CHAPTER 22

Marker-assisted selection: policy considerations and options for developing countries

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SUMMARY

Policy options for research, development and diffusion of the products of marker-assisted selection (MAS) depend on the development objectives and priorities of the agricultural sector, its various subsectors and cross-cutting activities dealing with science and technology (S&T), including biotechnology and the management of genetic resources. The policy agenda in each of these areas has shifted from the traditional focus of "raising productivity" to a broader agenda of improving rural livelihoods in both economic and non-economic terms in support of the Millennium Development Goals (MDGs). Securing financial commitments from national governments and donors to invest in MAS and related molecular approaches requires more active engagement by national agricultural research and extension systems (NARES) in the processes of revising poverty reduction strategy papers (PRSPs), and in developing policies and strategies for agricultural development, S&T and genetic resources. Agriculture and agricultural S&T are undergoing rapid change but few developing countries have either agricultural S&T or biotechnology policies. They need to develop these to build coherence across the agricultural sector including delineating the roles of public and private sector entities, and as a means to strengthen accountability with respect to priority setting, monitoring and evaluating the outcomes and impacts of both research and practical applications of MAS. Options are provided for developing and implementing MAS programmes and projects, for setting priorities and evaluating outcomes and impacts. Given the uncertain nature of technical change and the long time frames that often characterize translation of the research and extension services provided by NARES into sustainable improvements in productivity and livelihoods through genetic enhancement, it is concluded that greater emphasis needs to be placed on research to analyse systematically the critical paths involved in successfully transforming research outputs into development outcomes and impacts and that this can best be achieved using an innovation systems approach.

INTRODUCTION

This book provides a comprehensive description and assessment of MAS for increasing the rate of genetic gain in a wide range of agriculturally important species using DNA-based markers for both simple and quantitative traits. Its various chapters attest to the remarkable progress that has been made in researching this approach. This progress has only been possible through the determined pursuit of multidisciplinarity, i.e. by bringing together into teams the skills and knowledge of individuals who could: innovate around the suite of techniques provided by advances in molecular biology to isolate, multiply, identify and insert DNA sequences; produce innovations in electronics and engineering to miniaturize, automate and provide high sample preparation and analytical throughput; use statistical and computer science to analyse and manage the information (bioinformatics) obtained; extend knowledge of the mechanisms that regulate physiological processes in plants and animals; and use quantitative genetics in association with conventional and novel breeding and selection approaches. This research has contributed enormously to the processes of adapting the basic techniques and tools of molecular biology to study the genetic make-up of agriculturally important species at the molecular level, and to accumulating knowledge of the linkages between DNA sequences and in some cases genes and traits that are important for the livelihoods of farmers, foresters and fisherfolk.

Yet, while recognizing this admirable progress, for most species and most traits that are important for both large commercial enterprises in the industrialized world and more particularly for small-scale and resource-poor production systems that constitute the livelihoods of the majority of the rural poor in developing countries, MAS has still to deliver on its undoubted potential, and on the claims in academic and other circles that it would "revolutionize" the way advantageous varieties and breeding stock are developed. As a result, there is still a substantial mismatch between "the field" and the expectations of policy-makers, social scientists, community groups and non-government organizations (NGOs), etc. In fact, the reality is that, while the approach has certainly transformed laboratory operations, apart from its use by the private sector in backcrossing of transgenes into elite inbred lines of maize and other crops and some commercial applications in livestock, the impacts of MAS on rural livelihoods have to date fallen well short of expectations.

This chapter does not dwell on the scientific and technical issues underpinning MAS, nor does it challenge either the need for continued research or the unquestionably greater opportunities for scientific and technical breakthroughs and socio-economic benefits that will surely arise from sequencing and post-genomics research – provided levels of investment in gathering and analysing phenotypic data keep pace with molecular developments. Its focus is on the evolving political, policy and institutional settings (both nationally and internationally) within which agriculture and agricultural S&T institutions and extension services are operating in developing countries, and on some of the options open to governments and public sector institutions in these countries to engage more forcefully in MAS-related R&D and the diffusion of genetically improved products generated through this approach to producers. It argues that the challenges and opportunities for doing so cannot be divorced from the policies and objectives underpinning country-based and donor-assisted strategies for achieving the targets set by the World Food Summit (WFS), the MDGs, and as described in national PRSPs and in national and regional programmes for food security. Policies and strategies for successful implementation of MAS are also inextricably linked to those for the sector as a whole and its various subsectors, and encompass cross-cutting issues like the management of S&T including modern biotechnology, genetic resources and other developments in the international policy and regulatory arenas that cross lines of national sovereignty. Policy considerations and options for MAS are therefore described within these broader frameworks.

The chapter begins by outlining the social and economic contexts within which the agricultural sector currently operates, the challenges it faces, the main political forces driving change, and both the processes and considerations involved in developing comprehensive agricultural development policies. It then goes on to discuss and provide options available to countries for formulating policies for agricultural research, S&T, biotechnology and genetic resources for food and agriculture (GRFA), arguing that in most countries there is substantial scope for greater "joined up" thinking and coherence of action in formulating, implementing and monitoring the outcomes and impacts of programmes and projects involving MAS. Based on the author's interpretation of the information provided by other contributors to this book, there then follows a section covering some general points that policy- and decision-makers should consider before embarking on MAS, and this is followed by sections dealing respectively with considerations for priority-setting and options for implementing MAS. The chapter concludes by looking at the future of MAS, stressing the need for greater effort in building political support, in setting priorities and better delineating the roles and responsibilities of different stakeholders, in fostering partnerships and in creating more effective delivery mechanisms.

CONTEXT

Hunger, poverty and agriculture

The number of people who go hungry each day in developing countries stands at around 820 million and around 24 percent of the people in developing countries are absolutely poor, living on less than US$1 a day (FAO, 2006). Hunger and poverty in the midst of plenty are the central challenges in today's global economy and society, but if the trends of the past decade are extrapolated forward, there will still be 582 million undernourished people by 2015 (FAO, 2006). This is well short of the target of 412 million that was set at the time of the WFS in 1996, although possibly on track to meet the somewhat less ambitious MDGs that were set in 2000. More than half of the 582 million will be in South Asia and East Asia, with 203 million and 123 million respectively, while sub-Saharan Africa will be home to 179 million hungry. The challenge is not only to provide food security in 2015 for the present 820 million malnourished, but for the additional 600 million people born over the coming nine years and the nine billion people projected to make up the world's population by the middle of this century.

The nature and causes of hunger and poverty are many, varying widely between and within countries; they are also evolving and often interlinked. Even so, the fact that they are most concentrated in rural areas where people's livelihoods depend on agriculture (including fisheries and forestry) and the non-farm small and medium agro-industrial processing and servicing industries that are connected to it, means that investing in agriculture and more broadly in rural development must be at the heart of any strategy for hunger and poverty reduction. While the measures needed certainly go well beyond the issue of producing more food and agricultural products, achieving greater yields and higher value products from the same plot of land or enterprise must be a key ingredient for the great majority of developing countries.

How to do this at a lower cost to improve household access to food and the competitiveness of small-scale farmers while maintaining or improving producer incentives, the sustainability of farming systems, and the many services provided to societies by both managed and natural land and aquatic ecosystems, poses huge challenges. Particularly challenging is tackling situations where agricultural potential is low, resources poor and markets distant. Any investment in MAS needs to be justified on the basis of its potential to contribute in an effective and efficient manner to these challenges.

The evolving context of agricultural growth and policy

The situation facing rural producers, households and public institutions now is quite different from that of 20 years ago. Political support and consequently public sector investments in agriculture and rural development have fallen both nationally and from international donors and financial institutions. Privatization has been the overarching policy response, but often the private sector has failed to fill the gaps, leaving many producers with no or significantly reduced flows of the inputs and services critical for both production and access to markets such as technologies, extension and credit. Additionally, market access for poor producers has deteriorated due to greater integration of the global economy and other market distortions, and the need to conform to international sanitary, phytosanitary and food safety standards as well as to product accreditation schemes established by supermarket chains and others. Complicating the situation further are pests and diseases, natural resource degradation and climate change.

On the positive side, there is irrefutable evidence of a deepening political commitment within governments and the international community to tackle poverty, hunger and environmental degradation urgently and in a concerted manner. At the global level, this includes the Plan of Action that emerged from the WFS in 1996, the set of eight MDGs that followed the United Nations Millennium Summit in 2000, and the Plan of Implementation from the World Summit on Sustainable Development in 2002. Regionally, it includes the vision and strategic framework document for the New Partnership for Africa's Development (NEPAD) and its underpinning Comprehensive Africa Agriculture Development Programme (CAADP) (NEPAD, 2002).

Nationally, the most notable examples are: the development of revised country-driven PRSPs, which aim to link national public actions, donor support and the results needed to support the MDGs, and which provide the basis for World Bank and International Monetary Fund's concessional lending and for debt relief under the heavily indebted poor countries (HIPC) initiative; national development strategies, plans and programmes; sector-wide approaches (SWaps) that are aligned with the MDGs; and national and regional programmes for food security that are supported by FAO and its donors. In one form or another, these documents describe national macroeconomic, structural and social policies and programmes to promote growth and reduce poverty, and map out plans for their attainment and priorities for both domestic and external assistance. With respect to the latter, the 2005 Paris Declaration on Aid Effectiveness provides a multidonor commitment to improve aid effectiveness through harmonization, alignment and managing for results (see, for example, www.oecd.org/document/18/0,2340,en_2649_3236398_35401554_1_1_1_1,00.html).

Significant within essentially all of these processes is the shift from the traditional agenda of "raising productivity" for agriculture to the broader agenda of improving rural livelihoods in both economic and non-economic terms. Also significant is the fact that despite their positive track records, agriculture and, even more so, agricultural research are not high on the list of priorities in country PRSPs. This points clearly to the need for agricultural ministries and NARES to engage more actively in the process of revising future PRSPs. However, success in elevating the priority given to agriculture within PRSPs will only be achieved by formulating and delivering agricultural R&D policies, programmes and activities that are coherent within the agricultural sector, with national PRSPs and with the MDGs. Noteworthy here is that in 2004[1] the Economic and Social Council of the United Nations (ECOSOC) underscored that most developing countries are unlikely to meet the MDGs without a clear political commitment to making S&T among the top priorities in their development agendas, and recommended that governments increase R&D expenditure to at least one percent of gross domestic product (GDP).

COMPREHENSIVE AGRICULTURAL DEVELOPMENT POLICIES

Defining these policies basically entails determining the broad-based objectives of the sector,[2] which, in the new context of development, also needs to include goals for enhancing social equity and natural resource sustainability. Essential to the process is "mapping the terrain". This requires evidence-based stocktaking of past trends within each subsector (e.g. with respect to production, marketing and legislation), and identifying barriers to realizing opportunities for expansion, strategic alternatives for moving forward based on an assessment of what the future is likely to hold, and the instruments and means for their implementation (e.g. through new legislation, administrative decrees, public and/or donor investment, and participation by the private sector and civil society).

Preparation then moves on to develop an integrated sector-wide package of policies to guide implementation, including an investment programme. Policies directed towards rural poverty reduction through agriculture must be based on (a) determining where poor people intersect most prominently with agriculture and the major risks they face (e.g. drought, salinity, disease outbreaks); (b) the types of production systems and commodities they produce;

[1] UN Economic and Social Council (ECOSOC) Resolution 2004/68 "Science and Technology for Development" (E/2004/INF/2/Add.3).

[2] In many countries, forestry and fisheries are separate sectors with ministries responsible for developing National Forestry or Fisheries Action or Development Plans

and (c) the linkages they have to markets, research and extension systems, etc. Some approaches for obtaining this information are described later.

From the standpoint of planning investments and strategies, it should set the scene for how the government intends to pursue reductions in poverty and food insecurity through agriculture, answering questions such as: will greater emphasis be placed on self-sufficiency and, if so, for what commodities; to what extent does the government intend to promote production by sourcing seeds and planting materials, fertilizers, breeding and broodstock, and feeds for livestock, fish and shellfish from abroad or relying on its own genetic resources and research and dissemination systems; does it foresee greater private sector involvement and, if so, in what areas and how will this be achieved; what is its attitude towards modern biotechnology – does it intend to pursue this and, if so for what purposes and how? For example, for internal political, external trade, cost and technical skill considerations, do investments in MAS appear more attractive than pursuing the development and/or importation of genetically modified organisms (GMOs),[3] and should investments in MAS and/or GMOs be given priority over conventional genetic selection approaches?

The value of having an agricultural development policy in place lies not only in the end result, i.e. a description of the course of action that a country intends to take to move the sector and its various subsectors forward over a given time frame. It also comes from the process itself, which if done with commitment to detail and rigour in analysing both past trends and future scenarios for the sector, and inclusiveness and transparency to ensure the broadest possible stakeholder participation and buy-in, leads to policies and strategies that are coherent within and between subsectors and between agriculture and rural development. It also has better prospects of securing consensus within the sector and endorsement for its implementation from other ministries with a stake in rural development.

There is clearly no ready-made model for conducting this process or for how the policy itself is implemented, monitored and the lessons learned are fed back for updating, but sound leadership and commitment are critical for preparing relevant and objective inputs through analysis and synthesis of information available within the ministry itself and from other relevant ministries. Ideally, information is also provided by research, extension, higher education and other service institutions and bodies in the public and private sectors including from civil society through documentation and/or organizing meetings at central, local and even community levels, and by outside advisers. In other words, both "top-down" and "bottom-up" approaches are essential to achieve balance and consensus with respect to goals and objectives.

Agreeing and implementing policies and strategies that are mutually supportive and where the "sum" is greater than the "parts", to meet the needs of the huge diversity of farming systems that exist in developing countries while targeting poor producers and consumers is clearly a huge challenge requiring negotiation, compromise and realism. It is also something that can neither be rushed nor "set in stone", and a fully integrated "rolling" policy that is updated at regular intervals represents the ideal. Developing an agricultural policy

[3] Referred to as LMOs (living modified organisms) in the Cartagena Protocol on Biosafety (2000) to the UN Convention on Biological Diversity (1992).

reform package in Honduras, for example, involved around 80 meetings over a year in which both Campesino and large-scale producer organizations participated, while in Guyana more than 100 meetings of civil society task forces were held over several years (www.fao.org/docs/up/easypol//354/agrc_pl_str_cnpt_prct_031EN.pdf).

POLICIES FOR AGRICULTURAL RESEARCH AND EXTENSION

The absence of systematic and comparative data on the benefits arising from the use of different technologies in agriculture precludes attaching priority to any one approach. However, the high rates of return and the reductions in both economic (Pardey and Beintema, 2001; Evanson and Gollin, 2003; Raizer, 2003) and non-economic poverty (Meinzen-Dick *et al.*, 2004) are impressive by any standards, and justify many of the past investments made in research and technology transfer. Consequently, it is hardly surprising that mobilizing and directing national institutions and skills towards capitalizing more forcefully on the opportunities available through S&T to meet the MDGs and other global, regional and national targets are consistently stated commitments within different sectors and themes. Most noteworthy in this regard are the plan to achieve the MDGs prepared by the UN Millennium Project and the underlying report of its Task Forces on Science, Technology and Innovation (UN Millennium Project, 2005a and 2005b), Africa's S&T consolidated plan of action (NEPAD, 2005), and the CAADP and InterAcademy Council reports on realizing the promise and potential of agriculture in Africa (NEPAD, 2002; IAC, 2004).

Yet, here again, judged by the content of current PRSPs and agricultural development plans, the vision of how S&T can contribute to enhancing the value of GRFA and thereby to achieving national economic and social objectives is invariably either missing, or the belief is projected that "on the shelf" technologies and existing knowledge only have to be adapted to local circumstances to meet the challenges ahead.

Unquestionably, policies and strategies promoting adaptive research and dissemination of existing technologies with a successful track record must have highest priority in the short term. However, priorities that will respond to the needs of small producers and rural households for new technologies in 10 or 20 years time (and requiring more upstream strategic and applied research) also need to be identified now because (and despite the claims of some scientists), even with the availability of more advanced R&D methods and tools, there is no reason to believe that the uptake of new agricultural technologies will continue to be other than slow and incremental (described by Pardey and Beintema, 2001, as "slow magic"). In this regard, the importance of countries having pluralistic, participatory, client-focused, decentralized and gender-sensitive advice on the processes of technology diffusion and adoption should be emphasized.

Maximizing the relevance and future contributions of new technologies to overall agricultural development also requires greater attention to planning and decision-making about the direction and management of the scientific techniques and tools as well as the genetic resources to which they will be applied in food and agriculture against the backdrop of current and likely future driving forces of change.

These forces include:

- *political policies,* where, as outlined previously, the new framework for agricultural policy focuses on alleviation of rural poverty. By shifting future investments in research towards an emerging paradigm of "research for development", the research agenda is broadened to ensure functional linkages to national development policies and to include the wider dimensions of livelihood strategies in both planning and assessing the impact of projects and programmes. It also shifts past emphasis on input-based technology supply by scientists to demand and need-driven innovation systems involving many other actors. Political commitment is also crucial to ensure sustainability of funding;

- *advances in science, and most notably in the computing and biological sciences*, as these have provided new techniques and tools for researchers to locate better and therefore target production systems and communities most associated with poverty and food insecurity, and new technologies in the form of seeds, breeding stock, vaccines, etc. with the potential to increase productivity within agricultural systems and wider food chains and improve economic and social well-being. They are also helping to overcome barriers to wider social engagement in decision-making;
- *growing acceptance of the importance of optimizing system productivity* by better-managing the interactions among diversified farm enterprises and sustainable resource management and ensuring access to markets, rather than maximizing individual crop or animal performance;
- *expanded intellectual property rights (IPRs) for biological innovations* (see Chapter 20) and changed norms for accessing and sharing the benefits of genetic resources in general and plant genetic resources in particular, supported by international agreements, conventions and treaties (see later);
- *increased private investment in S&T in general*, and within agriculture, through both R&D directed primarily towards crop, livestock and fish genetic improvement, and the delivery of products through multinational and national seed and breeding companies and their franchises;
- *expanded public–private sector collaboration* in research, development and extension, in some countries supported by legislation;
- *increased public awareness* of the relevance of the uptake of new technologies and their significance for improving the livelihoods of rural people.

These changes have already been felt most forcefully in industrialized and large developing countries such as Brazil, China, India and South Africa, where the demand-pull created for products of R&D is greatest. However, their impact is increasingly spilling over into others, including the low-income food-deficit countries with much less capacity to benefit from or otherwise adjust to the new realities of conducting S&T in a globalized world. An important issue for all countries is therefore how to adapt their NARES to respond better to both the current and likely future needs of their agricultural sectors, and in so doing to consider their S&T "futures", one of which is clearly modern biotechnology. Nonetheless, judging by the content of both PRSPs and national agricultural development policies and strategies, few developing countries appear to have started along this road by producing an integrated agricultural research and extension policy. This situation is hardly conducive to obtaining political and financial support for R&D on approaches such as MAS, which, as is clear from other chapters in this book, still remains largely in the laboratories and experimental stations of research institutes in both industrialized and developing countries.

NATIONAL S&T AND BIOTECHNOLOGY POLICIES

Like the comprehensive agriculture development policy, the rationale for having a national policy on S&T and, within that or separately, on biotechnology, is to provide a framework for government and key stakeholders to work together in a coherent and mutually supportive way to ensure that developments are captured for national benefit. The principles involved and mechanics of how it can be developed and managed are essentially the same as those described earlier for agricultural development policy planning, the main difference being in the breadth of government involvement – being cross-cutting issues, developing and implementing national S&T and modern biotechnology policies are clearly cross-sectoral responsibilities with coordination normally assigned to the Ministry of Science and Technology. The examples given in Box 1 illustrate options for pursuing the development of a biotechnology policy. More information on national biotechnology policies in individual countries is available at www.fao.org/biotech/country.asp.

While many countries have an overall S&T policy in place, and these and some other developing countries now have biotechnology policies (the most recent examples being Bangladesh, Kenya, Malaysia and Nigeria), the vast majority do not. Most national agricultural R&D institutions therefore lack the compass provided by the process of developing an overall national policy to guide the development and management of an agricultural biotechnology policy and from there, to formulate programmes and projects specific to the agricultural sector. This paralysis in policy-making only serves to promote supply-driven, at the expense of demand-driven, priority-setting and hence targeting of investments towards questionable needs. It also leads to fragmented and uncoordinated activities, and in some cases to delays in the adoption of technologies that could help improve the efficiency of agricultural research and provide products and services that directly or indirectly improve livelihoods. Indeed, the survey conducted by FAO on applications of MAS in the crop subsector (Chapter 2) illustrates well both the dearth of skills in priority-setting and coordination within many countries that adopt this approach and the complete lack of such activities in many others. While this can be explained to some extent by the relative novelty of biotechnology applications, as far as MAS is concerned, the paucity of information on the actual or potential economic and social benefits of the products arising from its application in the different agricultural subsectors is surely a major stumbling block to priority-setting and investment.

National agricultural research and biotechnology policies

Even in the absence of an overall national biotechnology policy, countries have a number of options for improving the strategic planning, monitoring and evaluation of modern biotechnology applications, including MAS, within their agricultural and wider rural development sectors.

The preferred approach is for the Ministry of Agriculture in association with other relevant ministries (particularly Higher Education) to champion the process

BOX 1

National biotechnology policies: Thailand and South Africa

In Thailand, the National Biotechnology Policy Framework (2004-2009) was prepared by a National Biotechnology Policy Committee chaired by the Prime Minister. This then led to the setting up of a national centre specifically devoted to biotechnology (the National Centre for Genetic Engineering and Biotechnology) under the National Science and Technology Development Agency. It is both a granting and research agency with its own research laboratories and is funded from a combination of government finances, revenue from services and commercial projects and competitive grants from national and international sources. It has major activities in agricultural biotechnology including: on genome mapping and marker-assisted breeding of rice; on cassava improvement where a database of cassava expressed sequenced tags (ESTs) is currently being developed and employed in the study of starch biosynthesis; and shrimp, with major projects on ESTs and genome studies for application in breeding, disease diagnostics and shrimp domestication. Noteworthy also is that through joint government-private sector funding, Thailand will host "Biotechnology Asia 007" with the focus firmly on agriculture.

In the case of South Africa, the National Biotechnology Strategy (2001) arose from a government request and the work of an interdepartmental committee led by the Department of Arts, Culture, Science and Technology with participation of the Departments of Agriculture, Health, Trade and Industry, and Environmental Affairs and Tourism. This committee set up an Expert Panel to provide specific inputs based again on "mapping the terrain" in terms of current applications, legislation and finance, and participation by all key stakeholder groups, etc. Arising from the policies proposed within the strategy document, a National Biotechnology Advisory Committee was established in 2006 and the Department of Science and Technology created a Biotechnology Unit. Since then, three Biotechnology Research and Innovation Centres and a National Bio-informatics Network have been established, interdepartmental cooperation has been promoted, and bilateral agreements have been signed. Again, agricultural applications of biotechnology receive high priority in this national strategy.

of establishing an open learning process for a national agricultural S&T policy dialogue including biotechnology, leading eventually to a planning document and a process of monitoring and evaluating outcomes and impacts. This could be achieved by establishing a national committee that would then define terms of reference and set up various task forces/working groups in a participatory and pluralistic manner to report on specific subsector and thematic issues.

In common with other planning procedures, the first step should involve a diagnostic study and analysis of existing S&T policies as well as of the national, regional and international S&T landscape. Bijker (2007) provides an excellent description of the criteria for building an S&T policy via a policy dialogue and a methodology for carrying out a diagnostic study. Essential for promoting a well thought-out policy and its effective management is the closest possible involvement of all players with a stake in research, development and diffusion of genetic material (ministry personnel, representatives of NARES, private companies, NGOs, farmer's groups, etc.). However, its focus must be on developing new national agricultural S&T (including biotechnology) policies and strategies to: (a) support institutional reforms, including intensifying cooperation at national, regional and international levels; (b) strengthen national capacities; and (c) identify new funding mechanisms.

Within this process, countries need to identify priorities and appropriate levels of resources to assign to biotechnology in light of their socio-economic conditions and cultural contexts and, in situations of no-growth budgets, they need to decide on what is to be diverted from other important problems. A critical issue is also reaching agreement on the roles and responsibilities of public and private sector entities. Suggestions are given later for considering MAS within this overall context.

An alternative – or preferably as part of the process of preparing a national agricultural S&T policy – is to draw up specific subsector strategies. This has the advantage of focusing minds and resources within that subsector in a holistic manner, for example, in the case of the crop subsector, by bringing together stakeholders dealing with breeding, conservation and seed production/dissemination. Another possibility, very attractive from both the S&T angle and for avoiding the creation of new structures, is to cover modern biotechnology policy development and programming through existing structures for managing genetic resources (see below for more details on rationale). Least attractive and cost-effective, but unfortunately all too often the case, is for individual research institutions and universities to draw up and implement policies and programmes that lack coordination with others dealing with the same or closely related subject matter, in particular genetic resources management.

Whatever the path chosen and notwithstanding the need to ensure national ownership of the process, advice (if needed and requested) on the actual or potential role of MAS within the agricultural S&T landscape should be sought from independent sources. These include the Consultative Group on International Agricultural Research (CGIAR), FAO, the World Bank, the International Council for Science (ICSU), the InterAcademy Council (IAC), the InterAcademy Panel (IAP), regional academies such as the Federation of Asian Scientific Academies and Societies, and national academies.

National policies on genetic resources in food and agriculture

MAS needs access to DNA-based techniques, constructs, tools, databases, statistical packages, etc., and Chapter 20 describes the IPRs surrounding these which include patents, copyrights, trademarks etc., as well as providing suggestions to NARES about acquiring these technological resources. However, successful application of MAS also depends on accessing new breeding techniques and, as many national collections may lack sufficient diversity (e.g. to reduce vulnerability to pests and diseases), they may need to acquire genetic resources that are available in other countries within landraces, wild ancestors and relatives, parental and breeding lines, protected varieties, breeds and broodstock. Additionally, as knowledge grows of the linkages between phenotype and genotype, awareness increases of the potential value of genetic resources and, as participatory processes involving local communities become more prevalent, so the demands for both germplasm exchange and sharing the benefits of the final products that are generated from R&D will increase. In fact, over the last 30 years, and due to a combination of the new possibilities opened up by molecular biology and some well publicized cases of "biopiracy", governments have increasingly come to appreciate the actual and potential value of genetic resources. This has resulted in an expansion of legally-binding global and regional instruments, and national laws, regulations and policy concerning issues of access, ownership and control of genetic resources and the sharing of benefits arising from their use or enhancement.

For the further pursuit and future success of MAS, policy- and decision-makers as well as individual scientists need to be aware of the requirements for international exchanges of genetic resources such as those described in the CBD (1992), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (see Stannard *et al.*, 2004 and Bragdon, 2004) and its standard Material Transfer Agreement (MTA), and the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs), particularly Article 27.3 (b), which states that while members may exclude plants and animals from patentability, if they choose to do so in the case of plants, they must provide an effective "*sui generis*" system of protection such as the 1978 and 1991 versions of the International Convention for the Protection of New Varieties of Plants administered by the International Union for Protection of Plant Varieties (UPOV), or a combination of the two (IPGRI, 1999; Le Buanec, 2004; Donnenworth, Grace, and Smith, 2004; FAO, 2005a; Tripp, Eaton and Louwaars, 2006).

They should also be aware that international exchange of germplasm carries with it the risk of introducing diseases and pathogens through plants and animals and their parts such as seeds and propagules, semen and embryos, and that sanitary and phytosanitary certificates are required to facilitate the safe exchange of genetic resources between, and under some circumstances, within countries. Familiarity is therefore needed with the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), the WTO Agreement on Technical Barriers to Trade (TBT) and the instruments relevant to standard setting within these, including: the International Plant Protection Convention with its objective of preventing the introduction and spread of plant and plant product pests, and the Animal Health Code implemented by the World Organisation for Animal Health (OIE) that covers both livestock and fish.

This international policy and regulatory framework is both complex and continuously evolving. Hence, apart from the scientific and technical challenges involved in MAS, developing countries face formidable difficulties in crafting and implementing legal and regulatory frameworks that facilitate exchange of GRFA as well as the range of tools used in MAS for both research and commercial uses. It also challenges national policy-makers to keep abreast of the international policy-making processes and all that these imply in terms of both coordination between ministries of agriculture, trade, environment, and S&T, and in human and financial resources. However, the consequences of not being knowledgeable about these matters, and in particular about the appropriate national laws of countries from which genetic resources and scientific techniques and tools are sought, could be serious for individual researchers and their institutions. All of these aspects must therefore be managed in a well coordinated, efficient and fair manner if countries are to realize fully the potential offered by MAS to contribute to national food security and agricultural development.

Most developing countries have activities dealing with specific aspects of plant genetic resources for food and agriculture (PGRFA) and substantial numbers have established cross-institutional programmes and coordination mechanisms including crop-specific bodies and networks to set priorities, evaluate progress and in general to promote the more effective use of genetic resources. In the case of livestock, and as noted in the draft report on the State of the World's Animal Genetic Resources for Food and Agriculture, presented at the Fourth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, held at FAO headquarters in December 2006 (www.fao.org/ag/againfo/programmes/en/genetics/documents/AH473e00.pdf), apart from a few (mainly northern hemisphere) countries with well-developed commercial livestock enterprises, interest in the topic is often limited to isolated departments within institutes that are rarely involved in animal genetic resources-related activities. In the case of forestry, national programmes have been established with consultative fora and lead institutions often outside the Ministry of Agriculture, and essentially similar arrangements operate with fisheries. India, for example, has a National Bureau within the Indian Council for Agricultural Research (ICAR) devoted to fish genetic resources, which undertakes work with microsatellite markers for population genetic analysis and determining genetic variation among and within inland species.

With respect to national biodiversity programmes, by being Parties to the CBD, countries have committed themselves to establishing policies, legal and regulatory frameworks and programmes for conserving and using both wild and non-wild biodiversity in a sustainable manner and, in doing so, to establish national Biodiversity Strategies and Action Plans (BSAPs) through focal points invariably coordinated by Ministries of Environment.

At present, however, few countries emphasize the conservation and sustainable use of GRFA in their PRSPs and agricultural development plans, or have strategic and holistic roadmaps as to how these resources should be managed within a particular subsector, let alone how this will be accomplished across subsectors. Such deficiencies are not conducive to priority setting and reaching agreement on specific programmes and projects, and therefore jeopardize funding of the most critical needs and the attainment of national objectives. Since genetic resources are the raw materials to which molecular methods and approaches such as MAS are applied, these deficiencies inevitably also lead to ineffective and inefficient integration of modern biotechnology into national programmes.

To put management of GRFA on a better footing, including through the appropriate integration of MAS and related approaches, countries need to establish or strengthen existing organizational structures and programmes that respond to national development objectives. This means ensuring that: they are well linked to the wider policies and programmes drawn up for agriculture, biodiversity and biotechnology; that they take into account the perspectives both of public institutions dealing with research, genebank operations and the supply of seeds or breeding stock, and those of wider stakeholder groups such as farmer and community groups, private sector entities, breed societies, etc.; and they recognize the interdependencies between national, regional and global policies and laws concerning access to these resources and sharing the benefits from their use.

It is beyond the scope of this chapter to deal with the setting up and coordination of systems or programmes for the management of genetic resources at the species, subsector, sector and wider levels. These aspects are covered comprehensively for PGRFA by Spillane *et al.* (1999), and the principles involved are equally relevant to the livestock, forestry and fisheries subsectors. However, while recognizing the essentiality of having a national biodiversity system or programme that is overseen, for example, by a high-level interministerial coordinating body for pursuing national development objectives and reporting through the CBD process, there is simply no substitute for specialized genetic resources knowledge within each of the agricultural subsectors to promote effective and efficient planning and implementation of MAS, including through awareness building and advocacy within national and international policy forums and interactions with donors.

MAS: GENERAL CONSIDERATIONS FOR POLICY- AND DECISION-MAKERS

One of the main take-home messages from the experts contributing to this book is that MAS can be demanding in its requirements for specialized equipment, consumables, electricity supplies, laboratory design and management, data handling and statistics, and Internet connectivity. Another is that MAS is a complement to and not a substitute for skills in conventional breeding and selection. Embarking on MAS should therefore never be considered as a paradigm replacing classical crossbreeding and phenotypic screening programmes, which in many developing countries are in any case limited in terms of species coverage and the availability of, for example, temperature and humidity-controlled greenhouses and growth chambers and field sites, and fragile in terms of staffing and funding levels (see, for example, Chapter 8).

Yet another message is that efficient and effective application of MAS requires well-qualified staff. First and foremost, it needs staff who have the knowledge to lead decision-making on when and when not to embark on MAS. This has to be done strictly on a case-by-case basis, bearing in mind that MAS may accelerate genetic progress in some traits better than others, and that the costs and benefits of using MAS in a production system need to be weighed up in the same way as any other input. It also needs leaders who give the “end product” rather than the “laboratory/research process” the main consideration, and staff with substantial design, technical, analytical and problem-solving skills and who are up to date with developments in the field. Furthermore, it demands a sustainable funding base. What should never be forgotten is the bottom line – namely, the investment made will ultimately be judged on the number of people benefiting from planting improved plant germplasm or keeping improved farm animals or fish.

Another key message is the absolute necessity of ensuring effective coordination between breeders and the people working in molecular biology laboratories. While it is not essential for all of these to be located physically within the same institution, policy- and decision-makers need to know that investments in staff and infrastructure for the "molecular component" of MAS are wasted if they are not linked to the "breeding and selection" components.

Apart from countries with technologically advanced NARES (Type 1 and Type 2 described by Byerlee and Fischer, 2001), getting all of the above elements together is a big task for the vast majority of developing countries, particularly against the background of current and often deteriorating levels of public funding for agricultural R&D (Pardey *et al.*, 2006). So big indeed that, while recognizing the need/opportunities for molecular MAS, they may consider, in the first instance, other very valuable applications of molecular-based techniques such as the polymerase chain reaction (PCR) for plant, livestock and fish disease diagnosis (see, for example, Viljoen, Nel and Crowther, 2005), estimating genetic distances between varieties, strains, lines and breeds, conducting variety and parentage testing (De Vicente, 2004; Chapters 14 and 17) and for GMO characterization and detection. These applications are not considered further here since they fall outside the core subject matter of this book. Also, while recognizing the increasing role of the private sector, the options described below for pursuing MAS are based on the assumption that the public sector will continue to be the major investor in R&D for small-scale producers and increasing the access of poorer sections of society to affordable food and agricultural products. Additional options are available through public–private partnerships and these are discussed later.

A final consideration is that, unlike the development and release of GMOs, MAS does not require the establishment and the enforcement of a specific legislative framework. Apart from avoiding the need for specific capacities in public administration, this certainly reduces the final costs of adopting MAS-derived varieties and breeds.

PRIORITY SETTING FOR MAS

Targeting the farming systems, species and traits linked most to poverty and hunger

Investing in MAS has to be based on striking an appropriate balance between needs and opportunities for combating hunger and poverty through genetic enhancement. Essential to that process is determining where the greatest concentration of poverty and hunger exists and the causal factors. There are essentially four approaches for pursuing this.

- ***Poverty and hunger mapping***

Although still relatively new, this approach is gaining increasing acceptance in national and international development circles. One of the major challenges faced by all countries in targeting their development, and hence research efforts, towards the food insecure and poor lies in the diversity of their farming systems and socio-economic conditions. However, using a combination of survey and census information (e.g. household surveys), administrative data (e.g. markets, roads), geographical information systems (GIS) and small area estimation maps, it is becoming increasingly possible to develop correlations and maps that link population densities, welfare data and crop and livestock production and livelihood systems; in effect, to pinpoint where poor people live and the production and livelihood systems associated with high levels of poverty.

Increasingly, through programmes such as the Inter-Agency Programme on Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS) which works both locally and internationally, Ministries of Planning are developing disaggregated poverty maps to help target their interventions for greatest benefits to the poor. Recent examples include the high resolution Kenyan poverty maps developed by the Bureau of Statistics within the Ministry of Planning with the assistance of the International Livestock Research Institute (ILRI), the Rockefeller Foundation, the World Bank and the World Resources Institute (WRI) (Ndeng'e *et al.*, 2003), and the International Rice Research Institute's work linking poverty and rice systems in Bangladesh (www.irri.org/science/progsum/pdfs/DGReport2000/FP1.pdf).

- ***Rapid rural appraisals***

These are systematic but semi-structured activities conducted by teams with both technical and social science backgrounds, usually as part of farming systems research (see below and Crawford, 1997). Their chief characteristics are that they take only a short time to complete, tend to be relatively cheap to carry out and make use of more "informal" data collection procedures. The techniques rely primarily on expert observation coupled with semi-structured interviewing of farmers, local leaders and officials. In substance, the techniques of rapid rural appraisals (RRA) are executed over a period of weeks, or at most months, rather than extending over several years. To date, RRA has mainly been used in the field of rural development as a short cut method to be employed at the feasibility stage of project planning.

- ***The farming systems approach***

This groups farm households with similar characteristics and constraints and therefore from a R&D perspective has the potential of promoting technology and knowledge spillovers. Unquestionably, the most authoritative study of the link between farming systems and poverty is provided by Dixon, Gulliver and Gibbon (2001). These authors describe 72 major farming systems throughout the developing world based on available natural resources, patterns of farm activities and household livelihoods, intensity of production and their relationship to markets. They also describe the needs of those living within them (with an average agricultural population of about 40 million inhabitants), the likely challenges they face and opportunities open to them in the next 30 years, and the relative importance of different strategies for escaping from poverty and hunger. In sub-Saharan Africa for example, of the 15 major farming systems identified, both they and the IAC (2004) gave priority to four systems based on the economic value of production and the extent of malnutrition, namely: the maize-mixed; the tree-crop based; the cereal/root crop based; and irrigated systems. However, NARES need to undertake similar priority assessments to complement such analyses.

- ***The "rural worlds" concept***

This categorizes rural people as capital intensive farmers, mixed commercial/subsistence farmers, the near or totally landless and those without any economic activity (OECD, 2006).

While each of these approaches has merits and limitations for targeting interventions based on geography and population, they all embrace the principle of engaging farmers and rural consumers/households in diagnosing problems and identifying possible solutions adapted to their particular circumstances.

Analysis of the needs and opportunities for MAS

As noted earlier and in an ideal world, the needs and opportunities for embarking on MAS should emerge first and foremost through the policy dialogue processes that lead to country priorities and objectives for agriculture and for agricultural S&T. In any case, careful analysis is needed to determine whether, given the current S&T, socio-economic and cultural landscape and government/community plans for the foreseeable future, the use of MAS will realistically contribute to hunger and poverty reduction. This requires a team of competent analysts to conduct an *ex ante* impact assessment that makes the best use of existing knowledge to determine whether:

- the principal barrier to sustainable intensification or diversification of the production system(s) as a whole could be overcome by introducing a new plant or animal genotype or by changing the environment, e.g. introducing better soil, water and nutrient management practices, draught power, vaccination, tsetse fly or other disease/integrated pest management practices. Also to be considered are the management changes that would inevitably be needed following the introduction of such genotypes. For example, increasing the prolificacy of local sheep or goats through MAS brings with it the requirement, *inter alia*, for an improved feed resource base. Does the system have the potential to provide this, and is there a market demand for the animals and their products? Foresight and total systems thinking are clearly required here;
- the species x trait(s) combination(s) required is not available in locally available germplasm (or breeds/broodstock) or in varieties/pre-breeding materials developed by and available from the International Agricultural Research Centres (IARCs), or other countries growing the same crops within similar production systems and located in similar agro-ecological zones;
- the species x trait combination cannot be developed more easily, and/or at less cost, through phenotypic selection. A number of chapters in this book provide excellent guidance on the factors that are important here, which include, *inter alia:* the species involved; the genetic complexity and heritability of the trait(s) required (the current focus for most crop and many animal species is heavily on disease and pest resistance); the availability of markers for the trait(s) in question and ability to scale up their usage, whether the trait is sex-limited (livestock); and the availability of reliable phenotypic data, etc.;
- there is already an existing national breeding programme(s) for the species in question;
- the national breeding programme(s) for the species in question has the infrastructure and levels of human and financial resources needed to sustain selection and breeding activities;
- national infrastructures and capacities in molecular biology match the scientific, technical and information requirements for effectively supporting MAS;
- professional legal advice is available concerning laws, agreements, licences, etc. for the acquisition and diffusion of both the tools or enabling techniques, and the starting- and end-products of MAS (see Chapter 20 and earlier in relation to access and benefit sharing of genetic resources);
- efficient mass propagation systems (e.g. seed multiplication or semen production programmes) are in place;

BOX 2

Centralized national centres of excellence and sectoral/subsectoral institutions

More technologically advanced developing countries such as Brazil, China, India and South Africa and others have established one or a number of cutting-edge centres for biotechnology working on both basic and strategic techniques and tools, and providing analytical and other support to national sectoral or subsectoral centres working on more applied and adaptive research projects. For example, the African Centre for Gene Technologies (ACGT) is an initiative by the South African Council for Scientific and Industrial Research (CSIR) and the University of Pretoria to create a national centre of expertise and a world-class platform in gene and genome analysis. Its focus is on using genetic markers to understand disease resistance in plants and nitrogen metabolism in cattle under harsh and arid environmental conditions. It supports the more downstream work of the Forestry and Agriculture Biotechnology Institute as well as various crop centres. ACGT is a member of the Southern African Network on Biosciences (SANBIO) and part of the NEPAD-sponsored African Biosciences initiative.

- adequate technical advisory services are able to support technically the dissemination of the improved variety or breed; and
- effective delivery, monitoring and evaluation strategies are in place to bring the products of MAS-related R&D to users and beneficiaries.

COUNTRY OPTIONS FOR IMPLEMENTING MAS

Countries with high-quality personnel and facilities for phenotypic evaluation and selection and in molecular biology

Individually or collectively and for a number of crop species, public institutions in these countries have the skills both to choose the appropriate parental and segregating materials and to apply routinely and with high throughput the full range of techniques available (including those requiring sequence information) to develop molecular markers. Through the establishment of centralized centres of excellence and sectoral/subsectoral institutions (Box 2), they have the potential to validate putative markers by combining their use with the detailed and comprehensive phenotypic information available on large numbers of lines for multiple traits to produce genetic linkage maps for identifying genomic regions controlling variations in simple and quantitative traits (QTL), and to use the right combination of trait-linked markers to improve the efficiency of parental selection and breeding programmes.

These countries tend to have concentrated their MAS activities on the introgression of a few traits (for instance those encoded by transgenes) and in a few crops, although markers themselves are being used for many of the non-MAS applications mentioned earlier. However, they also contribute effectively to global and regional crop genomic projects directed towards developing and validating genetic and linked markers and testing their usefulness for MAS in breeding programmes. They may also have some skills in applying (some of) these methods and approaches to livestock, fish and especially forest species research. Generally, however, these efforts are of a small-scale experimental nature and, particularly in the case of livestock where most traits, even for disease resistance, are complex, they are unlikely to move beyond the research stage in the near term because of the large numbers of animals required, the limited amount of structured phenotypic data available and the long generation intervals of many animal species.

These countries have both considerable potential and many options to focus resources for MAS on poverty and hunger alleviation, including:

- mobilizing the techniques, tools, genetic resources and phenotypic data already available nationally and internationally (e.g. parental lines and segregating populations from international and other national programmes), tapping the vast and rapidly increasing molecular and genetic knowledge available internationally through collaboration with international and advanced agricultural research centres, and contributing to genomics consortia (e.g. the International Rice Genomics Consortium). Applications include extending non-transgenic and transgenic approaches by developing and validating markers based on fine genomic mapping of QTL (i.e. by identifying single nucleotide polymorphisms, [SNPs]) for more complex traits like drought, salinity and heat tolerance and nutritional quality in major food crops;
- pursuing MAS for both simple and complex traits in crops that although relatively minor and scientifically neglected are of tremendous importance to many poor households;
- recognizing the increasing importance of trees, livestock and aquaculture to their rural economies, strengthening efforts to characterize genetic diversity through both classical phenotypic and molecular marker approaches and then developing, validating and eventually using markers for improving economically important traits such as host resistance to diseases.

Countries with reasonable capacities for phenotype evaluation and selection and some capacities to apply molecular marker methods

These countries have less comprehensive breeding programmes and therefore can cover fewer species. They will likely have been relatively "late starters" in MAS and may not have the latest high-throughput equipment, which is invariably located in one or a number of institutes supporting a particular subsector. Neither of these features is a major limitation provided the country prioritizes its work appropriately. This means pursuing justifiable and doable genetic enhancements to the limited number of species for which it has an effective selection and breeding programme to: (a) provide the foundation for developing segregating populations from parental lines and for characterizing and validating markers for the trait(s) in question; and (b) evaluate populations in the environments for the traits that are prioritized.

Also, while recognizing the need to adapt specific molecular techniques to local circumstances, and markers for particular traits to their own genotypes, these countries should take full advantage of "lessons learned" with respect to both the molecular methods themselves and how best to integrate these into selection and breeding programmes. With the caveat that these conditions are satisfied, countries in this general category have the following options:

Strengthening existing national scientific and technical capacities and infrastructures in molecular laboratory(ies) and coordination with selection and breeding programmes

This can be achieved by:

- relying on their own germplasm and segregating populations and/or partnering with IARCs and advanced research institutes to obtain these. Using less sophisticated and largely "manual" sample preparation and analytical equipment even through to the point of sequencing since large-scale and high-throughput genetic analysers, accessories and other equipment are necessary only after the initial development and implementation of markers;
- taking advantage of the many kits, biological and other materials and the "how to do" and "what to avoid" protocols and manuals, statistical packages, bioinformatics freeware, software and analysis programmes. These, as well as specific markers that are available in the form of DNA clones for use as probes in restriction and amplified fragment length polymorphism (RFLP and AFLP) analysis, PCR primers for use as SSR (microsatellite) markers, and sequence information available in public databases that can be used to synthesize and clone specific markers are available commercially or for free from several of the IARCs belonging to the CGIAR, and from advanced research institutions and universities in developed and developing countries (e.g. Brazil, China and India). All of these resources help to avoid "reinventing the wheel" and to "short-cut" the process by assisting in getting round bottlenecks, e.g. the need to establish facilities and expertise in cloning; and
- taking advantage of the many opportunities available to upgrade scientific and technical expertise in molecular biology itself and in linking molecular and phenotypic approaches through species and theme-specific networks, workshops, training courses, scientific visits, etc. (see Box 3).

Using regional centres of excellence

While there is no real substitute for building national institutions and capabilities in MAS research, product development and transfer, countries with very limited infrastructures and skilled human resources can still engage in meaningful research by using the state-of-the-art analytical, bioinformatics and computing facilities located in regional centres of excellence (Box 4) and in advanced national institutes.

Countries with limited capacities in phenotypic evaluation and selection and no capacities to apply molecular techniques

These countries fall into the category of Type 3 NARES described by Byerlee and Fischer (2001). Unless the government commits itself to increasing substantially its level of investment in essentially all aspects of genetic resources management in one or a number of the different agricultural subsectors or at least one species, but particularly in selection and breeding programmes and in capacity-building for employing molecular techniques, their options are:

- to partner with institutes of the CGIAR system and other advanced institutions in developed and developing countries and import varieties and advanced breeding lines developed by these institutes through MAS that contain the needed trait(s). After testing these or their crosses with local varieties or landraces for

BOX 3

Regional networks

The East African Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN) is supported by the Swedish International Development Cooperation Agency and involves Ethiopia, Kenya, Uganda and the United Republic of Tanzania. It has a Governing Board and a Programme Advisory Committee that provides technical advice to the Board on project proposals, progress and continuing funding. MAS is a priority theme within BIO-EARN, being used to look for resistance markers for plant viruses and fungi (including sweet potato, maize, banana and sorghum) and genotype variation in coffee and banana. The programme has contributed substantially to the improvement of scientific and technical capacities, research infrastructure, equipment and stocking of consumables. Connectivity at all BIO-EARN Network institutions has been achieved and this has not only greatly improved communication among network members, but also access to information from the Internet to keep abreast with new biotechnology developments in the world. BIO-EARN Ph.D. students have developed close links with each other through common workshops and annual BIO-EARN student meetings and created a strong basis for future regional collaboration.

BOX 4

Biosciences eastern and central Africa hub and network

Located on the campus of ILRI in Nairobi, Kenya, the Biosciences eastern and central Africa (BecA) hub is the first of four regional networks of centres of excellence in biosciences sponsored by the New Partnership for Africa's Development (NEPAD). The establishment of BecA is funded mainly by the Canada Fund for Africa (CFA) of the Canadian International Development Agency (CIDA). It consists of a hub that provides a common biosciences research platform, research-related services and capacity building and training opportunities, and a network of regional nodes and other participating laboratories distributed throughout eastern and central Africa for conducting research on priority problems affecting Africa's development. It has a Steering Committee and a Scientific Advisory Committee responsible for the quality and relevance of the programme. The genomics platform includes state-of-the art equipment for genotyping, DNA sequencing, transcriptomics and bioinformatics, and current activities include microsatellite and EST marker development, genetic linkage mapping, MAS, and fingerprinting for distinctness, uniformity and stability and plant variety protection. It currently supports work being conducted on MAS by the International Maize and Wheat Improvement Center (CIMMYT), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Institute of Tropical Agriculture (IITA), and ILRI and their national partners. Further information is available at www.biosciencesafrica.org.

their suitability for local environments, they can be released to producers;

- to increase awareness among policy- and decision-makers of the importance of improving GRFA through a multidisciplinary approach including molecular methods to their national economies and poverty reduction strategies. Opportunities for doing so include through advocacy within national policy dialogue processes and within FAO's Commission on Genetic Resources for Food and Agriculture, and by its country representatives and staff in regional and subregional offices during the processes of revising PRSPs and agricultural development policies; and
- subject to increased investment for high priority activities, training and capacity-building in selection and breeding procedures should precede the introduction of molecular approaches. Both should be initiated through close collaboration with international, regional and/or national centres.

MAS: OTHER POLICY CONSIDERATIONS AND OPTIONS

Few people would question the stark realities of doing any kind of R&D in the vast majority of developing countries and of getting the products generated from it to the rural poor and hungry. Conducting R&D directed towards MAS raises the bar considerably in terms of its requirements for organizational, scientific, technical and legal skills, as well as for physical infrastructure and financial resources. Funds, however, for public sector agricultural R&D in all but a handful of developing countries are becoming ever more scarce.

While data on spending and human resources for modern biotechnology applications in agriculture are not available, inflation-adjusted spending on agricultural R&D as a whole is now growing at much lower rates than in the 1970s and currently runs at around US cents 53 for every US$100 of agricultural output (Pardey *et al.,* 2006). In developed countries, public research funding actually fell by 6 percent per year during the 1990s, but is still running at the rate of US$2.36 per US$100 worth of agricultural output. This reflects a strong shift in funding priorities away from public R&D by both governments and donors.

However, the big differences between these groups of countries lie in two broad and interconnected areas. First, in their levels of private investment. In developing countries, this runs at between 8 percent (in Asia and Pacific, but in only a few countries) and 2 percent (in sub-Saharan Africa, with 66 percent of that being in South Africa), and by and large is devoted to export crops and conducted by locally-owned companies or affiliates of multinationals. In countries of the Organisation for Economic Co-operation and Development (OECD), such investments now form around 55 percent of their total agricultural R&D spending (Pardey *et al*., 2006), with 93 percent of that R&D being performed in these countries.

The second difference lies in the organization/orientation of their research. In developed countries, there is a much clearer division of labour between the public and private sectors. This generally conforms to the notions of "public goods" and profit/market-oriented R&D, although for MAS this demarcation differs across commodities and is often characterized by public–private sector research collaboration. For example, MAS-related R&D activities conducted by public sector institutions are very much oriented towards basic or strategic research to develop and validate new knowledge, methods and procedures for variety, strain or breed selection through markers and quantitative genetics, attending to minor species and removing bottlenecks. However, for some crops such as maize (see, for example, Chapter 8), wheat, soybeans and cotton, and for some livestock (Narrod and Fuglie, 2000) and aquaculture species, the private sector is a significant player in both the upstream and applied molecular biology and quantitative genetics components.

This situation reflects the varying incentives provided for private agricultural research by a combination of income-driven demand-led market growth for the commodity(ies) or value chains in question, new technologies, changes in IPR regimes, market structure and the globalization of agricultural input markets, and public science and investment policies that have both supported private and undercut publicly-funded research. However, the impulses provided by effective demand-led market growth of commodity chains and by policies to promote private sector investment in R&D are much weaker in lower income countries, and governments that simply lack the cash are left to pick up the total bill. This, in turn, blurs the focus of the R&D conducted by their NARES which, rather than directing resources more towards science-oriented pre-product research (such as molecular marker development and validation for selection), attempt, often within one or two institutes, to cover the whole spectrum from strategic, applied and adaptive research, through to development and on to diffusion of products and services.

At the same time, the wider and interlinked contexts within which the agricultural sector now operates are increasingly requiring ministries, and the research institutes responsible for agriculture that are under them, to forward proposals for policies, legislation, programmes and projects that are not only sound, convincing and prioritized within and between subsectors, but also aligned with the needs perceived by other ministries, e.g. health, education, trade and the environment. Critically, in preparing plans for both domestic and donor finance, they must provide convincing evidence of engagement with those representing the interests of agricultural producers and other sectors of rural society including women's groups and the poor, private commercial and non-government organizations (in addition to involving their own officials and technical experts).

In other words, the pressure is real and growing both nationally and internationally for more "joined up" governance and greater participatory diagnostic and decision-making in helping to define, implement and assess the outcomes and impacts of public sector interventions, the expectation being that this will focus both minds and funds on tackling the problems of greatest relevance to the largest number of poor people in rural areas. This raises the issue of how NARES can better ensure that their agendas, including plans for using modern biotechnological approaches like MAS (that clearly requires long-term budgetary support), better meet the needs of the poor.

Besides macro and sectoral policies that provide appropriate price and market incentives to agricultural producers and service providers, developing countries have a number of options for creating the more conducive and enabling environment necessary for MAS research and the development and adoption of the products that emanate from it.

Building political support

The biggest policy gap in many developing countries is perhaps the lack of official appreciation of the importance of S&T for meeting their socio-economic objectives through agriculture. Hence, the necessity for agricultural research and extension institutions to engage in dialogue during the processes of revising PRSPs, comprehensive agricultural development and related policies and strategies cannot be underestimated. This promotes learning and capacity development among and between policy- and law-makers, technical experts and civil society, as well as greater appreciation of poverty and its different dimensions and the trade-offs between different approaches to its amelioration. It results in stronger linkages between S&T, national poverty reduction and agricultural development objectives, and greater awareness among high-level policy-makers of the contributions that S&T can make to achieve these objectives. The merits of such engagement also include greater need-driven priority-setting, elimination of duplication, more informed decision-making both on the roles of the public and private sectors, and partnership identification. All of this helps to create more efficient and coordinated activities within and between the different agricultural subsectors and their supporting NARES. Well-conceived studies on the socio-economic impacts of crops and breeds developed through MAS would also assist decision-making on S&T investment allocation as this is hardly available in the literature (FAO, 2005b).

Creating S&T policies for driving stronger priority-setting and better delineating roles and responsibilities

Many developing countries continue to work with outdated, isolated and highly fragmented NARES, each with their own set of rules, fiscal arrangements and government oversight, and they have weak or non-existent linkages between public institutions, the IARCs and private firms. Some possess many of the essential components including cutting-edge equipment, but they are not maximizing their potential to develop MAS capacity. While substantial progress has been made by a number of countries to establish a single framework for managing agricultural R&D, including mechanisms for setting and evaluating priorities, in most developing countries these are rare. Making a case for MAS, unsupported by a well thought out (evidence/diagnostic-based) S&T policy framework that promotes mutually supportive actions by the different actors, is a recipe for continuing with a science and supply-driven research agenda, minimal interaction among the different institutions involved, underfunding and tinkering around the edges by some dedicated individuals.

There are, however, a number of options open to governments to reinvigorate their agricultural S&T systems and make way for new technologies:

- use wider or agriculture-specific S&T legislation to promote enhanced collaboration among public sector institutions and between public and private sector entities, and to establish a national funding agency and/or agricultural research council that is independent from any specific ministry and provides competitive grants for research and fellowship training within the public sector. Thailand, through its National Science and Technology Development Agency established under a S&T Development Act, and Brazil with its National Council and National Fund for S&T Development and its Sectoral Funds (Box 5), are two good examples for other countries to consider following, e.g. some African countries that under NEPAD have committed themselves to increasing

BOX 5
Brazil's sectoral funds

To promote high-quality research and development in Brazil's industrial sector, the national government established a programme of "sectoral funds" in which a percentage of corporate taxes are targeted to funding specific research and development objectives. The sectoral funds programme serves four major national objectives:

- stability of financial resources for medium- and long-term research and development;
- transparency in funding decisions, merit review and evaluation;
- reduction of regional inequalities; and
- interaction between universities, research institutes and companies.

The selection of strategic sectors, their respective shares of the funds' resources, the blend of basic and applied research, the required overall budget, and sources of support are all jointly decided upon by the indigenous academic community, private sector, and government. No new taxes are involved, just the redirection of already-established government levies. A comprehensive set of 14 funds has been established. It includes agriculture, biotechnology, informatics and university-industry research.

their S&T spending from 0.5 to 1 percent of GDP.

- use wider or specific agriculture legislation, tax breaks, public S&T funds and funds from donors to provide incentives for public and private sector involvement in MAS and public–private, civil society collaboration.

Governments and development agencies have shown increasing interest in partnerships as a mechanism to promote market-driven development. Byerlee and Fischer (2001) provide an excellent review on the subject of enhancing public–private partnerships for transfer of genes and constructs for GM crops, and some of the principles and mechanisms described are also relevant to MAS. However, outside of the Latin American region where Hartwich, Gonzalez and Veira (2005) conducted a study of 124 cases of such partnerships in agricultural innovation, including a number dealing with basic and applied research on plant breeding, the evidence that these make research more efficient or "deliver" more or better products to small-scale producers is not strong. Indeed, ensuring that these partnerships comply with public needs was found to be one of the major challenges in these partnerships.

Nevertheless, there are clear signs of such partnerships flourishing for both basic and applied MAS-related R&D activities in industrialized countries. With strong and enlightened leadership on both sides coupled with matching interests, opportunities should also be available for NARES to benefit both from the molecular technology platforms and from the selection and breeding experiences of industrialized country-based private sector entities (Chapter 8), as well as from cooperation with their developing country affiliates, local private companies, NGOs and producer organizations in taking the products from the laboratory to the field.

At the same time, the nature and scope of IPRs for genetic resources, the research tools used in MAS and the breeding lines and varieties that are developed from it may be significant barriers to its furtherance by NARES, private sector entities and public–private partnerships. An excellent treatise of the influence of IPRs for plant breeding and the seed sector in developing countries, including the possible implications for MAS, is given by Tripp, Eaton and Louwaars (2006). By providing an empirical analysis of IPR developments in China, Colombia, India, Kenya and Uganda, this report provides government and institutional policy- and decision-makers with details of the different challenges faced by these countries in developing their IPR regimes, the options they have chosen through policies and legislation to develop these, and the lessons learned in implementing them. It concludes that while IPR regimes in developing countries require urgent attention, the supporting legislation and regulations should be the product of open debate among different stakeholders, and that, even if legislation is already in place, many countries will find that they have sufficient options for interpretation and application to warrant a thorough review of procedures and priorities. In terms of hunger and poverty reduction, the importance of segmenting markets into export and non-export crops, and into major and orphan crops, should not be overlooked for gaining preferential access to molecular tools, breeding lines and varieties (Spillane, 2000).

- make greater use of regional and bilateral agreements and organizations to foster international collaboration and obtain complementary assets for the furtherance of MAS.

Diplomatic level S&T agreements, knowledge exchange networks and research consortia (including those of a national and regional nature) can all build knowledge within and between molecular laboratories, genetic resources management programmes and organizations involved in product delivery. The benefits to developing countries of both the formal and informal networked world of collaborative research in molecular biology, genetic improvement and agricultural S&T in general are potentially enormous, providing sources of funding and making knowledge easier to access and researchers and policymakers more interconnected (safeguards are needed, however, to minimize disadvantages/risks). Developing countries are not sufficiently linked to these resources, the CGIAR's Generation Challenge and the EU Research Framework Programmes and competitive grants with partners from individual or groups of developed and developing country research institutions funded by bilateral donors being just some examples. Their governments need to help them do so by providing funds for building broadband connections, establishing databases and information systems, and attending conferences. Also, some functions of a R&D system such as accessing IP-encumbered technology may be accessed virtually or even shared with neighbouring countries (Box 6).

Creating effective delivery strategies to bring the products of MAS-related R&D to users and beneficiaries

The channels through which the products of agricultural research reach producers have undergone major structural changes worldwide, and there is now a wide range of public, private and non-government organizations involved in providing extension services. At the same time, those responsible for funding and supporting R&D have come to realize that getting technology and

BOX 6

Partnerships for technology transfer: the African Agricultural Technology Foundation

The mission of the African Agricultural Technology Foundation (AATF) is to promote food security and reduce poverty. It is a not-for-profit foundation set up in 2002 with the help of the Rockefeller Foundation, the United States Agency for International Development (USAID) and the United Kingdom's Department for International Development (DFID) to identify opportunities for royalty-free transfers of technologies useful to resource-poor smallholder farmers in Africa. In pursuing its mission, it negotiates access to technologies, enters into contractual arrangements to facilitate their deployment and provides stewardship over their deployment. It is the responsible party for addressing the concerns about technology owners while protecting the interests of smallholders, handling intellectual property management, regulatory compliance, liability, licensing and freedom-to-operate assessments. In effect it is a "one-stop-shop" for structuring and accessing agricultural technologies and know-how. Among its priorities is genetic improvement of cowpea. This is being tackled through a Network for the Genetic Improvement of Cowpea for Africa, involving African and United States' universities, IITA, the Kirkhouse Trust, which is a United Kingdom charity, and Monsanto. Part of the project involves developing ready-to-use molecular marker kits for cowpea breeding teams in Africa. The markers are being selected from the cowpea SNP programme in IITA and the cowpea genome-sequencing programme, with polymorphisms detected using agarose gel systems.

knowledge to the field does not follow a linear and top-down transfer path that begins with research, moves on to development and production, and ends with the successful introduction of new products or processes. Instead, it involves continuous feedback loops between researchers, extension agents and farmers within which the development, fine-tuning and adoption of the products of research take place within a specific context. All too often, technologies lie "on the shelf", lost between research and its transformation into useful products, because of the lack of understanding of the functional linkages between research institutions, extension services and farmers.

Policy- and decision-making about supporting agricultural research and technology development therefore need to shift away from traditional and often laboratory-based research and the supply of technology *per se*, towards fostering an innovation systems approach to understand better the ways in which the producers and users of technology interact, and thereby identify and get round the obstacles faced in transforming research outputs into development outcomes and impacts. For example, why has artificial insemination, a technology central for driving improved genetics into many species of farm animals, been successful in some countries and localities and not in others and what are the implications of this for applying MAS?

Unrealistic expectations of what agricultural research and agricultural biotechnology in particular can do to alleviate hunger and poverty have had a negative impact on the fiscal policies of national governments, financial institutions and donors for more than 20 years. It will be important, therefore, for policy-makers to provide incentives for getting the facts right before deciding on priorities and investments. They can do so by mandating that greater emphasis is placed on research to understand better the critical pathways involved in technical change, including the reasons for the long time frames between the research and extension efforts of their NARES and sustainable improvements in farm productivity through genetic enhancement. This can be achieved *inter alia* by requiring greater accountability, for example, through up-front specification of the R&D delivery strategy, and the introduction of monitoring and evaluation processes for research outputs and outcomes that use an innovation systems approach to promote information flow, and through this, to understand and improve current needs and priority assessments and levels of customer satisfaction.

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This book provides a comprehensive description and assessment of the use of marker-assisted selection for increasing the rate of genetic gain in crops, livestock, forestry and farmed fish, including the related policy, organizational and resource considerations. It continues FAO's tradition of dealing with issues of importance to agricultural and economic development in a multidisciplinary and cross-sectoral manner. As such it is hoped that the information and options presented and the suggestions made will provide valuable guidance to scientists and breeders in both the public and private sectors, as well as to government and institutional policy- and decision-makers.

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