and the United States. Right axis represents the proportion of GM by crop type in the North American agricultural systems.

Broadly speaking, countries making a substantial shift to GM crops are in a group where food security has either shown no improvement (e.g., United States) or is declining (e.g., Argentina) (Figure 3; and Heinemann, 2009).

Figure 3: Food security in GM and non-GM adopting countries in South America compared, 1992–2007 (kcal/person/day)



Source: FAOSTAT.

Note: A collection of South American countries that have not adopted GM-based agricultural systems show similar improvements in food security (top panel). Countries with varying proportions of GM (right axis, bottom panel) show mixed results. Those with rapid adoption of greater amounts of GM in their agriculture are more prone to increased insecurity levels (measured in kcal, left axis).

Chapter 3

How Some Biotechnologies Are Failing

Arguably, some GM products have lowered the overall impact of industrial agriculture. For example, the use of glyphosate-based herbicides on GM crops has reduced the need for tilling as a weed control strategy (Pengue, 2005; Service, 2007). Similarly, the use of GM insecticide plants (often called Bt plants), particularly cotton, has reduced the use of external chemical insecticides.

Unfortunately, these benefits are both contested and deterministically unsustainable (Heinemann, 2009). The predictable pattern and quantity of glyphosate herbicide use in GM agriculture has caused the evolution of resistance in weeds on a scale never experienced in the decades of glyphosate use prior to GM crops, leading to a return to tilling and the use of other herbicides for weed control (Gaines et al., 2010; Powles, 2008; Service, 2007). Meanwhile, the unique pattern of use of glyphosate on GM soybeans has reduced *in situ* nitrogen fixation by chelating nickel, a required co-factor for enzymatic activities in the microbial symbionts (Zobiole et al., 2010), and reduced normal iron uptake and storage in soybeans (Bellaloui et al., 2009). Glyphosate on herbicide-tolerant plants also reduces root biomass, elongation and lateral root formation (Bott et al., 2008). Systemic distribution of glyphosate throughout the plant is associated with increased susceptibility to colonization by disease-causing fungi (Kremer, Means and Kim, 2005). These effects further reduce the sustainability of GM approaches. Likewise, replacing complementary and diverse pest control practices, such as integrated pest management (Mancini et al., 2008), and the judicious use of natural sources of Bt insecticides, as in organic agriculture, along with the mass planting of GM Bt crops, is causing the appearance of secondary pests (Lu et al., 2010; Zhao, Ho and Azadi, 2011).

Moreover, whatever the comparative benefits of GE may be, they are largely lost when GE/industrial agriculture is compared with alternative biotechnologies such as agroecological technologies (Pimentel et al., 2005; Pretty, 2001). Land converted to agriculture from other uses, guided by agroecology, requires time to condition and bring to full potential (Badgley et al., 2007; Pimentel et al., 2005). Once this has been achieved, agroecological approaches have been observed to generate higher yields than industrial agriculture, as shown in several compilations and meta-analyses at country, continental and global levels (Badgley et al., 2007; Uphoff, 2007). Plants grown on agroecological farms are more resilient to stress than those grown by means of industrial agriculture (Lotter, Seidel and Liebhardt, 2003; Pimentel et al., 2005). Agroecological farms require far less fossil-fuel-derived energy and sequester more carbon (Pimentel et al., 2005; Scialabba, 2007b). In addition, the adoption of agroecological approaches contributes to sustainable societies by reducing poverty and improving food security (Scialabba, 2007a; UNEP and UNCTAD, 2008).

After approximately 30 years of commercialization and pre-commercial GE research and development, it has not made a substantial contribution to sustainable agriculture. The IAASTD (2009a) was therefore justified in questioning whether GE could deliver on Millennium Development Goals or reduce agriculture's contribution to climate change. However, had the incentives for delivering GM products been different, and the goals of public and private innovation not been so thoroughly intertwined in this biotechnology (Vanloqueren and Baret, 2009), would GE have produced different results? In other words, has GE failed because of policy decisions and its particular history of commercialization, or because the technology itself has been inappropriate?

Chapter 4

Why Some Biotechnologies Could Succeed

Again, comparisons with alternative biotechnologies may be instructive for responding to these questions. The two biotechnologies being contrasted with GE here are conventional breeding, with or without marker-assisted selection, and agroecology. The traits considered are drought tolerance and nutrient enhancement.

Drought tolerance

Agriculture makes tremendous demands on groundwater, and water shortages are a global drag on food production. This has driven the search for plants that maintain or improve yield under conditions of water deprivation. Despite many attempts, to date there are no commercially available GM plants with traits that reduce the effects of abiotic stress (Heinemann, 2008). The closest so far is a variety of “drought-tolerant” maize, called MON 87460, which is under regulatory consideration in some countries. According to the developer’s data, the GM maize had a marginally ($p<0.05$) statistically significant increase in yield in only one of four field tests, which is unconvincing for the general expectation that the variety is higher-yielding under stress. The developer claims that “the major component contributing to the improved yield of MON 87460 under water-limited conditions is the increased number of kernels per ear” (Monsanto, 2009: 45), rather than claiming that the variety produces more usable biomass. The developer calls this trait a change in "yield potential", rather than an increase in yield.

Drought tolerance has long been a goal of conventional breeding, and current hybrids already exhibit some tolerance (Monsanto, 2009), with improvements on this baseline expected. According to the World Bank (2007: 162), the "International Maize and Wheat Improvement Center (CIMMYT), after more than 30 years of research to produce drought-tolerant maize varieties and hybrids, is now seeing results in eastern and southern Africa. Evaluated against existing hybrids, the new ones yield 20 percent more on average under drought conditions. Similarly, recent evidence points to significant yield gains in breeding wheat for drought and heat-stressed environments."

Agroecological approaches further reduce the need for intensive breeding or GE to produce drought-tolerant varieties. Increasing the organic matter in soil, using cover crops and interspersing fallow years significantly increases latent soil moisture, making agroecological farms far more resilient to drought-related stress (Heinemann, 2008). Water percolating through the soils in agroecological test plots has been reported to be between 15 per cent and more than 30 per cent higher than in conventional plots under drought conditions, and those agroecological test plots have demonstrated commensurate increases in yields compared with matched conventional management (Lotter, Seidel and Liebhardt, 2003; Pimentel et al., 2005; Scialabba, 2007a).

Nutrient enhancement

Micronutrient deficiencies contribute significantly to malnutrition (Scialabba, 2007a), which is why developing plants that are enriched with micronutrients has been a long-term goal. It is therefore particularly unfortunate that the largest group of commercialized GM plants, those tolerant to glyphosate herbicides, are also less able to take up some important micronutrients from the soil (Bellaloui et al., 2009; Bott et al., 2008). Importantly, spray drift at non-lethal concentrations has a similar effect on non-GM crops (Bellaloui et al., 2009). Because glyphosate can be used multiple times during the growing season on herbicide-tolerant GM plants, non-GM crops are now routinely exposed to spray drift.

Attention has been drawn to the development of GM rice that produces β-carotene, which can be converted by humans to vitamin A (Heinemann, 2009; Schubert, 2008). However, high-micronutrient varieties are not unique to GE; for instance, maize lines that produce nearly four times the amount of β-carotene (8.57 $\mu g\ g^{-1}$) of second-generation GM rice varieties (2.6 $\mu g\ g^{-1}$) have been developed through conventional breeding (Yan et al., 2010). This is mentioned not to disparage the technical achievement of introducing the biosynthetic pathway for β-carotene into rice, but to emphasize the importance of protecting crop genetic diversity and its ongoing potential to be tapped for use in balanced diets (Zamir, 2008).

Combined studies have found that balanced diets are more accessible to poor and subsistence farmers using agroecological rather than industrial farming approaches. This is because of the use of multicropping and the integration of livestock rearing, and the higher micronutrient content of the plants they grow, and because these farmers tend to earn more, which allows them to purchase other foods (Scialabba, 2007a; UNEP and UNCTAD, 2008).

Proponents of β-carotene-enriched GM rice argue that safety regulations have been the primary hindrance to the transfer of this product to poor and subsistence farmers in societies that suffer from significant vitamin A deficiency (Dubock, 2009).

However, malnutrition is caused by the lack of a balanced diet rather than the lack of access to GM crops. Moreover, these commentators neglect to take into account the estimated 70 patents and 32 patent holders that had to agree to the use of their intellectual property prior to release of the GM rice (Graff et al., 2003; Spielman, 2007; WHO, 2005). These protracted negotiations were recently resolved with an agreement that exempted specified countries from having to pay royalty fees for growing this variety of GM rice provided that the rice was not exported (GRO, online). Given the difficulties in containing transgenes, including those in rice (Vermij, 2006), this humanitarian licence may transfer liability for gene flow and potential patent infringement to the farmer and the adopting country (Heinemann, 2007). Non-GM varieties and agroecological technologies are usually protected by less restrictive IP instruments, and as process innovations are not prone to accidental and unavoidable escape in the way that seeds and pollen are, this liability would not be incurred through their use.

Chapter 5

Conclusions

Technological solutions are rarely sustainable if they do not rectify the cause of the problem. Regardless of the ability of industrial agriculture to produce food surpluses in previous decades (Rivera-Ferre, 2008), future technologies must produce sustainable solutions and be useful to those who are now malnourished. As stated by Uphoff (2007: 218), “The most direct way to reduce poverty is to raise the productivity of those factors of production controlled by the poor: first of all, their labor, but also their knowledge and skills, and for many though not all, small areas of land. Increased factor productivity of land, labor, capital and water can have second-order benefits for the poor, urban as well as rural, by lowering the price of food and other things on which the poor spend most of their meager incomes.” The export of the industrial model of agriculture and its associated GE-based technologies that are embedded in particularly exclusionary IP instruments, such as patents, to food-poor countries shows little promise of addressing the needs of the hungry poor (IAASTD, 2009a; Pray and Naseem, 2007; WHO, 2005; World Bank, 2007).

Fortunately, other technologies show promise, both for increasing yield in yield-limited agroecosystems and for promoting what the present system has not been able to achieve, namely sustainable societies in poor countries (Rivera-Ferre, 2009; UNEP and UNCTAD, 2008). This is obtained when technologies reduce external inputs and on-farm costs of seeds, incorporate multicropping and livestock for balanced diets, promote ongoing farmer innovation under an appropriate IP rights framework, and are produced by a public sector that offers the appropriate incentives (Heinemann, 2009; Vanloqueren and Baret, 2009).

Climate change has been rapid, but not unpredictable; indeed, its occurrence has often been predicted even if the message has been resisted for decades. Likewise, a familiar message for decades has been that agriculture is making unsustainable demands on ecosystem resources worldwide, and is contributing to climate change. One of the most important lessons to be learnt before deciding on a technological pathway to reduce agriculture's appetite for resources and its footprint on the climate is that early warnings of deleterious but avoidable outcomes need to be taken seriously, rather than ignored as in the past. If we allow the same voices to be drowned out again, we will fail to protect those who will suffer the most from climate change and its damaging effects on agricultural production.

References

Badgley C, Moghtader J, Quintero E, Zakem E, Chappell MJ, Avilés-Vázquez K, Samulon A and Perfecto I (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems*, 22: 86-108.

Bellaloui N, Reddy KN, Zablotowicz RM, Abbas HK and Abel CA (2009). Effects of glyphosate application on seed iron and root ferric (III) reductase in soybean cultivars. *Journal of Agricultural and Food Chemistry*, 57: 9569-9574.

Bott S, Tesfamariam T, Candan H, Cakmak I, Römheld V and Neumann G (2008). Glyphosate-induced impairment of plant growth and micronutrient status in glyphosate-resistant soybean (Glycine max L.). *Plant and Soil*, 312: 185-194.

Daily G, Dasgupta P, Bolin B, Crosson P, du Guerny J, Ehrlich P, Folke C, Jansson AM, Jansson B-O, Kautsky N, Kinzig A, Levin S, Mäler K-G, Pinstrup-Andersen P, Siniscalco D and Walker B (1998). Food production, population growth, and the environment. *Science*, 281: 1291-1292.

Dubock A (2009). Crop conundrum. *Nutrition Reviews*, 67: 17-20.

Gaines TA, Zhang W, Wang D, Bukun B, Chisholm ST, Shaner DL, Nissen SJ, Patzoldt WL, Tranel PJ, Culpepper AS, Grey TL, Webster TM, Vencill WK, Sammons RD, Jiang J, Preston C, Leach JE and Westra P (2010). Gene amplification confers glyphosate resistance in *Amaranthus palmeri. Proceedings of the National Academies of Science*, 107: 1029-1034.

Graff GD, Cullen SE, Bradford KJ, Zilberman D and Bennett AB (2003). The public-private structure of intellectual property ownership in agricultural biotechnology. *Nature Biotechnology*, 21: 989-995.

GRO online (posting date). Intellectual property-related issues. Available at:http://www.goldenrice.org/Content2-How/how9_IP.html (accessed 6 July 2011).

Gustavsson J, Cederberg C, Sonesson U, van Otterdijk R and Meybeck A (2011). *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome, FAO.

Heinemann JA (2007). A typology of the effects of (trans)gene flow on the conservation and sustainable use of genetic resources. Bsp35r1. Rome, FAO.

Heinemann JA (2008). Desert grain. *The Ecologist*, 38: 22-24.

Heinemann JA (2009). *Hope not Hype. The future of agriculture guided by the International Assessment of Agricultural Knowledge, Science and Technology for Development*. Penang, Third World Network.

Hoffmann U (2011). Assuring food security in developing countries under the challenges of climate change: Key trade and development issues of a fundamental transformation of agriculture. UNCTAD/OSG/DP/2011/1. Geneva, United Nations Conference on Trade and Development.

IAASTD (2009a). *International Assessment of Agricultural Knowledge, Science and Technology for Development*. Washington, DC, Island Press.

IAASTD (2009b). *Agriculture at a Crossroads*. Synthesis report of the International Assessment of Agricultural Knowledge, Science and Technology for Development. In: McIntyre BD et al., eds. *International Assessment of Agricultural Knowledge, Science and Technology for Development.* Washington, DC, Island Press.

James C (2007). Executive summary of the global status of commercialized biotech/GM crops. *ISAAA Brief* No. 37. Manila, Nairobi and New York, International Service for the Acquisition of Agri-biotech Applications. Available at: http://www.isaaa.org/.

Khan S and Hanjra MA (2009). Footprints of water and energy inputs in food production: Global perspectives. *Food Policy*, 34: 130-140.

Kiers ET, Leakey RRB, Izac A-M, Heinemann JA, Rosenthal E, Nathan D and Jiggins J (2008). Agriculture at a crossroads. *Science*, 320: 320-321.

Kremer RJ, Means NE and Kim S (2005). Glyphosate affects soybean root exudation and rhizosphere micro-organisms. *International Journal of Environmental Analytical Chemistry*, 85: 1165-1174.

Lotter DW, Seidel R and Liebhardt W (2003). The performance of organic and conventional cropping systems in an extreme climate year. *American Journal of Alternative Agriculture*, 18: 1-9.

Lu Y, Wu K, Jiang Y, Xia B, Li P, Feng H, Wyckhuys KAG and Guo Y (2010). Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. *Science*, 328: 1151-1154.

Mancini F, Termorshuizen AJ, Jiggins JLS and van Bruggen AHC (2008). Increasing the environmental and social sustainability of cotton farming through farmer education in Andhra Pradesh, India. *Agricultural Systems*, 96: 16-25.

MEA (2005). Ecosystems and human well-being: Synthesis. In: *Millennium Ecosystem Assessment*. Washington, DC, Island Press: 137.

Monsanto (2009). Petition for the determination of non-regulated status for MON 87460 07-CR-191U.

Nature (2010). Editorial: How to feed a hungry world. *Nature*, 466: 531-532.

Nellemann C, MacDevette M, Manders T, Eickhout B, Svihus B, Prins AG and Kaltenborn BP (2009). *The Environmental Food Crisis: The Environmment's Role in Averting Future Food Crises*. Nairobi, United Nations Environment Programme.

Nord M (2009). Food insecurity less prevalent in Canada than in the United States. *Amber Waves*, 7. Washington, DC, United States Department of Agriculture.

Pengue WA (2005). Transgenic crops in Argentina: the ecological and social debt. *Bulletin of Science, Technology & Society*, 25: 314-322.

Pimentel D, Hepperly P, Hanson J, Douds D and Seidel R (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience*, 55: 573-582.

Powles SB (2008). Evolved glyphosate-resistant weeds around the world: Lessons to be learnt. *Pest Management Science*, 64: 360-365.

Pray CE and Naseem A (2007). Supplying crop biotechnology to the poor: Opportunities and constraints. *Journal of Development Studies*, 43: 192-217.

Pretty J (2001). The rapid emergence of genetic modification in world agriculture: Contested risks and benefits. *Environmental Conservation*, 28: 248-262.

Rivera-Ferre MG (2008). The future of agriculture. *EMBO Reports*, 9: 1061-1066.

Rivera-Ferre MG (2009). Response. *EMBO Reports*, 10: 105-107.

Schubert D (2008). The problem with nutritionally enhanced plants. *Journal of Medicinal Food*, 11: 601-605.

Scialabba N E-H (2007a). *Organic Agriculture and Food Security*. Rome, FAO.

Scialabba N E-H (2007b). Organic agriculture and food security in Africa. In: Nærstad A, ed. *Africa Can Feed Itself*. Oslo, AiT AS e-dit: 214-228.

Service RF (2007). A growing threat down on the farm. *Science*, 316: 1114-1117.

Spielman DJ (2007). Pro-poor agricultural biotechnology: Can the international research system deliver the goods? *Food Policy*, 32: 189-204.

Tilman D, Cassman KG, Matson PA, Naylor R and Polasky S (2002). Agricultural sustainability and intensive production practices. *Nature*, 418: 671-677.

UNEP and UNCTAD (2008). *Organic Agriculture and Food Security in Africa*. UNCTAD/DITC/TED/2007/15. Geneva, UNEP-UNCTAD Capacity-building Task Force on Trade, Environment and Development.

Uphoff N (2007). Agroecological alternatives: Capitalising on existing genetic potentials. *Journal of Development Studies*, 43: 218-236.

Vandermeer J and Perfecto I (2007). The agricultural matrix and a future paradigm for conservation. *Conservation Biology*, 21: 274-277.

Vanloqueren G and Baret PV (2009). How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Research Policy*, 38: 971-983.

Vermij P (2006). Liberty Link rice raises specter of tightened regulations. *Nature Biotechnology*, 24: 1301-1302.

WHO (2005). Modern food biotechnology, human health and development: An evidence-based study. Geneva.

World Bank (2007). *World Development Report 2008: Agriculture for Development*. Washington, DC.

Yan J, Kandianis CB, Harjes CE, Bai L, Kim E-H, Yang X-M, Skinner DJ, Fu Z, Mitchell S, Li Q, Fernandez MGS, Zaharieva M, Babu R, Fu Y, Palacios N, Li J, DellaPenna D, Brutnell T, Buckler ES, Warburton ML and Rocheford T (2010). Rare genetic variation at Zea mays crtRB1 increases [beta]-carotene in maize grain. *Nature Genetics*, 42: 322-327.

Zamir D (2008). Plant breeders go back to nature. *Nature Genetics*, 40: 269-270.

Zhao JH, Ho P and Azadi H (2011). Benefits of Bt cotton counterbalanced by secondary pests? Perceptions of ecological change in China. *Environmental Monitoring and Assessment*, 173: 985-994.

Zobiole LHS, Oliveira RS Jr, Kremer RJ, Constantin J, Yamada T, Castro C, Oliveira FA and Oliveira A Jr (2010). Effect of glyphosate on symbiotic N2 fixation and nickel concentration in glyphosate-resistant soybeans. *Applied Soil Ecology*, 44: 176-180.

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