19 Hungry for innovation: pathways from GM crops to agroecology

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Innovation's potential to deliver food security and solve other agriculture-related problems is high on the agenda of virtually all nations. This chapter looks at two different examples of food and agricultural innovation: genetically modified (GM) crops and agroecological methods, which illustrate how different innovation strategies affect future agricultural and social options.

GM crops are well suited to high-input monoculture agricultural systems that are highly productive but largely unsustainable in their reliance on external, non-renewable inputs. Intellectual property rights granted for GM crops often close down, rather than open up further innovation potential, and stifle investment into a broader diversity of innovations allowing a greater distribution of their benefits.

Science-based agroecological methods are participatory in nature and designed to fit within the dynamics underpinning the multifunctional role of agriculture in producing food, enhancing biodiversity and ecoystem services, and providing security to communities. They are better suited to agricultural systems that aim to deliver sustainable food security than high external input approaches. They do, however, require a broader range of incentives and supportive frameworks to succeed. Both approaches raise the issue of the governance of innovation within agriculture and more generally within societies.

The chapter explores the consequences of a 'top-down transfer of technology' approach in addressing the needs of poor farmers. Here innovation is often framed in terms of economic growth in a competitive global economy, a focus that may conflict with efforts to reduce or reverse environmental damage caused by existing models of agriculture, or even deter investment into socially responsible innovation.

Another option explored is a 'bottom-up' approach, using and building upon resources already available: local people, their knowledge, needs, aspirations and indigenous natural resources. The bottom-up approach may also involve the public as a key actor in decisions about the design of food systems, particularly as it relates to food quality, health, and social and environmental sustainability.

Options are presented for how best to answer consumer calls for food quality, sustainability and social equity in a wide sense, while responding to health and environmental concerns and securing livelihoods in local small-scale agriculture. If we fail to address the governance of innovation in food, fibre and fuel production now, then current indications are that we will design agriculture to fail.

19.1 Introduction

Would it not be a loss to humanity if society's science and policy institutions delivered wonderfully sophisticated technological tools for agricultural innovation, but yet were out of touch with the needs for food security, poverty alleviation and ecological sustainability? In agriculture, as in other industries, research and development is guided by innovation policies. Within these policies, the incentive systems set at the highest levels of policymaking largely determine who is innovative and what innovative products will look like. They also favor those who will most benefit. Under the current innovation policies for industrial agriculture, continuous increases in wealth, sufficient food production to more than feed the current population, and ongoing investment in particular kinds of research and technology fail nearly a billion people who are undernourished or hungry, well above Millennium Development Goals (FAO, 2010, 2011a). Has modern agriculture, despite good intentions, been unwittingly designed to fail?

A confluence of issues surround agriculture and its existing problems: Ongoing societal and trade issues, food price volatility (FAO, 2008), inefficient energy utilisation, harvesting/storage and production systems (Nellemann, 2009) as well as retail/consumer level waste (Gustavsson, 2011) to name a few. These challenges are building on decades of environmental degradation from high-external input farming, and centuries of environmental damage from inefficiencies within traditional farming that have exacerbated social inequities (IAASTD, 2009a). The extent of these environmental and social consequences of current agricultural practices in food-wealthy and food-poor countries alike means that food production must be rethought in order to achieve greater resilience and sustainability within these systems. The new goal for agricultural innovations is a transition towards social, economic, and environmental sustainability that can support needed production levels (De Schutter, 2010; EU-SCAR, 2011; UNEP, 2011).

Scientific and technological advances within agriculture have the potential to alleviate hunger and increase food security, particularly where food productivity and sustainability are solely limited by simple technical issues or their availability, rather than by institutional or societal constraints (Heinemann, in press). Science and technology have the capacity to produce valuable outcomes from investments in research and development. However, the efficacy of innovation is more than merely invention; it must also meet real needs and be effectively accessed, supported and adopted by farmers who, like retailers, consumers and community members must share in the benefits.

Agriculture is multifunctional (IAASTD, 2009a). It provides food, fibres and fuel for local and international needs, income for producers who purchase education, health and consumer goods, calories and nutrients for families, and cultural and social identity. Through its practice skills are transferred and developed, biodiversity and greenhouse gas emissions are changed — depending on how agriculture is practiced (Hoffman, 2011; IAASTD, 2009c). However, food production remains local. Local needs must be met through both technological and non-technological advances which can be adapted to fit local conditions through ongoing innovation (Altieri, 2011b; Vanloqueren, 2009).

In the global context, the policy focus on agricultural development and food production is shifting from 'how much' through to 'how long' to just 'how'. Some see the problem as not enough production to feed the world. Others note that we have a global food surplus, but the lack of good infrastructure, conflicts and appropriate tools for local farmers cause food shortages and insecurity in many places (MEA, 2005).

Even other commentators see farmers no longer as producers of food, but more accurately of biomass, as part of an economic system that can vary the usage of this biomass as human food, animal feed, biomaterial or biofuels (Pengue, 2005a). Competition among different markets (for energy, industrial products, food production or animal fodder) is creating further constraints on food availability in some parts of the world. Moreover, with the predominant food production practices, there are also concerns that current demands on yields require an unsustainable level of environmentally damaging external inputs of agrochemicals and supply of exogenous energy. For example, industrial agricultural practices on average require 10 calories of exogenous energy (used for everything from petrochemical production, extraction, transport etc.) for every 1 calorie of food produced (Giampietro, 1993; UNEP, 2011). Growing populations, competing demands for crop biofuels and demand for meat will continue to intensify these pressures on agricultural food production. This insight draws us full circle: food security will follow not only from producing more food, but how we produce and consume it (IAASTD, 2009c).

The role of innovation to end food insecurity and solve other problems caused by, and for, agricultural is high on the agenda of virtually all nation states. More and more frequently, governments are framing innovation as a means for economic competitiveness by using the promise of returns on intellectual property (IP) as incentive for both public and private innovators (Heinemann, 2009). As a result, those that innovate by inventing technologies — mainly products — that can be commodified in a form that meets the criteria for IP instruments, e.g. patents or patent-like plant variety protections, are incentivised by the prospect of financial rewards. Moreover, the problems identified for solution will tend to be those that can be packaged and sold — usually to the largest/wealthiest/most lucrative market and largely bypass the poor (Spielman, 2007). This was perhaps the most evident early warning of the so called 'Green Revolution', where supplying technological product packages of seed and agrochemical inputs for monocultures on large tracts of land in some developing countries would increase yields and production for cash crops (e.g. in Asia but not Africa), but would prove to be incompatible with the cultural and social structures surrounding farming practices in many places that it was implemented (e.g. Africa). Indeed, its successes for decreasing hunger and malnutrition was a useful stop-gap solution, yet has not shown to be a sustainable approach for contributing to local food security or diet diversity for resource-poor small tract farmers or generate sufficient surplus income for many to be a path out of poverty (IAASTD, 2009b). Meeting these needs for a healthy and diverse diet would require the development of locally adapted varieties that are tailored to local environments, agricultural practices and needs for a range of nutrient dense foods from local food crops (Reynolds, 2006). 'Although the world food system provides an adequate supply of protein and energy for over 85 % of people, only two-thirds have access to sufficient dietary micronutrients. The supply of many nutrients in the diets of the poor has decreased due to a reduction in diet diversity resulting from increased monoculture of staple food crops (rice, wheat and maize) and the loss of a range of nutrient dense food crops from local food systems.' (IAASTD, 2009d).

Those who might invest in research or invent solutions that are not derived from a technology or technological process leading to a product that can be licensed under existing IP instruments are often left out of the innovation development and support system. Instead of a view of agricultural innovation focused on seed products from genetic improvement or developing external inputs, the neglected innovations are often locally adaptable practices and services related to complex and dynamic ecological processes that do not lend themselves to commodification—at least not in the way current IP instruments require—but are transferable knowledge that can undergo further innovation at the local level by the end user. A good example of this is the 'push-pull' systems developed at the ICIPE in Kenya (Cook, 2006; Hassanali, 2008).

For this case study on innovation, we have chosen to contrast genetically modified (GM) crops and agroecological methods as two examples of innovation outputs and strategies that have very different outcomes in the way we produced food. We illustrate how these contrasting innovation strategies shape, and in some cases limit, future social options. The former is driven by production goals and short-term profit maximisation incentives, where the predominant types of GM crops developed thus far are economically profitable within a system of high-input industrialised monoculture that is largely unsustainable in its reliance on external, non-renewable inputs. In such systems, economies of scale allow the farmer to outweigh the higher costs of production of such farming practices (1). The latter innovation strategy, based on an understanding of co-evolution and dynamics at ecological and social levels of agriculture, is better suited to agricultural systems that are in transition to sufficient production and socio-ecological sustainability, and requires a broader range of incentives and shelters to succeed (Tilman, 2002). That is, agroecological systems may be better suited than the current practice with GM crops to answer the call from affluent consumers for food quality, sustainability and social equity in a wide sense, responding to health and environmental concerns as well as securing livelihood in local small-scale agriculture. These issues may be crucial for the future of diverse agricultural practices needed to address improvements to the resilience and sustainability of agricultural systems. If we fail to address the governance of innovation in food and fibre production now, then current indications are that we will surely design agriculture to fail.

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(1) While hypothetically not all GM crops would necessarily require high-input or monoculture farming methods, their development to date has focused on 'technology traits' amenable to agricultural practices focused on high-input and monoculture production methods.

19.2 Innovation: what kinds and for whom?

Agriculture has not escaped the wave of new policies behind the banner of 'innovation'. The European Commission (EC) is running the 'Innovation Union' campaign (EC, 2011). The explicit claim is that innovation 'speeds up and improves the way we conceive, develop, produce and access new products, industrial processes and services. It is the key not only to creating more jobs, building a greener society and improving our quality of life, but also to maintaining our competitiveness on the global market.' The EC further endorses innovation as a means for stimulating economic growth investment in knowledge generation where 'innovative ideas that can be turned into new marketable products and services help create growth and quality jobs' (EU-Council, 2011). Similar initiatives and campaigns will be found in most developed and developing countries (Kiers, 2008) (2).

How innovation is conceived shapes how it is promoted, and who benefits from the promotion. The EC sees 'expensive patenting, market fragmentation, slow standard-setting and skills shortages' as barriers to innovation because they 'prevent ideas getting quickly to market' (van den Hove, 2011). This preoccupation with how efficiently technology products flow from knowledge holders to technology users is what Altieri (2002) called the 'top-down transfer-of-technology approach' in the context of addressing the needs of poor farmers. Here innovation is often framed in terms of economic growth in a competitive global economy, a focus that may conflict with efforts to reduce or reverse environmental damage caused by existing models of agriculture, or even disincentivise investment into socially responsible innovation (Tilman, 2002). This is an aspect deserving of representation in European innovation discourses, policies, and actions (van den Hove, 2012).

Kiers et al. (Kiers, 2008) argue for a more comprehensive approach to innovation: '[i]nnovation is more than invention. Success is not based on technological performance in isolation, but rather how technology builds knowledge, networks and capacity…innovation demands sophisticated integration with local partners'. This emphasis on the appropriateness of the technology for the target user is what Altieri (2002) called 'a 'bottom-up' approach, using and building upon the resources already available: local people, their knowledge and their autochthonous natural resources. It must also seriously take into consideration, through participatory approaches, the needs, aspirations and circumstances of smallholders'. The bottom-up approach also may involve the public as a key actor in decisions in the design of food systems, particularly as it relates to food quality, health and environmental sustainability.

Either pathway could lead to policy decisions to drive efficiencies in food production, lower food costs through increased supply, and become a means out of poverty. Where these pathways differ is in *who is considered the critical innovator and thus who should primarily benefit from innovation policies*. The key innovator in the top-down approach is usually a specialist technology producer, such as an agroindustrial company that builds technologies optimised for a specific type of farming system that shape the agroecosystems in which they are to be applied. For example, the use of herbicide tolerant GM plants coupled with the application of a specific herbicide creates a type of farming suited towards low agrobiodiversity and high capital inputs (e.g. multi-row spraying equipment) to maximise efficiency, and demands a scale investment and specialised farmer. However, this approach is incompatible with the available resources and needs of the subsistence and small farmer (see Box 19.1), the key innovator in the bottom-up approach and the target of strategies to feed the world through local production (IAASTD, 2009a). Bottom-up approaches place emphasis on the ability of the small-scale farmer to innovate to address critical local needs.

Will the predominant top-down approaches to agricultural innovation— and the science policies and legal instruments which support them — be better pathways to achieving the Millennium Development Goals, namely, to sustainably feed the world nutritious and desirable food, and through the production of this food, provide pathways out of poverty for the poor? Or might there be alternative strategies better suited to meeting these needs?

Our focus here will be whether top-down innovation produces the necessary benefits to small-scale farmers as well as income- and food-insecure countries as has been claimed. And in this attempt to create a consistent set of common regulatory and market incentives

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(2) For example, New Zealand defines it this way: 'Innovation is defined as the introduction of any new or significantly improved goods, services, processes, or marketing methods' (see Statistics-NZ, 2012).

Box 19.1 Herbicide tolerant GM crops: a technology for developing country agriculture?

Starting in the 1990s, the agroecosystems adopting herbicide tolerant GM crops simplified weed management through a near exclusive reliance on a single agrochemical product ('Roundup'), with its active ingredient glyphosate. The Roundup and Roundup-tolerant GM crop package promises lower labour costs through a simplified weed management strategy. It is also compatible with no-till practices that can reduce soil erosion (Duke, 2008).

These advantages are, however, disappearing (Service, 2007; Pengue, 2005b;Benbrook, 2012). Extensive and continuous use of glyphosate with the introduction of GM crops (Powles, 2008) has led a rapid evolution of glyphosate-resistant weeds (Binimelis, 2009; Duke, 2008; Heap, 2012; Heinemann, 2008; NRC, 2010). This has a negative overall effect on sustainability, where minimising the use of external inputs such as agrochemicals is key. Since glyphosate tolerance can be overcome by using more glyphosate, farmers have entered into a treadmill where overuse of a single product leads to tolerance and tolerance is overcome with more product, leading to ever higher levels of tolerance in weeds and an increase in the number of species that display tolerance (Binimelis, 2009; Duke, 2008; NRC, 2010). In some cases, farmers are returning to tilling and using other (and possibly more toxic) herbicides (Binimelis, 2009; Duke, 2005; Heinemann, 2008b; Mortensen, 2012). Further, indications of harm stemming from the widespread and intensive use of glyphosate for the environment and human health has been documented in the scientific literature and remains a concern (Greenpeace, 2009; Séralini 2012).

The herbicide-GM crop package is not compatible with how most people farm, and especially with small and subsistence farming practices. The package is most economical when herbicide can be sprayed in great quantities using mechanised delivery (e.g. airplanes) or expensive, multi-row sprayers and this would not be possible in a mixed cropping landscape (Binimelis, 2009).

Moreover, this top-down solution to the problem of weeds threatens long-term retention of alternative weed control skills. 'Although seed and chemical companies can generate enormous revenues through the packaged sales of herbicides and trans- genic seeds, the [integrative weed management] approaches… are based on knowledge-intensive practices, not on saleable products, and lack a powerful market mechanism to push them along' (Mortensen, 2012). The farming system is 'deskilling' and losing the know-how to implement other pest management approaches (Binimelis, 2009). A second problem with this package is that it is encouraging the expansion of damaging agricultural practices. For example mixed agriculture/animal husbandry instead would require animal production further out into marginal lands or necessitate clearing new lands and accelerating rates of deforestation (Morello, 2007).

A bottom-up innovation for addressing weed problems is integrative weed management (IWM). The advantages of this system are that it uses, maintains and improves local knowledge of weed dynamics and ecology to develop multiple weed management approaches (Liebman, 2001) and is affordable to poor farmers. 'IWM integrates tactics, such as crop rotation, cover crops, competitive crop cultivars, the judicious use of tillage, and targeted herbicide application, to reduce weed populations and selection pressures that drive the evolution of resistant weeds' (Mortensen, 2012). IWM improves agrobiodiversity conservation, soil-quality, on farm energy efficiency — all of which enhance a more multifunctional system of agriculture that produce important environmental services (Boody, 2005). Farmers benefit from the same high yields and profits (Anderson, 2010; Liebman et al., 2008; Pimentel, 2005). Further, the soil-building under IWM helps to achieve conservation goals and improves soil quality even above no-till approaches based on herbicides (Venterea, 2006). This does not cause resistance problems of the magnitude seen with simplified chemical controls (Davis, 2007).

'Stacking additional herbicide tolerance genes into existing plants is not an alternative to IWM or other pest management strategies. They are likely to undermine sustainable agriculture further because 'the new traits will encourage continued neglect of public research and extension in integrated weed management' (Mortensen, 2012).

The transfer of herbicide tolerant GM crops to poor farmers, which has demonstrated not to be a sustainable approach for addressing the needs of developed country agriculture, appears to be another example of a top-down approach that has not, and will not produce the beneficial outcomes for the poor farmer (Heinemann, 2008b). However, there are already viable bottom-up approaches; all that is lacking is the political will and institutional capacity to make them available.

Box 19.1 Herbicide tolerant GM crops: a technology for developing country agriculture? (cont.)

Finally, the adoption of these crops is not leading to uniform or sustainable increases in income for farmers (Botta, 2011). The highest yielding varieties of GM crops are so because of ongoing and intensive genotype improvement through traditional breeding, rather than through the development of genetically engineered traits (Gurian-Sherman, 2009). Even in the most mature GM agroecosystems, such as cotton plantations in the US south, GM-farmers have not enjoyed a net economic benefit for adopting these plants compared to other high yield varieties (Jost, 2008). The high rent of patent-protected seeds is an upfront cost to farmers who may not realise a benefit from the trait each year, or would have to purchase other inputs, such as expensive agrochemicals, to gain any benefit. Here again, especially for poor farmers, those initial costs can be too high (Delmer, 2005).

(itself a top-down approach) if it in tandem will be suited to promoting the kind of innovation needed in countries with conditions favouring small-scale farms as well as those that are poor and food insecure. Building on the late lessons from prior top-down innovations in agriculture, we find that the promise of this approach to deliver the expected benefits will continue to be elusive when the pace and scale of innovations are prioritised over considerations for the intertwined institutional, governance and societal issues. Critically, innovation pathways that do not include such considerations may condition innovation directions, diversity and distribution away from the very kinds of innovation that are best adapted to meet local needs (STEPS, 2010). With this in mind, the lure of short-term wealth production from predominantly productivist frameworks for innovation must be re-balanced with those that prioritise long-term goals for sustainability — including financial sustainability and nutritional goals of small and subsistence farmers. This means supporting not just innovations which create new technology, but also those that create social good by addressing the non-technological, social, institutional, organisational and behavioural aspects along with new technology (van den Hove, 2012).

There is increasing evidence that the top-down approach to innovation will not achieve the expected stimulus to innovation (Baldwin, 2011), where an approach reliant on private incentives (primarily through IP protections) may actually have a negative effect on the progress in certain fields, including biotechnology (Murray, 2007).

19.3 GM crops as a top-down path out of poverty and hunger

The use of genetic engineering to produce commercially viable GM agricultural products is so far and for the foreseeable future restricted to crop plants (Heinemann, 2009). The crops are predominantly cotton, maize, rapeseed (canola) and soybeans (3) (James, 2011). Despite more than 30 years of research and development and nearly 20 years of commercialisation of GM crops, surprisingly only two traits have been significant in the marketplace — herbicide tolerance and insecticide production. And they are grown at scale only in a small number of countries. Industry-derived figures (James, 2011) report a large number of global hectares under GM cultivation, but when examined by country indicate an uneven global commitment to GM crops. The five countries USA, Brazil, Argentina, India and Canada account for 91 % of the global GM crop production, with the next five largest GM-cultivating countries accounting for another 8 %, leaving a total of 1 % of all GM acreage produced annually among just seven other countries. The proportion of agricultural land with GM varied from < 1 % to 17 % per country (Figure 19.1). These 17 so-called GM 'mega-countries' combined had 159 million hectares under GM cultivation in 2011 — seemingly a large figure, but in reality is just 3 % of the world's agricultural land (Figure 19.2). Some crop types have been converted entirely (or effectively entirely) to GM production in some countries. For example, nearly 100 % of the soybean crop in Argentina and the US is GM, sugarbeet in the US, and cotton in India at the present time is almost exclusively GM.

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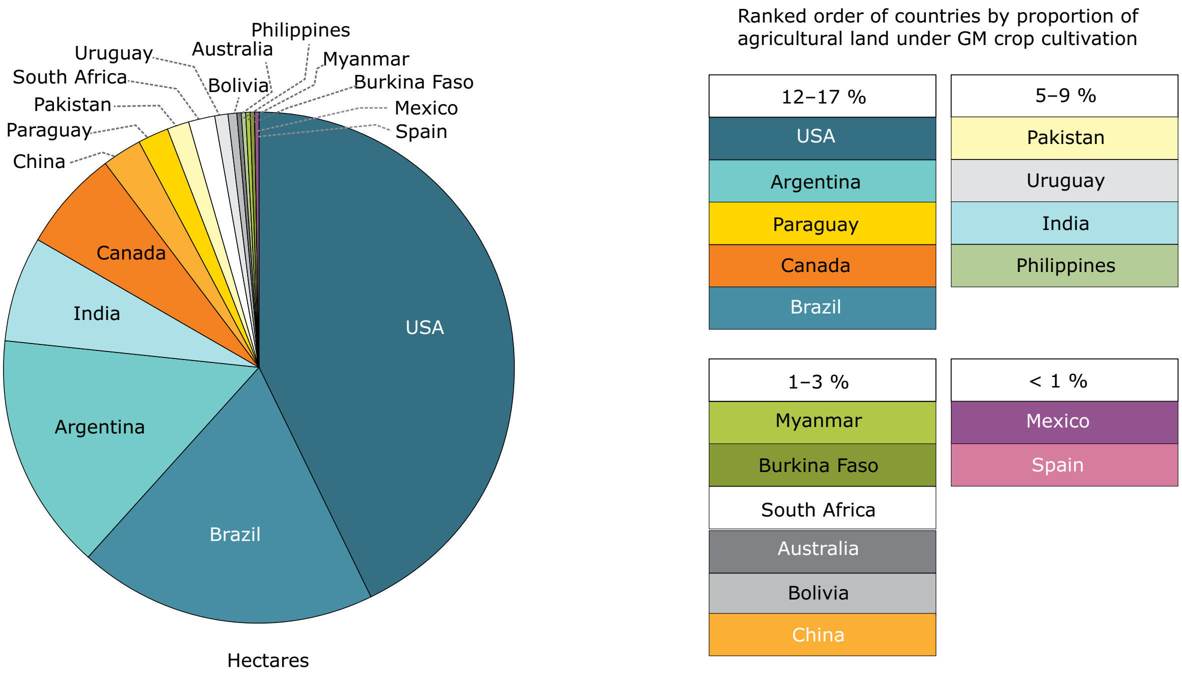
(3) However GM papaya, sugar beet and possibly alfalfa are grown commercially in the US, with tomato and peppers reported in China yet at very low levels.

Figure 19.1 Ranked commitments to GM by the 17 largest producing countries



Note: Left: Countries range from a high of 69 million (USA) to < 50 000 hectares. Lowest level shown in graph is Spain at an industry estimated 100 000 hectares.

Right: Countries range from a high of 17 % (USA, Argentina) to under 1 % conversion from conventional to GM plants in commercial production. The rankings by proportion differ from the rankings by absolute number of hectares showing significantly different commitments to GM for primary production.

Source: GM hectares data taken from the industry source ISAAA (James, 2011). Agricultural land values taken from FAOSTAT (FAOSTAT, 2012).

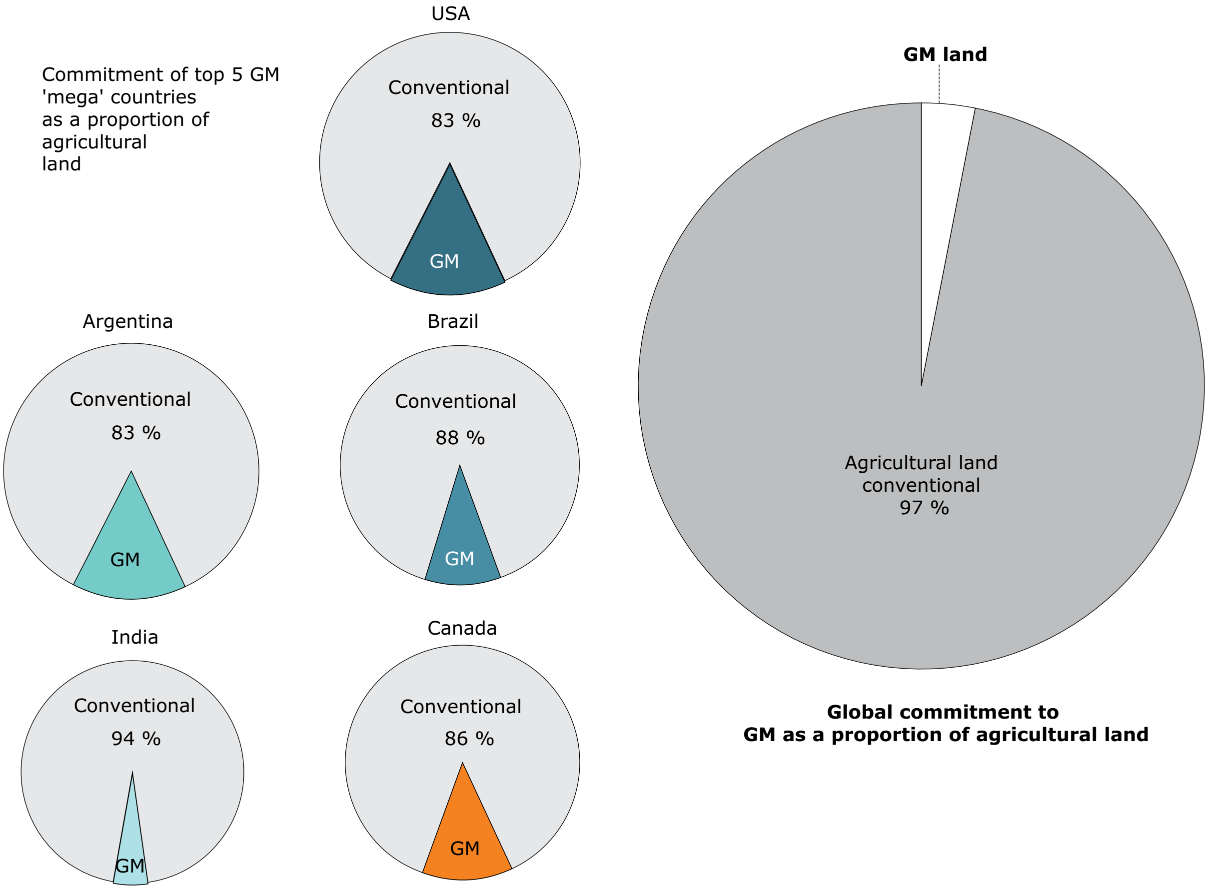
Why this patchy and limited global adoption of GM? There are several reasons. First, significant markets of high-income consumers have rejected GM (Gaskell, 2010). Given that the types of crops being commercialised, and the types of traits on offer, provide no direct benefit to consumers and may be introducing unintended adverse effects (see Box 19.2), in some places there exists skepticism on claims of net benefit. The main argument for adoption is the indirect benefits, financial and management-related, that GM crops offer to certain kinds of farmers (Heinemann, 2009).

Among the GM-adopting farmers are usually large-scale commodity growers that cultivate monocultures (e.g. soybeans in Argentina) or are in two-crop rotations (e.g. maize/soy in the US Midwest). The US and other OECD countries produce plenty of food or have the income to purchase it. While their agricultural systems deliver what they need, the OECD agroecosystems rely on heavy taxpayer subsidies to remain viable (Kiers, 2008).

It is perhaps no surprise that GM crops, the paradigmatic examples of top-down products, are most commonly crops that benefit from subsidies, such as maize, soy and cotton in the US (Pechlaner, 2010). These subsidies lead to the second reason for patchy adoption, where their use in developed countries undermines the market for these crops in developing countries. 'The average support to agricultural producers in the major developed countries as percentage of gross value of farm receipts was at 30 % for the period 2003–2005, representing an amount of almost USD 1 billion per day (OECD, 2006). These developed-country agricultural policies cost developing countries about USD 17 billion per year — a cost equivalent to five times the recent levels of ODA [official development assistance] to agriculture' (Hoffman, 2011).

The incentive brought by subsidies give a third reason for patchy adoption. The high rent of GM seeds and associated management inputs, such as proprietary agrochemicals, and other high costs of high external farming, confines these tools for agriculture to countries that redistribute wealth to farming for export, whether rich or poor (Delmer, 2005). Such capital and management intensive

Figure 19.2 Proportion of land in GM production



Note: Left: Charts indicate the proportion of total agricultural land per country in GM cultivation. The 5 countries shown have the highest absolute number of hectares in GM.

Right: Global value of GM production as a function of global agricultural land.

Source: GM hectares taken from the industry source ISAAA (James, 2011). Agricultural land values taken from FAOSTAT (FAOSTAT, 2012).

agricultural practices simply are not well adapted to use by small and subsistence farmers (see Box 19.1).

Poor countries that adopt this export lead are in danger of being caught on a loss leading treadmill where they produce agricultural goods at a net social loss and must continue to bear this debt as agriculture becomes a leading source of export income (Heinemann, in press; Pengue, 2005b). GM crops have not migrated to countries that have yet to commit to this strategy or are avoiding it, because the upfront costs are too high (Delmer, 2005).

19.3.1 Top-down incentives homogenise tool building

Too often the 'how to feed the world debate' (possibly a shorthand for the Millennium Development Goals) is presented as if it were an either/or choice between genetic engineering and agroecological science (Marris, 2008; Vanloqueren, 2009). Advocates for or against these technologies often are distinguished by their beliefs on whether it is genes or the environment that is the right substrate to manipulate to improve agriculture.

This dichotomy is in essence artificial, because few when pressed would argue against the relevance of both genotype and environment for meeting agricultural production and sustainability goals. However, there is an underlying truth to this division. The emphasis on genetics, or seed-based tools (Lal, 2009), is an unavoidable outcome of how innovation in the top-down model works. Modifying genotypes and capturing them as IP through plant variety protection and patent instruments is a far easier means of capturing financial benefits than attempting to commodify management-based innovations, such as cover crops, rotation schedules and composting, farmer-initiated training and education and small scale marketing and credit programs. When a singular, centralised and highly specialised approach to agricultural development is followed, such as through genetic engineering, it can stifle other approaches that might produce even more desirable outcomes.

The size of the market available to genotype-manipulated tools may also be larger than for management-based approaches ([4]). Provided that the agroecosystem can be homogenised through the use of external inputs (e.g. fertilisers, agrochemicals), then a small number of varieties based on a proprietary genotype can be sold to a large number of farmers. In contrast, management-based techniques are knowledge- rather than product-intensive and must be customised to the location and often the circumstances of the farmer (e.g. whether irrigated or non-irrigated land, mixed or monocropping, combined crop and livestock production) and thus require more investment relative to the size of the market. Yet the benefits of these investments to promote and sustain management-based agricultural improvements are better distributed because they are not concentrated back to a seed producer. However, these asymmetries in investment incentives mean that management-based approaches do not receive the same levels of support and investment as do approaches that are easily recaptured in the marketplace.

To some degree, however, the environment does offer commercial opportunities through top-down innovation yet even then it comes from selling farmers tools that homogenise the environment to support proprietary genotypes. These tools are usually in the form of external inputs such as fertilisers and agrichemicals. The success of the green revolution was its ability to convert very different lands into similar agroecosystems using external fertilisers and other inputs to achieve high yields, but at great long term environmental costs, fossil fuel consumption and greenhouse gas emissions (Giampietro, 1993; Pretty, 2011; UNEP, 2011). Indeed, the unsustainability of the green revolution shows it will not be the model for future agriculture.

The editor of Nature magazine summed up the duality of genotypic and environmental sources of technology for addressing future needs in agriculture when he said: 'A second green… revolution will require a wholesale realignment of priorities in agricultural research. There is an urgent need for new crop varieties that offer higher yields but use less water, fertilisers or other inputs — created, for example, through long-neglected research on modifying roots — and for crops that are more resistant to drought, heat, submersion and pests. Equally crucial is lower-tech research into basics such as crop rotation, mixed farming of animals and plants on smallholder farms, soil management and curbing waste. (Between one-quarter and one-third of the food produced worldwide is lost or spoiled.)' (Editor, 2010).

That is, the tools and knowledge needed to transform agriculture towards a more sustainable path are not sufficiently prioritised in research and development. The failure of current top-down approaches to deliver on promises of a wide range of trait innovations needed by farmers, for example those that are tolerant to various environmental stresses (i.e. salt tolerance, water stress tolerance) requires a fundamental shift in agricultural innovation priorities towards improvements in genotype and environmental management approaches.

19.3.2 Effects on the knowledge pipeline

At the start of the 21st century public sector spending on agricultural research and development was just under twice the amount spent by the private sector (IAASTD, 2009b). Developing countries invested the majority of public funding at around USD 12 billion per year while high-income countries invested only around USD 10 billion. To see the investment imbalance another way, consider that the Consultative Group on International Agriculture Research, the world's largest international public sector research body, has an annual budget of only 12 % of the combined research and development budgets of the world's 6 largest breeding and genetic engineering companies (Spielman, 2007). Private funding in agricultural research is largely focused on innovations that will allow a high return on that investment to shareholders.

These statistics require deeper analysis to be fully understood. First, the shift in responsibility for agricultural research and development from

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(4) While both classical breeding and genetic engineering are different ways to create plant varieties, the latter creates novelty through the use of modern biotechnology (involving the in vitro manipulation of nucleic acids or fusions across the taxonomic boundary).

public research institutions to the private sector is unequivocal in high-income countries. This shift has profound effects on what comes from innovation. Second, high income countries have cited the need for increasing their economic competitiveness through instituted 'industry-driven' priorities into the research and development spending that they still do, thereby further leveraging the public contribution toward (often privately held) top-down innovation. This compromises the unique function and capacities that public funding supports pro-poor agriculture (Spielman, 2007), which may lack sufficient financial incentives to attract investment from the private sector (Tilman, 2002). Third, much of the existing public funding has direct or indirect ties to industry. Direct ties can take the form of private-public partnerships at universities and indirect ties include preferential relationships with institutions that maintain long-term industry-friendly cooperation (Knight, 2003; Lotter, 2009b; Seabrook, 2011).

Top-down innovation is guided by patent and patent-like plant variety protection (PVP) instruments, many newly applied to agriculture only in the last decades of the 20th century (Heinemann, 2009). Patents 'provide more control since (PVP) certificates have a research exemption allowing others to use the new variety for research purposes' (Fernandez-Cornejo, 2006; Mascarenhas, 2006).

The general argument for this approach is that patent and patent-like IP rights instruments on biotechnology create net social benefits, by encouraging and then capturing wealth for developers whether they be private or public (Pray, 2007). The main limitation here is that such an approach ignores significant effects on the innovation pipeline (Heinemann, 2006b; Kleinman, 2003; Krimsky, 2004; Shorett, 2003b; Wright, 2000) which shift innovation priorities towards economic policies and financial incentives. Leading international institutions have dismissed prevailing IP instruments as agents of constructive economic or food security change in developing countries at least at their stage of development (WHO, 2005; WorldBank, 2007). Furthermore, they impede practices that uphold and improve both food security and sovereignty. For example, seed savings and exchanges have become incompatible with these more severe IP instruments as shown in the conversion of behaviour in the US, and would, if adopted by developing countries, undermine what is now seen as an important source of bottom-up innovation: farmer by farmer breeding and adaptation of germplasm (Bellon, 2011; Borowiak, 2004; Mascarenhas, 2006; WHO, 2005).

The patenting of germplasm is concentrating IP rights-based control of the seed supply under a very small number of multinational corporations (Adi, 2006; Barlett, 2008; Sagar, 2000; Howard, 2009). The consolidation of the seed industry also has resulted in lower competitiveness (Pinstrup-Andersen, 1999) as the 'concentration of the top four' (CR4) seed companies breached a critical threshold (WorldBank, 2007). For example, the UK Parliament now says that:

'The use of patents on genes is controversial. There are concerns that in countries where GM technology is widespread in agriculture, seed companies may have reduced incentives to develop conventional varieties, as the market for these varieties is reduced, and they tend to have weaker IP rights than the patents usually used with GM crops. In the US, this is the case for soy, with conventional breeding now mainly left to universities and to small seed producers who focus on niche markets. The presence of patents may also limit public-sector research in some areas' (POST, 2011).

Is the answer to empower public institutions to secure IP instead? If the goal is to stimulate innovation across the board, history to date indicates that it does not seem to be so. Intriguingly, the flow of IP to the private sector has been fuelled by an unprecedented accumulation of IP claims in biotechnology made by public sector institutions whose behaviour is consistent with top-down innovation models despite their historic public-good role (Graff, 2003). This creates a feedback loop in which the best-funded researchers are those with top-down innovation interests, and they in turn out-compete other researchers — and their possible innovations — from future funding. This loop can decrease bottom-up innovation, even products that would provide much greater benefit. The downstream effects are stifling of public-good knowledge commons, upon which the modern agroecosystems of North America and Europe were initially built, and neglect of the needs of poor and subsistence farmers who are key to feeding the world.

'[F]or scientific knowledge subject to both Open Science and private property institutional regimes, the granting of IP [rights] is associated with a statistically significant but modest decline in knowledge accumulation as measured by forward citations (in academic publications)…Overall, we are able to reject the null hypothesis that IP [rights] have no impact on the diffusion of scientific knowledge… These patterns provide a novel perspective on the economic consequences of the privatisation of the

Box 19.2 GM crops: a late lesson case in the making?

The benefits and harms of GM crops are still being verified, despite there being science-based calls for greater scrutiny concerning the release of genetically engineered organisms from early on in the US FDA (5) (Drucker, 2012) and elsewhere (Traavik, 1999). The literature is accumulating indicators both of inflated benefit claims and of evidence of adverse effects (Bøhn, 2008; Botta, 2011; Hilbeck, 2012; Jost, 2008; Mesnage, 2012; Rosi-Marshall, 2007; Service, 2007). The benefits that may have been overstated are the reduction in pesticide use (Service, 2007), the reduced use of more toxic pesticides (Mesnage, 2012; Séralini, 2009), higher yields (Gurian-Sherman, 2009) and farmer income (Jost, 2008).

While GM crops are not found at scale in many places (see Figure 19.1), because they dominate as commodity crops they can be present at low levels in many types of food and feed, fibres and industrial products. Thus, exposure is global even if production is mainly in a few countries.

At what point is there sufficient evidence to be concerned and take action about the effects of GM crops on human health and the environment? How strong is the evidence of safety vs. risks?

The outcomes of many risk assessment studies equate the conclusions of 'no evidence of harm' to be synonymous with safety. The troubling outcome is that the safety of GM crops is presumed when there is a lack of evidence of harm, as if this were equivalent to evidence of lack of harm, when it clearly is not. Hence many of the safety conclusions arising in risk assessments stating 'no evidence of harm' are assumptions-based, rather than evidence-based, reasoning (Spök, 2004). Critically, when this lower standard of safety assurance is followed, as is the case with the mainstream risk assessment approaches today, important effects may be missed.

Of course, it is plausible that there simply are no effects to be found. Yet, what is the likelihood that the existing risk assessment approaches would capture an adverse effect caused by a particular GM plant? Are there particular challenges to detecting biologically important but difficult to detect effects? If so, what regulatory approaches can help avoid or overcome these challenges?

Emerging from the experience with biosafety research and risk assessment is a number of obstacles and limitations in policy or methodology that can limit or underestimate the detection of potential harms that may be present.

Obstacles to conducting biosafety research

Biosafety research and the safety investigations required for regulatory approval are the two main means for identifying potential adverse effects. However, a number of obstacles may limit or prevent the observation adverse effects in research, if they were indeed occurring:

- Industry contracts with researchers and farmers restrict access to material for safety testing. For example, 26 scientists released a public statement criticising that confidentiality and material transfer agreements made conducting any independent research on GM foods virtually impossible (Pollack, 2009).

- GM innovation research and development is outpacing biosafety research necessary to evaluate for safety. When it comes to research funding for biotechnology (including genetic engineering research), biosafety-related research has been lagging behind. From 1992 to 2002 the USDA disbursed USD 1.8 billion for biotechnology research, yet only approximately 1 % (USD 18 million) of this went to risk-related research (Mellon, 2003).

- Safety interested scientists face tough career choices. Researchers who have published scientific evidence unfavourable to the interests of GM crop developers have experienced personal and professional attacks on their work (Delborne, 2008; Editor, 1999; Waltz, 2009a, 2009b), and in some cases leading to threats or loss of research funding and dismissal (Lotter, 2009a, 2009b).

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(5) FDA Memos. FDA Memos 1991, 1992a and 1992b above are 3 of 24 internal FDA documents obtained through a FOIA (Freedom of Information Act request by the Alliance for Bio-Integrity, see http://www.bio-integrity.org/list.html).

Box 19.2 GM crops: a late lesson case in the making? (cont.)

Risk assessment: barriers to detecting adverse effects
The release of a GM crop into the environment, or for use in feed or food, is preceded in many countries by a pre-market risk assessment. The principles, concepts and methodologies of assessment vary, but most countries use international guidance (e.g. OECD/Codex Alimentarius, Cartagena Protocol on Biosafety) as a basis of their systems. Scientific and other information may also inform the risk assessment or secondary evaluation by expert committees.

Policies can undermine the effectiveness of risk assessment (Pavone, 2011) by allowing risk standards which increase the likelihood that adverse effects, if occurring, would not be identified during the appraisal.

Key examples:

- Many jurisdictions require scientific testing to be done by the developer and supplied to the regulator, who often lacks any capacity to perform independent testing. This lack of independence in the testing sets up the situation of bias in the studies outcomes as a result of 'the funding effect' — where results tend to correlate with the wishes of the funder (Krimsky, 2004). Various research efforts have found that the funding effect reaches well into the public research community and especially into biotechnology (Diels, 2011; Heinemann, 2006a; Shorett, 2003a).

- Often there is a provision to keep secret information that the developer claims is of proprietary value. When regulators agree to keep some information in the risk assessment confidential, review or reproduce the study by independent scientists is prevented (Fontanarosa, 2005). Transparency is a fundamental principle of good science reporting and practice but lacking in many risk assessments (AHTEG, 2012).

- Risk research conducted for the purposes of a risk assessment by the developer often lacks sufficient methodologies to allow statistical rigor that would yield meaningful results. Risk studies with low sample numbers lack statistical power, and bias the outcome towards no observation of differences/effects between treatment groups (for examples, see Marvier, 2002). Further, they might not have been designed to test for potential hazards that the regulator has not asked the developer to test, or to the sensitivity that the regulator might find valuable (Séralini, 2009) or which have long lag time frames (Marvier, 2007).

- The regulator's policies on what to test will also affect what might be found. This approach may miss unintended changes to other gene products or metabolites or the effects of cooking and processing. For instance, applicants are often allowed to use a transgenic protein 'surrogate' (derived from a source other than the transgenic organism for which environmental release or consumption is being sought) in the place of the actual transgenic protein in safety testing from which regulatory approval is sought. Often the protein used in safety testing is that produced in bacteria, which is not going to be released into the environment or used as food — leaving the actual protein produced by the GM plant untested for safety. Since there can be significant biological differences in how the transgenic protein is produced in different hosts (e.g. in plants vs. bacteria), any differences would not be possible to detect (Freese, 2004).

- Currently, no regulatory framework requires mandatory toxicity or allergenicity testing from the consumption (or inhalation, see Kroghsbo 2008) of GM crops or their products. Commonly, only 90-day (usually rat) feeding trials are conducted and conclusions of long-term risk are based on these short-term tests, despite their critical deficiencies in revealing sub-chronic and chronic effects (Séralini, 2009; Spiroux de Vendomois, 2010). Research has indicated the importance of life-time studies for health affects where indications of adverse health impacts only manifested after 120 days (Séralini, 2012).

- A common practice in risk assessment is a comparative approach: the new GM plant is compared to a similar plant to see if there is any evidence of additional potential to cause harm. In actual practice, however, developers will often further include 'reference lines' (usually genetically less similar and grown under different environmental conditions) in the comparison which will expand background variation where any potential signals to be drowned in statistical noise and thusly concluded as 'within the range of biological variation' (Antoniou 2012; Dolezel and Gaugitsch 2009).

Box 19.2 GM crops: a late lesson case in the making? (cont.)

- Ongoing risk assessment may not be benefitting as much as it could from new information, because of a general lack of comprehensive post-release monitoring efforts. As pre-market risk assessments are based on information acquired over short term and/or small scale investigations, they are not designed to capture effects that may occur when exposure is on a larger scale, or for longer time periods, or result from unanticipated interactions with other GM plants post release. While monitoring is mandated in some jurisdictions there is very little information on its effectiveness and no uniformity in design or methodology (Züghart, 2008, 2011; AHTEG, 2012; Heinemann, 2012).

Can the precautionary principle make scientific risk assessments more scientific?
The precautionary principle has been legitimised as an important objective in GMO legislation (e.g. European Union, Cartagena Protocol on Biosafety). Nonetheless, it thus far has mainly been considered as a risk management tool and not part of the scientific risk assessment. While critics of the precautionary principle consider it easily misused as a barrier to trade and the cause of more regulation, this misrepresents how precaution may be appropriately applied. Importantly, precaution has a role to play in the scientific risk assessment itself in two fundamental ways. First, applying precaution within risk assessment practice also means applying more robust scientific standards — that is, the need for precaution and the need for scientific rigor are not incompatible but complementary (Groth, 2000). Second, particularly when testing hypotheses, value judgements within science practice (Funtowicz, 2003; Rudner, 1953) may be informed by precaution, including levels of evidence, directions of error (Brosi, 2009; Lemons, 1997), and by acknowledging and communicating what we know, do not know, and cannot know with existing methodologies (Aslaksen, 2006; Myhr, 2002). The formal acknowledgment of uncertainties and the choice of error type from the risk assessment and their communication to decision-makers are key components of rigorous science-based risk assessment.

Conclusion: avoiding old lessons from earlier late lessons
The critical late lesson that may be emerging from GM crops is not the evidence of harm — the early indications of harm are just emerging — but the persistence of the same institutional patterns that led to the old late lessons already learned from asbestos, benzene and BSE (Harremoes, 2001). In these cases, weak risk assessment standards were implemented that prevented identifying the harm and taking precautionary action. To avoid this old lesson, the appropriate application of the precautionary approach to risk standards would help ensure we are not repeating the same error with GM crops, and thus avoid a late lessons case in the making.

scientific commons. Rather than simply serving to facilitate a 'market for ideas,' IP may indeed restrict the diffusion of scientific research and the ability of future researchers to 'stand on the shoulders of giants,' at least for research of the type published in *Nature Biotechnology*' (Murray, 2007).

This has been a brief review of the predominant top-down innovation models that characterise the main policy developments of wealthier and food rich nations (Heinemann, 2009). We have found that if this framework of innovation for agricultural development is followed, the outcome is likely contrary to the stated objectives to create a global food production capacity that delivers on calories and nutrients to all. It will fail in the long run to produce food security because it does not have the necessary incentives to create resilient and sustainable production systems. If the demands on agriculture are reasonably expanded to include delivery of culturally diverse foods, produced locally by those most in need, and which serves as a path out of poverty, then the top-down innovation models of today are the wrong pathways to achieve it.

In coming to these stark realisations, we do not argue that top-down innovation is irrelevant at all times and in all countries. Indeed, the right mix of innovation is essential. Likewise, seed-based versus environmental approaches both have value in all agroecosystems at all times. The question is more complex. When industries or private providers become out of balance in scale, power or access to information, then one can smother the other. At the heart of it, most farmers are private sector, even if they are feeding themselves with the products of their labour and capital. But there is a difference between the economic scale of the large US farming unit and the farmer, especially the one most prone to hunger, and the one searching for long-term agroecosystem sustainability. Similarly, there is a difference in scale between the university and the multinational corporation, and between both and the farmer. When public institutions must act in a way that is consistent with how companies must act, then the imbalance between farmer and knowledge access grows.

19.4 The bottom-up path towards sustainable farming

A core quality of bottom-up approaches is that they can generate, harness and exchange information and innovation in a multitude of ways that bring users of innovations into the process so that local adaptation and shaping of technologies fit the ecological, socio-cultural and technical dimensions of the system (STEPS, 2010; Wagner, 2007).

Bottom-up innovation is demonstrating its potential to build not just sustainable farming systems, but also sustainable communities through the support of local food production and local markets (Altieri, 2011a; UNEP-UNCTAD, 2008). Discussions on increasing agricultural sustainability tend to put the emphasis on biodiversity, soil and water management and ecological principles to improve productivity and energy efficiency (including reductions in greenhouse gas emissions). This is a specialty of the science of agroecology. Instead of engineering nature to fit into our desired technological system, agroecological innovations fashion our technological solutions to fit nature (Schumacher, 1973) by applying ecological concepts and principles to the design and management of agroecosystems (Altieri, 1995). Agroecology strives to increase the sustainability of agriculture by minimising the use of agrochemical and energy inputs and instead leverage ecological synergisms and interactions between biological components of the agroecosystem to produce their own productivity, crop protection and soil fertility. This type of production system has also been captured as a means for transitioning to more sustainable agricultural practices under the banner of 'green agriculture' (UNEP, 2011).

While this science also values the importance of conventional breeding and genotype optimisation, it tends to address yield problems using management solutions, often through a modification of agricultural practices that remove, rather than adapt to, the problem (Lal, 2009). Biodiversity is important to create greater system resiliency within the agricultural environment (Enjalbert, 2011; Ensor, 2009; Li et al., 2009). Enhancing on-farm biodiversity and soil organic matter can make agriculture more resilient to climate change (drought, flooding, severe weather, and temperature change) and enhance ecosystem services (Hajjar, 2008). In a recent survey, of agricultural productivity after hurricane Mitch in Central America revealed that farms that engaged in agroecological practices such as intercropping, cover crops and agroforestry incurred less damage than neighbouring conventional monoculture farms (Altieri, 2011a). Hence, increasing the adaptive potential of agricultural systems will be vital in the face of global climate change (Bellon, 2011).

We have chosen to use agroecological science (including compatible organic certification schemes) as an example of an outcome of bottom-up innovation because this science is delivering excellent results in the farming systems most in need of innovation (Altieri, 2011b; De Schutter, 2010; FAO, 2011b; Pretty, 2011; UNEP-UNCTAD, 2008 (Khan et al., 2008)). The main feature of the bottom-up approach is that it decentralises solution providers and their solutions, thereby facilitating the transfer of products, services or information that allows continued innovation at the hands, skills and knowledge of the local user. In contrast to top-down approaches, the real innovation potential does not stop with the farmer, but often starts there. In addition, consumer concerns and desires for food quality, health and environmental concerns are facilitated by initiating discussions over agricultural innovations as a bottom-up approach (SCAR, 2012).

It is important to distinguish between traditional farming approaches and agroecological science. The former can, yet in different ways be as destructive to the environment, and unsustainable, as any high external input industrial 'modern' farm (IAASTD, 2009a). While in general agroecological science utilises a 'low tech' toolbox, it is far more sophisticated, knowledge intensive, and integrative both on environmental and institutional levels than simple kitsets of seeds, fertilisers and agrochemicals that characterise industrial farming operations. That is, this approach creates a strong need for farmer support through extension services and farmer-lead educational initiatives, calling for broad participation across a range of scientific disciplines and policy actors.

19.4.1 Bottom-up incentives homogenise productivity and resilience rather than tools

Rather than sell farmers packages of tools that bring in improved seed and convert their soils to near replicas of those for which elite varieties of plants have been optimised, agroecological science facilitates local development of soil conservation practices and supports farmer seed exchanges for breeding of local varieties or local elite varieties (Badstue, 2007; Jarvis et al., 2008). These practices support agrobiodiversity, which contributes to sustained productivity by creating resilience to unpredictable changes at the local level, such as to resource availability, or changes to climate, all the while making the farm less likely to attract pests (Bellon, 2011; Jarvis, 2000). Here the emphasis is on the farmer rather than the breeder, where they are different (Reynolds, 2006).

The focus on farmers is a viable alternative to the focus on genotypes. As the UN FAO have argued, '75 % of the additional food we need over the next decades could be met by bringing the production levels of the world's low-yield farmers up to 80 % of what high-yield farmers get from comparable land' (Molden, 2007). This suggests that the future of sustainable, low impact agriculture is one in which products and methods are developed at landscape rather than global or even national levels. In this way we agree that 'there is a need to invest in science and practice which gives farmers a combination of the best possible seeds and breeds and their management in local ecological contexts' (Pretty, 2011).

19.4.2 Bottom-up innovations are participatory

Bottom-up approaches often include participatory activities built on open collaborative models, with the aim to address problems that are relevant to the local ecological and sociocultural context through experimentation and education (Baldwin, 2011; Ceccarelli, 2006; Toomey, 1999; Witcombe, 1996). Even where the incentive systems are tuned towards generating IP, such as in plant breeding, the choice of relevant instrument can encourage ongoing innovation through participatory innovation development.

For example, legal instruments such as patent-like PVP and patents restrict farmer use of this legally protected germplasm from breeder innovation unless they negotiate permission for use from the license holder. Poor and subsistence farmers who may most benefit from their own local innovation are unlikely to have access to either public or private patent holders who reside in urban centres far away, often out of country (Howard, 2009). In contrast, PVPs which recognise breeder's rights allow farmers and others to continue development including making locally adapted varieties for sale or for exchange (Figure 19.3). PVP allows a wave of innovation to extend from an initial variety and contributes to the speed of technology transfer within an institutional context that supports agricultural sustainability (Gyawali, 2007; Steinberg, 2001). Thus breeding innovation that is centrally controlled by contracts between the license holder and selected breeders can bottleneck technology transfer. This phenomenon has been associated with the 'yield gap' experienced by GM varieties because of the use of patents to control these products (Fernandez-Cornejo, 2006).

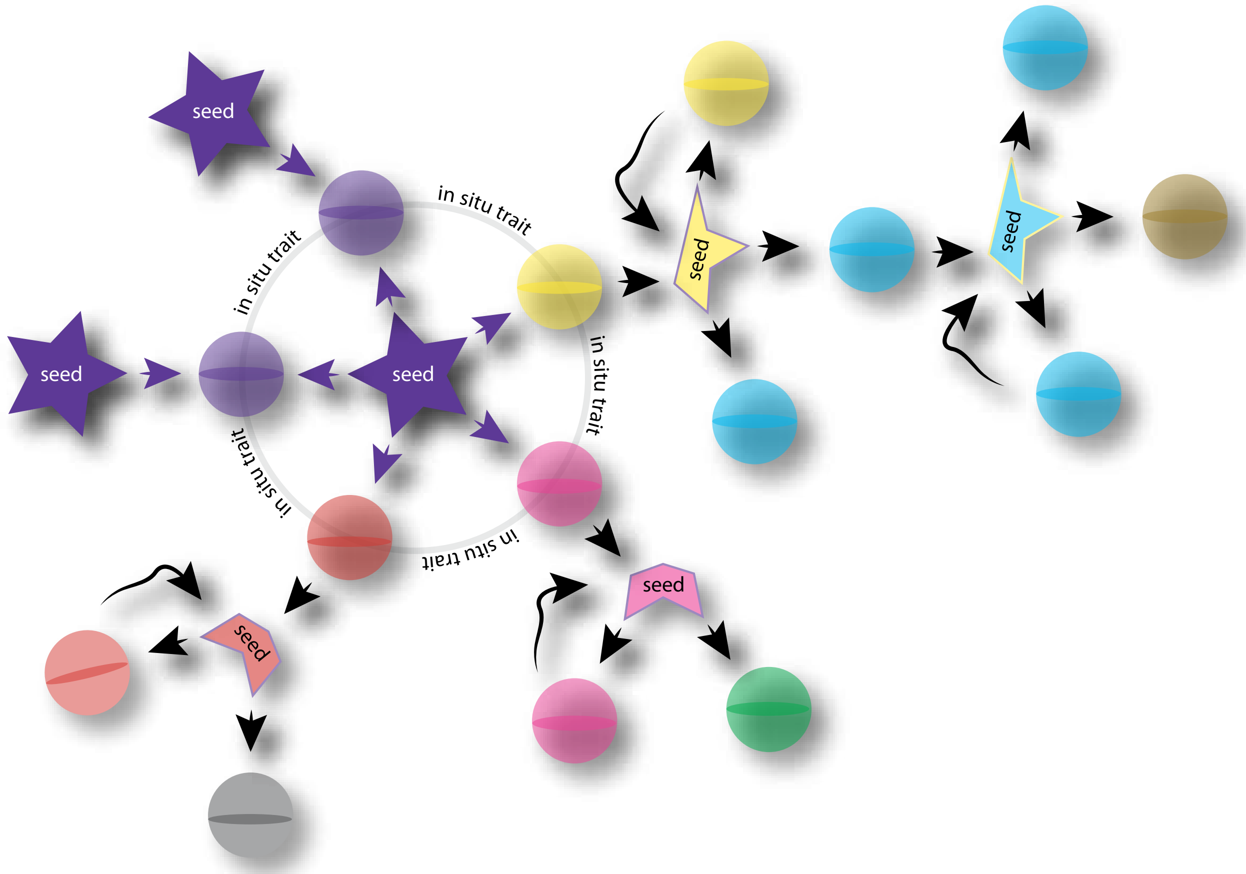
The knowledge required to select and save seed, and the infrastructure for exchanges, are also social resources that if (or when) lost may be difficult to re-establish (Howard, 2009). In a future of climate change, decentralisation of public breeding and in situ conservation are likely to be fundamental to the survival of billions of people (Bellon, 2011; Ceccarelli, 2006; McIntyre, 2011).

'Farmers (including pastoralists and agro-pastoralists) should not simply be seen as maximisers of food and agricultural commodity production, but also as managers of the food and agricultural commodity-producing eco-systems' (Hoffman, 2011). That role requires farmers to have freedom to innovate as well as the confidence of governments in the value of that innovation.

Participatory research that leads to new innovations in agriculture often starts from a point of co-inquiry, whereby farmers and scientist work as partners and bring their own, complementary knowledge, experience and insights to developing innovations that are relevant to the needs of farmers. That is, participatory research treats farmers as experts with their own scientific knowledge and experience that is complementary to more formalised training expertise. In participatory breeding initiatives, traits of value to local farmers might be identified and often are different than those valued by national and international breeders: 'Professional breeders, often working in relative isolation from farmers, have sometimes been unaware of the multitude of preferences — beyond yield, and resistance to diseases and pests — of their target farmers. Ease of harvest and storage, taste and cooking qualities, how fast a crop matures, and the suitability of crop residues as livestock feed are just a few of the dozens of plant traits of interest to small-scale farmers…' (Toomey, 1999).

Another example of participatory innovation models, the farmer field schools, have been instrumental in designing new ways to decrease

Figure 19.3 Participatory IP instruments



Note: When farmers and breeders can continue to innovate on seed or propagule stock, the benefits of elite varieties are more quickly adapted to local conditions and other desirable traits and may inspire new breeder income. Consider seed with a novel genotype (purple star) being sold to farmers who find a variety of phenotypes after planting (pink, yellow, orange circles) due to local gene x environment interactions. Some of these new phenotypes may be desirable and could inspire the farmer or professional breeder to capture the new variety for ongoing sale. Other farmers may wish to return to the original seed stock (purple stars to the left). The new varieties may be purchased by other farmers or the same farmer and additional breeding may bring new and some desirable traits (blue, brown, blue, green and black circles).

insecticide use in studies from Indonesia, Bangladesh and Vietnam, and increases in crop yield in China, India and Pakistan (Van den Berg, 2007). These programmes teach farmers how to problem solve and experiment independently through interactive learning, which will help adapt technologies to their specific environmental and management needs (Vasquez-Caicedo, 2000).

19.4.3 Bottom-up approaches deliver the right kind of innovation to the right kind of users

Agroecological bottom-up innovations are relevant and work. By focusing on locally adapted and developed integrative innovation over remotely developed standardised innovation they can help create sustainable farming systems that deliver more food, nutrition and wealth to the farmers and their communities that are needed to feed the world. There is mounting evidence that the scale-up of these approaches may offer, beyond improvements to crop productivity, enhanced environmental benefits, e.g. reductions in chemical inputs and soil erosion, improved water conservation and soil organic matter content, and higher levels of biodiversity (Pimentel, 2005). Further, bottom-up approaches offer a means to tackle issues related to land degradation to restore soil fertility (de Jager, 2005).

The world's largest meta analysis comparing science-lead industrial and agroecological (organic) farming systems found that the latter could match the former in the common metric of yield (Badgley, 2007). Critically, this intensification of farming systems through agroecological science achieved the same or superior yields with a concomitant reduction of external inputs, including a much lower dependence on agrichemicals and fossil fuel-derived fertilisers. Finally, this study also provided evidence to suggest that mature agroecological conversions (those in excess of five years old) consistently out produced industrial operations. This study exposed the reason for other studies reporting that agroecological farms are less productive: it takes about five years of intensive work to rehabilitate soils converted from traditional or industrial farming management to agroecological and past studies lumped young and mature conversions together.

International projects to initiate organic and sustainable agriculture have shown excellent overall results. UNEP-UNCTAD reported an average crop yield increase of 116% for organic and near-organic projects involving more than 1.9 million African farmers on roughly 2 million hectares of cultivated land within the 114 cases analysed. The benefits were not just in yield — improvements in natural, social and economic capital associated within these farming systems led to an array of benefits that have increased food security. The report authors concluded: 'Organic agriculture can increase agricultural productivity and can raise incomes with low-cost, locally available and appropriate technologies, without causing environmental damage. Furthermore, evidence shows that organic agriculture can build up natural resources, strengthen communities and improve human capacity, thus improving food security by addressing many different causal factors simultaneously' (UNEP-UNCTAD, 2008), and can be more economically profitable than conventional farming (Edwards, 2008; Nemes, 2009).

Another synthesis study investigated the increases in productivity since the implementation of 286 sustainable agriculture initiatives from the FAO, which covered 37 million hectares in 57 countries (Pretty, 2008). They found increased productivity on 12.6 million farms with an average crop increase of 79 %, and a rise in key environmental services.

A commissioned report from the Foresight Global Food and Farming Futures Project of the UK government (Foresight, 2011) appraised 40 sustainable intensification projects developed in the 2000s, from 20 countries in Africa. The projects were developed based on a range of bottom-up approaches to agriculture, including participatory plant breeding, integrated pest management, agro-forestry and agroecological soil conservation measures. The results speak for themselves: by 2010 the projects had led to a range of documented benefits and improvements to 12.75 million hectares for the 10.39 million farmers and their families, including a doubling of crop yields, on average (2.13-fold increase) spanning a 3–10 year period (Pretty, 2011).

Results from bottom-up approaches are also evidenced in the global North. In Wisconsin, USA, a 12-year study on productivity of organic vs. conventional cropping systems found that diverse, low-input systems can be as productive per unit of land as that of conventional ones (Posner, 2009). A 30-year study by the Rodale Institute in the US compared organic and conventional agricultural methods and found yields, economic viability, energy efficiency and human health indexes improved with organic farming (Rodale, 2011).

Scaling up these successes will require policies that stimulate investment into key sectors that support bottom-up approaches. In one modeling study (UNEP, 2011), the outcomes of targeted 'green' investments over a 40 year period are compared to the same amount of financial investment into conventional and traditional 'business as usual' agriculture of today. Overall, the green investments lead to numerous comparative benefits, including increased yield, soil quality, greater water efficiency and land use, increased GDP growth and employment, and reduced CO_2 emissions and energy consumption. Therefore the potential scale-up for agroecological based bottom-up approaches appear to be immense.

19.5 Case example: Contrasting top-down and bottom-up innovation solutions to water stress

Consider the anticipated application of top-down innovation to address the challenges of agricultural water stress. Agriculture is already the largest user of water among human activities and lack of access to water is an increasing problem (Hoffman, 2011; Marris, 2008). Climate change is expected to further exacerbate the problem (Schiermeier, 2008). The most likely top-down product for addressing this problem will be genotypic changes to germplasm to enhance traits that confer drought tolerance. Already progress is being made in some crops through classical breeding (CIMMYT, 2012; Heinemann, 2009), especially augmented through marker-assisted selection (⁶). Yet similar genotypic approaches using genetic engineering have not been as successful. As drought tolerance depends on the action of multiple genes, drought tolerant varieties require changes in multiple genes all at once, rather than adding genes singularly (as with genetic engineering). Developing adapted varieties will require more responsive breeding and development than can be offered through the extensive process for creating a commercially viable genetically engineered drought tolerant product (Gurian-Sherman, 2009; Heinemann, 2008a, in press). Further, plants with ever more extreme adaptation of genotypes will likely continue to exacerbate the depletion of the water table. Nevertheless, any seed (or propagule)-based product that is better adapted to drought stress would be amenable to prevailing IP instruments such as plant variety protection (PVP), patent-like plant variety protection, or patents and therefore it is no surprise that genotype innovation receives so much emphasis, especially from industry.

In contrast, bottom-up environmentally based management solutions, some of which have been in practice for decades, tend to raise latent water levels and retention capacities in soil as well as improve the genetics of crop plants (Heinemann, 2008a; Lotter, 2003; Pimentel, 2005; Scialabba, 2007). Environmental management using locally-adapted drought tolerant varieties, cover crops, polycropping, rotating in fallow years, compost and soil conservation to raise organic matter levels, agroforestry and building small dams all raise water levels (Altieri, 2002; Lal, 2006). The resiliency of this kind of system is equally affected: In fact, it may not be possible to feed the world in 2050 unless soil quality and water retention capacity are raised regardless of how efficient plants can become at extracting water (Hoffman, 2011). 'If soils are not restored, crops will fail even if rains do not; hunger will perpetuate even with emphasis on biotechnology and genetically modified crops' (Lal, 2008). Many of these improvements would be considered innovations by our bottom-up definition (Kiers, 2008), but by their nature could not be easily described or protected by patents or similar IP instruments in order to facilitate the knowledge transfer to the commercial sector, and thus are not innovations in the currently practiced top-down model. By following the top-down approach, the private sector will offer solutions to a problem that either possibly cannot be solved using technologies that are described under prevailing IP instruments or which will only shift the problem in time or space, addicting us to finding and producing even more extreme genotypes through genetic modification.

19.6 Conclusions

We have attempted to contrast two pathways to innovation and their relative opportunities and costs for agricultural development. We find limitations to top-down innovation because of largely productivist objectives. These tend to shut down rather than open up innovation and options, particularly those for addressing social welfare issues. Further, science and its role as a public good become conditioned within certain notions of progress (Callo, 1994). This framework will only continue to create technological lock-ins and path dependence to specific research choices at the expense of others (Stirling, 2007).

We find that both top-down and bottom-up approaches will have their roles to play, but getting them in the right mix, order and framing is critical to ensure their benefits and risks are more evenly distributed if we are to produce the kinds of innovations capable of achieving the Millennium Development Goals. This will require rebalancing innovation towards the public good, further requiring that innovation frameworks focus not only on scientific and technological developments, but also on the interlinked institutional, organisational and social changes. In terms of agriculture, taking these issues seriously means operationalising the outcomes from the IAASTD (2009a) and SCAR (2012) reports. The recent recommendations on research, innovation and agricultural knowledge coming from the European Commission's Standing Committee on Agricultural Research (SCAR) call for 'increased support be provided for research on the economic and social dimensions of these new technologies and farming practices. Approaches that promise building blocks towards low-input high-output systems, integrate historical knowledge and agro ecological principles that use nature's capacity should receive the highest priority for funding' (SCAR, 2012). To achieve this, a public sector free from political incentives for top-down innovation is an essential capacity. However, the small business and the farmer, while still private sector and benefiting from proprietary knowledge, will be an essential source of creativity, problem solving and income for their communities.

(⁶) Marker-assisted selection is a breeding technique that uses biotechnological tools to concentrate particular traits within the existing plant by traditional breeding. This allows for a more efficient breeding process for achieving varieties with specific traits of interest. It does not involve the use of in vitro modified nucleic acids as with genetic engineering.

Further, scientists are not passive members of the scientific enterprise, but a powerful force from within that influences the techno-sciences and the options available to society to benefit from scientific research. The modern techno-science culture took shape just after WWII in an unusual convergence of thinking across the East-West geopolitical divide. Nuclear power in the United States and space travel in the Soviet Union become exemplars of a new form of conceiving and doing science, and witness a deep transformation in its ethos and political economy. The convergence of internal culture, economic and political power was and is an irresistible force. Scientists today cannot shirk from their role and their responsibility on how science is done and governed, as practitioners and frequently as participants, entrepreneurs and citizens.

Lastly, top-down innovations will be most effective when scientific knowledge from specialised fields within biology, chemistry, ecology, genetics, soil microbiology, etc. converge with bottom-up approaches to innovate locally optimised solutions. In this way, the benefits of advanced scientific knowledge will naturally become be much more diverse and widely distributed.

We have made the case that the future of agriculture and global food security is one that requires a truly long-term vision, attendant to the environmental and social costs of production, and with an emphasis on the small and subsistence farmer. Long term, there will be enough food if agriculture both intensifies and remains local. We have found that if the bottom-up approach is followed, the transfer of knowledge and further innovation potential is augmented, and success far more likely, than the outcomes witnessed to date from the prevailing top-down approach, where the innovation potential downstream is severely limited. Conversely, the proceeds of bottom-up innovation disproportionately flow to adopters rather than the providers. By their very distributive and participatory nature, bottom-up innovation strategies do not tend to concentrate power, financial or political, into providers which otherwise are easily displaced by wealthier and more powerful champions of top-down policies.

If the policy demands on agriculture are reasonably expanded to include delivery of culturally and nutritionally diverse foods, produced locally by those most in need, and which serve as a path out of poverty and malnutrition, then the bottom-up innovation models are the responsible innovation models, and require investment and support (De Schutter, 2011).

On the one hand, we have explored a path directed by top-down innovation models. As a type of black-box technology that is protected by particularly restrictive IP instruments (patents and patent-like PVPs), so-called 'biotech' crops (GM and similar) and their co-technologies are expensive to buy, destroy local seed savings and exchange practices, and prevent further farmer tinkering and improvement of innovations. When working as advertised, we find that top-down innovation as promoted by the large market economies, directed at advancements in agriculture (which ironically is maintained by extra-market subsidies), undermines the stated national and international goals of poverty reduction, sustainability, and increases food insecurity. They contribute to a feedback loop that continues to concentrate wealth and power into a smaller number of companies and large farms (Botta, 2011; Spielman, 2007; USDA, 2009; World Bank, 2007). Top-down providers are invariably attracted to the largest markets (real or subsidised), the most uniform agroecosystems, and the highest volume farmer. They therefore will always serve last those who are foremost needed to feed the world in the future: the presently small and subsistence farmer on < 2 hectare plots of land where highly diverse and intermixed crops and livestock production work best to meet local needs.

On the other hand, bottom-up approaches emphasise the contextual role of innovation, even when the product is technology (van den Hove, 2012). Bottom-up innovation is the kind that provides useful tools, methods and knowledge that can be adapted to and by the farmer and farming system. Products that depend on ecosystem, cultural and financial homogenisation damage biodiversity and ecosystems, but also cultural identities as they eliminate the need for local knowledge (in the short term) and shift communities away from traditional foods and ethnobiological knowledge. Obstacles to taking bottom-up approaches need to be addressed and overcome by policy makers seeking to create a sustainable agricultural system (De Schutter, 2009, 2011).

If there is a solution to the global mal-distribution of access to sufficient quantities of nutritious foods, how do we find it? In the process, how do we build agriculture into a pathway out of poverty without also raising greenhouse gasses and increasing soil erosion? How can we support agricultural systems that are resilient and sustainable? A commitment and investment of public resources as incentives to promote strategies for agricultural and ecological sustainability will require a radical shift on how we think about and perform innovations in the future, where 'business as usual' in agriculture is no longer an option. As Einstein said, 'The solution will not come the same kind of thinking that created the problem'…

Innovations in agricultural food production have been deeply part of the human experience for over 10 000 years. They will continue to be central to how we feed the world. The agricultural innovations of the future will have to be more 'hands on' and local if we are to meet our goals of food security, poverty alleviation and environmental sustainability (Benessia, 2012). For as long as the problems needing products are framed as technological rather than social, behavioural or political, then innovation will be directed toward technological products (van den Hove, 2012). The technological 'solutions' are often just responding to symptoms of the underlying cause of existing socio-ecological solutions. As the late Nobel Laureate Joshua Lederberg said: 'Our imperfect solutions aggravate every problem.' (Lederberg, 1970).

We find the '3D Agenda' of the STEPS Centre (2010), cognisant of the ways which the directions, distribution and diversity of innovations affect their use, to be a compelling model for the future thinking of innovation in agricultural development.

As we have discussed, where the directions of innovation that follow top-down approaches — highly specialised, centralised and capital intensive — tend to shape innovation towards technological lock-ins. Economic and political forces that promote these innovation trajectories then become hard to reverse, or crowd out alternative approaches, such as agroecology. In contrast, bottom-up approaches facilitate participation of the user to shape the directions that innovation will take. The innovation direction further moulds the potential distribution of benefits, costs and hazards brought by the adoption of the innovation pathway. Often top down approaches leverage legal instruments of knowledge control that close down access to knowledge or further innovation, defines who indeed innovation is for, who can access it, based on who can afford to pay for it. An important consequence here is that top-down approaches marginalise those for whom innovations are more critically needed to increase the productivity and sustainability of agriculture. Lastly, these two aspects of innovation — direction and distribution — further determine the diversity of innovation possible, not only the scientific and technical aspects of innovation, but the social, organisational and innovations that support it. Diversity in innovation buffers against lock-ins and creates the potential for local adaptation within the ecological and economic contexts for which they are designed. This means a more integrative focus of the agroecosystem, beyond the genotype approaches towards augmenting biodiversity within agro-environments to develop sustainable and resilient agroenvironments as protection against future uncertainties.

19.7 Lessons learned

In 1961, outgoing President of the US Dwight D. Eisenhower warned society to be vigilant of the large, concentrated interests in technology when he said: 'The prospect of domination of the nation's scholars by Federal employment, project allocations, and the power of money is ever present — and is gravely to be regarded. Yet, in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific technological elite' (Wikisource, 2012).

The early warning, or perhaps late lesson, to be heeded here is that if one follows the top-down, usually technologically oriented, approaches to innovation,the desired outcomes for addressing food insecurity will not be achieved. Top-down approaches will most likely fail to deliver on the large promises of food security and alleviation of poverty, mainly because these approaches contribute to a feedback cycle that concentrates resources, knowledge, and influence as witnessed in the seed and agrichemicals sector (Adi, 2006; De Schutter, 2009; Fernandez-Cornejo, 2006; Howard, 2009). Through this power, top-down providers can artificially homogenise both the conception of the problem to be solved and the solutions — such as GM crop plants — they propose. All too often questioning the *rationality* of the approach gets lost in the background of the unquestioning discussion over the *use* of the approach (Pavone, 2011 and see discussion in Boxes 19.1 an 19.2). Perhaps greater reflection and social deliberation into why and for whom agricultural innovations should be produced is needed if we are truly going to follow more sustainable pathways in the production of food and fibre.

In the path ahead, societies will have to make more conscientious choices of how to define and shape innovation to produce solutions that are appropriate for meeting global challenges related to agriculture. Bottom-up approaches are proving capable of getting sustainable, participatory and locally adapted solutions into the hands of those that need them most (Altieri, 2011a;

De Schutter, 2011), but are incapable of flourishing where invention is limited to what can be easily described by prevailing IP instruments. Change the directions, distribution and diversity of innovation, and you change the world.

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