Biotechnology

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Biotechnology[8] is defined as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for a specific use." In this inclusive sense, biotechnology can include anything from fermentation technologies (e.g., for beer making) to gene splicing. It includes traditional and local knowledge (TLK) and the contributions to cropping practices, selection and breeding of plants and animals made by individuals and societies for millennia [CWANA Chapter 1; Global Chapter 6]. It would also include the application of tissue culture and genomic techniques [Global Chapter 6] and marker assisted breeding or selection (MAB or MAS) [Global Chapter 5, 6; NAE Chapter 2] to augment natural breeding.[9]

Modern biotechnology is a term adopted by international convention to refer to biotechnological techniques for the manipulation of genetic material and the fusion of cells beyond normal breeding barriers[9] [Global Chapter 6]. The most obvious example is genetic engineering to create genetically modified/engineered organisms (GMOs/GEOs) through "transgenic technology" involving the insertion or deletion of genes. The word "modern" does not mean that these techniques are replacing other, or less sophisticated, biotechnologies.

Conventional biotechnologies, such as breeding techniques, tissue culture, cultivation practices and fermentation are readily accepted and used. Between 1950 and 1980, prior to the development GMOs, modern varieties of wheat may have increased yields up to 33% even in the absence of fertilizer. Even modern biotechnologies used in containment have been widely adopted. For example, the industrial enzyme market reached US$1.5 billion in 2000.

Biotechnologies in general have made profound contributions that continue to be relevant to both big and small farmers and are fundamental to capturing any advances derived from modern biotechnologies and related nanotechnologies[10] [Global Chapter 3, 5, 6]. For example, plant breeding is fundamental to developing locally adapted plants whether or not they are GMOs. These biotechnologies continue to be widely practiced by farmers because they were developed at the local level of understanding and are supported by local research.

Much more controversial is the application of modern biotechnology outside containment, such as the use of GM crops. The controversy over modern biotechnology outside of containment includes technical, social, legal, cultural and economic arguments. The three most discussed issues on biotechnology in the IAASTD conceredt:

- Lingering doubts about the adequacy of efficacy and safety testing, or regulatory frameworks for testing GMOs [e.g., CWANA Chapter 5; ESAP Chapter 5; Global Chapter 3, 6; SSA 3];
- Suitability of GMOs for addressing the needs of most farmers while not harming others, at least within some existing IPR and liability frameworks [e.g., Global Chapter 3, 6];
- Ability of modern biotechnology to make significant contributions to the resilience of small and subsistence agricultural systems [e.g., Global Chapter 2, 6].

Some controversy may in part be due to the relatively short time modern biotechnology, particularly GMOs, has existed compared to biotechnology in general. While many regions are actively experimenting with GMOs at a small scale [e.g., ESAP Chapter 5; SSA Chapter 3], the highly concentrated cultivation of GM crops in a few countries (nearly three-fourths in only the US and Argentina, with 90% in the four countries including Brazil and Canada) is also interpreted as an indication of a modest uptake rate [Global Chapter 5, 6]. GM crop cultivation may have increased by double digit rates for the past 10 years, but over 93% of cultivated land still supports conventional cropping.

The pool of evidence of the sustainability and productivity of GMOs in different settings is relatively anecdotal, and the findings from different contexts are variable [Global Chapter 3, 6], allowing proponents and critics to hold entrenched positions about their present and potential value. Some regions report increases in some crops [ESAP Chapter 5] and positive financial returns have been reported for GM cotton in studies including South Africa, Argentina, China, India and Mexico [Global Chapter 3; SSA Chapter 3]. In contrast, the US and Argentina may have slight yield declines in soybeans, and also for maize in the US [references in Global Chapter 3]. Studies on GMOs have also shown the potential for decreased insecticide use, while others show increasing herbicide use. It is unclear whether detected benefits will extend to most agroecosystems or be sustained

[9] See definition in Executive Summary.

[10] These are provided as examples and not comprehensive descriptions of all types of modern biotechnology (see Fig. SR-BT1).

[11] Specifically those nanotechnologies that involve the use of living organisms or parts derived thereof.

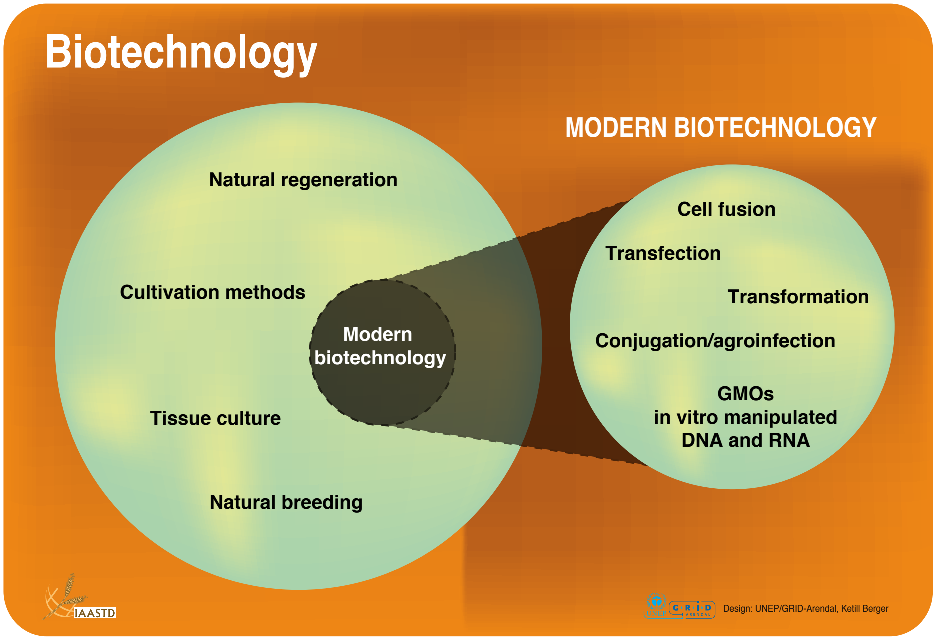

Figure SR-BT1. *Biotechnology and modern biotechnology defined.*

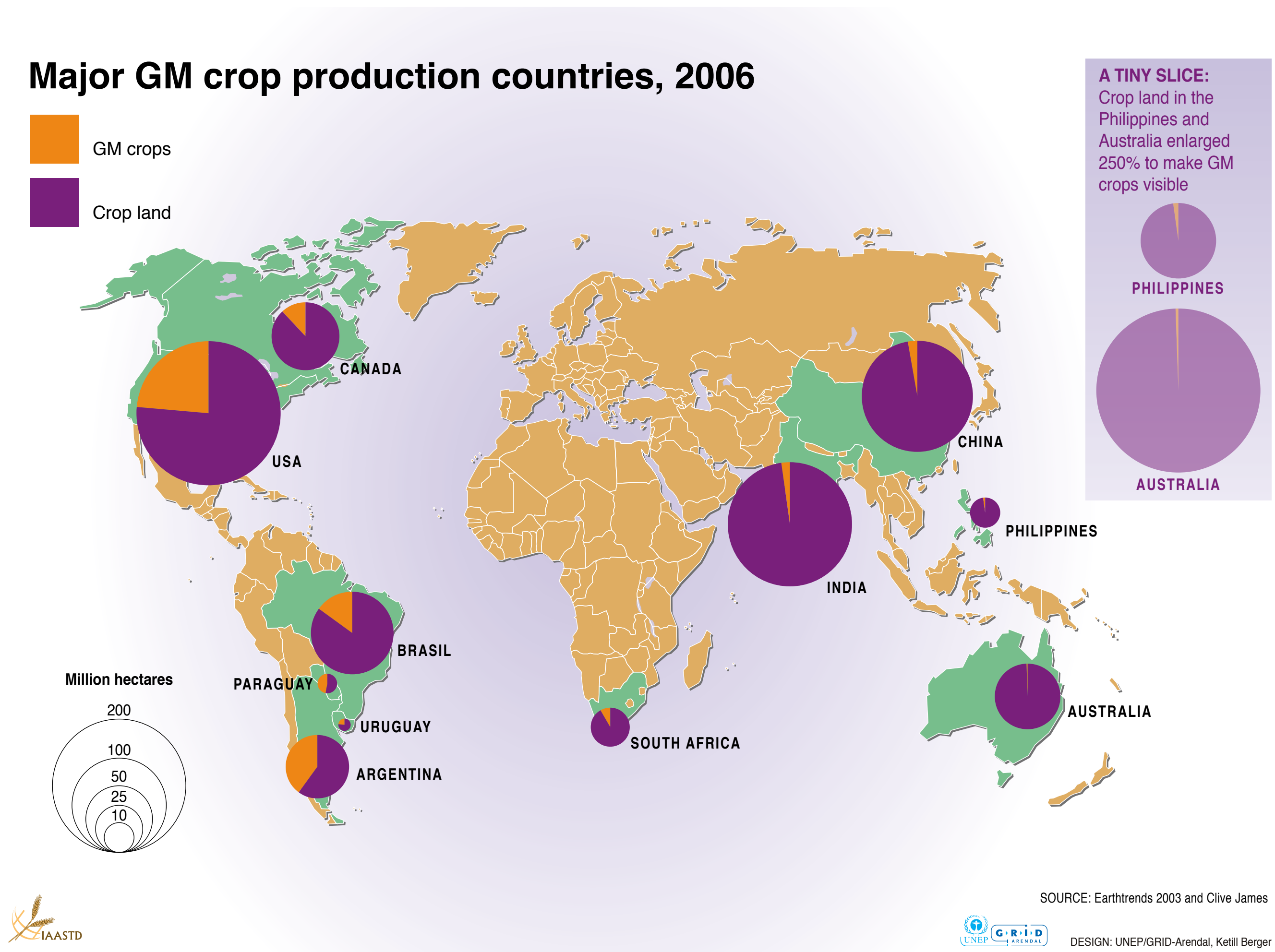

Figure SR-BT2. *Global status of GM 2006.*

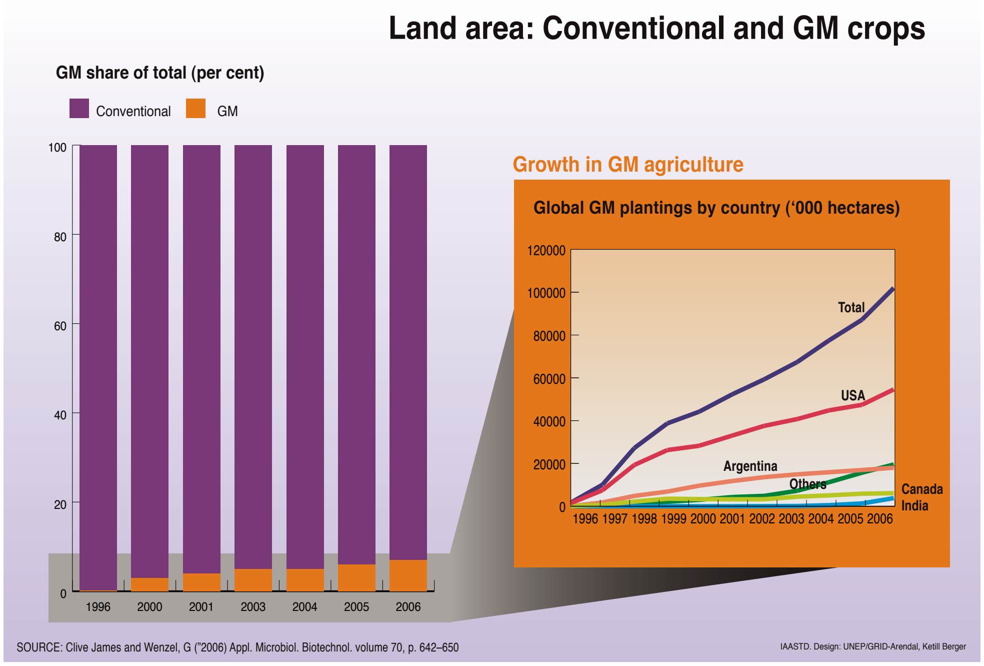

Figure SR-BT3. *Agricultural land (1996-2000) by GM and conventional crop plantings: keeping scale in perspective.*

in the long term as resistances develop to herbicides and insecticides [Global Chapter 3].

IPR frameworks need to evolve to increase access to proprietary biotechnologies, especially modern biotechnology, and address new liability issues for different sectors of producers. The use of IPR to increase investment in agriculture has had an uneven success when measured by type of technology and country. In developing countries especially, too often instruments such as patents are creating prohibitive costs, threatening to restrict experimentation by the individual farmer or public researcher while also potentially undermining local practices that enhance food security and economic sustainability. In this regard, there is particular concern about present IPR instruments eventually inhibiting seed-savings and exchanges.

Modern biotechnology has developed in too narrow a context to meet its potential to contribute to the small and subsistence farmer in particular [NAE Chapter 6, SDM]. As tools, the technologies in and of themselves cannot achieve sustainability and development goals [CWANA Chapter 1; Global Chapter 2, 3]. For example, a new breeding technique or a new cultivar of rice is not sufficient to meet the requirements of those most in need; the grain still has to be distributed. Dissemination of the technique or variety alone would not reduce poverty; it must be adapted to local conditions. Therefore, it is critical for policy makers to holistically consider biotechnology impacts beyond productivity and yield goals, and address wider societal issues of capacity building, social equity and local infrastructure [SSA Chapter 3].

Challenge: Biotechnology for Development and Sustainability Goals

Biotechnology in general, and modern biotechnology in particular, creates both costs and benefits [CWANA Chapter 5; ESAP Chapter 5; Global Chapter 3], depending on how it is incorporated into societies and ecosystems and whether there is the will to fairly share benefits as well as costs. For example, the use of modern plant varieties has raised grain yields in most parts of the world, but sometimes at the expense of reducing biodiversity or access to traditional foods [Global Chapter 3]. Neither costs nor benefits are currently perceived to be equally shared, with the poor tending to receive more of the costs than the benefits [Global Chapter 2].

Hunger, nutrition and health

Biotechnologies affect human health in a variety of ways. The use of DNA-based technologies, such as microchips, for disease outbreak surveillance and diagnostics can realistically contribute to both predicting and curtailing the impacts of infectious diseases [NAE Chapter 6]. The application of these technologies would serve human health objectives both directly and indirectly, because they could be applied to known human diseases and to plant and animal diseases that might be the source of new human diseases or which could reduce the quantity or quality of food.

Other products of modern biotechnology, for example GMOs made from plants that are part of the human food supply but developed for animal feed or to produce pharmaceuticals that would be unsafe as food, might threaten human health [Global Chapters 3, 6]. Moreover, the larger the scale of bio/nanotechnology or product distribution, the more challenging containment of harm can become [Global Chapter 6].

All biotechnologies must be better managed to cope with a range of ongoing and emerging problems [SSA Chapter 3]. Holistic solutions may be slowed, however, if GMOs are seen as sufficient for achieving development and sustainability goals and consequently consume a disproportionate level of funding and attention. To use GMOs or not is a decision that requires a comprehensive understanding of the products, the problems to be solved and the societies in which they may be used [CWANA Chapter 5]. Thus, whatever choices are made, the integration of biotechnology must be within an enabling environment supported by local research [Global Chapter 6] and education that empowers local communities [CWANA Chapter 1].

Social equity

Two framing perspectives on how best to put modern biotechnology to work for achieving sustainability and development goals are contrasted in the IAASTD. The first perspective [e.g., see Global Chapter 5] argues that modern biotechnology is overregulated and this limits the pace and full extent of its benefits. According to the argument, regulation of biotechnology may slow down the distribution of products to the poor [Global Chapter 5].

The second perspective says that the largely private control of modern biotechnology [Global Chapter 5] is creating both perverse incentive systems, and is also eroding the public capacity to generate and adopt AKST that serves the public good [e.g., see Global Chapters 2, 7]. The integration of biotechnology through the development of incentives for private (or public-private partnership) profit has not been successfully applied to achieving sustainability and development goals in developing countries [Global Chapter 7], especially when they include the success of emerging and small players in the market. Consolidation of larger economic units [CWANA Chapter 1; Global Chapter 3; NAE Chapters 2, 6] can limit agrobiodiversity [Global Chapter 3] and may set too narrow an agenda for research [Global Chapters 2, 5]. This trend might be slowed through broadening opportunities for research responsive to local needs.

The rise of IPR frameworks since the 1970s, and especially the use of patents since 1980, has transformed research in and access to many products of biotechnology [Global Chapter 2; NAE Chapter 2]. Concerns exist that IPR instruments, particularly those that decrease farmers' privilege, may create new hurdles for local research and development of products [Global Chapters 2, 6; SSA Chapter 3]. It is unlikely, therefore, that over regulation per se inhibits the distribution of products from modern biotechnology because even if safety regulations were removed, IPR would still likely be a significant barrier to access and rapid adoption of new products. This may also apply to the future development of new GM crops among the largest seed companies, with costs incurred to comply with IP requirements already exceeding the costs of research in some cases [Global Chapters 6, 7].

Products of biotechnology, both modern and conventional, are frequently amenable to being described as IP and increasingly being sold as such, with the primary holders of this IP being large corporations that are among those most capable of globally distributing their products [Global Chapter 2]. Even under initiatives to develop "open source" biotechnology or return some IP to the commons, the developers may have to adequately document the IP to prevent others from claiming it and restricting its use in the future.

This ability to develop biotechnologies to meet the needs of IP protection goals may undervalue the past and present contribution by farmers and societies to the platform upon which modern biotechnology is built [ESAP Chapter 5; Global Chapters 2, 6, 7]. It is not just the large transnational corporations who are interested in retaining control of IP. Public institutions, including universities, are becoming significant players and in time, holders of TLK may also [Global Chapter 7].

IP protected by patents can be licensed for use by others. Currently it is contracts and licenses [Global Chapter 2] that dominate the relationship between seed developers and farmers [Global Chpater 2]. For example, farmers and CGIARs enter into contracts and material transfer agreements (MTAs) with a seed company, or a community-based owner of TK. These contracts can help resolve some access issues, but can simultaneously create other legal and financial problems that transcend easy fixes of patent frameworks alone [Global Chapters 2, 5].

Technical and Intensification Issues

Since agriculture (excluding wild fisheries) already uses nearly 40% of the Earth's land surface [Global Chapter 7], biotechnology could contribute to sustainability and development goals if it were to help farmers of all kinds produce more from the land and sea already in use, rather than by producing more by expanding agricultural land [SSA Chapter 1]. In addition to meeting future food needs, agriculture is increasingly being considered as an option to meet energy needs [Global Chapter 6], which exacerbates the pressures on yield [ESAP Chapter 5]. Food security, however, is a multi-dimensional challenge, so the demands on biotechnology in the long term will extend far beyond just increasing yield [NAE Chapter 6, SDM].

Agroecosystems

How agriculture is conducted influences what and how much a society can produce. Biotechnology and the production system are inseparable, and biotechnology must work with the best production system for the local community [ESAP Chapter 5]. For example, agroecosystems of even the poorest societies have the potential through ecological agriculture and IPM to meet or significantly exceed yields produced by conventional methods, reduce the demand for land conversion for agriculture, restore ecosystem services (particularly water), reduce the use of and need for synthetic fertilizers derived from fossil fuels, and the use of harsh insecticides and herbicides [Global Chapters 3, 6, 7]. Likewise, how livestock are farmed must also suit local conditions [CWANA Chapter 1]. For example, traditional "pastoral societies are driven by complex interactions and feedbacks that involve a mix of values that includes biological, social, cultural, religious, ritual and conflict issues. The notion that sustainability varies between modern and traditional societies needs to be" generally recognized [Global Chapter 6]. It may not be enough to use biotechnology to increase the number or types of cattle, for instance, if this reduces local genetic diversity or ownership, the ability to secure the best adapted animals, or they further degrade ecosystem services [CWANA Chapters 1, 5; Global Chapter 7].

Agroecosystems are also vulnerable to events and choices made in different systems. Some farming certification systems, e.g., organic agriculture, can be put at risk by GMOs, because a failure to segregate them can undermine market certifications and reduce farmer profits [Global Chapter 6]. Seed supplies and centers of origin may be put at risk when they become mixed with unapproved or regulated articles in source countries [Global Chapter 3].

Trees and crops

Plant breeding and other biotechnologies (excluding transgenics discussed below) have made substantial historical contributions to yield [Global Chapter 3]. While yield may have "topped out" under ideal conditions [Global Chapter 3], in developing countries the limiting factor has been access to modern varieties and inputs instead of an exhaustion of crop trait diversity [Global Chapter 3], and therefore plant breeding remains a fundamental biotechnology for contributing to sustainability and development goals.

Biotic and abiotic stresses, e.g., plant pathogens, drought and salinity, pose significant challenges to yield. These challenges are expected to increase with the effects of urbanization, the conversion of more marginal lands to agricultural use [SSA Chapter 1], and climate change [CWANA Chapter 1; Global Chapter 7; SSA Chapter 1]. Adapting new cultivars to these conditions is difficult and slow, but it is again plant breeding perhaps complemented with MAS, that is expected to make the most substantial contribution [Global Chapters 3, 6]. Genetic engineering also could be used to introduce these traits [Global Chapter 5; NAE Chapter 6]. It may be a way to broaden the nutritional value of some crops [ESAP Chapter 5]. If GM crops were to increase productivity and prevent the conversion of land to agricultural use, they could have a significant impact on conservation [Global Chapter 5]. However, the use of some traits may threaten biodiversity and agrobiodiversity by limiting farmers' options to a few select varieties [ESAP Chapter 5; Global Chapters 3, 5, 6].

Breeding capacity is therefore of great importance to assessments of biotechnology in relation to sustainability and development goals [NAE Chapters 4, 6]. In developing countries, public plant breeding institutions are common but IP and globalization threaten them [Global Chapters 2, 6]. As privatization fuels a transfer of knowledge away from the commons, there is a contraction both in crop diversity and numbers of local breeding specialists. In many parts of the world women play this role, and thus a risk exists that privatization may lead to women losing economic resources and social standing as their plant breeding knowledge is appropriated. At the same time, entire communities run the risk of losing control of their food security [CWANA Chapter 1; Global Chapter 2].

Plant breeding activities differ between countries, so public investment in genetic improvement needs to be augmented by research units composed of local farming communities [Global Chapters 2, 6]. In addition, conflicts in priorities, that could endanger *in situ* conservation as a resource for breeding, arising from differences in IP protection philosophies need to be identified and resolved [Global Chapter 2]. For example, patent protection and forms of plant variety protection place a greater value on the role of breeders than that of local communities that maintain gene pools through *in situ* conservation [Global Chapter 2]. It will be important to find a new balance between exclusive access secured through IPR or other instruments and the need for local farmers and researchers to develop locally adapted varieties. It will be important to maintain a situation where innovation incentives achieved through IPR instruments and the need for local farmers and researchers to develop locally adapted varieties are mutually supportive. Patent systems, breeders' exemptions and farmers' privilege provisions may need further consideration here [Global Chapter 2]. An important early step may be to create effective local support for farmers. Support could come from, for example, farmer NGOs, where appropriate, to help develop local capacities, and advisers to farmer NGO's to guide their investments in local plant improvement. Participatory plant breeding, which incorporates TK, is a flexible strategy for generating new cultivars using different local varieties. It has the added advantage of empowering the local farmer and women [Global Chapter 2]. A number of *ad hoc* private initiatives for donating or co-developing IP are also appearing [Global Chapter 2], and more should be encouraged.

The decline in numbers of specialists in plant breeding, especially from the public sector, is a worrisome trend for maintaining and increasing global capacity for crop improvement [Global Chapter 6]. In addition, breeding supplemented with the use of MAS can speed up crop development, especially for simple traits [Global Chapter 3; NAE Chapter 6]. It may or may not also significantly accelerate the development of traits that depend on multiple genes [Global Chapter 6]. Provided that steps are taken to maintain local ownership and control of crop varieties, and to increase capacity in plant breeding, adaptive selection and breeding remain viable options for meeting development and sustainability goals [Global Chapter 6; NAE Chapter 6].

Gene flow

Regardless of how new varieties of crop plants are created, care needs to be taken when they are released because through gene flow they can become invasive or problem weeds, or the genes behind their desired agronomic traits may introgress into wild plants threatening local biodiversity [Global Chapter 5]. Gene flow may assist wild relatives and other crops to become more tolerant to a range of environmental conditions and thus further threaten sustainable production [Global Chapters 3, 6]. It is important to recognize that both biodiversity and crop diversity are important for sustainable agriculture. Gene flow is particularly relevant to transgenes both because they have tended thus far to be single genes or a few tightly linked genes in genomes, which means that they can be transmitted like any other simple trait through breeding (unlike some quantitative traits that require combinations of chromosomes to be inherited simultaneously), and because in the future some of the traits of most relevance to meeting development and sustainability goals are based on genes that adapt plants to new environments (e.g., drought and salt tolerance) [Global Chapter 5].

Transgene flow also creates potential liabilities [Global Chapter 6]. The liability is borne when the flow results in traditional, economic or environmental damage. For example, the flow of transgenes from pharmaceutical GM food crops to other food crops due to segregation failures could introduce both traditional and environmental damage. An important type of potential economic damage arises from the type of IPR instrument used to protect GM but not conventional and plants in some jurisdictions. The former are subject to IP protection that follows the gene rather than the trait, and is exempt from farmer's privilege provisions in some plant variety protection conventions [Global Chapter 6].

GMOs and chemical use

There is an active dispute over the evidence of adverse effects of GM crops on the environment [Global Chapter 3 vs. NAE Chapter 3]. That general dispute aside, as GM plants have been adopted mainly in high chemical input farming systems thus far [Global Chapter 3], the debate has focused on whether the concomitant changes in the amounts or types of some pesticides [Global Chapter 2; NAE Chapter 3] that were used in these systems prior to the development of commercial GM plants creates a net environmental benefit [Global Chapter 3]. Regardless of how this debate resolves, the benefits of current GM plants may not translate into all agroecosystems. For example, the benefits of reductions in use of other insecticides through the introduction of insecticide-producing (Bt) plants [NAE Chapter 3] seems to be primarily in chemically intensive agroecosystems such as North and South America and China [Global Chapter 3].

Livestock and aquaculture to increase food production and improve nutrition

Livestock, poultry and fish breeding have made substantial historical and current contributions to productivity [Global Chapters 3, 6, 7]. The key limitation to productivity increases in developing countries appears to be in adapting modern breeds to the local environment [CWANA Chapter 5; Global Chapter 3]. The same range of genomics and engineering options available to plants, theoretically, apply to livestock and fish [Global Chapters 3, 6; NAE Chapter 6]. In addition, livestock biotechnologies include artificial insemination, sire-testing, synchronization of estrus, embryo transfer and gamete and embryo cryopreservation, and new cloning techniques [see CWANA Chapter 5; Global Chapter 6; NAE Chapter 6 for a range of topics].

Biotechnology can contribute to livestock and aquaculture through the development of diagnostics and vaccines for infectious diseases [Global Chapter 6; NAE Chapter 6], transgenes for disease resistance [Global Chapter 3] and development of feeds that reduce nitrogen and phosphorous loads in waste [Global Chapter 3]. Breeding with enhanced growth characteristics or disease resistance is also made possible with MAS [Global Chapter 3; NAE Chapter 6]. As with plants, the difficulty with breeding animals is in bringing the different genes necessary for some traits together all at once in the offspring. Animals with desired traits might be more efficiently selected by using genomic maps to identify quantitative traits and gene x environment interactions.

There are currently no transgenic livestock animals in commercial production and none likely in the short term [Global Chapter 6]. Gene flow from GM fish also may be of significant concern and so GM fish would need to be closely monitored [CWANA Chapter 5; Global Chapter 3]. Assessing environmental impacts of GM fish is even more difficult than for GM plants, as even less is known about marine ecosystem than about terrestrial agroecosystems.

Ways Forward

Biotechnology must be considered in a holistic sense to capture its true contribution to AKST and achieving development and sustainability goals. On the one hand, this may be resisted because some biotechnologies, e.g., genetic engineering, are very controversial and the particular controversy can cause many to prematurely dismiss the value of all biotechnology in general. On the other hand, those who favor technologies that are most amenable to prevailing IP protections may resist broad definitions of biotechnology, because past contributions made by many individuals, institutions and societies might undermine the exclusivity of claims.

A problem-oriented approach to biotechnology R&D would focus investment on local priorities identified through participatory and transparent processes, and favor multifunctional solutions to local problems [Global Chapter 2]. This emphasis replaces a view where commercial drivers determine supply. The nature of the commercial organization is to secure the IP for products and methods development. IP law is designed to prevent the unauthorized use of IP rather than as an empowering right to develop products based on IP. Instead, there needs to be a renewed emphasis on public sector engagement in biotechnology. It is clearly realized that the private sector will not replace the public sector for producing biotechnologies that are used on smaller scales, maintaining broadly applicable research and development capacities, or achieving some goals for which there is no market [CWANA Chapter 5; Global Chapters 5, 8]. In saying this, an IP-motivated public engagement alone would miss the point, and the public sector must also have adequate resources and expertise to produce locally understood and relevant biotechnologies and products [CWANA Chapter 1].

A systematic redirection of AKST will include a rigorous rethinking of biotechnology, and especially modern biotechnology, in the decades to come. Effective long-term environmental and health monitoring and surveillance programs, and training and education of farmers are essential to identify emerging and comparative impacts on the environment and human health, and to take timely counter measures. No regional long-term environmental and health monitoring programs exist to date in the countries with the most concentrated GM crop production [Global Chapter 3]. Hence, long-term data on environmental implications of GM crop production are at best deductive or simply missing and speculative.

While climate change and population growth could collude to overwhelm the Earth's latent potential to grow food and bio-materials that sustain human life and well being, both forces might be offset by smarter agriculture. Present cultivation methods are energy intensive and environmentally taxing, characteristics that in time both exacerbate demand for limited resources and damage long term productivity. Agroecosystems that both improve productivity and replenish ecosystem services behind the supply chain are desperately needed. No particular actor has all the answers or all the possible tools to achieve a global solution. Genetically modified plants and GM fish may have a sustainable contribution to make in some environments just as ecological agriculture might be a superior approach to achieving a higher sustainable level of agricultural productivity.