Seed Systems and Plant Genetic Resources for Food and Agriculture

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PREFACE .1

This report examines the role of seed and seed systems in the conservation and the use of plant genetic resources for food and agriculture. It focuses on developments since the publication of the first report on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 1997).

The term 'seed' is used here to include any type of planting material that is intended for use in producing a crop, i.e. either generative or vegetative, such as roots, tubers, bulbs, cuttings, rhizomes and apomictic seed. The use of the word 'intended' implies that human intervention in handling seed is explicitly considered.

Seed performs many functions in agriculture. It is not only a carrier of the genetic diversity that underpins food and agriculture, it is also a primary input in crop production and thus important for food security and rural development. Seed is a commodity that can be traded, which makes it important in economic fields, including international trade and intellectual property rights (IPR). It is also an expression of culture, which brings in the issue of self-determination and calls for the protection of traditional knowledge. Seed is an important agent in agricultural change, technology transfer and technological development. Changes in the genes embedded in seed can bring about major changes in society, as shown by the short-strawed cereals in the Green Revolution.

The term 'seed system' is understood in various ways. It is often understood as referring to the organized, formal mechanisms through which farmers obtain seed and through which seed quality can be guaranteed. These formal seed systems consist of chains of interlinked activities, starting from genetic resource management, breeding research and crop improvement, through seed multiplication, marketing and distribution, to use of the seed by farmers. However, farmers, especially those in developing countries, obtain seed from many sources, including producing their own seed and exchanging seed with neighbours, and these 'informal' systems must be taken into account in any consideration of seed systems.

Formal and farmers' seed systems differ in how they use and maintain plant genetic resources for food and agriculture (PGRFA). Formal systems tend to produce uniform varieties through scientific breeding. Informal systems tend to generate and maintain less uniform materials adapted to local requirements (landraces) but also may provide a conduit for exchange of materials derived from modern varieties. Combining the strengths from both systems may broaden the genetic base of our crops and support use of wider genetic diversity in the field.

The focus of policies affecting seed systems depends on the particular policy environment. For example, efforts to support the cultural identity of communities commonly focus on farmers' seed systems, while efforts to promote the commercialization of seed commonly target the formal system and uniform high-yielding varieties. Efforts to support sustainable agriculture and promote food security could target either formal and farmers' seed systems, or both, depending on the ecological and institutional environment. These different policy objectives and focuses can lead to differing and often conflicting pressures on seed systems.

Seed systems available to farmers are the result of a balance of the policy environment and the individual choices that farmers make. These resulting seed systems in turn determine the opportunities for the conservation and sustainable use of PGRFA. This report seeks to analyse some of these aspects with a view to supporting efforts to conserve and use a broad base of PGRFA.

SEED SYSTEMS AND THE FIRST REPORT ON THE STATE OF THE WORLD'S PGRFA .2

The first *Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (SoW-1) (FAO, 1997) highlights the important role of informal seed systems to the conservation and maintenance of PGRFA.

Chapter 1 (section 1.4) notes that farmers may use different varieties for different purposes, making it very difficult for the formal seed sector to serve all their seed needs. Moreover, it notes that many farmers cannot afford to buy seed for each planting and thus produce and maintain their own seed supplies. The report notes that this reservoir of genetic diversity on-farm is a basis upon which a conservation strategy can be built.

Chapter 2, on *in situ* conservation, describes many examples of on-farm conservation, including aspects of farmer selection, local seed storage, etc., which are basically components of seed systems. However, these activities are presented mainly in terms of conservation of PGRFA and not explicitly as seed systems. The chapter does, however, identify the need to promote farmer-level seed production, and to support farmer-to-farmer seed exchange mechanisms (Cromwell and Wiggins, 1993).

Chapter 4 deals with the use of PGRFA, and focuses on the role of formal seed systems; little mention is given to farmers' seed systems. The chapter states that "seed production and distribution are today predominantly public sector activities in developing countries, and increasingly private sector activities for the major crops in Europe and North America." Mention of informal seed systems is limited to a statement that "farmer-saved seed and farmer-to-farmer seed exchange [are] the predominant source of supply for many farmers." It notes the poor performance of the formal seed sector in many countries, despite major investments in the 1970s and 1980s, and identifies a trend of gradual consolidation of the seed sector in the private seed industry and increasing linkages between seed companies and chemical and agricultural trade giants. There is mention of the need to stimulate farmer-to-farmer seed production and distribution networks, but the chapter gives little indication of how this might be done.

Chapter 5 on national programmes and capacity building notes that the commercial sector cannot be expected to meet all the needs of farmers, and identifies the need to promote on-farm seed production; however, again, it does not give much detail about how this might be done. Section 5.4 identifies the impact of seed regulations and plant breeder's rights on the development of effective seed systems that promote the utilization of genetic resources.

This report builds on these findings, concentrating on developments and trends since the publication of SoW-1.

TRENDS SINCE SOW-1 .3

A major trend in the field of seed systems since SoW-1 is an increased recognition of the value of different seed systems for different situations. Several countries have introduced integrated approaches to seed system development that support informal farmers' seed systems as well as formal systems. Seed certification authorities increasingly support farmer groups and NGO-led initiatives in Asia and Africa, sometimes leading to semi-formal controls based on the 'Quality Declared Seed' approach of the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2006).

Several initiatives have promoted both formal and informal seed systems. For example, the African Union now encourages member countries to take a more integrated approach to seed system development, including public, private and farmers' roles. In the European Union, special seed rules are being designed to allow for the local production and sales of landrace seed in its otherwise highly regulated seed market (Council of the European Union, 2002). These are a major deviation past practice in which policies were mainly aimed at gradually reducing farmers' seed systems and promoting fully commercialized seed systems distributing only modern varieties.

The integration of formal and farmers' knowledge and materials may be applied in all stages of the seed chain. These aspects are discussed in the following sections.

Crop improvement 3.1

Global trends 3.1.1

Public sector investment in agricultural research, including plant breeding, has declined markedly in many countries since 1997. This, together with consolidation in private-sector seed companies, particularly in industrialized countries, has reduced the number of plant breeding programmes.

Another global trend is that intellectual property rights systems dealing with PGRFA have strengthened markedly since 1997, including the coming into force of the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2001), and this has affected access to PGRFA for both public and private breeders worldwide.

Crop improvement in industrialized countries 3.1.2

Plant breeding in industrialized countries increasingly employs molecular techniques. Transgenesis and cisgenesis are increasingly important as research tools and as ways to introduce new traits in breeding programmes. These techniques cannot, however, replace conventional plant breeding. Unfortunately, a shortage of conventional plant breeders is emerging in large parts of the industrialized world, due partly to the emergence of biotechnology and partly to the declining interest of young students in agriculture (Morris *et al*., 2006).

Increasing protection of IPR is affecting plant breeding programmes, particularly in developed countries. In some crops, particularly maize, breeders are becoming wary of using competitors' varieties in their breeding programmes, despite this use being exempt in plant breeder's rights.

Finally, there is an emerging trend in industrialized countries towards breeding varieties specifically for the ecological or organic farming sector. The focus of these efforts is on disease resistance, through traditional genetic control of diseases (durable horizontal resistance), often obtained from 'recovery' of old varieties, or through growing genetically diverse crops. However, marketing of old varieties and multilines or other genetically diverse varieties is constrained in European countries by strict seed laws.

Crop improvement in emerging economies 3.1.3

Plant breeding is strong in emerging economies (BRIC countries and others). Public-sector institutions are generally well staffed and there is an emerging private sector or commercializing public organizations, as in China. The value of plant breeding is sufficiently well recognized in these countries to prevent the cuts in public investment that have occurred in developing countries.

Crop improvement in developing countries 3.1.4

National agricultural research systems in many developing countries are poorly funded and understaffed, and are under pressure to raise money from sources other than the government, including donors and commercializing their activities. Commercializing activities to raise funds, e.g. charging royalties on seed of varieties they have bred, risks changing the focus of public-sector activities away from smallholder farmers towards larger, commercial farmers who can afford to pay for seed and services.

There are a number of efforts aimed at supporting plant breeding efforts in developing countries. One example is the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB; http://km.fao.org/gipb/), coordinated by FAO and the Alliance for the Green Revolution in Africa (AGRA; http://www.agra-alliance.org/).

Participatory plant breeding, mentioned in SoW-1, has been mainstreamed in a growing number of developing countries and even some industrialized countries. Participatory plant breeding aims at developing better varieties for local conditions, often using local germplasm. Although the objective is often to upgrade local varieties, it may lead to a new uniform variety that replaces old ones.

New technologies for crop improvement 3.1.5

SoW-1 highlighted the spread of genetically modified (GM) crops as an increasing trend. The value of GM seed traded increased more than 25-fold between 1996 and 2007, from US$ 280 million to US$ 7 275 million (CropLife, 2008). However, only the USA, Argentina, Brazil, China, India and South Africa grow significant acreages of GM crops (Raney, 2006).

GM crops developed to date primarily offer herbicide resistance and resistance to biting insects. Recent advances have almost exclusively involved transfer of applications of known mechanisms to new crops. There have been no breakthroughs in e.g. resistance to sucking insects and bacterial diseases or improvement in nutritional qualities, mainly because biology is less predictable than was thought 20 years ago, and because the cost of research and regulatory requirements are very high.

Developing and commercializing a new type of genetically modified organism (GMO) that is not based on existing technologies may cost hundreds of millions of dollars. Biosecurity requirements are increasing, as are regulatory requirements to ensure environmental and food/feed safety. These requirements favour large corporations: the investments involved are too large for conventional seed companies. However, significant investments have also been made by governments in public–private partnerships (e.g. the Water Efficient Maize for Africa project; http://www.aatf-africa.org/aatf_projects.php?sublevelone=30&subcat=5), which may involve smaller players.

The high costs involved result in GM efforts in both the private and the public sector being targeted only at crops that are widely grown and generate large revenues.

Crop improvement: analysis 3.1.6

Plant breeding is a cornerstone of agricultural development and food security. However, public-sector investment in plant breeding has declined markedly since SoW-1 in 1997.

New emphasis on the value of plant breeding is emerging in Africa with the Alliance for the Green Revolution in Africa. Such emphasis will be effective only if the institutional environment is sufficiently conducive for the newly trained breeders to be productive. However, the seed industry in industrialized countries also needs to develop ways to make the job of the conventional breeder competitive with those of the 'laboratory' breeders (biotechnologists).

The field of plant breeding is widening with the introduction of, on the one hand, biotechnologies and, on the other hand, participatory breeding. This creates the need for breeders to specialize not only in particular crops, as was the conventional choice of breeders, but also in focus area. Such choices have to be included in the curricula of future breeders.

Seed production and distribution 3.2

Seed production and distribution in the public sector 3.2.1

Public sector involvement in seed production is declining in many countries in the face of government cut backs.

Public seed production started in many countries with the objective of facilitating modern farming through provision of improved crop varieties. These public enterprises concentrated on crops that were most important for national food security, such as cereals and pulses. The success of such programmes commonly became the basis of their failure. The more seed they distributed, the more it cost to run the business. In many cases financial losses were accrued when seed of less commercial crops were produced. Faced with increasing costs and losses, governments withdrew from the seed production sector, commonly following one of three strategies:

- ;(Public seed production infrastructure was sold to a foreign party (e.g. Malawi
- Local private seed companies were encouraged to emerge and to compete with the public enterprise (e.g. India), which often led to a decline of market share for the public sector and the sale of the infrastructure to one or more (private companies (e.g. Uganda
- .(Public enterprises were decentralized, reducing transaction costs (e.g. Ethiopia

A major problem is that private seed producers generally focus on seed of high-value crops such as hybrid cereals (e.g. maize and, in India, pearl millet), vegetables (notably in South-East Asia) and industrial crops, such as cotton and soybean. The private sector will produce seed of food crops only where there is sufficient demand to make it financially attractive, e.g. where there is a steady demand from relief agencies (notably in Africa) or where farming has intensified to the extent that farmers no longer save their own seeds (such as rice in parts of south and South-East Asia). This means that seed of many major food crops (self-fertilizing cereals and legumes) must either continue to be produced by public-sector agencies (which have lost the profitable products that they formerly used to cross-subsidize production of these crops), or must be produced by farmers themselves.

Seed production and distribution in the private sector 3.2.2

Developments in the seed market

The value of the global seed market increased from US$ 30 billion in 1996 to over US$ 36 billion in 2007, mainly in emerging economies and developing countries. International seed trade also grew, particularly because of off-season production of seed in the southern hemisphere for northern markets, and accounted for nearly 15% of the global seed trade by value in 2005.

The quantity of seed certified in seed schemes operated by the Organization for Economic Cooperation and Development (OECD) significantly increased from 300 000 tonnes in 1996/97 (OECD, 1997) to nearly 600 000 tonnes in 2005/06 (OECD, 2005). The increase occurred despite a decrease in officially certified seed in the USA and Canada; France is now the largest producer of certified seed. Other countries that have significantly increased their certified seed production during the past decade include Chile, Hungary, Italy, and Kenya.

The number of countries participating in the OECD schemes increased from 45 to 53. New members were Brazil, Egypt, Latvia, Lithuania, Mexico, Russia, Serbia and Uganda, doubling the participation in sub-Saharan Africa and almost doubling it in Latin America.

In the past, seed companies made most of their profits from seed of cross-fertilizing crops, specifically hybrids, but now some legumes and cereals are increasingly contributing to the commercial success of seed companies. This is largely because of continuing reduction of farm-saved seeds in the USA and collection of royalties on farm-saved seed in Europe. Commercial prospects in other parts of the world remain limited to high-value (horticultural) seed and small-seeded and hybrid field crop seeds.

Strengthening of seed associations

The past decade has shown a significant development of national, regional and international seed associations. At the international level, the International Seed Trade Federation (FIS) and the International Association of Plant Breeders for the Protection of Plant Varieties (ASSINSEL) joined forces in 2002. The new platform—the International Seed Federation—has members in 70 countries worldwide. ISF has a significant impact on policymakers both at the international level and on national agricultural and trade policies, including IPR and seed regulations.

Seed trade associations have been established in Latin America in 1986 (Latin American Federation of Seed Associations, FELAS), the Asia-Pacific region in 1994 (Asia-Pacific Seed Association, APSA), Africa in 2000 (African Seed Trade Association, AfSTA) and Central Asia in 2007 (Central Asia Seed Association, CASA). Some of these now have hundreds of members. These regional associations are important participants in intergovernmental debates on seed-related issues.

Another development is the emergence of seed associations with overlapping membership, such as the Seed Association of the Americas (SAA, established 2005), which brings together North American and Mercosur countries, and a new regional association launched in 2008 by the Economic Cooperation Organization in the central Asian region.

Continued consolidation in the seed industry

The trend of consolidation in the private seed sector identified in the SoW-1 has continued. Of the top ten seed companies listed in 1997, five have since disappeared as independent companies (Novartis, Advanta, Seminis, Dekalb and Cargill). Monsanto went from being the 11th largest seed company in 1997 to being the largest in 2008, with turnover equal to that in 1997 of the top six companies combined. The top five companies now account for over 30% of the global commercial seed market, but in some sectors the concentration is higher: in the sugar beet seed market the top three companies now account more than 90% of the market, the top five maize companies account for around 85% of the maize market and the top five vegetable seed companies represent around 70% of the vegetable seed market. Increasingly the emphasis is on the crops with the highest profit margins and the largest markets.

This trend is similar to the consolidation in the pharmaceutical and agrochemicals sectors. It is, however, unclear whether the trend in the seed sector will reach the same level of consolidation. The main difference between seeds and medicines or agrochemicals is that crop development has to be done on a local or regional basis given the interaction between the environment and the crop's genetic make-up.

The balance of global and local enterprises is particularly apparent in the vegetable seed market in Asia. This was initially dominated by imports from European, American and Japanese multinationals. Regional seed companies subsequently emerged in the Philippines, Thailand and Taiwan. These initially concentrated on regionally important crops for which the western companies did not provide seed, but now supply seed of a full range of crops. This indicates that niche players are likely to continue to emerge and grow. However, some of these will be taken over by the conglomerates as soon as they obtain a strategic market position.

Integrated approaches to seed production and distribution 3.2.3

Farmers are increasingly involved in seed production as contract growers. In many countries, small seed enterprises are being encouraged to use scientific seed production technology and modern business administration while maintaining the knowledge of local needs and preferences. This is of increasing importance in industrialized countries in support of ecological farming and the organic market, where the market for local varieties is small and fragmented and not suited to formal seed systems (see section 3.2.4, below).

Production and distribution of organic seed 3.2.4

The emerging organic sector poses challenges for seed production. Regulations increasingly require that for products to be labelled 'organic' the seed must be produced under 'organic' conditions as well. This is being facilitated by the development of varieties specifically for organic production systems.

Regulatory issues may create additional issues in countries with compulsory variety listing and seed certification. For example, special lists of organic varieties may be needed featuring results from trials under organic growing conditions measuring characteristics relevant to the organic sector. Such trials have led to the addition of a 'green list' to the official variety list in The Netherlands, but the sustainable funding of such parallel official variety trials may be difficult to obtain.

Databases of sources of organic seed have been developed in the USA (http://seeds.omri.org/) and the European Union (http://ec.europa.eu/agriculture/qual/organic/seeds/links_en.htm) to assist farmers in obtaining quality organic seed.

Seed technologies 3.2.5

Developments in pelleting, seed coating and priming technologies since SoW-1 offer great promise to the seed sector, and their sales have more than doubled since 1997, from US$ 700 million to US$ 1 550 million in 2007 (Le Buanec, 2008).

New applications of seed coating include the use of polymer coatings that protect the seed against early germination when the soil moisture content too low to sustain healthy seedlings (see, for example, Sharratt and Gesch, 2008). Studies have also shown the possibility of regulating seedling development, for example through the use of compounds that stimulate root development under drought stress (see, for example, Farooq *et al*., 2008)

Advanced technologies for seed priming, or pre-germinating seed, offer precise control of germination processes, increasing seedling vigour and creating a much more uniform crop. Horticulture is the main trigger for this kind of technological innovation.

Seed conditioning technology is steadily advancing, facilitating production of high-quality, clean and healthy seed.

These developments influence seed markets, giving commercial seed producers the possibility of offering products that cannot be matched by farm-saved seed.

Seed production and distribution: analysis 3.2.6

Major changes are taking place in the global seed industry. Consolidation in the seed industry is driven by the cost of introducing valuable but expensive new technology, and by the need to effectively capture increasingly broad markets through combining research investments with strong implementation of IPR.

However, there is broader recognition that it will be impossible in the near future—if at all—to create sufficient incentives for the private sector to deliver seeds of all crops to all farmers, including remote and resource-poor farmers. This means that, in addition to policy initiatives to support commercialization of the seed sector for commercial seed crops, public investments are needed to ensure the quality and availability of seed of other crops. In industrialized countries this is mainly done at the level of pre-competitive research; in developing countries this may involve support for development of small-scale seed enterprises, services for seed quality assessments, etc.

Diversity 3.3

General trends 3.3.1

The decrease of public sector involvement in crop improvement and seed production and the subsequent rise of the private sector may have two contrasting impacts on the use of PGRFA and genetic diversity in the field.

The declines in number of breeding programmes in the private sector and in investment in public sector plant breeding globally threaten to narrow the genetic diversity in farming systems that are already using modern varieties. Conversely, however, the greater research capability of the industry giants may create opportunities to use more diverse genetic resources in breeding programmes, thus potentially broadening genetic diversity. However, in some cases, large public programmes are better able to widen the genetic base of crop than many smaller ones. The increased diversity of CIMMYT's wheat germplasm in recent years is a good example (Reif *et al*., 2005). Thorough analysis of global plant breeding activity and genetic diversity is needed to determine which scenario is developing.

The consolidation of plant breeding and seed production in the hands of a few large companies is likely to reduce the number and types of crops that companies work with. An emerging global interest in underutilized crops (demonstrated by the establishment of Crops for the Future, which brings together the former International Centre for Underutilised Crops and the Global Facilitation Unit for Underutilized Species) has not yet offset this trend.

The formal recognition of integrated approaches to seed sector development in Africa and elsewhere, the emergence of seed systems for organic seed, and policies to facilitate use of 'conservation varieties, particularly in the EU, may create opportunities for developing and distributing less-uniform varieties, such as traditional landraces. Such approaches also facilitate participatory plant breeding.

Local seed systems are increasingly being supported with conservation objectives in mind. This is sometimes combined with the reintroduction of gene bank materials (e.g. cereals and pulses in Ethiopia).

Diversity in industrialized countries 3.3.2

Breeders in industrialized countries are increasingly aware of the dangers of a narrow genetic base of crops. The large breeding programmes resulting from consolidation in the seed industry has increased capacity to introduce new germplasm into elite breeding lines. Together, these are contributing to broadening the genetic base of crops. The demands of organic agriculture are also broadening genetic diversity. Even if organic agriculture is not very significant in terms of area planted, it may have an important effect on the overall genetic diversity used in crop production.

Diversity in emerging economies and developing countries 3.3.3

Participatory plant breeding is gaining momentum, contributing to broadening the genetic base of crops. Even though the coverage of such programmes is limited due to major upscaling challenges, their impact on diversity may be significant.

Climate change has large implications for use of genetic diversity. In the face of climatic instability, with greater extremes in temperature and rainfall, farmers are likely to pursue yield stability rather than maximum yield, and since diversity is one of the mechanisms contributing to yield stability, breeders will need to venture into the development of genetically diverse varieties.

Diversity: analysis 3.3.4

There have been numerous changes affecting the diversity of crops since SoW-1, and it is not yet clear whether these have contributed to broadening or narrowing the genetic base of crops. Thorough and detailed analysis of the use of genetic diversity in breeding programmes of major crops is needed to guide developments in this sector.

Seed policy and legislation 3.4

General trends 3.4.1

Formal seed systems are generally highly regulated. Laws generally regulate the release of new varieties, control the quality of seed, and, increasingly, protect new varieties through plant breeder's rights.

The main trend since SoW-1 is towards regional harmonization of seed laws. The European Union has operated joint variety lists and uniform certification methodologies and seed quality standards for some decades. In the southern African region (SADC) harmonization has created a joint variety list for common agro-ecological zones. Harmonization efforts are also growing in Western Africa (ECOWAS members), with a joint variety list and a recent (2008) *Regulation C/REG.4/05/2008 on Harmonization of the Rules Governing Quality Control, Certification and Marketing of Plant Seeds and Seedlings in ECOWAS Region*.

In the informal seed sector, little has been done to develop legislation that provides a legal framework to support farmers' seed systems while maintaining incentives for the development of commercial markets. The strengthening of IPR on innovations in biotechnology and seed technology, and particularly the inclusion of patents in plant breeding and seed supply, is not likely to support the diversity of actors and programmes needed to support diversity of genetic resources in the field. Whether the implementation of farmers' rights will help reverse that trend remains to be seen.

Seed policy and legislation in industrialized countries 3.4.2 and emerging economies

Few major changes have occurred in industrialized countries and emerging economies. However, the EU has developed legal space to allow for so called 'conservation varieties' (Council of the European Union, 2002). These are varieties that have a defined regional origin and use and that do not meet the standard uniformity requirements. This opening is strictly limited to old and locally used varieties, and does not seem to open the door for significant improvements of such materials through, for example, participatory breeding.

Such mechanisms are not needed in many other regions. For example, the largely voluntary nature of variety release and seed certification in the USA allows for the marketing of seeds of local varieties without restriction.

One important trend is the growing use of accreditation principles in some countries, introducing private certification and testing services or in-company systems to replace or complement government tasks.

Seed policy and legislation in developing countries 3.4.3

During the last decade seed laws in many developing countries have been reviewed and changed, particularly to support the emergence of the private sector. Compulsory rules on seed certification and variety release have been replaced by voluntary ones, notably in Latin America and a number of countries in Africa and Asia. In contrast, in India the changes went from voluntary to more compulsory rules in order to strengthen farmer protection. In many countries, the law applies to all seeds and planting materials, but implementation rules are available for only a few major crops. Despite the growing awareness of the value of the farmers' sector, very few countries have explicit exemptions for farmers' seed systems, which makes marketing of local variety and landrace seeds technically illegal.

The concept of farmers' rights, adopted in the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2001), prescribes involvement of farmers in the development of policy and gives farmers the right to save, use, exchange and sell farm-saved seed. This may require countries to revise their seed laws or regulations. The *Act on Plant Breeders and Farmers Rights in India*, for example, includes the right of farmers to "save, use, exchange, share and sell seed" provided the seed is not branded and conforms to quality requirements (art 43.1). However, it is not clear how this right should be read in the light of the new *Seed Act of 2005*, which introduces compulsory certification.

In some countries the laws explicitly apply only to seed that is packed and certified, leaving the farmers' seed system untouched. These laws basically protect the seed label.

Private rules 3.4.4

In addition to the official national rules and standards, members of ISF must adhere to the Federation's 'private rules', which were updated in 2009 (ISF, 2009). These rules deal with contracts among seed merchants and between companies and contract growers. They also include rules for dispute settlement through mediation, conciliation and arbitration. This is particularly useful since regular courts may not have the technical capacities to deal with disputes in the seed sector, particularly in international trade.

More recently, ISF developed guidelines for the settlement of disputes arising from the concept of 'essential derivation' introduced by the *Act of the Convention for the Protection of New Varieties of Plants* of the International Union for the Protection of New Varieties of Plants (UPOV). These guidelines bring together the legal principles and their application in different plant breeding practices.

Seed policy and legislation: analysis 3.4.5

In recent years there have been extensive developments in seed regulation and plant breeder's rights. Several developments outside the purview of the seed sector itself have also had a marked impact on seed systems, including in the fields of intellectual property rights (business), biosafety (environmental and food safety), and access and benefit sharing (originating in environmental policies).

There are a number of policy issues that governments need to address. For example, public investment in breeding research in industrialized countries used to be geared towards domestic seed companies; how should it now deal with local branches of multinational companies? Seed regulation used to be focused on national seed production; how should it now deal with the increasingly international seed market, for example in terms of accreditation of quality control tasks? How should seed regulations be adapted to address policy priorities in biodiversity? How can governments address the fact that the commercial seed sector is not likely to produce the seed of all important food crops in developing countries? These are just a few of the major questions that arise from an overview of current developments.

The approach to seed system development followed in previous decades was based on the beliefs that seed systems follow a natural development pathway from farmers' production through government involvement towards a perfectly competitive private seed market, and that policies and investments simply need to assist in the transition from one phase to the next. However, this conceptual framework cannot capture the diversity of trends, the diversity of policy fields involved (business, food, biodiversity policies) and the diversity of commercialization opportunities of crops and target seed users (farming systems) in diverse economic environments.

Thus, legislation may need to address multiple targets. This could mean different levels of intellectual property (IP) protection for different sectors (strong IP protection for commercial crops, stronger farmers' rights for major food crops and smallholder farmers), and strong regulation of formal seed systems (for consumer protection) while leaving farmers' seed systems explicitly untouched by variety and seed quality control requirements. Models containing some of these issues are being developed in several countries.

It also means that international agreements need to be sufficient flexible to allow countries to include a diversity of goals and seed systems in their national legislation. Such flexibility could be built in regionally or globally harmonized concepts.

Seed legislation regulations are commonly biased towards the formal seed sector, and tend to concentrate on controlling the sector rather than supporting its development. Seed laws should support the diversity of seed systems within a country, i.e. private sector development where it may be expected to find commercial opportunities, ensuring seed quality and availability where the commercial sector may not be interested, and assuring conservation and sustainable use of plant genetic resources and seed security generally. A seed law must create customer confidence in commercial seed supply through appropriate seed certification and quality control measures, while at the same time allowing farmers' seed systems to operate freely. In framing rules and standards for seed certification and quality, care should be taken to develop procedures that do not cost too much to implement. If countries intend to create centralized quality control mechanisms, staff and funds must be made available to operate them sustainably. For example, in some countries certification is compulsory only for those crops where the facilities for such control are up to standard. The FAO-developed concept of Quality Declared Seed (FAO, 2006), introduced in several countries, reduces the burden of certification significantly while at the same time providing a significant level of consumer-protection.

Operating effective seed certification and quality control is a challenge for governments in emerging economies and developing countries. In emerging economies, such services may be charged to the users in the seed industry at cost, but in many developing countries this approach would hamper the emergence of a healthy and diverse private sector.

Plant breeder's rights and other rights 3.5

Plant breeder's rights 3.5.1

General trends

The number of countries that provide legal protection to plant varieties through plant breeder's rights increased enormously during the past 10 years. This increase is mainly attributed to the World Trade Organization (WTO) Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS). This stipulates in Article 27(3)b that WTO members should offer such protection through "patents or an effective *sui generis* system". Subsequent bilateral trade agreements have also supported introduction of plant breeder's rights and encouraged membership of the UPOV. By March 2008, 65 countries were members of UPOV.

Plant breeder's rights provide a temporary exclusive right to the breeder of a new variety in the commercialization of that variety. However, the use of the protected variety in further breeding is explicitly permitted by the so-called 'breeder's exemption'. The rights thus protect the breeder against competing seed producers and also against farmer seed producers, but ensure that the genetic resource is available in the public domain for further research and breeding.

Some members of the ISF, particularly larger companies in the USA, consider the breeder's exemption too wide, particularly in light of developments in molecular biology, such as marker-assisted backcrossing, that allow breeders to use material more efficiently. This has stimulated other debates on access to genetic resources. For example, some breeders argue that if nations can restrict the use of genetic resources for plant breeding through their access laws, making access subject to prior informed consent and mutually agreed terms, there is no reason why breeders should be obliged to make available their latest varieties for further breeding for free. This debate is likely to continue.

Most countries that are not members of UPOV have not joined because of the concept of 'farmer's privilege', introduced in the 1991 *Act of the Convention for the Protection of New Varieties of Plants*. Farmer's privilege allows farmers to reproduce seed for their own use "taking into account the legitimate interest of the breeder" but does not allow them to share, exchange or sell seed to their neighbours and relatives. This is highly contentious in developing countries as it is seen as constraining informal seed systems. In contrast, the wide interpretation of farmers' privilege in some countries (notably the USA) is considered to provide insufficient protection to plant breeders. This is a major reason why more and more breeders in the USA prefer to resort to the patent system, which does not have such exemptions.

Plant breeder’s rights in industrialized countries

Many industrialized countries have implemented the provisions of the 1991 Act of the Convention, and particularly the concepts of ‘essential derivation’ and farmer’s privilege.

Essential derivation rewards actual breeding as opposed to cosmetic breeding or other forms of copying, such as the use of inbred lines derived from existing lines by repeated backcrossing. The industry is currently developing guidelines for assessing whether a new variety may be considered essentially derived on the basis of genetic distance. This creates challenges for the courts as to how to interpret claims.

In the EU the ‘legitimate interest’ clause in the 1991 Act is interpreted as the right of breeders to obtain royalties on farm-saved seed. Small farmers—those producing less than 92 tonnes of grain equivalent per year—are exempted from such payments. Some countries collect such royalties through the seed certification agency, some through the seed cleaners who clean and treat farm-saved seed and some through grain handling agencies. Breeders are now generating significant income from these royalties, and there has been a gradual reduction of seed saving in Europe.

The USA has not implemented the legitimate interest clause, to the detriment of rights holders.

Plant breeder’s rights in emerging economies and developing countries

Implementation systems are under development in many countries that recently introduced breeder’s rights. Key elements include establishing a registration office, defining effective variety testing for the requirements for protection (DUS-NN—Distinctiveness, Uniformity, Stability, Novelty, Name), campaigns to increase awareness and knowledge with stakeholders, and raising the capacity of the judiciary to deal with infringements.

Regional cooperation in the implementation of breeder’s rights can significantly reduce transaction costs and thus reduce the cost of introducing new varieties. For example, the use of foreign DUS reports, which is common among UPOV members, removes the requirement for countries to develop variety testing infrastructure for all crops. Breeders’ rights can be protected at a regional basis through complete harmonization of laws and the establishment of a regional registrar along the lines of the Community Plant Variety Office in the EU. Discussions among South-East Asian countries may lead to increased collaboration in this field.

Patents 3.5.2

Global trends

Few countries offer patent protection to new crop varieties. Exceptions are the USA, where it is widely used, Australia and Japan. During the past decade, however, many more countries have started offering patent protection for parts of varieties (e.g. genes or traits) and biotechnological processes (e.g. transformation). Such patents do not impact any single variety, but may apply to all varieties containing such traits, or that have been developed using such processes.

Whether this development is good for individual companies or for the seed industry as a whole is widely debated. The general belief is that large companies have an advantage in using the patent system and defending their rights, whereas the breeder’s rights systems are generally more easily operated by smaller companies.

Although in theory countries are free to formulate patent laws that meet their specific circumstances, there are signs that the freedom of countries to design their IPR laws will be restricted further in the coming years. This is despite the fact that the formulation of the Substantive Patent Law Treaty within WIPO was put on hold.

Patents in industrialized countries

Patents include neither breeder’s exemption nor farmers’ privilege. There is a research exemption, but in some countries, notably the USA, the scope of this exemption has been significantly reduced during the past decade, precluding any type of research use that might lead to a product without the consent of the patent holder. This limits possibilities for use of patented materials in plant breeding. The absence of farmers’ privilege prevents farmers from saving and reusing seeds.

The EU has taken steps to introduce farmers’ privilege in the patent system, i.e. farmers are allowed to reuse seed even when a component of that seed is included in a patent claim. Similarly, some European countries, notably France and Germany, introduced an explicit breeder’s exemption into their patent system, i.e. anyone is allowed to use plants that contain patented components for further breeding. If the patented component is retained in the variety produced, the breeder has to obtain the consent of the patent holder. If, however, the patented component is bred out of the new variety, it is free of any obligations. This keeps the genetic background of the variety in the public domain while retaining legitimate rights of the patent holder.

Recent discussions within the European Patent Office and among major patent offices indicate that a more strict interpretation of the basic requirements for patentability (novelty, non-obviousness, industrial application) may result in a many applications relating to genes and biotechnologies being turned down in future.

Patents in emerging economies

Many countries with emerging economies are in the process of updating their patent laws. For example, India recently changed its patent law to accept applications for product patents as well as patents on processes. China updated its patent law in 2008. Key in these changes is the continuing struggle to distinguish between biological processes, which may be exempted from patentability under TRIPs, and the inclusion of claims on living organisms.

Patents in developing countries

Developing countries are under strong pressure to extend their patent systems to cover innovations in plant sciences. In theory, countries can, within the broad limitations of TRIPS, match their system of patents on biotechnology to their specific needs. However, this sovereign right is limited through bilateral trade negotiations. For example, African countries maintain their view that life forms cannot be patented and that plant varieties should be protected through *sui generis* forms, but negotiations with the EU are discussing where the boundaries of patentability will lie.

Other IPRs 3.5.3

In addition breeder's rights and patents, other IPRs are important in the seed sector. These include trademarks, trade secrets and geographic indicators.

Trademarks are essential for protecting the identity of the seed company in the market and avoiding misrepresentation. The protection of trademarks is more widely implemented in most countries than are other IPR mechanisms.

Trade secrets are important in breeding. Companies consider the methodologies they use to gain maximum genetic advances part of their corporate property. Trade secrets can also be essential in protecting parent materials of hybrids from misappropriation by competitors. These trade secrets are, however, being challenged by requirements to declare the origins of new varieties and patented inventions under access and benefit-sharing obligations on the use of genetic resources. The implementation of trade secrets protection varies among countries; some have an explicit IPR law, others bring violations of trade secrets under their business regulations.

Finally, there is debate about the use of geographic indications in the seed sector, notably for the support of value chains for local niche products. Such 'appellation of origin' type of protection is particularly sought after to protect the final product, but there may also be opportunities to use such legal tools for small seed producers operating at local markets.

Farmers' rights 3.5.4

Farmers' rights do not deal with the protection of intellectual property *per se*, but it is discussed here because countries that have enacted these rights have done so in their breeder's rights laws. Farmers' rights are "rights arising from the past, present and future contributions of farmers in conserving, improving and making available plant genetic resources, particularly those in the centres of origin/diversity" (FAO, 2001). These rights, laid out in article 9.2 of the International Treaty on PGRFA, include:

- ;protection of traditional knowledge relevant to plant genetic resources for food and agriculture
- the right to equitably participate in sharing benefits arising from the utilization of plant genetic resources for food and agriculture; and
- the right to participate in making decisions, at the national level, on matters related to the conservation and .sustainable use of plant genetic resources for food and agriculture

Article 9.3 states that "Nothing in this article should be interpreted to limit any rights that farmers have to save, use, exchange and sell farm-saved seed/propagating material, subject to national law and as appropriate."

Farmers' rights are not much discussed in industrialized countries. Farmers' organizations in these countries are commonly well connected to policy processes; traditional knowledge is not important in conventional agriculture, famers do not seek benefit-sharing for the use of 'their' genetic resources, and the debate on the use of farm-saved seed is conducted in the framework of IPRs and seed legislation. However, some industrialized countries support the implementation of farmers' rights in developing countries or contribute voluntarily to the funding mechanism of the International Treaty by way of implementing the benefit-sharing component of farmers' rights. For example, Norway announced that it would contribute annually a percentage of the value of its national seed sales to this mechanism.

Some developing countries have placed particular emphasis on the provisions of Article 9.3, creating a demarcation between breeder's rights and the rights referred to in Article 9.3. India, for example, gives farmers the rights stated in Article 9.3, including the right to sell seed on a non-commercial basis, while commercial sales of seed of protected varieties fall under the breeder's rights. The labelling of seed bags is identified as the demarcation between commercial and non-commercial; if there is a company name and/or a variety name on the bag, the sale is considered commercial and the consent of the rights holder is required.

Other aspects of farmers' rights have found their way into national legislation, notably benefit-sharing. Ethiopia, India, Thailand and some other countries introduced a 'gene fund' aimed at supporting farmers who maintain genetic diversity and other conservation initiatives. No countries have implemented specific measures for the protection of traditional knowledge on PGRFA, although some counties do protect traditional knowledge at large. Many countries consider the right of farmers to participate in decision-making on genetic resources as being implemented through the inclusion of farmers as stakeholders in official committees such as a national seed board and a variety release committee.

Plant breeder's rights and other rights: analysis 3.5.5

Intellectual property rights are important for the operation of commercial plant breeding by protecting breeders' investment in new varieties. The plant breeder's rights system was designed to balance the rights of farmers and breeders and to maintain a wide availability of genetic resources for further breeding. Biodiversity laws make the availability of genetic resources subject to mutually agreed terms and prior informed consent, while farmers' rights give farmers the freedom to reuse their seed.

The patent system was not designed to be applied to living organisms and its current application in the seed sector creates high transaction costs. EU solutions of introducing exemptions may provide a useful example for countries that cannot avoid approving patent claims that extend to plants and varieties.

Countries often apply different protections to different agricultural sectors. For example, a country may want to provide strict IPRs in their export-crop sector while at the same time emphasizing farmers' rights in its food-crop sector. The complex of international policies and regulations makes it difficult for countries to choose implementation mechanisms that satisfy the diverse views and needs of stakeholders.

No formal mechanisms are in place for countries to learn from each other in terms of solutions developed to address these issues. There is a role for international organizations and academia in assisting countries in this matter.

Biosecurity 3.6

General 3.6.1

The introduction of transgenics is in most countries regulated by special biosafety rules that have been enacted during the last decade, such as the Gene Technology Act (2000) in Australia, European Union *Directive 2001/18/EC*, Mexico's *Law on Biosafety of Genetically Modified Organisms* (2005) and Brazil's *Law no. 11.105/05 of Brazil* (2005).

At the international level, the Cartagena Protocol on Biosafety (http://www.cbd.int/biosafety/) to the Convention on Biological Diversity (CBD), which came into force in 2001, aims at ensuring the safe transfer, handling and use of living genetically modified organisms (LMOs). The Codex Alimentarius Commission under FAO and the World Health Organization develops international guidelines on the safety assessment and labelling of food and feed products derived from LMOs.

Biosecurity in industrialized countries 3.6.2

The USA does not regulate biotechnology unless a specific need is demonstrated. Institutions such as the National Academies that advise the government on matters related to science, technology, engineering and medicine can initiate research on biotechnologies, leading to new regulations. During the last decade, research into the impact of transgenic corn on monarch butterflies (Sears *et al*., 2001), the inadvertent commingling of regular maize with transgenic corn (Starlink) that had not been approved for human consumption (Lin *et al*., 2003), and concerns over gene flow have resulted in recommendations for strengthening biological containment practices for GMOs.

In contrast, the European Union has sought to introduce an approach based on the 'precautionary principle', which requires substantive evidence that a transgenic is safe before it can be released. This is in line with the Cartagena Protocol. Very few GMOs have been approved for commercial use.

Strategies towards the coexistence of traditional and GM crops have been developed that aim to keep conventional and modified crops apart and prevent any mixture of transgenic and conventional seeds. For example, in Italy, regional administrations set up coexistence plans for typical regional products. These also contain references to liability, where the burden of proof is on farmers growing transgenics when damages occur due to traditional agriculture.

Biosecurity in developing countries 3.6.3

Many donors are supporting the development of biosafety frameworks in developing countries. This has led to concerns about possible lack of coordination. For example, in sub-Sahara Africa alone the following organizations (and possibly many others) have active biosafety/biosecurity programmes: AU/Nepad, UNEF/GEF, BioEARN, ASARECA, CORAF, CILSS Biosafety Initiative; RAEIN-Africa; FANR-PAN, ACTS, Programme for Biosafety Systems and SADC-BAC.

Biosecurity: analysis 3.6.4

A number of countries have implemented very strict biosecurity rules that require very costly research into food, feed and environmental safety. Only the largest seed companies are able to meet these requirements, leaving smaller innovators unable to test or release their research products. This may be one reason why so few truly novel products of transformation research reach the stage of actual use in the field. It may also be the reason why large multinational companies are the only ones reaping the benefits of the growing market for GM seeds. This may be compared with the novel food regulations in Europe, which are so strict that it is almost impossible to introduce 'new' food products on the market, particularly products derived from underutilized crops and other forms of biodiversity.

Seed in disaster preparedness 3.7

General principles 3.7.1

A major problem in farmers' seed systems is that seed availability fluctuates from year to year. After a poor cropping season, many farmers may not harvest enough seed to save any for planting in the following season, and other farmers in the community may be in the same situation. An effective formal system should be able to avoid these fluctuations, but maize seed shortages in Kenya in recent years illustrate that this is not always the case.

Seed insecurity can be chronic or acute, and individual or communal. Coping strategies differ for these four types. Acute individual seed shortages are commonly solved within the community. Such shortages may arise when a farmer has sudden expenses that force him or her to sell the whole harvest, including the portion meant for planting the following season. In such situations, farmers commonly obtain seed from neighbours or relatives. Chronic individual seed insecurity is poverty based. Such farmers commonly buy grain from the market at planting time for use as seed.

Acute communal seed insecurity may arise when a disaster affects a crop in the field, for example a tornado or a grasshopper infestation. The repatriation of refugees after civil strife may also create severe seed shortages. Finally, chronic communal seed insecurity may arise after repeated disasters, such as long-term drought or an ongoing civil strife. In both acute and chronic seed insecurity, seed relief programmes are necessary.

Seed relief 3.7.2

Lessons learnt from emergency seed relief (or seed aid) schemes in the 1990s show that it is vital to properly assess the needs of farmers in areas struck by environmental disaster or civil strife. Providing the wrong type of seed is not only a lost investment by the relief agency, but also harms farmers. Non-germinating seed or seed of varieties that are not adapted to environmental conditions or local food needs puts farmers' investments in labour and land at risk.

Seed aid is not always the only option for dealing with seed shortages. Food aid may in some cases release farm-saved seed that would otherwise be eaten. When the emergency is not acute, support to local seed systems through seed fairs or seed bank facilities (providing central storage facilities and risk management for individual farmers) can alleviate the problem.

FAO provides guidelines for seed relief operations. These stress that seed relief activities should be based on a solid understanding of the seed systems farmers use and should focus on maintaining the local seed system. A basic requirement is that seed interventions should facilitate access to crops and varieties that are adapted to environmental conditions and farmers' needs.

These guidelines create challenges for relief agencies, which commonly do not employ seed specialists. Emergencies commonly require immediate action, which makes it difficult, but no less necessary, to analyse available options before acting. For example, while it is logical to look for certified seed, which has assured quality standards, there may be no certified seed of locally adapted varieties or crops. It may be better to purchase seed or grain from local sources, but that may require facilities for cleaning and testing which relief organizations may not have.

FAO and some other organizations (notably the Catholic Relief Service and the International Center for Tropical Agriculture, CIAT) are active in supporting relief agencies in improving their seed aid programmes and in collecting and making available lessons from past emergencies.

CONCLUDING REMARKS .4

Seed is a vital component in crop production and thus is central to rural development and food security. Seed is a commodity that can be traded, and may carry harmful organisms, and thus is the subject of business and trade policies. It is a carrier of genetic information that is combined with traditional or scientific knowledge, and thus the subject of policies focusing on private (intellectual property), community (traditional knowledge) and national (biological diversity) rights. Finally, as a carrier of genetic information, seed provides a tool for technology transfer and as such is able to increase output and reduce risk, and in some cases transform farming systems.

The development of the seed sector follows diverse pathways around the world as a result of differing weights given to the various policy fields and of the opportunities offered by local institutional and commercial settings. The result is that farmers' and formal seed systems operate side by side. The balance between public and private roles in formal seed systems varies, as does the relative sizes of the formal and farmers' seed systems. These differences are apparent between and within countries and regions, and between crops and farming systems.

The challenge for policymakers is to create policies and laws that support each of these various seed systems where they are most effective. For example, a seed law may need to prescribe control measures for commercial supply of seed while providing room for supporting seed quality and availability in farmers' seed systems. This does not mean that there is no scope for regional or international harmonization of seed regulatory frameworks, but that these frameworks should have flexibility to allow countries to move sectors (crops, farming systems) from lower to higher levels of regulation, or vice versa, as developments dictate.

The ongoing consolidation of the commercial seed industry presents a major challenge globally. While consolidation creates opportunities for increased investments in innovation, concomitant declines in public investment in the seed sector, which have occurred in many developing countries, harm those farmers for whom commercial solutions are either not accessible or do not respond to their specific needs. There is the danger that consolidation can lead to monopoly power or become an obstacle to new entrants in the market. Such monopoly powers arise when:

- the market share of one company increases through mergers—as may be developing at the global level in the field ;of vegetable seeds
- when a patented trait gives the patent holder control over the majority of the seed market of a particular crop, which is the case in herbicide-resistant soybean and insect-resistant cotton in some countries; or
- when a country is too small to provide a viable market for more than one seed company, which is the case in .several countries in Africa

Monopolistic tendencies may be avoided through anti-trust legislation (ranging from strong in the USA to very weak in almost all developing countries), compulsory licenses that require patent holders to license their technology to more than one breeder, and by creating regional markets. It appears however, that it is very difficult to fight (near-) monopolies when they arise.

Strong intellectual property rights have proven to contribute to strong private companies with significant increases in shareholder value. These strong companies have been able in turn to gradually widen the scope of the patent system by pursuing test cases in court. The ban on the protection of mere expressed sequence tags, and current efforts within the major patent offices to examine submissions more vigorously for novelty, industrial applicability and lack of obviousness may, however, limit these developments.

There is a great divide within the commercial seed industry between those favouring the patent system and those wanting to put more emphasis on plant breeder's rights as the key protection system in breeding. Plant breeder's rights seem to lead to more competition in the sector, and can be combined more easily with the concept of farmers' rights. Trends towards globalization of IPRs, such as WIPO's Substantive Patent Law Treaty, limit the ability of countries to frame their protection system towards national societal goals. Similarly, UPOV's lack of flexibility in the interpretation of its clause on 'private and non-commercial use' has discouraged developing countries from joining UPOV and implementing UPOV's model for plant variety protection.

Large-scale commercial seed systems require large markets. There is little profit for private seed companies in minor crops, especially where farmer seed systems operate. Limiting farmer seed systems through regulatory measures may create an incentive for the private sector for some crops. Where this cannot be achieved, governments may need to make targeted investments in the seed sector. Such public investments could be targeted to research and the promotion of seed quality, or could involve more direct support to seed producers, notably to small seed companies that operate at a local/regional scale. Such strategies could lead to a locally vigorous, competitive seed sector for major field crop seeds. This approach is being promoted by the Alliance for a Green Revolution in Africa.

Farmers' seed systems are important sources of seed of many crops, especially in developing countries. While the local knowledge and traditional institutions that these systems are built on may be valuable, they can also hinder adoption of improved practices and better-performing varieties. For example, local varieties may have high levels of yield stability but average yields may be low. Traditional explanations of crop diseases, for example, obscure the fact that some diseases may be seed borne and could be controlled through better seed production methods. Such limitations in both knowledge and landraces provide excellent opportunities for upgrading farmers' seed systems through targeted provision of relevant knowledge and careful selection of traits that could strengthen the landraces through participatory plant breeding. Major obstacles to the upscaling of such alternative breeding strategies include the complex nature of interdisciplinary research and the reward systems for researchers at the national institutes, which reward traditional breeding efforts. Changing breeders' reward systems from 'number of varieties released' to 'impact on farming' may require significant institutional change. Interest in participatory plant breeding is growing in Europe and North America, notably in the context of ecological or organic farming systems.

There are various opportunities for seed systems to contribute to conserving and using plant genetic diversity. These include participatory plant breeding to improve local varieties, supporting local entrepreneurship instead of large private companies, and targeted interventions to encourage interspecific crosses and other pre-breeding efforts to broaden the genetic base of our crops. The last of these can be done either by large companies with the resources for such long-term investments or by the public sector, which can then make the broadened parent materials available to breeders and seed producers. Such investments could be international, as is the case in wheat, or national, but require explicit targeted investments in research.

Challenges from outside the seed sector itself include ecological pressures, such as the emergence of new strains of important diseases and climate change. For example, the new strain of wheat rust, Ug99, that originated in Uganda has the potential to decimate wheat crops worldwide. Developing new varieties with a durable source of resistance to this disease is a major challenge for plant breeders, but an equally large challenge will be to deliver the new varieties to farmers. In large 'recommendation domains', such as the Punjab, the disease can be addressed by developing a few varieties and distributing these through existing seed supply systems, complemented by additional efforts to promote spread of the new varieties to farmers who normally do not purchase seed. In ecologically diverse areas, such as Ethiopia, such approaches will not work because the diversity of ecological areas requires numerous, locally adapted varieties. Here, the solution will likely be to breed resistance into a wide variety of locally adapted genetic backgrounds and provide segregating populations to farmer-breeders, combined with policies to support small seed enterprises.

Climate change provides particular challenges to the farmers' seed systems. When the changes merely move ecological zones north or south, farmers will quickly learn to use varieties from farmers in these neighbouring zones. Participatory variety selection may facilitate this. If, however, the changes mainly increase the occurrence and severity of extreme weather—be it tornados, drought, or excessively cold or mild winters—then the genetic diversity in the available landraces is not likely to be wide enough to adapt to these changes quickly enough. Outside help in plant breeding will have to be sought, ideally in a combination of scientific and participatory methodologies. Climate change may also further increase the need for emergency seed provision, with the risk that local seed suppliers will come to depend on aid organizations as their best customers. This may help to get new local seed companies started, but the more they depend on such aid organizations, the more difficult it becomes to refocus on farmers as customers. There are signs of this happening in some parts of Africa.

Recent rises in food prices appear to offer promise to the formal seed systems. Prices increased in 2008 following drought in some major production areas, the large scale cultivation of crops for biofuel, and speculation. If the speculative effects die out and prices settle at levels that gradually increase over time, farmers may have the opportunity to invest more in crop production, including the purchase of commercial seed. This would expand the market for existing companies dealing with maize, soybean and oil crops but would also create opportunities for local companies, and start-ups, producing seed of self-fertilizing cereals, such as wheat, rice and sorghum, and possibly seed of legumes, such as beans and cowpea.

Overall, seed markets have a tremendous potential to grow if suppliers are able to produce good alternatives to farm-saved seed at a price farmers are able to pay. It is, however, impossible to replace farmers' seed systems completely and it would be unwise to try to. Farmers' seed systems provide an important component of seed security, a vital haven for diversity and space for the further evolution of plant genetic resources. Policymakers have to realize this and carefully balance incentives and regulations to safeguard an ever-changing optimal mix of private, civil and public roles. Donors will have to respond to such policies wisely. In the past decade, few donors have substantially supported seed system development, and those that have have often done so with a limited focus, e.g. only setting up certification organizations, or only providing seed processing equipment.

Following the re-emergence of the role of agriculture in the global debate in the wake of the Sachs report (UN Millennium Project, 2005), the 2008 World Development Report (World Bank, 2007) and the International Assessment on Agricultural Science and Technology for Development (IAASTD, 2009), there is a risk of over-investment in some regions, and again an unfounded confidence that one approach will solve all seed-related problems. It is high time to create a broad vision that allows for strategies that support the diversity of seed systems that optimally serve farmers in their diverse situations.

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