CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

Systemwide review of plant breeding methodologies in the CGIAR

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

This report comprises:

(a) Extract from *Summary of Proceedings and Decisions,* CGIAR International Centres Week 2000, Washington, DC, USA

(b) Letter from TAC Chairman transmitting the Report of the Systemwide Review of Plant Breeding Methodologies in the CGIAR

(c) TAC Commentary on the Systemwide Review of Plant Breeding Methodologies in the CGIAR

(d) Transmittal letter from Panel Chairman to TAC Chairman

(e) Report of the Systemwide Review of Plant Breeding Methodologies in the CGIAR

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SYSTEMWIDE REVIEW OF PLANT BREEDING METHODOLOGIES IN THE CGIAR

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

October 2001

Consultative Group on International Agricultural Research - CGIAR

From: The Secretariat December 2000

CGIAR International Centres Week
October 23-27, 2000
Washington D.C., USA

CGIAR Plant Breeding Review[1]

A panel of experts under the chairmanship of Donald N. Duvick reviewed plant-breeding methodologies throughout the CGIAR System. Mr. Duvick reported that the review looked at conventional plant breeding, biotechnology and transgenics, synergies among Centres, synergies with the private sector, intellectual property rights, participatory plant breeding, and outsourcing.

The main findings of the review follow:

- Centres are effectively and efficiently using traditional plant breeding techniques;
- Centres are effectively using new tools, but these will not replace traditional methods, at least in the short term;
- Biotechnology can increase the efficiency and effectiveness of breeding programs but entail increased costs;
- Centres are already effectively outsourcing some aspects of their biotechnology work with institutes outside the CGIAR, but this should be expanded;
- Financial support for germplasm development and enhancement should be increased, and appropriate changes should be made in funding mechanisms that hinder inter-Centre collaboration;
- Improved collaboration, consolidation, and even centralization of some operations across Centres, particularly in the new technologies and biotechnology, can further increase the effectiveness of plant breeding.

Decision: The Group endorsed the recommendations of the review of plant breeding methodologies throughout the CGIAR System.

[1] Extract from "Summary of Proceedings and Decisions", CGIAR International Centers Week, Washington, D.C., October 23-27, 2000.

Consultative Group on International Agricultural Research (CGIAR)

TECHNICAL ADVISORY COMMITTEE

Emil Q. Javier, Chairman

6 October 2000

Dear Mr. Johnson,

The report of the Systemwide Review of Plant Breeding Methodologies in the CGIAR, which was completed by a Panel chaired by Dr. Donald N. Duvick of the USA, is attached. Also attached is the TAC Commentary summarising the Committee's reactions to this report.

This report is based on the findings of nine reports from the sub-panels that visited the Centres involved in crop improvement: CIAT, CIP, CIMMYT, ICARDA, ICRISAT, IITA, INIBAP, IRRI and WARDA.

We are pleased with the general conclusion of this report that the plant breeding methodologies applied at the Centres are generally appropriate considering the crops and the specific needs of the beneficiaries. Furthermore the Centres are developing and adopting new tools for breeding, which include biotechnological tools and participatory methods.

The Panel found that the Centres have formed partnerships with NARS and advanced institutes outside the CGIAR, which can be further strengthened. Moreover, the Panel highlighted significant opportunities for synergies in inter-centre collaboration, which was often found lacking. Thus the Panel's major recommendation is to form "Collaboration Groups in Biotechnology" and to consider consolidation, centralisation and outsourcing as appropriate, for increasing effectiveness of the System's plant breeding operations as a whole.

We endorse the Panel's analysis and urge that mechanisms such as task forces be used to achieve synergies in existing areas of research and in emerging fields, such as genomics and bioinformatics. The Centres are well placed in the global crop breeding and biotechnology continuum. Their familiarity with the environmental conditions and specific requirements in the developing countries as well as their knowledge of and access to very diverse germplasm is complementary to the basic science done at advanced institutes in the private and public sectors. Thus the Centres have excellent opportunities to harness modern biological science for reaching food security for all.

.../

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On behalf of TAC I wish to thank Dr. Duvick and his Panel for this report, which offers a balanced analysis to guide the CGIAR's efforts on germplasm improvement in the future. The review also provides a timely contribution to the ongoing discussions on the CGIAR's structure and governance. We look forward to a fruitful discussion at ICW2000.

Yours sincerely,

Emil Q. Javier
TAC Chair

TAC COMMENTARY ON THE SYSTEMWIDE REVIEW OF PLANT BREEDING METHODOLOGIES IN THE CGIAR

TAC thanks Dr. Duvick and his Panel for producing this Systemwide Report, which is based on the findings of nine sub-reports. The Report covers the Terms of Reference most adequately and provides a balanced and sensitive treatment of the various issues discussed. The Report also gives timely input into the current effort to develop a new vision and strategy for the CGIAR, and its implications for structure and governance.

TAC notes with interest the main findings of the review: First, that the methodologies in use are generally appropriate considering the crops and widely variable needs of the beneficiaries. Second, there is limited scope for cost-saving in the immediate future by modifying the methodologies used or by substituting them with newer tools. Third, the research in biotechnology is problem driven and focused on areas where useful applications are expected in short to medium term. New biotechnology methodologies (e.g. doubled haploids, marker-assisted selection and genetic transformation) are presently in use in varying degrees. Fourth, the application of new biotechnological tools will add new, hitherto unattainable, value to breeding outputs and speed up their delivery. However, not only is there need to maintain and even expand investment in conventional plant breeding and the associated disciplines to take full advantage of new tools in the future, but the direct and indirect costs (e.g. in biosafety testing) of their implementation will be substantial at least in the initial stages.

The Panel finds that the main opportunity for increasing the effectiveness of plant breeding in the CGIAR is by improved collaboration across the Centres, on the basis of common themes (e.g. rice or apomixis), as well as utilisation of new methodologies. In the Panel's analysis there is also scope for increasing outsourcing and collaboration in biotechnology with institutes outside the CGIAR and, in some cases, for improving the communication between scientists in breeding and in biotechnology. The review has 23 recommendations, most of which relate to areas where there are opportunities for inter-Centre synergies. TAC agrees generally with the Panel's recommendations and has the following additional commentary.

Any consideration of the relative merits of the plant breeding tools must be related to the holistic poverty alleviation focus of the CGIAR. This requires careful definition of the traits, which are of most importance to poor producers (e.g. yield in terms of productivity, resistance to various kinds of stress) and consumers (e.g. yield as it affects affordability, nutritional quality, cooking time). This in turn affects the relative effort that can be justified on genetic compared with non-genetic methods of improvement and also the methods used in genetics. For instance, while Participatory Plant Breeding (PPB) is widely used in the context of taking producers' interests into account, TAC observes that the long term interests of poor consumers must also be represented.

TAC sees as particularly important the potential for increased effort in marker-assisted selection in speeding up the breeding processes. TAC agrees that there is need to bring the capacity in bioinformatics to adequate levels to meet the needs of each centre and to match with the expansion to new areas of research. The concerns in bioinformatics and data base management (linking agronomic, ecological and molecular data) are systemwide and should be shared among the Centres. TAC agrees with the Panel that the degree to which the centres engage in structural and functional genomics must depend on a case by case analysis of the

probable costs and benefits taking into account the alternative sources of supply. Whatever the degree of involvement, the CGIAR research and breeding programmes must find ways to get access to relevant knowledge deriving from genomics research.

TAC appreciates the Panel's view on the obstacles associated currently with the development and farm level utilisation of transgenics but emphasises the value of recombinant DNA technology as research tool for understanding gene functions. TAC strongly agrees with the Panel that the CGIAR Centres must work in close partnership with NARS in developing appropriate biosafety protocols and in building public awareness. The associated research is typically of an international public goods nature and the investments are complementary to those of the private sector.

TAC reinforces the Panel's view that assessment of benefits and costs associated with the development and application of different types of tools should also guide the setting of research priorities. This should also apply to PPB, which, following such an assessment of its utility in each case, should be fully integrated with other plant breeding methodologies.

With respect to engagement in various areas of research and adoption of new methodologies, TAC concludes that the CGIAR System must be permanently poised to introduce new tools into its operations, as appropriate. This requires "hands on" expertise within the System to estimate benefits of introductions and well integrated research groups to put those tools into use without delay. The Centres must maximise the benefits from partnerships with advanced research institutions, including the private sector, and act as a bridge between these and the weaker NARS, in particular. The advancement of biological sciences increases the need for capacity building in the NARS.

TAC fully agrees with the Panel's view of the urgency of establishing coherent systemwide guidelines on intellectual property. TAC notes that the Centres are revisiting the guidelines on IP, adopted at MTM98. TAC expects the Centres to actively join in a common debate on how to guarantee the access of their beneficiaries to the relevant technologies and products.

With regard to the implication of this Review on the future structure of the CGIAR System, TAC draws particular attention to the Panel's view that successful genetic improvement depends on expert knowledge of the phenotype and growing conditions as well as access to the germplasm. This requires that a substantial part of the research must be retained at the regional level. Nevertheless the Panel identifies several themes that justify cross-centre treatment and TAC agrees that solutions, which stimulate collaboration, must be explored. TAC notes that the Panel did not recommend outright centralisation of any of the System's plant breeding research efforts and agrees that at least in the immediate future synergies should be fostered by other means. Channelling resources in Task Forces will be an appropriate approach in some cases.

TAC recognises the considerable amount of effective co-operation presently in place in the System in the overall area of plant breeding. Nevertheless TAC agrees with the Panel's main recommendation that the Centres should think of themselves as part of a functioning System and that greater collaboration within and between Centres is required. TAC would like to see a work plan to implement this recommendation and monitor future progress, with milestones, for consideration at TAC 80.

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September 7, 2000

Dr. Emil Q. Javier, Chair
Technical Advisory Committee
Consultative Group on International Agricultural Research
Institute of Plant Breeding
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Philippines

Dear Dr. Javier:

I am pleased to submit to you the Report of the Panel that conducted the Systemwide Review of Plant Breeding Methodologies in the CGIAR.

This report is based on visits to Centres by members of the panel, and also on information provided by a questionnaire survey conducted by the TAC Secretariat. Visits were brief, three to four days, were made only to Centre headquarters, and were made by sub-panel teams composed (usually) of three members. The report was written by the chair and was substantially aided by valuable and numerous suggestions from panel members, who received successive drafts for comment and criticism.

The report, despite its rather general title, has concentrated on ways to introduce efficiencies in the Centres' breeding programs, as aids to coping with the twin problems of declining funds and increasing costs to incorporate essential new technologies, especially those of biotechnology. We start with an overview of the programs as they now stand, and then look to the future, considering what probably lies ahead, both opportunities and problems.

Our chief conclusion is that the Centres have done well, and are still doing well, with traditional plant breeding programs, each Centre operating for the most part as a separate entity. But in order to accommodate and efficiently utilise the new technologies, in particular various aspects of biotechnology, they must collaborate, consolidate, and even centralise some operations at a much higher level than is realised at present. Organizational and funding changes at the CGIAR level may be needed to effect this change.

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We wish to thank the TAC Secretariat for invaluable assistance during the entire course of this review, in particular Dr. Sirkka Immonen. As chair I also acknowledge with thanks the many hours of work contributed by the panel members, whose multifarious talents have been essential to assembling and interpreting the information that is distilled in this report.

Yours sincerely,

Donald N. Duvick
Chair, Review Panel

SDR/TAC:IAR/00/18

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

SYSTEMWIDE REVIEW OF PLANT BREEDING METHODOLOGIES IN THE CGIAR

Panel:

Donald N. Duvick (Panel Chair)
Malachy Oghenova Akoroda
Derek Byerlee
Elizabeth D. Earle
Gebisa Ejeta
Michael Denis Gale
Jean Christophe Glaszmann
Randy A. Hautea
Hiroshi Ikehashi
Edson Jair Iorczeski
Wayne Powell
Calvin O. Qualset
Ignacio Romagosa
Patrick R. Rubaihayo
Leocadio Sebastian
Josef Franz Seitzer
Richard G.F. Visser

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TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

August 2000

TABLE OF CONTENTS

SUMMARY AND RECOMMENDATIONS

This review examines the balance of instruments and procedures currently employed in plant breeding by the Consultative Group on International Agricultural Research Centres (CGIAR). It gives particular consideration to the possibility that the breeding programmes and associated research could be made more efficient and effective by using opportunities for synergies, outsourcing and centralization. It focuses on the extent to which appropriate biotechnology and bioengineering techniques are used as effective support to more conventional breeding practices. To this end, sub-panels visited nine Centres: CIAT, CIMMYT, CIP, ICARDA, ICRISAT, IITA, IPGRI/INIBAP, IRRI and WARDA. Their findings are summarized as follows:

All of the Centres use conventional plant breeding tools[2] to develop new varieties of their mandate crops. The nature and extent of use of the breeding tools varies with the crop (e.g., cereals vs. roots and tubers) and with the capacity of the expected clients (e.g., commercial farmers vs. semi-subsistence farmers). The CGIAR is serving a highly diverse group of national programmes, from some with very limited capacity to others carrying out sophisticated research. The review teams were satisfied, on the whole, with the conventional tools and techniques now in use at the Centres. These tools and techniques have produced crop germplasm well suited to the varied needs of the Centres' clientele. Improvements in conventional tools and techniques can increase effectiveness of the breeding programme for some crops but they cannot produce major cost reductions.

The new tools of biotechnology will beneficially supplement but not, at least within the short-medium term, replace present conventional plant breeding techniques, with possible minor exceptions. Therefore the use of biotechnology as a tool in plant breeding will increase rather than decrease expenditures and requirements in overhead costs and personnel. However, in the near future and particularly in the long run, the Centres expect to increase their effectiveness in reaching particular goals, some of which may be unattainable without the new technological innovations. The time saving from applying marker-assisted selection (MAS) in breeding is likely to yield considerable benefits. The Centres devote substantial proportions of their plant breeding budgets and scientist-years to various aspects of biotechnology. Centres vary in regard to effectiveness of implementing the new tools of biotechnology but on the whole they have made satisfactory progress. Centres tend to acquire those new technologies with most promise of application to their specific crops in the short term, and with minimal requirements for expensive new equipment. A recurring criticism was that biotechnology researchers and field breeders at individual Centres did not communicate (operate as a team) as much as seemed desirable.

Centres have room for some improvement of synergies *within* Centres, and they are doing well (but have some room for improvement) in development of synergies with *outside* institutions. However, there is need for *large* improvement in synergies *between* Centres (e.g., systemwide collaborations, uniform systems, and consolidations and/or centralizations of certain technologies).

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[2] "Conventional plant breeding tools" are defined in this report as those commonly used by professional plant breeders but excluding tools of biotechnology such as tissue culture and genetic transformation. One must understand that this definition is arbitrary, for the definition of "conventional" changes over time — use of Mendelian genetics in breeding was "unconventional" in 1905.

Outsourcing to advanced research institutes (ARI) by means of collaborative research agreements is widely practised by the Centres, and is endorsed by this Panel. This is a sound and efficient way to acquire knowledge and skills in biotechnology. More attention may be needed to make use of hired outsourcing as a substitute for in-house investments.

Gains in efficiency would be achieved if Centres were to increase systemwide collaborations, consolidations (and possibly centralization) of some functions, particularly in regard to new technologies and discovery tools such as identification of markers, genomics and bioinformatics[3]. The Centres lack systemwide evaluations of potential efficiencies (and consequent prioritization) of such collaborations or consolidations, taking into account the unique needs of individual Centres as well as the potential advantages of collaboration and/or consolidation.

Strategies for deploying genetically engineered varieties are lacking at all Centres, even though some transgenic varieties have been produced. Also lacking are strategies for educating the public about the involvement of the Centres with genetic engineering and its consequences, or about involvement of the Centres with private industry and its consequences.

Centres have made good progress in establishing and updating their relationships with National Agricultural Research Systems (NARS). Relationships need to be updated continually because of the evolving diversity of NARS (largely because of increasing importance of universities, non-governmental organizations [NGOs] and private industry). Intellectual property rights (IPR) play an increasingly important role in establishing contractual relationships with all institutions, public and private. Centres need to develop and follow a common strategy to ensure security in accessing and protecting patentable materials, or materials covered by plant variety protection. Centres, acting in concert, can also give important assistance to NARS in development and implementation of harmonized biosafety regulations at the regional level.

Participatory plant breeding (PPB) of various kinds (e.g., participatory variety selection [PVS]) is practised by all of the Centres, often on an experimental basis. PPB emphasizes a bottom-up approach to plant breeding as compared to the top-down approach of many formal programmes. The Centres systematically need to evaluate the utility of using PPB as an integral part of the entire CGIAR plant breeding mission. This should be done in concert with NARS, including NGOs. Cost-benefit analyses covering the entire breeding process and technology dissemination should be used as aids to developing the strategy.

[3] Particular attention should be paid to synergies in use of "platform" technologies, those with broad application across species, environments, or geographic regions.

LIST OF RECOMMENDATIONS

Synergies for Incorporation of Advanced Technologies

1. The Centres systematically should assort themselves into "Collaboration Groups in Biotechnology", based on whatever categories (crop, geography, methodology) seem most useful. The intent would be for Centres to share their knowledge, equipment and personnel in ways that will increase each Centre's scientific competence, and improve the efficiency and power of its use of specific biotechnology tools in service of plant breeding.

2. The Centres collectively should support and use a data base system (such as the International Crop Information System [ICIS] or a superior system), to enable systemwide integration and utilisation of agronomic, ecological and molecular data.

3. Collaboration across CGIAR Centres in Geographical Information Systems (GIS) should be enhanced through open call of proposals in which more than one Centre with common research interests may participate. GIS can be used to facilitate the storage, manipulation, analysis and visualization of agronomic data of interest for plant breeding activities.

4. The Centres should develop a systemwide programme in bioinformatics to meet needs for data analysis and information management. The programme could be linked to ICIS or a similar system. It also might benefit from links to the CGIAR Systemwide Information Network for Genetic Resources (SINGER). A specific goal should be to gain access to major gene discovery programmes based on expressed sequence tags (ESTs) and genomic sequencing.

5. The Centres should develop a systemwide programme, or plan of action, for CGIAR involvement in genomics, particularly functional genomics. The programme should consider the unique contributions (e.g., in germplasm and its agronomic traits) that the Centres collectively can make, as well as the uniquely valuable contributions that can be made by Centres that breed those crops (such as rice) that are at the centre of global genomics research. The goals should be to maximize each Centre's ability to use genomics information in its own plant breeding programmes, and to enhance bargaining positions of individual Centres in striking collaborative agreements with both public and private ARIs.

6. The Centres should develop a systemwide mechanism for evaluation of the potential efficiencies of MAS in the CGIAR, taking into consideration the differences among crops and breeding systems as well as the ways in which cross-species data could help breeders of all crops.

7. Centres collectively should coordinate their research and combine their data (when helpful) as they develop or acquire new markers for use in MAS. In particular, data and research on a given crop species, or on related species, should be coordinated.

Synergies with Private Industry

8. The CGIAR should discuss and elaborate a policy of collaborative research with for-profit organizations, particularly those that are headquartered in the more developed economies and in regard to biotechnological methodologies.

9. Centres should develop a transparent communication system to inform all stakeholders, especially NARS, of the specifics of agreements with the private and public sectors for accessing proprietary materials. Particular attention should be given to any bilateral agreements that include restrictions in use of (e.g.) germplasm and technology. Details of transparency will need to be negotiated with certain partners. The Central Advisory Service on Intellectual Property and Proprietary Science (CAS) at the International Service for Agricultural Research (ISNAR) could help here.

Synergies in Product Delivery

10. The CGIAR should provide systemwide information on best methods for product delivery and technology transfer, to enhance efficiencies and increase effectiveness of product introduction. Particular attention should be paid to use of networks and other collaborations with NGOs and private industry, in addition to traditional government institutions.

Product Delivery: Transgenics

11. The Centres should coordinate and/or inform each other of their actions in initial deployment of transgenic materials, taking into consideration country-specific regulations.

12. The Centres, individually and collectively, should carefully evaluate and explain to the public the biological and social consequences of any new technologies (e.g., transgenics) that they propose to implement.

13. The Centres individually and collectively should involve client NARS in priority setting for transgenics.

Product Delivery: Intellectual Property Rights

14. The Centres should follow common general policy guidelines (systemwide) for intellectual property rights (IPR). The services of CAS should be used to the fullest extent that is practical. Using the CAS office will ensure that information of use to the system in general is not lost and then can be used to inform IP-related decisions in the future. The guidelines should be designed to ensure access, security and convenience in regard to Centre dealings with protected or potentially protected materials, tools and technologies.

15. Each Centre, assisted by CAS, should hold workshops with NARS to explain the IPR status of its materials, tools and technologies and discuss with NARS options for making the materials, tools, technologies and their derivatives available to client countries.

Synergies for Incorporation of New Methodologies in Conventional Plant Breeding

16. Inter-Centre workshops should be convened to discuss the genetics, physiology and agronomy of traits associated with new ideotypes such as IRRI's New Plant Type (NPT) for rice, WARDA's NPT for rice, and CIMMYT's NPT for wheat. The goal should be to identify experiences and data from one Centre that might be used by other Centres to advance breeding progress, or to avoid breeding pitfalls.

17. A similar workshop should be convened for those Centres working on apomixis with intention of breeding self-reproducing F_1 hybrids. The goals should be to exchange knowledge about the genetics of apomixis, about its utility for variety development in the broader plant breeding community including farmer-selectors and the private sector, and also to examine the consequences of apomictic hybrid release on crop biodiversity in relevant socio-economic settings.

Participatory Plant Breeding

18. Centres should evaluate the use of PPB as an organic part of each Centre's entire breeding programme, rather than an isolated endeavour. To help reach this goal, they might convene a systemwide workshop on PPB that specifically includes "formal" breeders who are not part of present PPB teams. The workshop also should include selected NARS and NGOs and representatives from the Systemwide Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation (PRGA). The conferees could devise ways to systematically evaluate the utility of different kinds of PPB as an integral part of conventional plant breeding. (Utility would be considered from various points of view: economic, social and biological.) Conferees would take into account the roles of NARS and NGOs in functional PPB systems, as well as the future roles of IPR and biotechnology (transgenic materials in particular) in PPB.

Budgets

19. The Centres should further develop their budget presentation within the current logframe. The goal should be to facilitate analytical comparisons of Centres, or crops, or technologies, as well as to enable preparation of a coherent summary of CGIAR plant breeding expenditures.

20. Existing core breeding programmes must be maintained at present capacity or in some cases strengthened, with particular consideration to the interests of the large number of weak NARS.

21. Centres should include in their budgets the provision of funds for database creation and maintenance and cost associated with intellectual property (IP) protection.

22. Centres should perform *ex ante* cost/benefit analysis before initiating extensive new projects in germplasm improvement, in particular those that use the new technologies. Such analyses could help breeders as they set research priorities.

Systems Level Responsibility

23. The Panel recommends that a systems level body or mechanism (such as Centre Boards, or a specific council or officer) be given responsibility to consider, implement and monitor improvement of inter-Centre collaborations, as well as any types of consolidation that may be needed. Funding mechanisms that hinder inter-Centre collaboration could be identified and modified as needed.

1. BACKGROUND AND NATURE OF THE REVIEW

1.1 Purpose and Procedure

The Technical Advisory Committee (TAC) of the CGIAR organized this systemwide review of plant breeding methodologies in response to the recommendation of the Third System Review of the CGIAR. The review is to focus on whether the plant breeding methodologies are applied in an optimal way with respect to the specific crops and the specific needs of the range of partners that the Centres must satisfy. In view of this charge, it considers questions such as, Are the modern biotechnology techniques developed and incorporated into the breeding process in an effective way? Are there opportunities for synergies and consolidation of certain activities for improving the effectiveness and the cost-efficiency of the breeding programmes? What consideration should be given to participatory plant breeding, a relatively new introduction among breeding methods used by the Centres? (See Appendix I, "Terms of Reference for the Systemwide Review of Plant Breeding Methodologies in the CGIAR" and Appendix II "Terms of Reference for Sub-Panels of the Review of Plant Breeding Methodologies".)

A broadly based panel of experts was assorted into nine sub-panels, usually three members per panel. (See Appendix III, "Sub-Panel Members and Biographical Information") Each sub-panel visited one of the following nine Centres: CIAT, CIMMYT, CIP, ICARDA, ICRISAT, IITA, IPGRI/INIBAP, IRRI and WARDA. (See Appendix IV, "List of CGIAR Centres with Crop Improvement Mandates".)

Briefly, the sub-panels were to assess effectiveness of methodologies, assess trends and strategies for incorporating new methodologies, and assess opportunities for synergies, internally and externally. Aspects of access and the chosen methods for delivery of goods were to be considered. Following their visits, the sub-panels reported their observations and recommendations to the chair of the review panel, and to the panel secretary at the TAC Secretariat.

A questionnaire survey, conducted by the TAC Secretariat, preceded the sub-panel visits. It provided information for the panellists on details of the Centres' plant breeding methodology with an emphasis on biotechnology. The questionnaire, additionally, requested information about the Centres' activities in PPB and their interactions with NARS broadly defined.

2. FINDINGS OF THE REVIEW

As a preliminary to presentation of our findings, it is noted that the sub-panels uniformly commended the Centres for the overall success of their plant breeding efforts to date. A highly detailed analysis of Centre achievements in crop germplasm improvement is available in a recent report by R. E. Evenson[4]

[4] Evenson, R. E., 2000. Crop Genetic Improvement and Agricultural Development, *Report on the IAEG Study on the CGIAR's Impact on Germplasm Improvement.* Paper prepared for CGIAR MTM 2000, Dresden, Germany, May 2000. TAC Secretariat, Rome.

2.1 Techniques and Tools, Expenditures, and Staff Years now being used in Plant Breeding

2.1.1 Techniques and Tools

All of the Centres use conventional plant breeding tools to develop new varieties of all types of crops (cereals, legumes and clonally propagated). (See Appendix V, "Breeding Methods Used for Different CGIAR Commodities".) Crossing desirable parents and selecting from segregating populations is at the heart of all the programmes. Modifications and special techniques aid each crop. For example, clonally propagated crops such as sweet potato utilize tissue culture for elimination of systemic diseases such as viruses, and polyploid crops such as wheat or potatoes may use doubled haploid techniques to develop homozygous strains more efficiently. Performance trials at all Centres depend on statistical theory for design and analysis of the trials. Breeders also use statistical theory for design and analysis of the results of breeding schemes such as recurrent selection. The review teams were satisfied, on the whole, with the conventional techniques and tools now in use at the Centres.

All of the Centres also are beginning to use new tools of biotechnology as an integral part of their plant breeding. (See Appendix VI, "Biotechnology Methods Used and Developed in the CGIAR Centres".) The degree of use varies with the Centre and also with the crop. For example, biotechnology applications are more advanced for rice and maize than for most other crops, partly because of the generally advanced state of biotechnology research in these crops worldwide, and partly because breeding of these crops is relatively well-funded in the CGIAR. Centres with responsibilities for several crops, especially the minor crops, have less opportunity to apply biotechnology to their crops because of funding constraints (dividing funds among several crops) and/or because the worldwide base in biotechnology for the crops is greatly restricted or non-existent ("orphan" crops).

The new tools of biotechnology include (a) marker-assisted selection (MAS) and DNA fingerprinting, (b) genetic transformation, (c) genomics, and (d) bioinformatics. Centres also use tissue culture, one of the first applications of biotechnology. Tissue culture is especially helpful for those Centres that breed clonal crops (e.g., CIP, CIAT, and IITA).

MAS can be subdivided into (a) use of markers as an aid for introgression of well-characterized individual genes (e.g., for virus resistance), and (b) use of markers to identify less precisely identified "quantitative trait loci" (QTL). Both of these techniques are used (or are in the research stage) at most of the Centres.

Genetic transformation has been used by most of the Centres to create transgenic cultivars. Transformation can provide (for example) pest resistance for crops where no satisfactory genetic resistance can be found within the species or its close relatives, or where incorporation of new genes is otherwise very difficult. None of the transformed cultivars has been released, although CIMMYT is evaluating transgenics in the field. Safety-testing and subsequent release is blocked in most host countries by lack of national regulations on transgenics. The technology of genetic transformation is still cumbersome for many of the crops that are bred by the Centres, but it is being improved continually.

Genomics and bioinformatics[5] cannot yet be used as aids (e.g., gene discovery tools, gene expression, data mining) for practical plant breeding although they show great promise (and some items may well be useful sooner than generally expected). Centre personnel are acquiring knowledge in these fields, and in a few cases are doing so by working in collaboration with advanced research centres.

Use of the new tools of biotechnology has also obligated the Centres to add more fields of expertise. These include (a) international and country-specific intellectual property rights (IPR) applied to plant germplasm and technology components of all kinds[6], and (b) country-specific biosafety regulations. Centres also must have expertise and engagement in (c) public education initiatives regarding advantages and disadvantages of transgenic cultivars, and (d) social and ethical implications of use of biotechnology in plant breeding. The Centres vary in the extent to which they have acquired expertise in these essential fields. All of the Centres can be classified as in the learning stage.

Looking to the future, the Centres generally expect that MAS, used as an aid in gene introgression, will be the most useful application of biotechnology in the near term. It holds promise of saving time and money for transferring genes governing traits that cannot easily be identified, phenotypically. Faster delivery of improved germplasm is also a major benefit for the users. Nevertheless, one cannot always assume it will be an improvement over conventional techniques. The use of MAS for locating and transferring QTLs (defined here as imprecisely identified genes or gene clusters) is attractive in concept, but its practical utility is not proven on a large scale. (It may be important to note that MAS does not run the risk of poor public acceptance or regulatory problems.) Genetic transformation, although potentially the most useful, is usually ranked as second to MAS in near-term utility.

Genomics and bioinformatics challenge the Centres, as potentially powerful disciplines that will require expensive and extensive new expertise and equipment if they are to be utilized. The type of computer modelling associated with the full exploitation of these new techniques is not a traditional strength in plant breeding laboratories. Centres also face a situation where knowledge in these areas is increasingly becoming protected. Research on genomics is done in many advanced laboratories and in the private sector. The Centres need to consider what is their optimal role in this research field. Outsourcing some of the operations can give some assistance, and systemwide collaborations can help, but the Centres will need to have some minimum amounts of equipment and expertise if they are to apply evolving technologies to their own specific needs.

Nevertheless, individual Centres should not try to be self-sufficient in the full range of either genomics or bioinformatics applications. In bioinformatics, there is likely to be a shortage of skilled technical staff, which will add to difficulties if each Centre tries to be self-sufficient.

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[5] The terms "genomics" and "bioinformatics" are new and do not have precise, tight definitions. In this report we use genomics (in a broad sense including also functional genomics) to refer to molecular characterization of all the genes of a species, their functions and phenotypic products, and their interactions. Bioinformatics may be described as the assembly of data from genomic analysis into accessible forms. It involves the application of information technology to analyse and manage large sets resulting from gene sequencing or related techniques.

[6] IPR considerations are not due solely to the advent of biotechnology. Plant Variety Protection (PVP) legislation, originating in industrialized countries, is now being adopted by an increasing number of developing countries. (PVP is also known as "Breeders' Rights".) And the 1992 Convention on Biodiversity (CBD) pervades all aspects of germplasm utilization in developing countries, with concerns about matters such as benefits sharing, traditional/indigenous knowledge, and distribution of gene bank materials (crop genetic resource collections).

To maximize skills and minimize expense, the Centres collectively will need to set up a systemwide (and possibly centralized or centrally coordinated) set of operations that serve all Centres according to their unique needs. Availability of complete DNA sequences of some plant species and efficient methods for comparisons of crop plant genes and genomes will permit new approaches to crop improvement, applicable to all crops and all Centres. Breeders at the smaller Centres and those who breed orphan crops will benefit most from establishment of systemwide operations.

One must emphasize that an additional set of skills and facilities is essential for utilization and/or exploitation of genomics and bioinformatics. The observations and descriptions of field scientists — breeders, entomologists, pathologists, and agronomists — are fundamental to successful utilization of genomics and bioinformatics information. The laboratory data have utility only when they can be associated with agronomically important plant traits such as insect resistance, tolerance to drought or high yield. To use the advanced tools of biotechnology, one must invest more, not less, in field breeding and accompanying specialities. Or at the least, competence in field breeding and ancillary disciplines must be maintained at full strength. At present, the Centres have large comparative advantage in these field technologies combined with their extensive germplasm collections and breeding pools. Such strengths may give the CGIAR Centres an advantage in designing partnerships with others involved in genomics research. Genomics research is likely to reveal new synergies, also, between the crop research Centres and the International Livestock Research Institute (ILRI), working on forage species, their wild relatives and feed quality.

2.1.2 Expenditures

The Centres now devote substantial proportions (on average nearly 25%) of their plant breeding budgets to various aspects of biotechnology, and a correspondingly large proportion of professional staff time is devoted to work in biotechnology. (See Appendix VII, Table 1, "Resource Commitments for Plant Breeding and Biotechnology by Centre".) As a general rule, Centres seem to design their biotechnology research programmes to provide needed applications for particular breeding problems (a "needs" basis).

The Centres overall spend about equal amounts on biotechnology Research and Development (R&D) and biotechnology applications, but the ratio varies widely depending on the crop and the Centre. Data are not on hand to indicate what dictates the variations, or trends, in these activities. The Centres frequently find it hard to identify the expenditures for biotechnology applications because those expenditures often are integral parts of the entire breeding operation. Assembling a uniform data set is further complicated by the fact that Centres itemize their budgets in a diverse way; they do not follow a systemwide format.

Most of the Centres spend more on MAS than on any other category of biotechnology[7]. CIMMYT and CIP also spend relatively large amounts on genetic transformation. Breeders of clonally propagated crops spend relatively large proportions of their biotechnology budget on tissue culture for preparation of disease free materials to distribute to clients and for clonal increase of selected genotypes.

[7]Marker identification plus MAS accounts for 28% of CGIAR biotechnology expenditures, the largest single item. Next is genetic engineering at 22%, then tissue culture at 12% of biotechnology expenditures. (See Appendix VII, Table 2, "Resource Commitments by Biotechnology Activity by Centre".)

Investments in equipment and facilities for biotechnology have increased annually during the past five years, and now total about US$ 5 million. (See Appendix VII, Table 3, "Investments in Biotechnology by Centre 1995-1999".)

A biotechnology expenditure that is certain to be required (and substantial) in the future is the cost of tests of safety that must precede release of genetically engineered cultivars (transgenic organisms) into the environment. Most of the client countries do not yet have appropriate rules and regulations in place, but one expects that in time they will be in force (and enforced). Centres wishing to disseminate products of genetic transformation will have to provide evidence that their products meet the safety requirements of the country in question, or they may need to provide such information to clients who plan to release the products. Experience in the industrialized countries shows that this procedure will be expensive and time-consuming, to the point that one must weigh carefully the expected benefits of the engineered cultivar against the costs in time, money and personnel that are required to enable its release. These costs conceivably will be reduced in the future, but one cannot predict if or when this might be. Current trends indicate increased rather than reduced costs for such tests. Centres individually and the CGIAR collectively need to have cost/benefit analyses of genetic engineering as part of their plant breeding programmes.

NARS and Centres can collaborate on safety testing of transgenic products, to improve efficiency and provide assurance that national requirements are met. This procedure also would contribute to institutional strengthening.

In contrast to this future and constantly increasing expense (i.e., requirements for safety-testing continually increase in response to public concerns about safety of genetically engineered plants), is the fact that costs per unit of output for some of the biotechnology operations (such as DNA sequencing) consistently trend downward. Although one cannot build a budget based on expected savings, plans for future investment in biotechnology should take into account the probability that new capabilities can be added within budget limitations, in future years.

2.2 Effectiveness of Methodologies Used, with Assessment of Opportunities for Improving Cost-Efficiency

2.2.1 Effectiveness of Methodologies Used

Sub-panels generally approved of the traditional plant breeding methods in use at the Centres in regard to cost-effectiveness, efficiency in achieving goals, and (to a smaller extent) integration of different tools. They noted that Centres have used appropriate breeding approaches and methodologies in the improvement of their mandate crops. Depending on the type of crop (diploid versus polyploid, self-pollinator versus cross-pollinator, seed multiplied versus vegetatively propagated) different routes are followed to obtain the best genotypes.

Some comments were critical, however. In a few instances, communication and collaboration among different parts of a programme — for example between base and outpost programmes — were said to be lacking or insufficient in amount. A commonly expressed concern was that breeding programmes are understaffed because of recurrent budget cuts during the past several years. Other reports said that vital breeding programmes have been de-emphasized in favour of new and different (non-plant breeding) goals for the Centre (although the critics also noted that such change in emphasis often was due to donor choice).

Comments were mixed regarding implementation of new methodologies in biotechnology. On the whole, Centres have added useful (or potentially useful) new competencies as allowed by budgetary limitations, and have made satisfactory progress in integrating them with practical plant breeding programmes. However, Centres varied in this regard. In some cases, the Centres were handicapped because there is no global base of information and expertise to draw on for some of their crops (often called "orphan crops"). In other cases, biotechnology researchers and field breeders did not communicate as much as seemed desirable. This was perhaps the most common criticism. And as one might expect, utilization of and competence in the newest fields of biotechnology (such as genomics) are less than for the older ones such as tissue culture.

Client relationships and product delivery are in a state of transition. NARS want training in the new kinds of biotechnology but often have no capacity to practice them. In fact, some countries have little capacity even in traditional plant breeding, although other countries are improving their capacity including competence in biotechnology. Continual updating in plant breeding methodologies (both new and conventional) is essential; Centres can give valuable service to NARS in this regard, as they themselves acquire new skills and techniques. IPR questions complicate the process of germplasm release and distribution to clients, particularly in regard to products of biotechnology. In some crops in some countries, private sector seed breeding and production are advancing and can benefit from certain Centre products in germplasm. In other cases there is no prospect of private sector activity. Networks are an important way to distribute germplasm and knowledge, but they tend to come and go; Centres continually must re-evaluate their positions with them. Reviewers generally were satisfied with the way Centres are handling the challenges of client relationship and product delivery, although they suggested that Centres start now to build capacity to train NARS personnel in the new technologies. The Centres also need to learn more about how to use IPR strategically.

Typical sub-panel comments on these various topics are as follows:

General Comment

- "Progress in moving biotechnology into ... breeding programmes is [on] the right track and it is expected that in the next years [it] will prove successful." (CIMMYT sub-panel)

Tissue Culture

- "Cellular biotechnology [tissue culture] has experienced a good penetration into the breeding efforts of cassava, cowpea, *Musa* and yam. It is well advanced and regularly used for the conservation, multiplication and distribution of elite germplasm. Working hand in hand with the germplasm health unit, cellular biotech has ensured the distribution of healthy plant material. New developments in this field are the use of cryopreservation technology for maintaining core collections at reduced labour costs." (IITA sub-panel)
- "Another culture [has] been practised [with rice] for all inter-specific progenies...It is the best way to eliminate sterile progeny ... in wide crosses.... Regenerated plants are mostly homozygous diploid as the result of spontaneous diploidization from anther-derived haploid calli." (WARDA sub-panel)

Marker-Aided Selection

- "Marker-aided selection (MAS) has not yet been incorporated as an everyday part of the breeding [programme], however the Centre has already started to benefit from the use of MAS as a research tool. Unique and valuable genetic stocks, such as isogenic lines and pyramids that would not have been possible otherwise have been developed." (IRRI sub-panel)
- "At present IRRI does not have a MAS laboratory that can really service the ... breeding programme. It has a number of small facilities with molecular marker capability. On the whole these are associated with ongoing research programmes that use a range of marker types. Management might profitably review the several facilities with a view to amalgamation and more efficient use of resources." (IRRI sub-panel)
- "As of today, there is just one breakthrough in molecular marker development in the wheat breeding programme: one micro-satellite identifies lines carrying the Barley Yellow Dwarf Virus (BYDV) resistance gene. This marker is used in the mainstream breeding routinely. However, many more interesting projects are in prospect or in preliminary stage such as pyramiding genes for durable resistance to leaf and stripe rust resistance, Fusarium head scab resistance, karnal bunt resistance, photoperiod and vernalization requirements, aluminum tolerance, drought tolerance." (CIMMYT sub-panel)
- "Improved cost-effective (reduction mainly in time) marker assisted selection for individual genes is currently used [for example, to] speed up selection of genotypes carrying [important] single genes, such as ... a mutant gene conferring certain levels of herbicide resistance [in maize] to be used in *Striga* control in Africa." (CIMMYT sub-panel)
- "We recommend that IITA establishes the capability to perform MAS for *Striga* by using the existing and additional segregating populations and looking for advanced labs that work on *Striga* and set up relationships." (IITA sub-panel)
- "[Adoption] of [MAS] in traditional breeding programmes can make a great advance in cost reduction, but also would allow the expansion of breeding programmes for little added cost. The caveat, of course, [is] that desirable genes can be discovered and that closely linked markers can be found." (INIBAP sub-panel)

Quantitative Trait Loci (QTLs)

- "CIMMYT is conducting research on the manipulation of quantitative traits in marker-assisted schemes. However, its potential use has yet to be assessed." (CIMMYT sub-panel)
- "The panel is concerned that the concept of MAS, particularly for quantitative traits [to identify and transfer QTLs], is premature and the implications and requirements for implementation are not fully comprehended. This is probably an issue for CG Centres generally." (ICARDA sub-panel)

Transgenics

- "CIP already has constructs with various types of promoters ... for use in transformation and is working on selectable marker systems that do not involve antibiotic resistance. [Several transgenic lines with resistance to major insect pests have been produced, but are

not yet tested for safety.] ... It is not clear whether or when the ... [transgenic] lines ... will be deployed." (CIP sub-panel)

- "Because of previous investment in tissue culture and transgenic technology IRRI is today probably in better shape to supply its breeders with transgenic breeders' lines than any other CG Centre. Up to now IRRI has been quite successful in obtaining genes from elsewhere with freedom to deploy them freely with improved germplasm. Inevitably, however, some of the genes that IRRI will want to use in the future will only be available with some strings attached." (IRRI sub-panel)
- "Genetic transformation of maize is being carried out ... for resistance to tropical insects using alternative constructs of Bt genes and for herbicide resistance for the control of *Striga spp.*, a highly potentially damaging parasite weed in Africa." (CIMMYT sub-panel)

Allocation of Resources

- "The review team wishes to stress that although we fully agree that new technologies in plant breeding should be expanded this should not be at the cost of 'traditional' plant breeding. Methodologies considered at this moment 'new' are 'old' tomorrow and should become an intrinsic part of all the methodologies available to the plant breeder to be used if needed." (IITA Sub-panel, also quoted by INIBAP Sub-panel)
- "With the exception of *Vicia faba*, all of ICARDA's mandate crops are associated with some form of biotechnology. At one level, this observation is commendable but it does raise the issue of whether ... efforts are spread too thinly. We, therefore, urge management to critically examine current allocation of resources to maximize output and impact. A greater awareness and understanding of technology limitations is also required." (ICARDA Sub-panel)
- "Research efforts in biotechnology ... are minimal. Many of the plant breeders may not have fully embraced the utility of the new tools to their germplasm development effort which they, understandably, consider is their primary task. There have been collaborative linkages, established with other institutions in Europe and the USA where ICRISAT breeders or their germplasm are involved in genome mapping or QTL identification". (ICRISAT Sub-panel)

Clientele: Service and Relationships

- "CIP should consider budgeting for the costs of licensing transgenes from private industry. At present CIP expects companies to donate their technologies with freedom to operate in the mandate areas. This may not be a realistic method for most efficient development of improved transgenic plants for CIP's clientele." (CIP Sub-panel)
- "CIMMYT may need to obtain IPR on some of its products in order to guarantee that they can be used freely by its customers, the poor farmers of the developing countries. In either case, proper and efficient use of IPR requires a body of knowledge and experience that is not sufficiently available at CIMMYT." (CIMMYT Sub-panel)
- "The time is ripe for IRRI to implement a professional MAS facility as an adjunct for breeding, rather than as a research tool. The initial capital outlay required is substantial but it will complement other necessary new initiatives, such as IRRI's functional genomics programme. There is also a need to remove the facility from the control of research scientists, so that their own agendas do not compromise the availability of a

service that should be run along quasi-commercial lines. The facility could rapidly improve the power of the practical breeding programme and provide leadership for NARS wishing to develop similar capability and for other CGIAR Centres." (IRRI sub-panel)

- "Linkages with various NARS are evident. However, given the varying levels of capacity of its partner NARS, it may not be realistic to expect that NARS will be able to take up biotechnological methods in the coming three to five years and integrate them in their own breeding programmes. In this regard, the setting up of a regional service facility at CIAT that caters to the needs of its partner NARS, both for capacity building and research and development, should be immediately pursued." (CIAT sub-panel)
- "CG Centres have played a major role in building the research capabilities of the NARS that have benefited both the public and private sectors. Plant breeding is in transition but there is a vital need to retain this core competency in the CG Centres. Future plant breeding will be partially based on various new enabling technologies. ICARDA, as well as the other CG Centres, through the judicious choice of these new technologies can offer a unique environment to retrain current plant breeders and train the next generation of leading plant breeders. Practical workshops that outline the value of the technology need to be coupled with courses tailored to the needs of decision-makers and legislators. The direct role of the CG Centres, and indirectly through the NARS, is also very important in arising public awareness of cost and opportunities of Biotechnology." (ICARDA sub-panel)
- "The cassava programme most closely co-operates with NARS through two root crop research networks (EARRNET and SARRNET) in Africa at the level of distributing and maintaining advanced materials sent out for testing as well as *in vitro* propagation for the different countries. ... Very few national programmes have systematic cowpea breeding programmes. Of over 60 NARS, who are collaborating in cowpea international trials, only 4 have initiated cowpea breeding programme. These are Nigeria, Ghana, Senegal and Burkina Faso. However, their infrastructural facilities would not permit initiation of any biotech activity in the near future. It is expected that these NARS would take interest and work with IITA and learn the new biotechnology tools in the long term." (IITA sub-panel)
- "[A] preferred model for [banana and plantain] research ... is exactly as promoted by PRO*Musa*, whereby shared responsibility among advanced research institutes and Centres concerned with producing and evaluating new varieties is the best practical arrangement for advancing *Musa* plant breeding research and variety development." (INIBAP sub-panel)
- "An important feature of the structure at CIAT is the association with external groups and research themes, such as the hosting of the von Humboldt Institute laboratory, which is, involved in biodiversity analyses. This indicates a trend towards the integration of CIAT's comparative advantages in the country and in the region at the service of local programmes for biodiversity conservation and utilization." (CIAT sub-panel)
- "[Cost] of wheat variety development is lower at CIMMYT than at any National Agricultural Research System (NARS). The paradox is that at the same time CIMMYT should increase its activities in high-risk, long-term research in those areas where it is qualified to do so in order to sustain significant long-term genetic gains. The current CGIAR funding trends do not easily support this strategic research, given the current focus towards short-term products or services, as required by most donors." (CIMMYT sub-panel)

- "There is no reason to expect that the private sector will become a major CIAT partner in bean improvement in the near future. National public sector institutions, especially the Universities, remain to be the key partners of CIAT in bean research and development, including bean breeding and germplasm exchange and dissemination. Traditionally, CIAT has had strong platforms for linkages with NARS through the regional networks such as the Programa Cooperativo Regional de Frijol de Centroamérica, Mexico y el Caribe (PROFRIJOL) and the Proyecto Regional de Frijol para la Zona Andina (PROFRIZA), and similar bean networks in Africa. The transformation/weakening of the Latin American networks have deprived the member countries, including CIAT, of these traditional institutional mechanisms for partnerships. Universities, in particular, may assume a more important role in CIAT's linkages, especially in the areas of upstream research and its applications on bean improvement." (CIAT sub-panel)
- "[It] is reported that farmers express much interest in [pigeonpea] hybrids and are willing to pay more for their improved performance and yield stability. The price for hybrid seed is about three times that of the commodity price (35 vs. 100 INR/kg). The private sector has also expressed its interest in this technology and collaborative work, partially financed by the private sector, is under way. It is estimated that 80% of the farmers will most likely grow hybrid varieties. ... The private seed industry in India is well advanced and capable of seed production and distribution. Given a marketing opportunity such as that provided by hybrid seed, the private sector is sure to respond by making seed available through production and distribution. Presently the Centre has a good relationship with the private seed industry and it should be further developed as a cornerstone in the Centre's strategy." (ICRISAT sub-panel)

In Conclusion

The Centres show ingenuity and competence in finding a diversity of ways to serve their customers with products of germplasm, training, and knowledge. Centres (and crops) do not appear to differ significantly in competence for application of conventional breeding technologies, but there is uneven progress in application of the newer technologies, even MAS. This seems to relate in part to whether or not the crop is an "orphan" (differentiation by crop) and in part to available funds per crop (differentiation by Centre). There is little evidence that the Centres are pooling resources to increase effectiveness of access to the newer technologies, even when (in the opinion of the sub-panels) the situation clearly calls for such collaboration.

2.2.2 Opportunities for Improving Cost Efficiency — Conventional Techniques

Although presently known potential improvements in conventional techniques do not promise, individually, to produce large savings in expenditure, they can improve efficiency and so reduce cost per unit of product. Their collective effect can improve efficiency of the CGIAR plant breeding programme. Several of these opportunities are listed below. Some of them are in use now; others wait to be adopted.

Field Trials

Design of field trials can be improved by choice of new statistical techniques such as the alpha-lattice uni- and bi-dimensional families of designs, as demonstrated by CIMMYT. Similarly, advances in software development for statistical analyses may facilitate effective data processing. These examples illustrate the fact that opportunities continually arise to

improve the speed and efficiency of "routine" breeding operations. Centres need to stay alert to such possibilities and adopt the improvements when they seem worthwhile.

Faster Development of Homozygous Lines

Improved technologies for production of doubled haploids can speed up production of new cultivars, especially of polyploid crops such as wheat. But as with all technologies applied to plant breeding, the method works better on some genotypes and some species than on others. It cannot be called universally useful. Anther culture is used routinely in rice and barley to shorten the time for obtaining homozygous lines. Another culture also is an efficient way to eliminate hybrid sterility in rice (the result of interspecific crosses), and allows rapid fixation of the progeny lines.

Data Management

Data management techniques can be improved. This is a key area and one in which the CGIAR Centres are behind ARIs and industry. A good start has been made in the development of ICIS, although a review of components, organization and objectives of ICIS is essential. (This task might be outsourced.) This generalized CGIAR-orientated data management tool linking germplasm collections with breeding must be linked to maps, ESTs and other genomics programmes. It also might be linked productively to SINGER for access to information on CGIAR genetic resources collections.

Moreover, links with bioinformatics groups, particularly in the USA and Europe, should be set up at this early stage. With the advent of genomics and more rapid gene discovery, the Centres' germplasm collections are becoming even more important as resources for gene and allele 'mining', as well as providing information for genomic modelling projects such as "metabolic reconstruction" schemes. Almost all of the Centres already are beginning to incorporate molecular marker data alongside phenotypic data describing the various accessions in the several germplasm collections. Powerful applications of genotyping data will include gene mining, core collection assembly, production of diversity maps, and direct parental selection for breeding programmes. Almost all Centres have the same needs and objectives. A workshop to establish those needs, followed by centrally funded software development, could be cost-effective.

As noted above, ICIS may be the platform from which these objectives can be reached, although one should recognize that other possibilities may be better and should be examined if they seem to warrant inquiry. The Centres collectively need to agree on what kind of data management system(s) they require in common and then support their effective development, maintenance and use.

Participatory Plant Breeding

Participatory plant breeding potentially can extend desirable benefits of formal plant breeding to farmers that are not now served, improve the accuracy of variety selection for smallholders with specialized adaptation or quality requirements, and bring other advantages such as increased genetic diversity. Further discussion of PPB is presented in the section, "Participatory Plant Breeding", in the latter part of this report.

2.2.3 Opportunities for Improving Cost Efficiency — New Techniques

There are virtually no opportunities at this time for cost reduction through substitution of new applications (e.g., biotechnology) for conventional techniques. None of the Centres at present can substitute biotechnology techniques for conventional breeding methods on a large scale, although they anticipate that in some cases eventually they can do so. MAS and genetic transformation are in the transition from development to use.

Marker-Assisted Selection

- CIAT estimates in an initial study that a 60% cost reduction is possible using MAS for Bean Golden Mosaic Virus.
- CIMMYT routinely uses MAS as an aid in backcrossing a major gene for virus resistance into selected lines of wheat.
- CIMMYT uses markers to introgress a major QTL for maize streak geminivirus into susceptible lines of maize.

MAS should be able to substitute for at least some of the field trials now required when backcrossing to insert genes for resistance to "difficult-to-identify" insect or disease pests. It is expected, however, that each proposed MAS programme would be case-specific, with potential savings depending on ease of locating close markers, difficulty of identifying phenotype, etc. Systematic evaluations to identify and prioritize economically viable MAS programmes are needed and will be worthwhile.

The implementation of MAS at a CGIAR Centre is not trivial. The equipment needed is expensive, and likely to become more so, as and when the optimum levels of automation are installed. These facilities at the least should be shared among programmes within Centres. The Panel finds lack of agreement as to sharing at the next level (i. e., whether or not several Centres can or should share a single MAS laboratory). Such a centralized operation, one per crop (or per group of crops in the case of minor crops) is a common practice, and recommended, in commercial plant breeding companies that breed multiple crop species at widely scattered locations. They say it reduces error as well as saving money. But our sample of public sector scientists is divided in opinion as to whether each Centre must have its own MAS laboratory, or could use facilities at another Centre[8]. Perhaps continuing reassessment of this matter is warranted. Obstacles to collaboration (such as poor delivery service) may be less in the future, and inducements to collaboration (such as high cost of improved equipment) may be greater. At any rate, MAS applications should be 'needs' driven for specific projects, rather than 'technology' driven.

In most Centres adequate experience now exists to prioritize target traits for MAS. This will take account of the value of the trait as a selection criterion, the precision of phenotype assessment required, and the costs associated with achieving that precision with direct

[8] IITA and CIAT provide an example of how Centres can collaborate in use of MAS. Both Centres are involved in cassava breeding, in Africa and South America, respectively. IITA phenotypes cassava populations from both Centres for cassava mosaic disease because the disease is absent in South America. CIAT has provided facilities for screening DNA samples from IITA cassavas, as well as furnishing SSR markers. The resulting information has enabled IITA to start construction of a linkage map for its own needs in MAS. Key to progress for both Centres is exchange of marker information and DNA, reciprocal visits by involved scientists, and most importantly, "outsourcing" to each other for access to critical equipment, expertise, and environments.

selection methods compared with the costs of indirect MAS. This information then can be used to prioritize research efforts to uncover the genetic control of the trait and identify suitable markers. This exercise should take place within Centres (and is happening in some of them at this time) and probably between Centres, especially within crop groups such as legumes or cereals.

Equipment costs aside, almost all other recurrent consumable costs associated with MAS technology are becoming cheaper. Other efficiencies are expected for specific applications. For example, less land should be needed, particularly for pathology screens.

Transgenic Breeding

- Breeders at CIP hope that transgenic breeding will reduce the time and expense required for insertion of desirable genes (as for pest resistance) into the polyploid crops potato and sweet potato. They have no data to show whether or not this would be the case.

All Centres agree that genetic transformation will be important as a breeding tool. The technologies are crop-specific and necessarily need to be developed and applied at the Centres. Significant advances are being made at almost all Centres and transformation of some crops is now almost a routine operation. However, public acceptance of transgenic crops is a significant problem in several countries and the difficulties in deployment and field trials are leading to significantly greater than expected costs. The Centres will need to collaborate with NARS to educate farmers and the public about advantages and disadvantages of genetically engineered crops, and this will be another added expense.

An additional complication — the IPR situation surrounding transgenics is critical and omnipresent. CGIAR Centres must deal with the complexities involved, such as multiple patents and ensuing multiple licenses or other arrangements often required for use of critical transgenes. Potential costs, including infringement liabilities, are another hazard.

2.3 Trends and Strategies for Incorporating New Methodologies for the Future

In general the Centres are choosing new methodologies (particularly in biotechnology) that have the most probability of immediate utility for practical plant breeding, and that (hopefully) can be managed within current budget constraints. Strategies for incorporating them run the gamut from establishing in-house capabilities to outsourcing to ARIs (usually via collaborative research agreements). Although reviewers generally approved of the direction and pace of incorporation of new technologies, they did have some suggestions for improvement.

As noted in an earlier section, some Centres need to improve integration of their biotechnology research with field breeding programmes. Reasonably, Centres tend to start a new methodology as a stand-alone research programme, in order to build competency and give opportunity to examine the potentials of the new technology for use in plant breeding. Moving from this stage to integration with a particular plant breeding programme sometimes seems to go slower than reviewers believe it should. Although the Panel knows of no method to "grade" progress in integration, it does suggest that any in-depth review of Centre plant breeding activities might include some method of ranking integration. The rankings could be used to support recommendations to individual Centres or to programmes in the Centres.

Strategies for deploying genetically engineered varieties (i.e., for effecting their release for unrestricted on-farm use) are lacking or incompletely developed at most of the Centres. In part the delays are forced by the lack of policy and regulations in client countries (as noted in a previous section). For example, Centres cannot make and implement plans for safety testing until the country in question has appropriate laws and regulations in place. Systemwide strategies and policies must be devised and followed, in order to minimize the problems with what inevitably will be a tortuous and sometimes hazardous process. (Rather than to only react, the Centres, collectively, could help to direct the process. They could give great assistance to client countries as they develop biosafety policy and regulations, providing valuable scientific expertise and also connections with appropriate experts and offices in industrialized nations.)

Strategies for informing the concerned public in client countries about Centre involvement in genetic engineering also seem to be lacking or incompletely implemented. This is an entirely new public relations obligation, deriving directly from use of genetic engineering. It is not unique to the CG Centres, but it does exist and must be met by any breeding organization that plans to use genetic engineering as a plant breeding tool. The CGIAR needs to initiate, and lead the Centres in, such an activity.

Another new obligation for Centres is to keep their stakeholders informed about what kinds of agreements they make with various research partners in both the public and the private sectors. As in other instances, a certain amount of consistency across Centres will be advantageous for all. For example: the kinds of information to be transmitted, the best media for transmittal, and key categories of clients to inform could be parts of a package of "recommended practices" for all Centres. The CGIAR should assume responsibility for assembling and informing the Centres of such a bundle of recommended practices.

Typical sub-panel comments follow:

Private Industry, Intellectual Property Rights

- "We recommend that CIAT should give more attention to communicating with donors and other interested parties the nature and scope of its bilateral collaborations with private companies, especially the multinationals." (CIAT sub-panel)
- "An issue for the future is appropriate protection of intellectual property developed at CIP, particularly technologies that may be developed by the biotechnology programme. Such protection would enhance CIP's ability to access materials from the private sector and could help ensure that [its] discoveries are used in accordance with its mandate. The Central Advisory Service on Proprietary Science (CAS) at ISNAR may be helpful here." (CIP sub-panel)
- "The IPR surrounding the creation and ultimate deployment of transgenics is a key issue and cannot be divorced from the technological aspects of this endeavour. We urge that Centres recognize the complexity of this technology and consider ways of centrally dealing or outsourcing these activities to be globally competitive in this area." (ICARDA sub-panel)
- "It is recommended that [INIBAP] take a leadership role through [the PRO*Musa*] network to clarify intellectual property rights for developers and users of protected germplasm and molecular tools, especially for providing access and benefit-sharing to local users." (INIBAP sub-panel)

- "The Panel notes that a key issue is how much effort IRRI should put into protecting its discoveries. The chosen traits of initial specialization – plant pathology and abiotic stress – are both likely to yield key intellectual property that could be used as collateral for the provision of rice for developing countries in the post-genomic age. In any event the programme will realize a large number of collaborations, most of which will be targeted at gene discovery and protection by the collaborators. IRRI must have a clear IP [intellectual property] position. The IP policy should be forthcoming soon and should also include the IP rules for collaborators wishing to visit IRRI to carry out functional analyses on specific knockouts [inactivation or removal of specific genes]. For example, [it] might consider the possibility of NARS patenting the materials obtained from IRRI in the name of IRRI in return for a [non-exclusive] license allowing [the transfer of products to third parties]." (IRRI sub-panel)

Collaboration among Centres

- "In order to derive greater value from germplasm collections a coordinated effort to create genotypic databases is initiated using informative, previously mapped SSRs. This is a task that could be implemented immediately by a single Centre taking the lead and ensuring that all CG Centres have access to appropriate databases and associated visualization software." (ICARDA sub-panel)
- "CIP does not have the instrumentation required for a modern genomics programme, and it would be hard to justify the high purchase costs for use by CIP alone. Alternatives include a systemwide genomics centre, a regional centre serving CIP, CIAT, CIMMYT and IITA (perhaps located at CIP), or paying another research institution or private firm to do the analytical work on CIP materials. A cost analysis of a Centre's genomics facility is needed, including not only the initial cost of equipment but also the costs of upkeep and skilled staff needed to maintain the facility. The possibility of rapid obsolescence or changes in technology should also be considered. Outsourcing or collaborative projects may well prove preferable, if CIP hopes for a position in potato genomics. Short or medium term visits of CIP personnel to advanced laboratories may offer overall cost savings by providing intensive training in genomics or other advanced biotechnology techniques." (CIP sub-panel).
- Systemwide discussion of bioinformatics approaches and training may be worthwhile. CGIAR-sponsored workshops for scientists throughout the system could be considered. Alternatively, training workshops like the one run by CAMBIA [the Centre for the Application of Molecular Biology to International Agriculture] may be more suitable for CIP personnel." (CIP sub-panel)
- "Infrastructure development is costly and should clearly be determined by a shared common vision that is articulated and accepted by all participating scientists including breeders. The panel is concerned that existing plans for biotechnology appear to be developed independently with insufficient consultation with other centres." (ICARDA sub-panel)
- "Linkages with sister Centre institutes like CIMMYT and CIAT exist and should be intensified in the field of Biotechnology. Also contact with other Centres ... should be considered. Linkages with several advanced laboratories exist and these should also be intensified." (IITA sub-panel)

Delivery Systems and Potential Roadblocks

- "If it becomes impossible to deploy the transgenic plants developed at Centres (or elsewhere), much cost and effort will have been wasted. Now is the time for a concerted systemwide effort by CGIAR to explain the benefits of this technology for subsistence farmers in developing countries. Without that the forces hostile to the technology may succeed in preventing its use. Scientists at CIP (or other Centres) cannot be expected to deal with this problem on their own." (CIP sub-panel)
- "It is recommended that INIBAP assume a leadership role in promoting national policy on the introduction and evaluation of transgenic plants in selected countries, especially Nigeria, for example, where IITA and Catholic University of Louvain (KUL) are ready to do field studies of transgenic plants." (INIBAP sub-panel)
- "Considering the issues and controversies associated with biosafety it may be a more appropriate strategy for IRRI to conduct final product development together with concerned NARS. [It] may focus on placing relevant gene constructs in appropriate rice lines, which may not necessarily be an elite line of a particular country. Collaborating NARS can then take the responsibility of transferring the gene to the elite lines of their interest. In the case of field testing, NARS institutions should be given the responsibility because they are in a better position to justify such needs for the material and the testing in the context of their national interest." (IRRI sub-panel)
- "The Panel was convinced that IRRI should continue in its aggressive efforts to map or tag genes of significance in the international rice improvement programme. Nevertheless the time is probably also here whereby a planned programme aimed at tagging those genes [with] highest priority first could be undertaken. We hope that IRRI will consider implementing a priority-setting exercise to determine those traits for which molecular tags will provide maximum savings, in cost and time, relative to field selection and be most effective when used in practical rice improvement." (IRRI sub-panel)
- "Through the ARBN [Asian Rice Biotechnology Network] IRRI has significantly helped build the capacity of ten NARS institutes in the Philippines, Indonesia, India, Thailand, Vietnam, and China in the use of molecular marker technology and biotechnology in general. This has led to NARS institutions achieving capability in MAS, particularly for disease resistance and gaining a better understanding of pathogen and insect pest ecology. The Panel endorsed the network as an effective system of transferring modern techniques and in influencing biotechnology priorities in the NARS, and strengthening IRRI itself as the hub." (IRRI sub-panel)

2.4 Opportunities for Synergies, Outsourcing and Centralization within the CGIAR and with other Partners

It is no longer possible (if it ever was) for individual programmes within a Centre to operate in isolation from other programmes in the Centre, or for individual Centres to ignore the help that they can get from (and give to) other Centres in the CGIAR. Nor is it possible for the Centres, collectively, to operate in isolation from other research institutes with complementary technology and genetic materials.

In respect to synergies within Centres, individual Centres need to do all possible to be sure that their laboratory and field breeding personnel operate as one team, with each sector contributing its expertise as needed to expeditiously produce the end product — improved

germplasm. This is a special concern as new biotechnology techniques are brought on line. Reviewers found that in most instances Centres are doing reasonably well, considering that they are still in the learning stage. But some are doing better than others; in all cases the goal should be to improve in-Centre synergies.

As for synergies among Centres, reviewers universally recommended more collaboration and mutual assistance than is found at present. In nearly all instances, the Centres' entrance, or consideration of entrance, into expensive and highly technical new fields of biotechnology (such as genomics and bioinformatics) brings on a need for more CG-wide collaboration. These technologies operate at such a basic level (DNA level, or computer programme level) that for some procedures (but not for all) a single centralized operation could serve all crops at all Centres, with relatively small adjustments for individual needs. The result would be not only savings in expense for equipment and personnel but also more importantly, more crops would be served at a high level of expertise. Breeders of the minor crops (often called "orphan crops") would get the most benefit, for they would have access to services in bioinformatics and/or genomics that they probably could not otherwise afford.

A second kind of useful Inter-Centre synergy is based on crop type, such as cereal grains, grain legumes, roots and/or tubers, or simply the same crop, at different Centres. Some Centres have built productive collaborations in this category, but more is needed. The Centres must take the initiative in this regard.

Another type of needed Inter-Centre synergy is based on yield trial analysis and data gathering, but in concept it goes well beyond yield trials. As noted earlier, a Centre-wide system can be built — and reviewers believe it is needed — that would manage and integrate genetic, breeding and agronomic information, genetic resources, genealogies and selection histories, and various kinds of molecular data, for crops with different crossing systems. Precision, speed and power would be added to operations ranging from field plot trials to gene discovery. Some modification of ICIS (previously described) might be the basis for this system, although other possibilities (such as an entirely new design) might be better.

Synergies between Centres and other institutions are well exploited by all Centres, primarily as collaborative research agreements. Universities and government institutes in industrialized nations are the most common partners, although similar institutions in some of the developing countries are equally valued as partners. Large private sector firms with strength in biotechnology are beginning to emerge as favoured partners. Small local commercial businesses also may be potential partners for specific research tasks.

Outsourcing is highly recommended, not only to save money but also (and perhaps primarily) to provide information and technologies that otherwise would be unavailable to a Centre. Recommended sources primarily are advanced laboratories, both public and private, in industrial countries, although in some cases strong ARIs will be found in developing countries. Local entrepreneurs can be valuable outsourcers for certain specialized services. Outsourcing often will be facilitated by increased amounts of systemwide collaboration and/or centralization, especially in the fields of genomics and bioinformatics, and in regard to legal concerns such as with IPR. In fact, it is likely that collective multi-centre negotiations will almost always improve the position of the individual Centres. Collective negotiations may be the preferred first option.

Centralization or some kind of consolidation of operations or technologies should be seriously considered whenever three conditions exist, (1) the operation/technology has broad utility for all Centres, (2) it is so expensive that individual Centres cannot afford it, and (3) information transfer is synergistic. The CGIAR needs to have an ongoing analysis of consolidation/centralization opportunities, and it should implement recommended actions. This Panel cannot prescribe detailed specifics of such intensification of effort for any of the operations or technologies. The Centres collectively are best suited for that. But we do state that without such intensification money will be wasted and the plant breeding potential of the CGIAR will be reduced, especially for smaller Centres and minor crops.

Sub-teams presented various suggestions for synergies, outsourcing and centralization. Several of them are summarized (and endorsed) in the following list. They are sorted into internal and external opportunities.

2.4.1 Internal Opportunities

Crops in Common

Centres can collaborate in development of research techniques (particularly biotechnology research) applied to crops that are common to their mandates. Examples are maize at IITA and CIMMYT, cassava at CIAT and IITA, wheat at ICARDA and CIMMYT, and rice at CIAT, IRRI, and WARDA. Alternatively (or additionally) Centres can collaborate to develop techniques (such as MAS or gene discovery) suited to *categories* of crops, such as cereal grains, grain legumes, or roots and tubers, particularly where syntenic genomic regions have been described.

Breeding Techniques in Common

Synergies in breeding techniques can be exploited among Centres. For example, two new approaches to plant breeding are use of (a) apomixis to make self-reproducing hybrids, and (b) development of "new plant type" cultivars to enable cereals such as rice and wheat to achieve higher yield levels. Thus, CIAT works on apomixis for *Brachiaria,* IRRI for rice and CIMMYT for maize. IRRI works on a new plant type (NPT) for rice, CIMMYT for wheat and WARDA for rice. In either case (apomixis and NPT), the Centres work on these projects independently, even though they deal with similar problems in genetics and physiology. Breeders of these different crops should be able to help each other, sharing new knowledge about common genetic actions (and perhaps common genes). They could plan joint experiments to test important principles in physiology and/or genetics that are not restricted to species, and they also jointly could evaluate consequences of use of these revolutionary but similar new products. Such collaboration could increase efficiency of each of the individual projects and reduce the cost of achieving the goals.

Technical Systems

Centres can collaborate in use of broadly applicable technical systems such as Geographical Information Systems (GIS). Although a formal Inter-Centre GIS initiative has been established, only ad hoc collaboration (rather than formal links between Centres) exists today.

Laboratory Information Management

A laboratory information management system for the CGIAR will increase efficiency. Laboratory information management systems are not in place anywhere. Nevertheless, software for data acquisition, storage and retrieval and to track all components through high-throughput MAS is vital to optimize use of the expensive facilities. There is justification for joint acquisition and customization of such a system. Every Centre will need it.

Purchasing

Centralized technology assessment and purchasing can save money and can represent an IPR management tool — a procurement centre can check licenses, etc. Although Centres are becoming well equipped with standard molecular biology hardware, molecular marker technology continues to progress and the next generation of equipment is likely to be even more expensive. Almost all Centres are exploring various robotics systems; there are already a range of technologies available for SNP detection, and some, such as time-of-flight mass spectroscopy and various chip-based systems are very expensive. Central evaluation and purchasing is likely to be cost effective.

Training

Centralized training of local staff in generic biotechnology techniques will improve and stabilize staff capabilities, thereby increasing efficiency. Trained MAS or molecular biology laboratory technicians are highly mobile because of their skills. Such mobility means that local staff turnover within institutes can become an important expense item, and therefore plans for timely replacement with well-trained individuals will be an essential part of efficient laboratory operations. Centralized training facilities can help to alleviate replacement problems.

Outsourcing Advisory Service

Centres can increase efficiency in outsourcing biotechnology operations by establishing a systemwide cooperative outsourcing advisory service. CAS may be a useful example.

"Outsourcing" within the CGIAR

Centres can "outsource" or productively collaborate with other CGIAR Centres for basic research. At present, the Centres tend to look only to outside ARIs for such assistance. The Panel concurs with the following statement in the CIMMYT sub-panel report, "It is unfortunate that Centres seem to maintain closer links with third institutions for pure research purposes than with other CGIAR Centres. Collaboration [among Centres] is stronger for development of training and research protocols than for the development of common research projects."

In some cases, a single Centre might do service work for others, thus eliminating needs for duplication of expensive equipment and/or personnel. For example, in the case of bioinformatics, although data are best applied at the Centre where the crop is grown, much of the needed software and skills for using it will be identical across crops and Centres. One Centre, more advanced than the others, might take on systemwide responsibility for operation of a system. The Panel concurs with the advice of the IRRI sub-panel, "Other CGIAR

Centres will be experiencing exactly the same needs [for bioinformatics] associated with their own mandated crops. Much of the [needed] software ... will be identical. A Systemwide application group, possibly associated with other public groups such as the U.S. Department of Agriculture (USDA) ... will be valuable."

Intellectual Property Rights

Intellectual property rights matters can be organized and conducted more efficiently if Centres will readily and routinely get expert assistance from the Central Advisory Service on Proprietary Science (CAS), located at ISNAR. Although the larger Centres might require their own IPR and contracts experts and others might prefer to outsource, almost all sub-panels acknowledged the value of a central advisory service such as CAS.

The CGIAR should steer towards development of an ideal Centre IPR policy, while acknowledging that a hard-line common policy is probably not what is required. Advice could be based on a growing corporate experience of interactions between public ARIs and industry. They have been involved in negotiation on the use of proprietary technologies being used by almost all Centres, such as transformation methods, patented marker systems and marker DNA sequences and DNA constructs used in transformation experiments. The most important issue remains the ownership and deployment of CGIAR-improved germplasm, and this problem is common to all Centres. Complications are presented, for example, by claims of national patrimony (of germplasm) and ensuing "access and benefit sharing" deriving from the 1992 CBD, or by conventional IPR that may apply to a multiplicity of specific items in advanced germplasm used for improvement.

These same issues also affect NARS as they incorporate the technologies in their programmes. Centrally organized IPR workshops with NARS might be valuable.

Some of the Centres are wary of centralization of IPR activities, saying that required confidentiality agreements could not be upheld under a centralized system. But other Centres say the CGIAR should have a set of common IPR guidelines for all Centres, and it also should furnish a Centre of expertise in IPR matters relating to the Centres' breeding activities. The Panel concurs with the second point of view; to do otherwise can needlessly expose individual Centres and the CGIAR to expensive and delaying legal and political entanglements, as well as entailing expensive duplication of effort and loss of information that should be shared systemwide. (A specific example: Centres need to be watchful of indemnity issues, whereby an institution — public or private — will ask the Centre to assume the responsibility of possible infringement of background intellectual property.) The Panel, however, notes with emphasis that to be effective the common guidelines must have provision for satisfying special needs of individual Centres and their clients and crops. A set of real, case-by-case examples will provide the best guidance, even for the development of general policy guidelines.

There are concerns about the nature of Centre relationships with private industry, especially with large multinationals. Germplasm and knowledge conceivably could be unduly restricted in distribution because of industry IPR policies. And influential segments of the public fear that any dealing with "the multinationals" is likely to have secret clauses that work against the interests of the rural poor in developing countries. In actuality, dealings with private sector institutions should follow the same rules as with any institution, public or private. Public research institutions now are as concerned with moneymaking potential of patentable

products as any multinational, as a consequence of reductions in funding for food and crop science research. At the least, any contractual arrangement should ensure that results (such as new germplasm or new technologies) can be used without restriction to fulfil the Centre's mandate, and terms of the agreements should be made known to the concerned public. With this topic as with all other IPR dealings, CAS can be of great assistance.

2.4.2 External Opportunities

Collaborations with ARIs

Linkages with advanced laboratories should be actively pursued and maintained. The Centres, individually and collectively, should reflect on the particular advantages of these relationships and should try to put an economic value on them. Most of the linkages exist on a temporary basis. "It would be beneficial if longer lasting collaborations could be initiated not depending solely on the availability of extra funding but based upon research interests of advanced laboratories." (CIAT sub-panel)

Centres can use their unique germplasm collections combined with their field-testing capabilities to attract collaborations with global leaders in public sector genomics or bioinformatics programmes. Centres can contribute diverse germplasm sources of their mandate crops plus knowledge about their agronomic traits, and the public sector institutions can contribute genomics and/or bioinformatics technology. Centres can be attractive partners for such collaborations because of the diversity of well-characterized germplasm in their plant breeding programmes and seed banks and their knowledge of this germplasm.

An interesting experiment is being undertaken at IITA, which has entered into an affiliation with CAMBIA, as a source of advice and relevant technology. The CG should watch this experiment as a means of allowing smaller Centres to maintain access to scientific advances and to contract out some aspects of the work that may not be viable at the Centre itself.

What to Outsource

Some technical operations can be outsourced thus saving investment in equipment, training, and personnel. For example, "If cloning of QTLs is required, outsourcing the actual cloning work would be more appropriate than attempting it at CIP given the current status of technology and resources." (CIP sub-panel) In another example, outsourcing may be the best option for some kinds of sequencing. And as noted previously, local entrepreneurs may provide valuable services for certain specialized operations. It might be helpful to all Centres if collaboratively they would prepare a list of categories (or operations) that they deem especially well suited for outsourcing.

Some operations should not be outsourced, such as those that require intimate knowledge of the crop under the conditions where it is to be grown. For example, "It seems that, first and foremost, the transformation and regeneration process should be established and under the Centre's control. With very few exceptions, this process has in many crops proven to be a major bottleneck." (ICRISAT sub-panel)

Where to Outsource

Commercial or quasi-commercial institutions can perform specialized analytical or bioinformatics tasks. This can relieve a Centre of the need to build infrastructure and hire personnel, unless (or until) the task clearly is seen as routine and essential for the Centre. However, Centres should be canny and business-like when hiring such an organization. "Outsourcing agreements with commercial institutions should provide a clear specification of tasks (around two or three specified projects) for each of the two parties." (IITA sub-panel) Proposed contracts should be reviewed by CAS and by the Centres' legal counsel.

Centres might collaborate in identifying reliable organizations to be outsourced for (especially) technologies that can be useful to all Centres. "Some Centres have had poor results in outsourcing, so care will be needed in choosing such assistance." (CIMMYT sub-panel)

Particular attention must be paid to demands for specific outsourcing and/or collaborative research that may accompany grant offers from certain donors. If such demands are not in line with Centre objectives, the grants should not be accepted.

Private Sector

Collaborations and/or outsourcing with private industry can bring valuable and otherwise unavailable expertise, knowledge, and even germplasm to the Centres. The CIP sub-panel, for example, recommended licensing some transgenes from the private sector if terms were favourable, a strategy than might be called a special kind of outsourcing.

Hybrid Crops

Breeding of hybrid crops such as maize, sorghum, and millet (and more recently hybrid rice and pigeonpea) presents special opportunities and challenges for collaboration with several elements of NARS. As a general rule, it seems best for the Centres to concentrate on basic research and development of parental materials. The parental materials then can be released to the public (government institutions, NGOs, and private industry) to be combined into hybrids which will be produced and sold (or otherwise delivered) by those institutions. The Centres thus "outsource" hybrid production and distribution. This is standard practice for all Centres that deal with hybrid crops at this time, and it should be continued.

One should point out that such "outsourcing" to small indigenous seed companies presents a unique opportunity for product delivery to smallholders who otherwise might not be served. Small indigenous seed companies (especially those that are too small to do their own germplasm development) can use Centre parental materials to make hybrids that they produce and distribute, often for small or fragmented markets and at affordable prices. The small local companies thus can provide hybrid seed to a class of smallholders who might never be reached by centralized public sector institutions, or large international private sector firms. With proper legal arrangements (on the part of the Centres), such practice could even enable (for example) distribution of the products of genetic engineering to smallholders at prices they could afford.

2.5 Participatory Plant Breeding

For the most part, Centres are in the exploratory stage of this new kind of plant breeding, although some programmes are described as established and successful. The CIAT sub-panel reports that 250 farmer communities in Latin America participate in PPB programmes and the results have been very encouraging and sometimes "spectacular". A PPB model for barley is decentralized and designed for specific adaptation to drought-prone areas, and it incorporates use of local genetic resources as well as "enhancement" of seed distribution (ICARDA sub-panel). In Nigeria, participatory variety selection (PVS) has been employed to develop sorghum lines with high yield and resistance to *Striga* (ICRISAT sub-panel).

As a rule, the Centres incline toward PVS. A consideration may be that farmers have neither the time nor the land to spare for the extensive operations required for the earlier stages of variety development (such as making crosses and growing large segregating populations). Formal breeders also say that farmers would not be able to provide the precision needed to ensure progress at each step of the breeding process (e.g., multiple replications, statistical tests of significance, etc.).

On the other hand, the breeders also know that they often have had poor results in attempts to develop varieties suited to (for example) marginal and often highly diverse environments, or unique (but essential) agronomic practices, in large part because evaluations were not made in those unique conditions. Likewise, special requirements for quality may be unsatisfied because farmers have had little or no chance to express their needs to the formal breeders. The odds of success — of producing varieties that satisfy the needs of these "left out" farmers — would be greatly increased if appropriate forms of PPB could allow for evaluation and selection in those unique conditions at various stages of the breeding process. Breeders believe farmers also would more readily adopt good new varieties if they (the farmers) had been part of the development and selection process. The farmers would have more confidence in future performance of such jointly selected varieties. Another potential benefit has broader implications. PPB, in contrast to formal breeding that typically develops a relatively small number of varieties with wide adaptation, would produce a greater variety of genotypes because they were required to fit a greater variety of growing regimes and quality requirements. Genetic diversity of the crop species thus would be increased, and in a sense it also would be conserved *in situ*.

Participatory plant breeding is a field of plant breeding that will require networks and collaborations that either are not developed at the Centres, or that sometimes have been reduced in scope due to cutbacks in funding. In common with biotechnology, it is a new field that can be rewarding and well worth the effort, but that will require more rather than fewer funds and personnel for successful operation.

And as with biotechnology, outsourcing some parts of it may be the best strategy for Centres to follow. Some Centres believe that PPB, to be most effective, would have to be largely implemented and monitored by governmental NARS, because inherently the work will be widely dispersed and location-specific. On the other hand, as noted above, ICARDA says that it has implemented a decentralized PPB project for barley. And WARDA is helped by NGOs in its PPB programmes, which include PVS and community-based seed multiplication schemes. Probably various types of outsourcing and/or networks are required, depending on the specific project.

Efficient use of Centre resources lies at the heart of discussions about PPB. Opinions vary, from statements that properly conducted PPB can save resources because it would result in a higher proportion of farmer-accepted varieties, to the other extreme, a concern that Centre resources will be wasted. Proponents of the second opinion fear that breeders will devote valuable time and resources in aid of far-flung farmer selection schemes that in the end give poor results because of inherent and irremediable flaws in design.

Perhaps the best advice is that data should be gathered and cost/benefit analyses be made to compare various scenarios in which PPB (in one form or another) and formal breeding are compared to each other (suggested by the IRRI sub-panel). The Panel concurs and suggests that such analyses (including aspects of disseminating the breeding products) should precede (as well as accompany) any large-scale efforts in PPB.

Such analyses might be the first step to formally incorporating PPB (in its various forms as appropriate) into Centre plant breeding programmes as an integral part of the system, rather than as a separate and sometimes even competing programme. The concept of plant breeding in the CGIAR (but also anywhere in the world) must be enlarged to encompass all sorts of breeding/selection, their interactions, and all intermediate stages. The concept must include farmer breeding/selection, formal breeding/selection by the public sector and formal breeding/selection by the private sector. The multiplicity of seed distribution system(s) also must be considered. With the full plant breeding and seed distribution system in view, the CGIAR and its Centres then rationally can decide when it will (or will not) be appropriate to integrate suitable parts of PPB into those sectors of the seed system where the CGIAR operates (or should operate because it has comparative advantage). If such a holistic analysis has not been made, the Panel recommends that it be done, perhaps by means of a small workshop conference. The list of conferees should include PPB breeders, formal breeders, representatives of PGRA, NARS and NGOs, and ISNAR working on institutional aspects.

The Centres need to develop a common philosophy and plan for integration of PPB broadly conceived into their plant breeding programmes. PPB in appropriate forms and places should be an organic part of each Centre's total breeding programme rather than an isolated endeavour.

2.6 CGIAR-NARS Interactions

Relationships with developing country NARS broadly defined are perhaps more important in the long run than any other synergy, since the inhabitants of developing countries are the specified clients of the Centres. The Centres' interactions with NARS are highly variable, depending on the crop, the region of the world, and the sub-set of NARS (e.g., government institution, university, NGO, private sector). The following summary gives a brief overview of the existing interactions as related in the Centres' answers to the TAC questionnaire survey.

Level and Variability of Capacity in Plant Breeding and Biotechnology

NARS government institutions are highly variable in their capacity in breeding and in biotechnology applied to breeding. Capacities vary greatly, from extremely advanced to essentially none. As a rule, capacity is lowest in sub-Saharan African countries and greatest in some of the eastern and southern Asian countries and southern Latin America. NARS capacity for breeding the major cereals such as rice and wheat tends to be greatest, that for

breeding non-commercial roots and tubers is generally lowest, and that for legumes is intermediate (but each of these generalizations has exceptions). With a few exceptions (e.g., China, India, Brazil, Kenya) institutional capacity in biotechnology is limited or entirely absent. As with the Centres, the NARS institutions usually enter biotechnology via MAS. (China, an exception, is producing and deploying transgenics.) Because of the wide variation in breeding capacity, some NARS depend strongly on CGIAR Centres for finished varieties or nearly finished varieties whereas others make best use of more basic breeding materials, or even collaborate with Centres in advanced breeding research.

Trends in NARS Partnerships and Changes in Programme Activities in Relation to NARS

All Centres are involved in regional networks, usually involving several countries, and sometimes involving private sector as well as public sector institutions. The networks may be concerned with training, plant breeding (including PPB), field testing, or product distribution, depending on the crop and capacities of the partners. Networks are evolving into an effective way to extend Centre benefits to their clients, as well as to foster communication and collaboration among and within the NARS themselves.

When their capacity warrants, NARS take on increasing responsibility for breeding and selection of basic germplasm furnished by the Centres. In such cases Centres have reduced obligation (or perhaps no obligation) to produce materials ready for release. But one cannot always be sure that NARS' advanced capacity will be fully utilized. For example, IITA furnished *in vitro* plantlets of yams to the Botany Department of the University of Ghana, for micropropagation. Unfortunately, equipment failure caused losses of the valuable materials. The basic infrastructure at the Botany Department did not support the capabilities of the staff.

A clear trend is for government research institutes in a few NARS to advance to levels similar to ARI in industrialized countries. Such institutes can collaborate with Centres as equals, each contributing its strength. Simultaneously there is a trend for government institutes in some of the NARS to deteriorate, primarily because of reduced funding and management. They lose personnel, facilities and expertise to the point that they have little or no capacity even for adequate variety testing.

Certainly, in regard to NARS/Centre interactions, one policy cannot fit all countries or even all regions of a country, and even the best policy for any given time and place will require constant updating. The Panel recommends that institutions that fund CGIAR Centres should be apprised of this shifting mosaic of NARS capacities, with a suggestion that their funding policies be adjusted accordingly. They must understand that for some crops in some regions, funds must be provided to enable Centres to continue variety development, whereas in other cases Centres should be engaged in more basic types of "upstream" research, for best service to the NARS. Such upstream research often might be done in collaboration with NARS ARIs. In fact, Centres may find some good opportunities for outsourcing to certain NARS ARIs. CIAT and IRRI are involved in an interesting partnership with the Fund for Latin American and Caribbean Irrigated Rice (FLAR). This is a regional consortium in which public and private organizations are in charge of the more applied breeding phase, and CIAT is responsible for a more strategic research agenda.

In regard to some members of the second category (the "stronger" NARS), several reviewers said that Centres need to do more to provide training in the advances in agricultural biotechnology. We recommend that Centres continue to pursue opportunities to set up

networks, regional facilities or other appropriate venues to care for perceived needs of NARS partners in capacity building and applications of biotechnology in agriculture. The Asian Rice Biotechnology Network (ARBN) is a good example.

Involvement of NGO/Private Sector in CGIAR-NARS Collaboration

The NGOs assist all of the Centres in variety evaluation (often via PVS) and/or dissemination. With a few exceptions (e.g., salinity research at IRRI, barley breeding at ICARDA) they are not involved in formal research programmes. The NGOs help the Centres to increase and deepen their contacts with farmers. For example, NGOs are involved with WARDA in community-based seed multiplication schemes, as well as with PPB and PVS.

The private sector interacts closely with Centres in breeding and distribution of hybrid crops such as maize, pearl millet, sorghum, and rice. Typically, Centres develop parental lines, that are used by seed companies (often in addition to their own proprietary lines) to make hybrids that are produced and sold to farmers who can afford them. Private industry thus disseminates the Centres' breeding products to a particular class of clients, typically farmers producing crops for commercial markets. In Latin America the private sector sometimes finances breeding research, usually via networks. Regions vary in use of hybrids. Pearl millet hybrids (for example) are widely grown in India but not in sub-Saharan Africa. This contrast may reflect differences in economic and social organization of agriculture in these two regions, differences that may or may not disappear over time. It points out that CGIAR breeding (or non-breeding) of hybrid crops needs to take into account the particular capacities of each country and/or region.

NGOs and the private sector individually and collectively provide valuable assistance to the Centres in serving the Centre clients; they help the Centres stay in touch with the farmers and their needs and they test and disseminate the breeding products. But as a rule, NGOs and the private sector serve quite different categories of farmers. NGOs tend to serve farmers growing non-commercial crops; private industry primarily serves those growing commercial crops. This means that Centres need to (and the Panel believes they now do) tailor breeding and outreach efforts not only to intended clients (farmers) but also to those who will help deliver the products to the farmers.

Additional Information and Recommendations

The important subject of CGIAR-NARS interactions is discussed in greater depth and breadth in Appendix VIII, "CGIAR-NARS Interactions in Plant Breeding and Biotechnology". Its analysis and recommendations are based in part on findings of the sub-panels and in part on other sources of information about the topic.

3. CONCLUDING REMARKS

This review has established that use of biotechnology in breeding at the CGIAR Centres will not enable replacement of any significant amount of the ongoing conventional plant breeding operations, and it will not produce any savings in expenses, equipment or personnel. Instead, it significantly will increase the Centres' budgetary, equipment, and personnel requirements. Nevertheless, the new tools of biotechnology very likely will enable breeders to speed up the delivery of materials with improved traits. They also will be able to develop varieties and

breeding stocks with hitherto unattainable kinds of tolerance to disease and insect pests, new (and needed) levels of tolerance to abiotic stresses such as mineral deficiencies or drought, and new kinds of desirable quality traits. The fruits of molecular biology are expected to be indispensable aids to plant breeding in future years. But most of their projected benefits are not likely to be realized soon, for various reasons: scientific, technical, and political.

The critical question facing all of the Centres is, "How can we acquire and integrate the invaluable new tools of biotechnology in appropriate amounts and timely fashion, knowing that to do so will increase budget costs in a time when CGIAR funding is decreasing, annually?"

The underlying charge to the Systemwide Review was to look for ways in which efficiencies might be introduced that could allow addition of the tools of biotechnology without adding unduly to budget, equipment, or personnel requirements.

As stated in the Terms of Reference (Appendix I), one option would be to substitute some of the tools of biotechnology for some of the operations of conventional breeding, but the reviewers have said that only limited savings are possible in this way. Indeed, conventional breeding must be maintained at or above its present levels, if biotechnology advances are to be used to advance plant breeding. For example, field research capacity is essential for complementing basic research in functional genomics.

A second option would be to effect savings by organizational means, and so make room for new operations. Organizational changes could be to (a) increase *efficiency* of ongoing methodologies, (b) *outsource* some operations to avoid in-house investment in infrastructure and personnel, or (c) *consolidate or centralize* unnecessarily duplicative functions to produce economies of scale and (importantly) increases in power, proficiency, and scope of action.

In regard to *efficiencies*, the review indicates that Centre breeding programmes use conventional tools of plant breeding at a high level of proficiency. The Centres also are making good progress in incorporating and efficiently using new methodologies of biotechnology, although there are several ways in which the progress could be improved. Considering their relatively small size (as independent organizations) and their relative isolation from global centres of excellence, most of the Centres have achieved remarkably high levels of proficiency in some of the tools of biotechnology. Although we recommend improving efficiencies where possible, we see little room for large fiscal savings via this route, at this time.

In regard to *outsourcing*, the Centres have initiated several kinds of collaborations with outside organizations in order to gain access to knowledge and improve their technical proficiency in several of the newly arising fields of biotechnology. Such relationships essentially are "outsourcing with payments in kind". That is, the Centres contribute materials and knowledge that the outside organizations need and want (e.g., germplasm and intimate knowledge of its biological and agronomic traits), and in return they get use of technology, knowledge, or other items that they need. In general these collaborations are with centres of excellence (often in universities, sometimes in private industry) in the industrialized countries, although some are with advanced institutions in developing countries. These collaborations have been mutually advantageous to the Centre and to the outside institution. They enable Centres to increase output without unduly increasing expense. The Panel commends the Centres for those initiatives and recommends that the practice be increased,

although with some caution as regards arrangements with ARIs, private and public. Centres, for example, must be sure that agreements provide a clear specification of inputs and outputs for each of the two parties and are not unduly restrictive regarding the distribution of products to CGIAR clients.

Outsourcing in the more traditional sense — payment for services rendered — appears to be less strongly used by the Centres, although most of them do outsource some operations. As far as the Panel knows they have not made systematic comparisons of investments in hired outsourcing versus investment in Centre assets and personnel, in regard to accomplishment of a specific operation such as DNA sequencing or cloning a useful QTL. Such comparisons should be made, especially for operations that could have systemwide application.

Consolidations or centralizations could follow several routes. Collaborations among Centres could result in systemwide consolidations of certain functions such as data management systems, or they could stay at a lower scale such that two or three Centres with crops in common or with technologies in common shared information, technology and trained personnel. Consolidation also could give rise to complete centralization of some functions, with staff and equipment operating either as a specialized department in an existing Centre or as a separate service organization such as CAS.

The reviewers believe the Centres should do more to capitalize on each other's scientific knowledge, and on access "within the family" to unique CGIAR-mandate crops, people, and geography. Although Centres have initiated several collaborative projects (e.g., in breeding, data management, and biotechnology) the reviewers suggested that the Centres should increase the number, intensity, and scope of ways in which they pool and share knowledge, equipment and personnel. Such collaborations would help the partners to achieve greater savings, more technological proficiency, and get faster results than if they operated independently.

Sub-panels recommended Inter-Centre alliances based on geography, on commonality of crops, on commonality of crop category, on commonality of a DNA-based technology such as genomics, and computer-based technology such as ICIS and bioinformatics. Such alliances would have value within the CGIAR and would also strengthen Centre relationships with organizations outside the CGIAR.

In some cases systemwide programmes or service laboratories may be the best way to enable individual Centres or breeders of especially the minor crops to use some of the new biotechnology tools and scientific knowledge. Preferably these would reside in existing Centres, as a department or programme whose primary clients were the CGIAR Centres. On rare occasions a separate entity such as CAS may be best, but we suggest that forming new entities should be a last resort, for they would require expensive new overhead in administrative and maintenance personnel, and in facilities. And importantly, as isolated entities they might be less able to sense and serve the needs of the Centres because of physical and emotional isolation from the "real world" of the operating CGIAR Centres.

This, then, is the primary recommendation from the Review Panel, that organizationally the Centres should increase the amount of beneficial systemwide collaborations, consolidations and centralizations. In doing so, the Centres should think of themselves as part of a single functioning system — the CGIAR — rather than as independent and sometimes competing organizations. This would allow easier conceptualization of associations and delegation of

duties that benefit the complete working system and therefore all of its parts. At the same time, it will be essential to recognize the individuality of needs, mandates, and capabilities of each Centre, so that any consolidation or centralization of functions does not block or ignore individual needs of any Centre.

Such actions would increase efficiency and breeding power for each of the Centres, and increase their bargaining power with outside institutions. And most importantly, it would increase their ability to fulfil their mandate, to ensure that international scientific capacity in food production systems is brought to bear on the problems of the world's disadvantaged peoples.

ACKNOWLEDGEMENTS

The Panel wishes to acknowledge the invaluable co-operation of the Centre Directors and staff throughout the systemwide review process. They are warmly thanked for providing extensive background information to the Sub-Panels and for their generous hospitality during the visits of the Sub-Panels. The programmes carefully planned by the Centres allowed effective use of the limited time. The Panel is also grateful to the Centre staff for their valuable time in responding to the questionnaire prepared by the TAC Secretariat.

The Panel expresses its sincere thanks to TAC, especially to Dr. Lucia de Vaccaro, Chair of the Standing Committee on External Reviews (SCOER), and Dr. Usha Barwale-Zehr. Dr. Donald L. Winkelmann, former TAC Chair, is warmly thanked for his contribution during the initial phase of this review. The Panel is also grateful to the TAC Secretariat, especially Dr. Sirkka Immonen, the Panel Secretary, for the organization and implementation of the Review. They deserve our special thanks for ensuring that the Sub-Panels received the relevant information and documentation and for providing assistance during the entire review process and during the writing of this Report. The help of Ms. Ann Drummond-Setaro and Mr. Jan-Peter Groenewold in the preparation of the Report, and Ms. Irmi Braun-Castaldi in assisting with travel arrangements and budget matters is gratefully acknowledged.

LIST OF SUB-PANEL REPORTS
SYSTEMWIDE REVIEW OF PLANT BREEDING METHODOLOGIES IN THE CGIAR

This summary report is based on the findings presented in the following nine sub-reports[9]:

1. Systemwide Review of Plant Breeding Methodologies in the CGIAR. CIAT Sub-panel report, Cali, Colombia, March 27-31, 2000 (Hautea, R. A., Glaszmann, J. C., and Visser, R. G. F.)
2. Systemwide Review of Plant Breeding Methodologies in the CGIAR. CIMMYT Sub-panel report, El Batan, Mexico, February 23-26, 2000 (Romagosa, I., Duvick, D. N. and Iorczeski, E. J.)
3. Systemwide Review of Plant Breeding Methodologies in the CGIAR. CIP Sub-panel report, Lima, Peru, April 3-6, 2000 (Earle, E., Akoroda, M., Byerlee, D., and Duvick, D. N.)
4. Systemwide Review of Plant Breeding Methodologies in the CGIAR. ICARDA Sub-panel report, Aleppo, Syria, March 20-23, 2000 (Powell, W., Romagosa, I., and Rubaihayo, P. R.)
5. Systemwide Review of Plant Breeding Methodologies in the CGIAR. ICRISAT Sub-panel report, Patancheru, India, March 14-18, 2000 (Ejeta, G., Hautea, R. & Seitzer,.J-F.)
6. Systemwide Review of Plant Breeding Methodologies in the CGIAR. IITA Sub-panel report, Ibadan, Nigeria, February 28 - March 2, 2000 (Rubaihayo, P. R., Qualset, C. O. and Visser, R. G. F.)
7. Systemwide Review of Plant Breeding Methodologies in the CGIAR. IPGRI/INIBAP Sub-panel report, Montpellier, France, April 17-20, 2000 (Qualset, C. O)
8. Systemwide Review of Plant Breeding Methodologies in the CGIAR. IRRI Sub-panel report, Los Baños, March 20-24, 2000 (Gale, M. D., Ikehashi, H., and Sebastian, L. S.)
9. Systemwide Review of Plant Breeding Methodologies in the CGIAR. WARDA Sub-panel report, Bouaké, Côte d'Ivoire, February 2000 (Ikehashi, H.)

[9] The sub-reports are available at the CGIAR website (http://www.cgiar.org) under Technical Advisory Committee.

TERMS OF REFERENCE FOR THE SYSTEMWIDE REVIEW OF PLANT BREEDING METHODOLOGIES IN THE CGIAR

I. Background and rationale

In dealing with System Review Panel (SRP) Recommendation 4, pertaining to Integrated Gene Management (IGM), the Consultative Council endorsed the use of an IGM approach at CGIAR Centres. Recommendation 4 also advocated that TAC review the efficiency of Centre plant breeding, focusing on the extent to which appropriate biotechnology and bioengineering techniques are being practiced as effective support to more conventional breeding practices. The aim was to assess the possibility of freeing up resources, implicitly by reducing the resources involved with conventional practices, so that applications of new techniques could be expanded as appropriate. In this context, the Council endorsed such a review, assigned the task to TAC with collaboration from Centres, and asked that TAC present Terms of Reference for the review at MTM99.

II. Broad issues to be addressed by the review

Plant breeding has been one of the basic strengths of the CGIAR and its products continue to be of great relevance to the constituencies the CGIAR serves. A full review of its dimensions would encompass a broad range of themes. In framing the review, TAC has opted to focus on those elements that are central to the SRP's concerns. In doing so, the Committee has, in effect, assumed that work on the conservation of germplasm is being done effectively, that plant breeding projects underway are consistent with the priorities of the CGIAR, and that the current investment in plant breeding relative to investment in other undertakings is roughly consistent with CGIAR goals at the System and Centre levels. Each of those assumptions will be reviewed in the course of the next few years in conjunction with the development of a revised strategic plan and priority framework for the CGIAR. What is being emphasized in the current review, then, is the balance of instruments and procedures employed in plant breeding projects and programmes currently operated by the Centres, along with the possibility that costs could be reduced were some activities further centralized or out-sourced.

There was discussion about the extent to which such a review should incorporate the many interactions between Centres and NARS. Again, these relationships will be an important part of the more extended review in conjunction with a revised priority framework and strategic plan. Even so, some part of the possibilities is reflected in the question dealing with outsourcing in the questions that immediately follow.

What will be the featured elements in such a review? What questions or issues will guide and orient the effort? At this time there are thought to be five principal considerations. For each of the Centres:

1. What techniques and tools are being used in plant breeding for each relevant crop?
2. For plant breeding and for each crop, what are total expenditures and what are the expenditures on biotechnology for that crop? How much total professional time (including post doctorals and deputed staff) is devoted to that crop and how much of that is from professionals in biotechnology?
3. What opportunities are there for achieving cost reductions through:
    a. the substitution of new applications (including bioinformatics) for those of conventional techniques?
    b. improving on the applications of conventional techniques?
4. What opportunities for efficiencies are there through concentrating applications currently found in several Centres or through further out-sourcing to NARIs, advanced institutions, or the private sector?
5. What are the likely gains to be achieved through the implementation of different methods and what would be the estimated capital costs for doing so?

While TAC has contacted Centres and a few experts about the issues, the list might well change as the review unfolds. As well, of course, the issues pursued in visits must be individually tailored to fit the specialized opportunities of each situation. Finally, while pinpoint accuracy would be quite costly, e.g., for the second issue, something less will be sufficient to indicate significant opportunities.

III. Modus operandi

For now the intent is to deal with the first two issues with desk studies through the TAC Secretariat. This effort will clearly involve interaction with the individual Centres on a crop-by-crop basis.

For the remaining issues TAC intends to form a panel of experts with experience in well known plant breeding institutions. Suggestions for potential members will be sought from Centres and a variety of non-Centre sources. The panel will include enough members that constraints on available time should not be a major problem in attracting the desired people, but small enough that there will be overlaps in the membership of the various sub-panels. Each sub-panel will consist of two to three persons. In most cases it is believed that sub-panels can be so formed that each could effectively cover the plant breeding in a single Centre. To fix ideas, panel members might participate in the review of as many as two or three Centres. Given the SRP's interest in assessing the potential for reducing the investment in conventional breeding, it will be necessary to visit Centres and work directly with relevant staff. To date the evidence suggests that a visit will take around four days per commodity, more with larger programmes (e.g., rice), fewer with smaller programmes (e.g., cowpeas). The fifth issue can probably be based on the reports dealing with the other four issues and effectively treated by a specially selected sub-panel.

While a considerable amount of travel will be involved, it seems necessary to visit only the main station or stations for each Centre. Costs of the review will be on the order of $250,000. TAC aims to have the review completed by ICW99, but notes that this depends heavily on the availability of experts and the seasonality of the breeding work in the various Centres.

IV. Conclusions

TAC believes that the approach described is an efficient way to get at the issues raised by the SRP in a timely fashion. TAC notes that current EPMRs include a significant segment on the applications of biotechnology to plant breeding with acknowledged experts engaged to make such assessments (witness the recent reviews of CIMMYT, ICRISAT, IRRI). In this way and in the course of a few years, many of the issues of concern to the SRP will be covered. However, to the extent that the Group is concerned with more immediate insights into all relevant Centres and with observations about the advantages of centralizing some of the functions currently undertaken by several Centres (but note the counsel of the Biotechnology Panels), TAC commends this Terms of Reference to the Group and recommends its endorsement.

TERMS OF REFERENCE
FOR SUB-PANELS OF THE REVIEW OF PLANT BREEDING METHODOLOGIES

The System Review in its Recommendation 4 on an integrated gene management approach recommended a review of plant breeding efforts and drew attention to the role of molecular methods in crop improvement. As a response to these recommendations TAC is conducting a Review on Plant Breeding Methodologies. The review will assess the methodological tools applied in crop improvement with special emphasis on the integration of biotechnology. The general Terms of Reference endorsed by the group at MTM99 list the principal considerations to guide this review (see Annex I). The description of techniques and tools applied to each crop programme and the expenditures in breeding and in biotechnology in detail will be covered by a questionnaire survey supporting the review. The considerations dealing with opportunities and efficiencies will be cover by sub-panel visits to individual centres. As stated in the general Terms of Reference, the issues pursued during the visits must be individually tailored to fit the specialized opportunities of each situation.

In the light of each centre's goals for improvement of the crop(s) under consideration and the specific needs of the range of partners which the centre must satisfy the sub-panels will:

1) Assess effectiveness of methodologies in use for each crop, giving particular consideration to cost-effectiveness, to efficacy in achieving set goals and to optimal integration of different tools, molecular technologies in particular.

2) Assess the trends and strategies for incorporating new methodologies for the future, giving particular consideration to opportunities provided by new methodologies and the mechanisms in place to guide choices in breeding methodology and in research. Aspects of access and the consequences of chosen methodologies in delivery of goods must also be considered.

3) Assess opportunities for synergies within each centre between its various crop improvement programmes, between individual centres giving consideration to similarities in crops, genome synteny and breeding themes, and between centres and other institutions. The latter involves assessment of opportunities for outsourcing.

The sub-panels consisting of 1-3 members will visit centre headquarters for 4 working days. A questionnaire survey and relevant documents on crop improvement activities for each centre, will provide background information for the sub-panels. The sub-panel will complete a draft report on its findings during the visit to the centre, and one member of the sub-panel will help to incorporate the findings into the final report.

SUB-PANEL MEMBERS AND BIOGRAPHICAL INFORMATION

Donald N. Duvick (USA) is an Affiliate Professor, Department of Agronomy, Iowa State University, Ames, Iowa. He has expertise in plant breeding, genetics, preservation and utilisation of genetic diversity. He holds a Ph.D in Botany (genetics and biochemistry), from Washington University, St. Louis, Mo. (1951) and a B.S. degree in Agriculture from the University of Illinois (1948). From 1951-1990 he worked with Pioneer Hi-Bred International, Inc. holding various levels of responsibility:- 1986-1990: Sr. Vice President, Research, 1984-86: Vice President, Research, 1975-1984: Director, Plant Breeding Division, 1971-75: Director, Corn Breeding Department, 1965-1971: Corn breeding coordinator, 1951-1965: Corn breeder and geneticist, with Pioneer Hi-Bred International, Inc. While employed by Pioneer Hi-Bred International, Inc., his managerial responsibilities included coordination of the company's worldwide plant breeding activities in cotton, corn, sorghum, pearl millet, wheat, soybeans, alfalfa and sunflowers. He also was a member of the Corporate Executive Committee and of the Corporation's Board of Directors. Research contributions over the past 50 years have been in several fields, including the developmental cytology and biochemistry of starch and protein components of the maize endosperm, the genetics and practical applications of cytoplasmic male sterility in maize, elucidation of changes in productivity of commercial maize hybrids since the advent of hybrid maize, and genetic diversity as affected by plant breeding. He has published pioneering papers in each of these fields. He is a member of the Board of Directors for the Iowa chapter of The Nature Conservancy, is a past member of the Board of Trustees for CIMMYT (The International Maize and Wheat Improvement Centre), and for IRRI (The International Rice Research Institute). **[Panel Chair and Sub-Panel member at CIMMYT and CIP]**

Malachy Oghenova Akoroda (Nigeria) is a Crop Breeder, International Society of Tropical Root Crops – Africa Branch, IITA, Ibadan, Nigeria. He has expertise in plant breeding, farming systems, genetics, statistics; sweetpotato, cassava, soybean, yams, okra. He holds a PhD in Agronomy/Plant Breeding (1976–81) and a BSc in Agriculture/Crop Science, 2nd Class Upper Division (1972–75) from the University of Ibadan (U.I.), Ibadan, Nigeria,and a Certificate of completion: International Course on *Cell and Tissue Culture and Biotechnology for African Scientists,* U.I., Ibadan, Nigeria. IITA, Ibadan, Nigeria. 1989-99: Senior Lecturer (1989) and Professor (1994) in the Department of Agronomy, University of Ibadan, Ibadan. Executed some 50 consultancy assignments on farmer participatory activities, technology adoption and project assessment (plant breeding, agronomy, general crop production); 1987-90: Breeder/Agronomist of IITA in the Gatsby Root Crops Project on cassava, sweetpotato, and yams at the Institute of Agricultural Research in Adamaoua Province of Cameroon; 1984-87: Part-time breeder, Yam breeding Section, TRIP, IITA, Ibadan; 1983-87: Lecturer II (1983) and Lecturer I (1986), Plant Breeding/Seed Technology Unit, Department of Agronomy, University of Ibadan, Ibadan, Nigeria; 1980-83: Okra and *Corchorus* breeder, and head of the Seed Production Unit of the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. Over 60 publications including 38 journal articles on crop breeding and genetics, seed production and reproductive biology, agronomy and cropping systems, technology transfer and delivery systems, ethnobotany, impact Assessment, horticulture, genetic resources management, agro-meteorology and training. **[Sub-Panel member at CIP]**

Derek Byerlee (Australia) is a Principal Economist, Agricultural Policies Division, Agricultural and Natural Resources Department, World Bank. He has expertise in agricultural economics, natural resource economics and natural resources management. He holds a Ph.D. in Agricultural Economics, Agricultural Development, Natural Resource Economics and Quantitative Methods, Oregon State University, U.S.A. (1968-71); M.Ag.Ec. in Agricultural Economics, University of New England (1967-68); and a B.Ag. Sc. in Agriculture, University of Adelaide (1962-66). 1987- 1994: Director, Econ. Programme, CIMMYT, Mexico. Administered a programme of 12-15 internationally recruited economists based in Africa, Asia and Latin America. The programme conducted research and training in technology design and evaluation, natural resource management, research resource allocation and impacts, and applied policy analysis; 1992: Visiting Fellow, Dept. of Agricultural Economics, Cornell University, USA; 1984-87: Regional Economist, CIMMYT, South Asia (based in Islamabad). Major emphasis on developing a farmer and systems orientation to agricultural research programmes, and on research on technical change and sustainability issues in South Asia's irrigation cropping systems; 1986: Visiting Professor, Department of Agricultural and Applied Economics, University of Minnesota; 1977-83: Economist, CIMMYT, Mexico, Development of methodologies for incorporating a farming system's approach to research, and application of those methods in national agricultural research systems. Directed research on long-term trends and policy issues in the world food economy with emphasis on comparative advantage and policy incentives; 1971-77: Assistant and Associate Professor (tenured), Dept. of Agric. Economics, Michigan State University. Leader of research projects on the links between technical change and employment and income distribution; 1974-75: Research Fellow, Dept. of Agricultural Economics and Extension, Njala University College, Sierra Leone. Organized and implemented a nation-wide rural household survey of production, consumption and migration; 1970-71: Specialist, Dept. of Agricultural Economics, Michigan State University. Part of a multidisciplinary research team to construct a simulation model of the Nigerian economy, with emphasis on the links between the macroeconomy and the agricultural sector; 1966: Agricultural Development Officer, Papua New Guinea, Preparation of projects for small-holder tree crop production. Author/co-authors of over 130 publications. **[Sub-Panel member at CIP]**

Elizabeth D. Earle (USA) is Chairperson and Professor, Dept. of Plant Breeding, Cornell University. She has expertise in plant breeding and biotechnology; applications of cell and molecular biology to crop improvement; disease and insect resistance; organelle genomes (especially cytoplasmic male sterility); gene transfer; protoplast fusion; potato, and various other crops. She holds a Ph.D. in Biology (1964) from Harvard University, a M.A. in Biology (1960) from Radcliffe College and a B.A. degree in Zoology with High Honors (1959) from Swarthmore College. Aug. 1993-Jan. 1994: Visiting Geneticist, Dept. of Vegetable Crops, University of California, Davis, CA (sabbatical leave); 1988-92: Graduate Field Representative, Field of Plant Breeding; Feb.-June, 1986: Visiting Scholar, Dept. of Biology, Stanford University (sabbatical leave); 1979-86: Associate Professor, Dept. of Plant Breeding; 1975-79: Research Associate, Senior Research Associate, Plant Breeding; 1974-75: Visiting Research Associate, Biology Dept., Stanford University; 1970-74: Research Associate, Lecturer, Dept. of Floriculture, Cornell University; 1968-69: Research Associate, Biology Dept., Harvard University; 1964-65: NIH Postdoctoral Fellow, Biology Dept., Princeton University; 1959-63: NSF Predoctoral Fellow, Biology Dept., Harvard University; 1959-63: NSF Predoctoral Fellow, Biology Dept., Harvard University. Selected professional activities: 1986-present: Editor, Plant Cell

Reports; 1991-93, 1995: Review panellist for selection of NSF predoctoral fellowships; 1992: Attended Cassava Biotechnology Network Meeting, Cartagena, Colombia; 1992: Consultant on cassava biotechnology for USAID in Indonesia; 1992: Consultant for on site evaluation of biotechnology projects for Ministry of Agriculture and Forestry, Finland, 1990: Participated in Conference on "Biotechology: Enhancing Research on Tropical Crops in Africa", IITA, Ibadan, Nigeria. 1988-present: Co-principal investigator, Cornell Plant Science Center. **[Sub-Panel member at CIP]**

Gebisa Ejeta (Ethiopia) is a Professor of Plant Breeding and Genetics, Department of Agronomy, Purdue University. He has expertise in plant breeding, genetics, plant sciences, sorghum, pearl millet. He holds a Ph.D. in Plant Breeding and Genetics (1978) and a M.S. in Plant Breeding and Genetics (1976) from Purdue University, 1976; and a B.S. in Plant Sciences (1973) from Alemaya College, Ethiopia. 1988-1992: Associate Professor of Plant Breeding and Genetics; 1984-1988: Assistant Professor of Plant Breeding and Genetics; 1974-1978: Graduate Research Assistant, Purdue University; 1973-74: Principal Plant Breeder, International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Wad Medani, Sudan; 1973-74: Research Associate, Ethiopian Sorghum Improvement Project; 1971-1972: Research Assistant, Institute of Agricultural Research, Ethiopia. Member of a number of professional societies, examples of which are: American Society of Agronomy, Crop Science Society of Agronomy, American Association for the Advancement of Sciences and Sigma Xi. Over the last five years he has been the author or co-author of over 40 scientific publications. **[Sub-Panel member at ICRISAT]**

Michael Denis Gale (UK) is Associate Research Director, John Innes Centre, Norwich Research Park, Colney, Norwich. He has expertise genetics, molecular mapping, plant breeding and germplasm; cereals: wheat, barley, rice. He holds a PhD from the University College of Wales, Aberystwyth (1969), and a B.Sc. in Genetics (Hons) from the University of Birmingham (1965). 1992-94: Acting Head of Cambridge Laboratory; 1988-1992: Head, Cereals Research Department, Cambridge Laboratory; 1985-88: UG6 IM, Cytogenetics Department, Plant Breeding Institute, Cambridge; 1984-85: Study leave, Canberra; 1968-1984: Cytogenetics Department, Plant Breeding Institute, Cambridge. Has carried out various consultancies:- Consultant, molecular mapping in Hevea, Rubber Research Institute of Malaysia (1987);Technical co-operation expert for International Atomic Energy Agency for wheat, barley and quinoa breeding programmes in Bolivia (1987). Member of various committees and panels:- Ministry of Agriculture, Fisheries and Food, Novel Crops and Livestock Enterprise Review Group (1987-88); Scientific Advisory Committee for the Rockefeller Foundation Rice Biotechnology Programme (1989-); Overseas Development Administration, Plant Breeding and Physiology Management Advisory Panel (1990-); External review panel CIRAD, Montpellier, France (1992); Science Advisory Group, School of Biological Sciences, Reading University (1992-); Member of UK H&S Committee on Genetically Modified Organisms, representing BBSRC (1995-); Nuffield Bioethics Committee on Genetically Modified Plants (1997-). He was a panel member of the 5th EPMR of IRRI (1998). **[Sub-Panel member at IRRI]**

Jean Christophe Glaszmann (France) is Program Leader, Plant Biotechnologies and Genetic Resources (Biotrop) and Geneticist at CIRAD. He has expertise in plant breeding, genetic resources, sugar cane, rice, sorghum, maize, genome analysis, comparative mapping,

biochemical and molecular markers. He holds an Habilitation à Diriger des Recherches (1993) from the University of Paris XI (Orsay), a Docteur-ingénieur (1982) and an Ingénieur Agronome (1979), from the Institut National Agronomique Paris-Grignon (INAPG). 1996-1997: Head, Annual Crop Breeding Research Unit; 1991-1996: Secretary of the CIRAD genetic resources Working Group; 1987- CIRAD, genome analysis laboratory, Montpellier; 1985-1987: seconded to IRRI, Plant Breeding Department, Los Baños, Philippines; 1982-1984: Seconded to the International Rice Research Institute (IRRI), International Rice Germplasm Centre (IRGC), Los Baños, Philippines; 1979-1982: Doctorate preparation, Plant Breeding Division, Institut de Recherches Agronomiques Tropicales et des cultures vivrières, Montpellier. Major endeavours, for diverse tropical crops: - management of plant genetic resources for their conservation and utilisation; - genome analysis for the localisation and use of genes of agricultural value; - proper application of biotechnologies for the creation, multiplication and distribution of improved genetic materials. His main impacts have been on establishment of a varietal classification scheme now widely used for rationalising rice genetic improvement; elucidation of the genome structure and dynamics in modern sugar cane cultivars; initiation of gene tagging with molecular markers in sugar cane (collectively). He has published 43 journal articles and over 70 other publications. **[Sub-Panel member at CIAT]**

Randy A. Hautea (The Philippines) is the Director, International Service for the Acquisition of Agri-biotech Applications-Southeast Asia Centre (ISAAA-SEAsia Centre). He has expertise in plant breeding, plant genetics and plant pathology. He holds a Ph.D in Plant Breeding (Plant Pathology and Physiology - cognates), Cornell University, Ithaca, New York (1986). 1994-97: Director, Institute of Plant Breeding, University of the Philippines Los Baños; 1994-97: Vice-Chairman, National Committee on Plant Genetic Resources, Philippines; 1986-1997: Member of the Faculty, Graduate School, and Legume Breeder/Research Associate Professor, Institute of Plant Breeding, University of the Philippines Los Baños; 1993-94: Research and Extension Co-ordinator, College of Agriculture, University of the Philippines Los Baños; 1992: Visiting Scientist, Department of Agronomy and Plant Genetics, University of Minnesota; 1989-91: Division Head and Program Leader, Field Legumes Division, Institute of Plant Breeding, University of the Philippines Los Baños; 1989-91: Deputy Director, Institute of Plant Breeding, University of the Philippines Los Baños. Member, External Review Committee, Genetic Resources Centre, International Rice Research Institute, Los Baños, The Philippines (1995). Chairman, External Review Committee, Bureau of Plant Industry, The Philippines, (1996). Chairman, CCER, IPGRI-APO (1996). Panel member of 4th EPMR of ICRISAT (1996) and panel member of 5th EPMR of CIAT (2000). **[Sub-Panel member at ICRISAT and CIAT]**

Hiroshi Ikehashi (Japan) was Professor of Plant Breeding, Graduate School of Agriculture, Kyoto University until March,2000 (presently Prof. at NihonUniversity). He obtained a Doctor of Agriculture from Kyoto University in 1973. 1987-1993: Professor of Plant Breeding, Faculty of Horticulture, Chiba University; 1985-1987: Genetic Resources Coordinator at Nat. Inst. Agrobiological Resources; 1981-1985: Laboratory Head at Tropical Agr. Res. Centre (Okinawa); 1979-1981: Senior Researcher at Nat. Inst. Agr. Sci., Japan; 1975-1979: Plant Breeder at the International Rice Res. Inst.; 1959-1975: Researcher (Rice Breeding) at research stations in Japan. Examples of other professional experience he has had are: Breeding of several rice cultivars and related researches in Japan, Rice breeding and researches for adverse soils and etc. (at IRRI), Studies on breeding procedures (rapid

generation advance, etc.); identification of Wide-Compatibility Gene for hybrid sterility in rice; Administration on genetic resources in Japan; FAO Short-term Consultant, 1990-1993, for Asia and Latin America; FAO-UNDP Review Panel for Hybrid Rice Programme in India, 1995 and 1997. **[Sub-Panel member at IRRI]**

Edson Jair Iorczeski (Brazil) is Head of the Project, Development and Application of Cellular and Molecular Techniques to Cereal Breeding at EMBRAPA Trigo. He has expertise plant breeding, plant physiology, wheat, genetics, agronomy, barley, seeds. He obtained a Post-Doctor in Plant Breeding (1997) from North Carolina State University and a Ph.D. in Plant Physiology and Plant Breeding (1990) from Cambridge University, an M.S. degree in Genetics and Plant Breeding (1977) from Purdue University, USA and a Bachelor degree in Agronomy from University of Passo Fundo (UPF). Past positions he has held are: - 1990-95: Technical and Administration Chief of EMBRAPA Trigo; 1993-95: General Substitute Chief of EMBRAPA Trigo; 1990-93: National Coordinator of the Wheat PROCISUR Programme; 1983-86: Wheat Breeder at EMBRAPA Cerrados; 1979-83: Manager of the seed pelleting project in Celanese of Brazil; 1979-82: Wheat and Barley Breeder at EMBRAPA; March-December 1974: Assistant Professor in Genetics and plant breeding at the University of Passo Fundo; January-December 1973: Wheat Breeder at DNPEA. **[Sub-Panel member at CIMMYT]**

Wayne Powell (UK) has been seconded to DuPont from early 1999 from his position as Head of Cell and Molecular Genetics Department (Band 3 – IMP), Scottish Crop Research Institute. He has expertise in plant genetics, genome science, population genetics, biodiversity and conservation of genetic resources, molecular breeding, crop improvement; breeding of wheat, barley, potato; molecular studies on rice, soybean, groundnut and various tree species. He holds a: D.Sc. in Plant Genetic Manipulation (1993) and a Ph.D. Quantitative genetics (1985) from the University of Birmingham, a M.Sc. degree (Distinction) in Genetics & Plant Breeding (1980), a Postgraduate Certificate in Education (1975) and a B.Sc. degree (Hons 2:1) in Agricultural Botany (1974) from the University College of Wales, Aberystwyth. Currently he manages DuPont's strategic research alliance with the John Innes Centre, co-ordinates and align programs on wheat genomics and molecular breeding, contributes and participates in strategic planning through the analysis of internal and external opportunities and pressures. Scientific achievements: Discovery and exploitation of a high resolution chloroplast polymorphic assay system based on SSRs; In collaboration with colleagues at DuPont developed and used a pre-cloning enrichment procedure for plant SSRs. Developed the most comprehensive genetic linkage maps of barley which are currently available and used this resource to locate both quantitative and qualitative characters; Undertaken a comparison of the four major molecular assays: RFLPs, RAPDs, SSRs and AFLPs. This experimentation has provided new scientific guidelines for the deployment of marker systems in genetics, breeding and biodiversity studies; Currently exploring the potential of Radiation Hybrid mapping as a new approach to genetic mapping in plants; Initiated a comprehensive structural and functional genomics program for wheat. Evaluation of research proposals for BBSRC, NERC, EU, UNDP, FAO and International Foundation for Science. **[Sub-Panel member at ICARDA]**

Calvin O. Qualset (USA) is Director, Genetic Resources Conservation Program, Division of Agriculture and Natural Resources, University of California, Davis, 1985-present. He has expertise in genetics, plant breeding, biodiversity conservation and management, and agronomy. He holds a Ph.D. in Genetics (1964) and a M.Sc. in Agronomy (1960), University of California, Davis and B.Sc. in Agronomy, University of Nebraska (1958). 1994-present: Professor Emeritus, University of California, Davis; 1980-85: Associate Dean, College of Agricultural and Environmental Sciences, University of California, Davis, 1992-94: Acting Director Foundation Seed and Plant Materials Service, University of California, Davis; 1975-81, 1991-94: Chairman, Department of Agronomy and Range Science, University of California, Davis; 1967-94: Assistant Professor, Associate Professor, Professor of Agronomy, University of California, Davis; 1964-67: Assistant Professor of Agronomy, University of Tennessee. Program reviews for CIMMYT, ICARDA, and IPGRI; Fulbright Fellow to Australia and Yugoslavia. Panel Chair 4th EPMR (1997) of IPGRI. Member Board of Trustees, IRRI since 1999. **[Sub-Panel member at IITA and INIBAP]**

Ignacio Romagosa (Spain) is a Professor of Plant Breeding, barley geneticist and breeder at the Institut de Recerca i Tecnologia Agroalimentària - University of Lleida, Spain (he is currently Dean of the College of Agricultural and Forestry). He is also the Scientific Coordinator of the Plant Breeding activities at the Mediterranean Agronomic Institute of Zaragoza, Spain. He has expertise in plant breeding, genetics, statistics, agronomy, cereals, and sugar beets. He holds a PhD in Agronomy (1983) and a MSc in Agronomy (1980) from the Colorado State University, USA. In his present posts, apart from his temporary administrative duties, (i) he is responsible for teaching courses in Plant Breeding and in Applied Statistical Methods, (ii) co-responsible for a barley breeding program, and (iii) he coordinates an international 10-month postgraduate course in Plant Breeding and advanced short courses for professionals in Plant Sciences. 1991-93: Chair, Agricultural Sciences Committee, Spanish National Agency for Scientific Evaluation – his task in this position was to assign each research proposal (around 300 a year) to external reviewers and to prepare a final evaluation report for a funding panel based on peer reviews; 1982-84: Sugar beet geneticist and breeder at the Aula Dei Research Station of the Spanish High Council of Scientific Research; 1979-81: Postgraduate student at Colorado State University in sugar beet genetics and breeding. **[Sub-Panel member at CIMMYT and ICARDA]**

Patrick R. Rubaihayo (Uganda) is a Professor at Makerere University, Uganda. He has expertise in plant breeding, genetics, botany, grain legumes, bananas, tomatoes, potatoes. He holds a Ph.D. in Plant Breeding/Genetics, University of Illinois, Urbana/Champaign (1969-71), an M.Sc. (Agric.) in Plant Breeding/Genetics, Makerere University (1967-69) and a B.Sc. (Hons.) in Botany, Makerere University (1964-67). 1995: Appointed Professor. His current research involves tissue culture and molecular polymorphism in bananas. 1977-95: Held the position of Associate Professor, Makerere University. His major research work was on the Improvement of Grain Legume, Bananas, Tomatoes and Potatoes in Uganda; 1981-85: Member of Ugandan Parliament and Minister of State for Agriculture and Forestry. Was in charge of the Coffee Rehabilitation Programme (CRP) and the Agriculture Rehabilitation Project (ARP); 1971-80: Moved through the ranks from Special Lecturer to Associate Professor in the Department of Crop Science, Makerere University. The work involved teaching and research in the field of annual and perennial crops; 1969-71: As a Ph.D assignment carried out a research project on the Genetics of soybeans; 1968-69: Worked as a

Graduate Assistant and later as a Special Assistant in the Department of Crop Science, Makerere University; 1967-69: Worked with grain legume (soybeans, cowpeas, pigeon peas, beans) and their mixtures with cereals (intercropping). **[Sub-Panel member at IITA and ICARDA]**

Leocadio Sebastian (The Philippines) is Executive Director, Philippine Rice Research Institute (1998-July 2000: Deputy Executive for Research and Development). He has expertise in molecular biology, plant breeding, research administration, and rice. He holds a Ph.D. in Plant breeding, minor in Genetics and International Agriculture from Cornell University, USA (1994), a M.Sc.degree in Genetics from the University of the Philippines Los Banos (1987) and a B.Sc. in Biology from the University of the Philippines Los Banos (1983). 1999-present: Team Leader, Rice Commodity Team, Bureau of Agricultural Research (BAR) Department of Agriculture, (Leads in formulating and implementing the rice R & D agenda of the Philippines); teacher of the graduate course on advanced genetics, graduate student advisor, Central Luzon State University; 1998-present: Member (current Chair for 2000), Steering Committee, Rainfed Lowland Rice Consortium, IRRI; 1996-present: Member(current Team Leader), Agricultural and Environment Biotechnology Team, Philippine council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) (leads in formulating the agricultural biotechnology agenda of the Philippines). 1999-2002: principal investigator, Rockefeller Foundation (RF) funded project on rice biotechnology. 13 journal articles, 60 conference publications including poster abstracts. **[Sub-Panel member at IRRI]**

Josef Franz Seitzer (Germany) is retired as Director, Plant Breeding Institute, KWS SAAT AG, Germany. He has expertise in plant breeding, biotechnology, maize, wheat, soybean, etc. He holds a Ph.D. in Plant Breeding and a M. Sc. in Plant Breeding from the University of Manitoba, Canada and a Diploma in agronomy (1957-58), School of Agriculture Nürtingen/Germany. 1979-98: Director KWS SAAT AG; 1975-78: Soya breeder, Agriculture Canada, Ottawa; 1967-69: Wheat agronomist, Plant Breeding Station Njoro, Kenya (BMZ/GTZ) Germany; 1961-66: Junior Plant Breeder, Hege-Züchtung (cereals, legumes). Has carried out a number of evaluations/ consultations:- In 1991 German Government on Agricultural research agenda, in 1992 EU research proposal Brüssel, in 1993 to 1997 contact scientist at CIMMYT; in 1996 member of "Technology board" , German Government on biotechnology, genetics, innovation, in 1997 assistance to PSC of CGIAR; in 1998 member of biotechnology panel CGIAR from 1999 onwards, consultant to KWS SAAT AG; in 1999 member International Scientific Advisory Board, Center of Plant Molecular Biology, Tübingen University. 26 publications in journals, conferences and popular press. **[Sub-Panel member at ICRISAT]**

Richard G.F. Visser (The Netherlands) is a Professor, Laboratory of Plant Breeding, Wageningen University (Temporarily in charge of the Chair, Genetic Variation and Reproduction for a period of five years, University of Wageningen). He has expertise in molecular microbiology, cell and plant genetics, plant breeding, research on potato and cassava. He holds a Ph.D. with thesis entitled 'Manipulation of the starch composition of *Solanum tuberosum* L. using *Agrobacterium rhizogenes* mediated transformation' (1989) and an M.Sc. degree in Molecular microbiology (1984), both from State University of Groningen. (1993-98): Associate Professor, at the University of Wageningen; (1989-92): Assistant

Professor at the Department of Plant Breeding, University of Wageningen – was employed to introduce cell biological, molecular and biotechnological research in the field of plant breeding. The first two years were spent to set up cell biological -, molecular-, recombinant DNA- and isotope-laboratories, as well as growth chambers (PCI).; Since 1990: Group leader within the BION (now SLW) working party on Molecular Cell Biology; Since 1991: Lecturer and examiner for the undergraduate school course "New developments in Plant Breeding" and Plant Breeding practicals. **[Sub-Panel member at IITA and CIAT]**

APPENDIX IV

LIST OF CGIAR CENTRES WITH CROP IMPROVEMENT MANDATES

Centre	Full name	Year founded	Host country	Mandate crops
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)	1967	Colombia	cassava, beans, rice, tropical forages
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)	1966	Mexico	maize, wheat (bread wheat, durum wheat, triticale)
CIP	Centro Internacional de la Papa (International Potato Center)	1970	Peru	potato, sweetpotato
ICARDA	International Center for Agricultural Research in the Dry Areas	1975	Syria	barley, wheat (durum species), lentil, chickpea, faba bean, forage legumes
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics	1972	India	sorghum, millet, groundnut, chickpea, pigeonpea
IITA	International Institute of Tropical Agriculture	1967	Nigeria	cassava, yams, maize, soybean, cowpea
IPGRI/INIBAP	International Plant Genetic Resources Institute/ International Network for the Improvement of Banana and Plantain	1974/1985	Italy/France	genetic resources, cocoa, coconut/*Musa* species
IRRI	International Rice Research Institute	1960	The Philippines	rice
WARDA	West Africa Rice Development Association	1970	Ivory Coast	rice

BREEDING METHODS USED FOR DIFFERENT CGIAR COMMODITIES

Crop	Breeding methods by goal*
CEREALS	
Maize	1. Use of landraces; Markers for diversity studies; Farmer participation in identifying landraces; African landraces and teosinthe for incorporation of resistance to *Striga* and post-harvest quality; Recurrent selection and pedigree breeding methodologies; From intra-population to inter-population improvement; Orientation along heterotic groups; MAS on experimental basis for drought tolerance, stem borer and maize streak virus (MSV) resistance; Elite maize germplasm characterisation with markers 2. Marker for opaque 2; Backcross selection followed by mass selection for upgrading the characteristics 3. Population improvement methods and selection indices; Reciprocal recurrent selection used for two heterotic sets of breeding populations; Inbred lines, to be used as sources of desired traits or as parents, extracted using pedigree selection and testcross evaluation; S1 family selection frequent for stress tolerance 4. Screening for grain quality for specific end-users; Novel screening techniques for incorporating aflatoxin resistance 5. Inoculation and infestation for a number of diseases; Use of "hot spots" for other diseases and insects; Source germplasm with highest levels of tolerance/resistance; MAS for MSV 6. Managed stress environments during germplasm development and early-generation testing; Keysites and multilocation testing under random stress at advanced generation testing; Environment-specific breeding approach; Improved statistical designs for yield (lattice, row-column, augmented designs); REML, G x E analysis for multilocation yield trials; More effective data management tools 7. NARS supported to develop sustainable cost-effective seed production schemes; Base seed production; Collaboration with NGOs; Distribution of bulk breeder seed and foundation seed to collaborators
Spring bread wheat	1. Molecular characterisation; Cytogenetics; Elite wheat germplasm characterisation with molecular markers; MAS 2. Selection for enhanced non-homologous combination in wheat wide crosses (*Ph1* gene; MAS) 3. Shuttle breeding; Multilocation testing; Advanced statistics 4. Refined parental choice; SDS-page of HMW glutenins; Indirect tests; Milling and baking; LMW-protein analysis; "Earlier" testing 5. Refined parental choice; Seedling tests; Slow-rusting; Cytogenetics; MAS for BYDV 6. Selection methods; Shuttle breeding; Multilocation testing; Advanced statistics; IWIS
Winter wheat	1. Crossing, backcrossing; C-banding; Fingerprinting 2-3. Crossing, backcrossing; Doubled haploids 4. Established analysis methods; HMW-glutenin banding 5. Field/artificial screening; Gene postulation; International nurseries 6. Yield and yield stability 7. Chemical application to seed to assure healthy seed production
Durum wheat	1. Greenhouse and field evaluations; Conventional and physiological tools; Fingerprinting; Greenhouse and field evaluation combined with shuttle breeding; Use of wheat wild relatives; Biotechnology; Estimate parameters to monitor existing genetic variation for directed genetic base expansion; Selection using all patterns of gene controlling desirable traits; Recurrent selection to pyramid genes of interest 2. Selection methods; Cytogenetics; Same as above 3. Selection methods; Multilocation testing; Advances statistics; Same as above 4. Refined parental choice; Early testing; SDS-page of HMW glutenins; Indirect tests; Gluten index 5. Refined parental choice; Seedling tests; Cytogenetics; Screening techniques; Stress physiology; MAS 6. Shuttle breeding; Multilocation testing; Advanced statistics; Improved crop management research; Early generation testing; IWIS
Barley	1. Evaluation of new accessions; Use of landraces and *Hordeum spontaneum*; SSD; Purification of populations; Identification of potential parents; Wide crosses; MAS for powdery mildew, cold tolerance and scald; Three-and four-ways crosses; Pure line selection within populations; Bulk method; Recurrent selection; Construction of populations for base broadening 2. Backcross; SSD; MAS 3. Bulk-pedigree and direct selection in the target environment, SSD 4. End-use participation 6. α-lattice design; G x E analysis; Unreplicated designs with systematic checks; REML

Crop	Breeding methods by goal*
CEREALS	
Sorghum	1. PRA-tools; Field trials; Statistics; Participatory tools; Population improvement; Inter-racial crosses; Population introgression; Mass selection; Pedigree selection; Testcrossing 3. Population improvement; Pedigree selection 4. Visual scores; Component tests; Farmer participation on station 5. Field trials; Specific assays; Regional nurseries 6. Multilocation trials with statistical analysis of stability related parameters; Farmer variety evaluations 7. Isolation on-station for breeder seed; Collaboration with national seed service; Extension organisations and NGO for seeds for distribution to farmers; Analysis of strengths and weakness of existing seed systems
Pearl millet	1. Pedigree selection; Populations/composites; Backcrossing; Selfing; Partial inbreds; Evaluation for target traits; Classical backcross breeding for incorporation of male-sterile cytoplasm (Seed parents); Recurrent selection; Pedigree breeding; Progeny selection on basis of both *per se* and test cross performance; Recurrent backcrosses in downy mildew disease nursery; Evaluation of effects of incorporating markers for drought tolerance 2. Pedigree and backcross breeding; Near-isogenic populations; MAS for gene pyramiding 3. Recurrent selection and pedigree breeding; Back-cross breeding; Evaluation of experimental varieties and hybrids; MAS; Evaluation of effects of incorporating markers for drought tolerance 4. Conventional laboratory test 5. Field and glasshouse evaluation of population progenies; Disease nurseries (especially downy mildew); Head miner infestation with eggs 6. Multilocational evaluation through regional trials 7. Standard seed production methods for open-pollinated crops; Morphological traits for purity test; Controlled pollination by hand and in isolation; Participatory seed production at village level
Rice	1. Characterisation (morphological, physiological, molecular, enzymatic); Cross breeding with *japonica* from different countries; Characterisation of progenitors in hot spots; Improved screening for rice blast, RHBV; Tagosodes and grain quality; Recurrent selection; Male sterility facilitated recurrent selection; Pedigree selection; Advanced backcrossing; Pure line selection; Mass selection; Modified bulk breeding; Screening of cultivated and wild species for resistances; Backcrossing for CMS and TGMS mutation breeding; Diallel analysis; Intergroup crosses: Tropical *japonica* x *indica*; Interspecific breeding; Wide hybridisation also using new interspecifics in bridging; Introgression of new alien genes into new plant types; RGA; Molecular markers and FISH for characterisation of alien introgressions; Doubled haploids; Embryo rescue; Somaclonal variation; Isoenzymatic characterisation; Fingerprinting; MAS for TGMS; QTL-analysis; Gene mapping; Transformation; Candidate genes for allele mining 2. Single, double or three way crossing program; Pedigree; Modified bulk method; Backcross; Backcrossing followed by embryo rescue; Anther culture; Evaluation/selection under high disease pressure; High density genomic maps; Transformation; MAS; Markers for pyramiding. 3. Single, double or three way crossing; Interspecific breeding; Recurrent selection; Modified bulk method; Gene pyramiding; Evaluation/selection under high disease pressure in upland condition; phenotypic selection and progeny testing at advanced generations; Molecular technology for drought resistance; Anther culture; QTL identification and mapping for the useful trait coming from *Oryza glaberrima*; Trends towards candidate genes rather than linked markers; Transformation 4. Strict grain quality and physic-chemical analyses; DNA markers to identify good quality rice; Panel testing and quality preference; NIRS method for quality control; Biosafety standards for RHBV 5. Screening under artificial conditions for major stresses; Screening in hot spots under field conditions; ELISA for virus diagnosis; Greenhouse screening and field testing in target sites; Conventional and molecular technologies; Natural field selection resistance; DNA markers and candidate genes used to select MAS products in field trial; Molecular kits for detection of viruses; Molecular tagging of resistance genes; DNA markers and candidate genes; Molecular tagging of resistance genes; MAS; Adoption of PCR based diagnostics for biotic stress 6. New ideotypes and heterosis breeding for increased yield potential; Multiple resistance to diseases, insects and tolerance to abiotic stresses; Screening in INGER nurseries; Conventional multilocation; Multi-season station and on-farm trials with G x E analysis; Observational and replicated yield and stress trials; Farmer participation; Regional breeding and varietal selection trials; Field trial and location or site testing; Better selection of representative sites for yield tests and regional trials by NARS; Regional stability trials; Exploitation of tropical *japonica* x *indica* and heterosis breeding; Biosafety guidelines for transgenic rice developed; AMMI analysis for G x E; Molecular technologies diversity identification

Crop	Breeding methods by goal*
CEREALS	
Rice (cont.)	7. Cytoplasmic male sterility for hybrid rice; Head to row- breeder seed production; Single plant selection to pure line selection; TGMS; PGMS; Breeder and foundation seed production; Seed of hope production to revive farming in disaster areas of countries relieved of civil wars; Community-Based Seed Multiplication scheme; NARS involvement; Better selection by NARS of sites for seed multiplication; Storage and processing 8. Use of economic data to determine priorities in research activities; Elaboration of national rice production plans to solve production constraints
STARCHY STAPLES	
Cassava	1. Conservation in the field and *in vitro* (slow growth, cryopreservation improved; expensive); Searching for useful variability in wild species: for resistance to diseases, new starch forms, other useful traits (accession found with resistance to whiteflies, based on antibiosis); Sampling of seeds and/or stem cuttings from farmers' fields or wild habitats; Use of GPS to pin point the geographical co-ordinates of collection sites; Morphological and molecular characterisation; Field/laboratory evaluation of local cultivars for superior agronomic and quality traits; Systematic and agroecologically-based introduction, evaluation and selection of Latin American germplasm in selected agroecologies of Africa, followed by testcrossing with African adapted genepools, progeny testing, selection and recombination; Interspecific hybridization between African germplasm and wild *Manihot species* used to create diploid genepools with resistances and polyploid genepools; Statistical genetic analyses; Gene complementarity and combining ability analyses; DNA finger printing techniques (RAPDS and SSR, AFLPs) in addition to agrobotanical characterization and combining ability analysis to identify diversity patterns and heterotic relationships among germplasm; Somatic autotetraploidy to improve sexual tetraploids; Ploidy manipulation through unilateral and bilateral hybridization; Recurrent selection (ineffective); Polycross breeding and half and full-sib recurrent selection schemes for the development and improvement of source populations for special traits and for the development and improvement of broad-based populations; Development of selfed-line selection scheme; Parental selection for recombination on the basis of diversity, Progeny testing and combining ability analysis 2. Conventional backcrossing and mass selection methods; Little breeding for monogenic traits 3. Polycross breeding and population improvement methods by half-sib and full-sib recurrent selection; Selection of parental material on the basis of diversity; Progeny testing and combining ability analysis; Renewed breeding scheme to shorten the length of each cycle and to reach the replicated trial stage earlier 4. Increasing involvement of the private processing sector in cassava research (Latin-America); Main issue is reducing cyanide content on roots, after artificial drying; Screening/evaluation of genotypes for quality traits for food, feed, and agro-industrial uses using standard lab and field methods, as well as conformation and ease of peeling of roots; Characterisation of functional properties for various end-users geared towards markets; Screening for high micro-nutrient content (provitamin A activity, Fe, Zn) 5. Materials developed with adequate resistance/tolerance to major abiotic or biotic stresses; Electron microscopy and ELISA for detection of viruses; PCR-based diagnostics design primers for virus detection; Search and characterisation of components and mechanisms of resistance from various germplasm sources for enhancing durable resistance; Rapid screening for drought and heat tolerance with the infrared multimeter 6. Selection under strong biotic and abiotic stress pressure; Field trials conditions simulate the farmers' conditions of soil fertility with no use of pesticides; Collaborative multilocational and multinational trials of elite breeding lines conducted in various target agroecologies where these lines will be grown; Farmer participatory evaluation and selection; Mixed models of SAS and AMMI used for performance assessment and G x E interaction analyses; GPS assist in the rationalisation of selection and testing sites distribution areas "Biofactory" for satisfying the need of large amounts of "clean seed" involving RITA (*in vitro* culture using liquid growth media) and then regeneration in greenhouse; Private cassava seed industry encouraged; Shoot-tip culture and virus indexing for disease elimination; Micropropagation using nodal cuttings of disease free planting materials and dissemination to NARS; Field rapid multiplication techniques for planting material supply; Pure hybrid production (true seed) system for cassava as a seed-based production methods for intensive commercial production and utilization systems in areas combining high production potential and market opportunity; Certified ministakes and large-scale delivery of *in vitro* plantlets under development; NGOs and growers associations getting more involved with multiplication and distribution; Genetically diverse male sterile parents (female lines) for enhancement of hybridization under development.

Crop	Breeding methods by goal*
STARCHY STAPLES	
Potato	1. Observations of characters related to reproductive biology; Classical tools in labs, field and screen houses for screening (phenotypic expression mainly) for major resistant traits (late blight [LB], viruses [analysis also at protoplast level], bacteria, insects and nematodes); Wild and cultivated genebank accessions for new sources of resistance to LB, BW and viruses (ELISA screening) and low/stable sugars; Inheritance of resistance traits; Sexual hybridisation followed by hybrid seed selection based on embryo morphology and size; Cytogenetics; GIS; MAS for limited single-gene inherited traits; Novel major factors for LB characterised for specificity/genetic control; Genetic designs developed to characterise new sources of resistance to PLRV; Multiplex progenitors and early phenotypic screens for increasing frequency of resistance genes for PVY and PVX; 4x-2x mating is applied to capture diversity from cultivated/wild species; Different genetic backgrounds introduced for LB and BW resistance; Intercrossing; Backcrossing; Somatic hybridisation; Parthenogenetic seeds for the selection of lines with higher order of homozygosity and multiple copies of desirable genes; Phenotypic recurrent selection; Population breeding; Parental line development; Controlled challenges to verify durability of major genes across known and new pathogen races; Support populations for new diversity; Haploids for genetic studies and use at 2x level 2. Pedigree breeding; Population breeding for increasing the frequency of genes for important monogenic traits (extreme PVY resistance, RKN resistance in seed potato); Dihaploids, and ploidy manipulation; Transformation (PVY, Bt-genes); Genotyping using morphologic traits; Phytopathology 3. Population breeding followed by bi-parental crosses with high combining abilities for traits under selection; Recurrent selection with progeny testing for traits with additive variance combined with negative selection; Phenotypic (and some genetic) selection for yield and tuber quality traits; Ploidy manipulation; Candidate gene collection for disease resistance; Search for linkage disequilibrium in populations derived from breeding program; Early screens for PLRV; Candidate gene and QTL approaches for quantitative resistance to LB; Split plot harvest for early tuberisation 4. Evaluation for organoleptic quality, glycoalkaloid content (spectrophometric estimations), post-harvest quality and processing characteristics 5. Hot spot testing for biotic and abiotic stresses; Standard field and screenhouse methods; ELISA for virus and bacteria; Indicator plants; Improved scales and serology kits 6. Multilocation trials; STABLE programme for stability evaluations; Simple lattices; Augmented designs; Randomised complete block designs; Split plots; Quantitative genetics; Farmer evaluation in farmer field schools; Early testing with large numbers of farmers; Modelling for LB 7. Special procedures for true potato seed (TPS) production and quality estimation; *In vitro* clean stocks; Mini tuber production (pre and basic seed); Seed farms with low virus content; Dormancy release procedures; Hydroponics developed; Farmers supported in multiplying healthy seed
Sweetpotato	1. Agronomic characterisation of germplasm; DNA fingerprinting for germplasm identification and diversity assessment; Farmer participation of germplasm evaluation; Polycrossing and recurrent selection; Progeny testing; Evaluation of combining ability; Transformation; Heritability estimation; Genetic linkage mapping; Fingerprinting for measuring genetic distances among parent 2. Bi-parental crossing; Mass selection 3. Measurement of genetic distances in parents; Heritability estimation 6. New statistical tools to dissect G x E interaction and stability; Farmer participatory cultivar evaluation 7. Tissue culture; Immunological tools for clean seed; Molecular virology for quality checking
Musa	1. Tissue Culture; Morphological characterisation; Molecular techniques (RAPD, RFLP, cDNA, SSR); Cytogenetics; Karyological analysis (DNA flow cytometry, FISH, fiber-FISH or PRINS, Chromosome painting, etc); Micropropagation through shoot apex tissue culture and cell suspension and somatic embryogenesis; Cryopreservation methods; Recurrent diploid breeding; Recurrent polyploid breeding; Segregating populations 2. Support to FHIA breeding programme (INIBAP); Transformation 3. Visual selection; Progeny testing SCA and GCA; diploid x diploid crosses producing tetraploids crossed with diploid for secondary triploids; Embryo rescue 4. Post Harvest Methods 5. Screening in greenhouse e.g. nematodes; Early selection through *in vitro* and/or greenhouse screening, using pathogen derivatives: conidia, toxins, etc. 6. Hybrid performance multilocation trials; Performance and in-depth evaluation sites.

Crop	Breeding methods by goal*
STARCHY STAPLES	
Yams	1. Sampling of seed populations and tubers/bulbils from farmers' fields, or in wild habitats in areas where diversity is found; GPS to pin point the geographical co-ordinates; Morphological and molecular characterisation, fingerprinting; Field genebanks; Sub-culturing/maintenance in *in vitro* cultures under slow growth conditions; Transfer by shoot-tip culture; Selection of core collection(s); Test plant method; ELISA and electron microscopy for assessment of health status and morphological characters for assessment of genetic stability of germplasm maintained *in vitro*; Field (multi-site) and laboratory evaluation of local and introduced germplasm for identification of sources of superior agronomic and quality traits; Intra-specific hybridisation involving local and exotic landraces; Inter-specific hybridisation; Chromosome counting; Fidelity confirmation of hybrids through plant morphology and isozyme patterns; Studies of genetics of economic traits and combining abilities; Multiple planting dates; Sett size manipulation and site selection to improve flowering; Synchronisation of flowering and seed set of a broad range of landraces; Bi-parental intra-specific crosses of genotypes chosen on the basis of morphological and molecular characterisation as well as systematic field evaluations; Flow cytometry for ploidy determination; Improved choice of parents for inter-specific hybridisation guided by results of phylogenetic studies; Hybrid confirmation assisted through DNA-based techniques; Recurrent selection; Broad based populations for *D. alata* and *D. rotundata* targeting adaptation to the southern guinea savannah zone of West Africa; Special populations for improved food quality of the tuber in *D. rotundata* and anthracnose resistance in *D. alata*; Parental selection improved through the establishment of heterotic groups 2. Backcrossing and mass selection 3. Recurrent selection 4. Physical and chemical analyses in the laboratory; Evaluation through taste panels 5. Electron microscopy; ELISA 6. Multi-site (including multi-country), multi-year clonal evaluations, on-station and on-farm; Analyses of genotype by environment interactions; Farmer participatory varietal evaluation 7. Disease elimination using shoot-tip culture and virus indexing; Micropropagation using nodal cuttings in semi-solid and recently in liquid medium; Production of certified minitubers; Rapid field multiplication using the minisett technology; Large scale production of certified minitubers in screenhouses; Development of compact packaging system for large-scale delivery of *in vitro* plantlets; Large-scale delivery of germplasm (*in vitro* plantlets and minitubers) to NARS; Inclusion of hot water therapy of mother seed yams to ensure improved health status of the resulting seed yams
LEGUMES	
Bean	1. Exploration with FloraMap; Core collection of wild and cultivated beans; Characterisation with RAPD & AFLP; Multiplication and storage under low moisture; User friendly package as compact disc; Extensive laboratory characterisation of the core; Marker classification; Advanced backcross method using wild bean accessions; QTL analysis applied with microsatellite markers; Congruity backcross with *Phaseolus acutifolius* interspecifics; Increased emphasis on inter-gene pool crosses in Africa; Larger population size and analysis of BC_2F_3 generation; Climber x bush crosses to overcome incompatibility among gene pools; Crosses between *P. vulgaris*, *P. polyanthus*, *P. coccineus*; QTL dissection of P uptake traits; QTL to select parental lines from RIL; Crossing on multiple constraint resistance 2. Phenotypic selection in field in F1 from complex crosses (gamete selection); MAS with a major viral resistance gene; Simpler crosses (3X, double); Larger population sizes 3. Gamete selection based on phenotype in field; MAS for two important genes; Flanking markers used for MAS of QTLs and other important genomic regions; Multi-parent crosses to develop multiple constraint resistant genotypes using gamete, early generation and pedigree selection; Simpler crosses (3X, double); Larger population sizes; QTL analysis of many traits; Shift to selection for multiple traits 4. QTL analysis of mineral content (Fe, Zn); Assessing export canning quality, cooking time and consumer/trader preference testing for food types 5. Characterisation of pathogenic Andean and Mesoamerican races angular leaf spot and *Pythium spp.* 6. International yield trials analysis with SEQRET program; Yield trials in 2-3 contrasting environments; Participatory Plant Breeding (PPB); Farmer involvement at early stages of selection; Novel probability functions to cluster trial environments 7. Development of informal seed systems, particularly for lines identified by PPB

Crop	Breeding methods by goal*
LEGUMES	
Chickpea	1. Collection in chickpea growing areas and unexplored areas; Characterisation of germplasm; Evaluation under controlled conditions; *In situ* conservation of wild *Cicer* species; Hybridisation - intra and inter-specific; Mutation breeding; Genetics of important traits; Embryo rescue and tissue culture; Search for higher level of resistance in related species 2. Backcross breeding; Mutation breeding; SSD 3. Bulk-pedigree method; Modified pedigree; SSD; random mating; Accelerated generation advance; Three-way crosses for useful recombinant progenies 4. Testing of protein and cooking quality parameters of fixed lines 5. Study of economic importance of different abiotic and biotic stresses; Identification of hot spots for evaluation of stresses; Evaluation of germplasm under hot spots; Screening under controlled conditions 6. Multilocation testing across years for general adaptation; Zoning /characterisation of environments; Targeted evaluation for specific zones; Dissemination to NARS for testing under their conditions; Decentralised breeding 7. Contract farmers; Government Agreements; Seed production unit
Cowpea	1. Seed sampling from farmers' fields, in wild habitats; GIS to pin point the geographical co-ordinates; Morphological traits and fingerprinting; Field/laboratory evaluation; Regeneration mostly under greenhouse conditions; Wide crossing; Embryo rescue; Molecular markers for the assessment of genetic diversity in cowpea and wild *Vigna*; Backcrossing; Modified recurrent selection; Rapid screening for drought and heat tolerance as well as root characteristics; Selection under inter-cropping 2. Pedigree and backcross breeding; Screening for strain variations in pathogens and host differentials 3. Modified recurrent selection, and pedigree methods; Selection under intercropping; Multilocation early generation testing 4. Determination of cooking qualities, seed coat colour and texture; Protein content in grains and quality of fodder evaluated 5. ELISA for virus detection; Molecular markers for *Striga* and drought tolerance identification 6. Randomised block design; Additive main effects and multiplicative interaction 7. Standard seed production methods; Private seed company given contract to multiply seed; Farmer to farmer seed diffusion
Faba bean	1. Identification of new genetic resources for Chocolate spot and ascochyta diseases; Artificial inoculation with pathogens under epiphytotic conditions, using misting system; Combined genes from different sources by crossing, selection, testing and re-crop crossing (recurrent selection); Crossing stress resistant sources with locally adapted lines, for building gene pools for resistance to biotic stresses; Honey bees used for inter-crossing within each target population (S_0) 2. Backcrosses 3. Mass and single plant selection within populations and crosses; Recurrent selection 4. On-farm test compared with the farmers variety (on the farmer field); Demonstration plants, in comparison with the farmer variety 5. Planting early in October for cold tolerance and exposed materials to artificial infection + planting early 6. Multilocation trials under the farmers' conditions 7. Breeder seed →Registered Seed →Foundation and certified seed
Groundnut	1. Diverse gene pool in genetic enhancement; Molecular tools for identification of diverse germplasm; Crossing and selection under hot spot locations for specific traits; Wide hybridisation; Tissue culture; Embryo rescue 2. Pedigree and backcross breeding; Mutation; SSD; transformation 3. Hybridisation followed by mass, bulk, pedigree and SSD selection; Complex crossing, selection and evaluation at hot spot locations; Intercrossing of segregants in early generations 4. Characterisation of advanced lines for seed quality traits; NMR for oil analysis: HPLC for fatty acid 5. Interspecific hybrids following hexaploid/amphidiploid routes/embryo rescue techniques; Monoclonal antibodies and PCR for aflatoxin and a range of viruses 6. Station trial; On-farm trials
Lentil	1. Collection in lentil growing and unexplored areas; Characterisation; Patterns of lens (wild &cultivated) biodiversity compared for morphology, isozyme, DNA marker; Evaluation under controlled conditions; Wide hybridisation; Mutation breeding; Inheritance study of traits of interest 2. Backcross breeding; Mutation breeding 3. Bulk-pedigree method of selection; Mutation breeding; Modified bulk method of selection; Decentralised breeding; Segregating populations to NARS 4. Seed, cooking, nutritional quality

Crop	Breeding methods by goal*
LEGUMES	
Lentil (cont.)	5. Screening in hot-spots; Artificial screening for combined resistance to multiple stresses 6. Testing of genotypes over year across locations; Use of suitable designs to capture experimental error and interaction variance; Targeted evaluation for specific environments 7. Government agencies; Contract farmers; Seed production unit
Pigeonpea	1. Pure line selection from germplasm; use of wild relatives; genetic purification through selfing; Suitable germplasm for particular environments 2. Pedigree; Backcrossing 3. Pedigree breeding; population improvement; hybrid breeding based on CMS 5. Screening germplasm and breeding populations in sick nursery 6. Station trials followed by multilocation trials 7. Isolation
Soybean	1. Germplasm introduction from existing institutions; Morphological characterisation; Field evaluation of genebank accessions for biotic and abiotic stresses; Laboratory tests to screen lines with high rates for germinating *Striga hermonthica* 2. Pedigree breeding method 3. Pedigree breeding method 4. Standard procedures 6. All field trials simulating farmers conditions of soil fertility and no use of insecticides or fungicides; Farmers evaluation of varieties 7. Conventional methods; Private seed company given contract to multiply seed
Forage legumes	1. Collection in unexplored areas and in specific environment; *In situ* conservation & characterisation; Hybridisation; Study of inheritance of desirable traits; Evaluation of wild relatives; Inter-specific hybridisation 2. Natural selection; Artificial mutation; Hybridisation 3. Hybridisation and selection; F_2-derived family-line mass selection 4. *In-vitro* lab test screening; *In-vivo* evaluation using small ruminants 5. Screening under hot spots; Screening under artificial conditions 6. Multilocation/years testing; Target environment for specific end-uses 7. Contract farmers; government agencies; Seed production unit
FORAGE GRASSES	
Brachiaria	1. Direct field collection of wild germplasm; Maintenance in semi-permanent field plots and as seed; Fingerprinting; Synthetic sexual populations; Upgrading of sexual population by mass selection on field performance (two sites) and bioassays 3. Recurrent mass selection; Bioassays for insect resistance and Al-tolerance; *In vitro* determination of forage digestibility 4. Assessment of animal performance in grazing trials; NIRS to determine forage digestibility 5. Assessment of animal performance in grazing trials; Reduced size of experimental unit in spittlebug bioassay; Refined *in vitro* bioassay for Al-tolerance; NIRS for measuring *in vitro* dry-matter digestibility in segregating populations 6. Multilocational field experiments 7. Field trials; Germination tests 8. Reproductive mode assessed in hybrid populations by cytological examination of embryo sacs and/or by progeny test; Open pollinated progeny assessment for uniformity by molecular markers being implemented

*Breeding goals:

1. Pre-breeding
2. Breeding for monogenic traits
3. Breeding for polygenic traits
4. End-use quality testing
5. Resistance diagnostics
6. Field performance
7. Seed production
8. Other

APPENDIX VI

BIOTECHNOLOGY METHODS USED AND DEVELOPED IN THE CGIAR CENTRES

Crop	Centre	Research and applications
Maize	CIMMYT	• Markers (SSR) for diversity studies and IPR purposes, for opaque 2 (improved nutritional quality); Single gene markers available for seed colour and certain level of herbicide resistance; Markers especially with non-radioactive detection: RFLPs, RAPDs, SSRs, AFLPs • MAS on experimental bases (insect resistance, drought tolerance, *Fusarium* ear rot, maize streak virus, *Striga*) • QTLs identified for low soil pH and Al toxicity tolerance, stem borer, fall armyworm, *Fusarium moniliforme*, downy mildew and *Striga* resistance; potential application for maize streak virus (MSV) • Linkage maps • Protocol for maize Bt and herbicide resistance • DNA chip and microarray technologies
Maize	IITA	• MAS for *Striga* in the pipeline
Rice	IRRI	• Anther culture for breeding and mapping; Embryo rescue; *In vitro* pollination, Ovary culture; Regeneration for transformation • Molecular markers for germplasm characterisation; FISH; RAPDs, STS markers • Markers (isozymes, RFLPs, AFLPs, STS) for development of genetic stocks; Markers available for wide-crossability genes and for quality; MAS kits for 2 gall midge resistance genes • Alien genes mapped (e.g. *Xa21*); Candidate genes • Genetic map for interspecific population; Molecular maps for salinity tolerance, P-deficiency tolerance, submergence, elongating ability; Cytogenic stocks for mapping; Mapping populations shared with NARS • Identified favourable *wild* species' QTLs; Identification and mapping of QTLs for orthologous loci governing agronomic traits • Transformation with *Agrobacterium* and biolistic methods; Transformation for Bt, resistance to bacterial blight • Novel genes, constructs and promoters (apomixis, methylation –resistant constitutive expression) • Transgenic seeds transferred to NARS • "Knockout" populations; Near isogenic lines (NILs), recombinant inbred lines (RILs); cDNA libraries; DH populations (isogenic lines and pyramids); *indica* BAC library
Rice	WARDA	• Another culture for fixation of interspecific hybrids; eliminating hybrid sterility; for QTL analysis • Microsatellites; CAPS marker for RYMV resistance; Fingerprinting for blast fungus; Tagging genes for traits contributing to dynamic plant architecture • Interspecific reference genetics map • QTLs for the useful traits from *Oryza. glaberrima*, for resistance • Work on transformation of RYMV
Rice	CIAT	• Anther culture; Embryo rescue; Regeneration from immature panicles and immature embryos; Somaclonal variation • Molecular characterisation of rice blast; Blast DNA fingerprinting • Public molecular maps available • Transformation with *Agrobacterium* and biolistic methods • RHBV resistance transformed; Also successful with *indica* rice varieties; Field testing depends on permission

Crop	Centre	Research and applications
Spring bread wheat	CIMMYT	• DH (maize system) for breeding, DHs being produced from key crosses; Embryo culture for transformation • Molecular characterisation (limited by cost) • Markers used (RFLPs, RAPDs, SSRs, AFLPs – especially with non-radioactive detection); MAS (SSR) used for BYDV; MAS for enhancing non-homologous recombination (*Ph1* gene) • Finalizing marker for high protein gene and for CCN; Sought for *Vrn/Ppd* development genes; Preliminary markers for resistance genes (leaf and stripe rust, *Fusarium* head scab, karnal bunt) • Linkage maps • Transformation protocol close to routine; Transgenic wheat containing fungal resistance, Basta herbicide resistance, resistance genes (Chitinase, Glucanase, ribosome-inactivating protein, Thaumatin-like proteins) • ESTs for wheat
Durum wheat	CIMMYT	• Testing DH system • Initiating MAS, QTL • Initiating transformation
Durum wheat	ICARDA	• Molecular markers for germplasm characterisation • Non-radioactive marker technologies developed (AFLP, RAPD, RFLP, SSR) • Identification of major genes under way; identification of QTLs
Barley	ICARDA	• DH for development of mapping populations • Fingerprinting for germplasm characterisation • Non-radioactive marker technologies developed (AFLP, RAPD, RFLP, SSR); Markers identified for cold tolerance, growth habit, scald, early growth vigour, plant height under drought stress, brittle rachis from *Hordeum spontaneum* • QTL analysis performed • Linkage mapping • Work on transformation system
Sorghum	ICRISAT	• Identification of molecular markers for *Striga* resistance • Identification of QTLs for mildew resistance
Pearl Millet	ICRISAT	• Markers for downy mildew resistance; genetic maps; primers; Work on markers for resistance gene pyramiding and drought tolerance; SSR markers being developed for pearl millet • Studies on QTLs for downy mildew, heat and drought tolerance, grain and stover yield components, ruminant nutritional quality in residues
Brachiaria	CIAT	• Regeneration from tissue culture • Molecular map being developed (based on RAPD, RFLP, AFLP, and SSR markers) • Molecular tag for apomixis gene • Identification of QTLs for insect resistance, Al tolerance and forage quality • Transformation technique developed; Work on resistance to spittle bug and increase content of soluble sugars

Crop	Centre	Research and applications
Cassava	CIAT	• *In vitro* culture for multiplication; Cryo-preservation • Genetic map developed, saturated map under work • Marker for Cassava mosaic disease CMD in Latin American cassava genepools; MAS for an African virus resistance under research • adjusting protocol for transformation: herbicide resistance, Bt, novel starch forms • BAC library
Cassava	IITA	• Micropropagation; Cryo-preservation being set up; Embryo culture; Certified ministake production system • DNA finger printing for molecular characterisation • PCR-based diagnostics design primers for virus detection at small scale • Saturated maps and linkage maps using SSR markers; tagging of genes for cassava mosaic disease, East African mosaic virus; application of virus specific primers and RFLP analysis; PCR-based diagnostics for Cassava mosaic virus • Work on QTLs (low cyanogenic potential, high storage root protein, root mealiness) • Adjusting protocols for transformation (*Agrobacterium*) for herbicide resistance, Bt, novel starch forms
Potato	CIP	• Hybrid clones; Dihaploids • Molecular characterisation of pathogen populations • Mapping populations produced; Candidate genes for potato late blight; Probes and primers corresponding to plant defence genes • Search for QTLs for resistance to potato late blight; Association of several mapped QTLs with known defence genes • Transformation efficiency needs improvement; work on selectable marker systems • Transformation for potato tuber moth resistance; work on bacterial wilt resistance • *Rxadg* and *Rxacl* genes cloned • BAC library containing Rysto gene
Sweet potato	CIP	• Meristem culture; Micropropagation • Markers (RAPD, AFLP, SSR); fingerprinting • Genetic linkage map produced • Tagging single/oligogenes; Tagging QTLs • Success in transformation with weevil resistance (soybean proteinase inhibitor); Safety testing needed; Search for appropriate Bt gene
Yam	IITA	• Cryo-preservation under study; Micropropagation; Immature seed culture; Regeneration studies • DNA finger printing; Molecular markers developed; PCR primers as diagnostic tools for characterising viruses • Molecular map being constructed

Crop	Centre	Research and applications
Musa	IITA	• Micropropagation; Embryo rescue • Diagnostic tools for viral diseases (polyclonal and monoclonal antibodies, PCR primers etc.) • Markers (RAPD for A and B genomes, RFLP, SSR) • Markers sought for parthenocarpy, apical dominance, resistance to black Sigatoka, nematodes, fruit quality • Biotechnology for study of the expression of viral sequences in the host genome and for development of disease diagnostics • Transformation protocol established, resistance to fungal diseases transferred
Musa	INIBAP	• Shoot apex culture; Cell suspension; Somatic embryogenesis; Cryo-preservation • RAPD, SSR, cDNA, STMS • FISH, fiber-FISH, PRINS • *Agrobacterium*-mediated transformation method developed; specific promoter identified for *Musa*
Coconut	INIBAP	• Micropropagation • Molecular markers for diversity studies and characterisation; Microsatellite primers • Initial work on genome mapping
Beans	CIAT	• RAPD, AFLP for characterisation • Preliminary genetic map ready • New SCAR (work on disease resistance and nitrogen fixation genes) and microsatellite markers; MAS for major viral resistance gene; Genomic and cDNA microsatellites being developed • QTL analysis combined with SSR markers for pre-breeding; QTL for many traits (P uptake, mineral content); Flanking markers used for MAS of QTLs and other important genomic regions; QTLs for selecting parental lines from RIL • Transformation under development • Gene tagging from other *spp.* to facilitate gene transfer
Forage vetches	ICARDA	• Somaclones low on neurotoxin • DNA finger printing; molecular markers for germplasm characterisation • Initial map published; Saturated map under work; Marker identification initiated (drought, *Striga*)
Cowpea	IITA	• Fingerprinting; Molecular markers for assessment of genetic diversity of cowpea and wild *Vigna* • Initial map published; Saturated map under work • Marker identification initiated (drought, *Striga*) • DNA markers associated with QTLs identified • Transformation system being developed

Crop	Centre	Research and applications
Chickpea	ICARDA	• Embryo and ovule rescue for interspecific hybrids; Tissue culture • Fingerprinting • STMS markers developed; Marker-trait linkages for fusarium wilt, work on *Ascochyta* blight; linkage map available (RAPD, DAF, AFLPs, STMS, isozymes) • Transformation system available, target *Ascochyta* blight
Chickpea	ICRISAT	• Embryo culture • Molecular markers for diversity analysis • Preliminary, reasonably-saturated, marker-based chickpea linkage map developed • Transformation protocol available
Groundnut	ICRISAT	• Tissue culture; embryo rescue • RFLP and some SSR markers and a skeleton molecular map available; Diseases resistant genes, and markers (RAPD) linked with resistance identified; SSR and AFLP markers specific to groundnut identified • Transformation employed for Indian peanut clump virus and groundnut rosette virus; materials evaluated in containment facilities
Lentil	ICARDA	• DNA markers for germplasm characterisation; Fingerprinting of fusarium wilt isolates • Non-radioactive marker technologies developed (AFLP, RAPD); STMS under way; Marker-trait linkages for fusarium wilt and radiation frost tolerance; linkage map (RAPD, AFLP, RFLP, isozymes) • Transformation system in place, target *Sitona ssp.*, later broomrape
Pigeonpea	ICRISAT	• Work elsewhere on markers and linkage maps • Transformation protocol, particularly regeneration under investigation

RESOURCE COMMITMENTS FOR PLANT BREEDING AND *BIOTECHNOLOGY IN 1999*

Table 1: Resource Commitments for Plant Breeding and Biotechnology in 1999 by Centre (US$ '000)

	CIAT	CIMMYT	CIP	ICARDA	ICRISAT	IITA	IPGRI/ INIBAP	IRRI	WARDA	Total
Biotechnology[1]	1,324	3,280	1,469	928	698	1,997	853[2]	2,630	640	13,819
Crop improvement[3]	8,270	10,500	5,450	4,900	5,000	9,760	2,600[4]	11,440	2,500	60,420
Professional staff years in biotechnology	12	42	14	15	8	10	2	38	3	144
Professional staff years in crop improvement	14	84	46	50	24	19	2	63	7	309

[1] Including salaries and running costs, excluding overhead and capital costs for research, development and applications.
[2] *Musa* and coconut only.
[3] Source: Centre Medium-Term Plans 2001-2003: 1999 actuals (including overhead) for crop improvement output.
[4] Including all IPGRI activities for crop improvement.

Table 2: Resource Commitments by Biotechnology Activity in 1999 by Centre (US$ '000)

Biotechnology Activity	CIAT	CIMMYT	CIP	ICARDA	ICRISAT	IITA	IPGRI/ INIBAP[1]	IRRI	WARDA	Total
1. Tissue culture (somaclonal variation, embryo rescue, haploids, micropropagation)	125	164	133	140	94	186	-	118	178	1,138
2. Tissue culture (protoplast culture and fusion)	-	-	-	10	-	-	469	56	-	535
3. DNA Fingerprinting	163	492	-	100	27	196	-	117	330	1,425
4. Marker identification and MAS	330	820	449	300	193	919	55	791	-	3,857
5. Gene sequencing	133	492	124	95	-	21	-	304	-	1,169
6. Genetic engineering	225	820	703	105	95	209	329	504	-	2,990
7. Diagnostics	205	164	-	10	201	230	-	196	-	1,006
8. Networks and training	143	328	60	168	-	104	-	354	132	1,289
9. Other	-	-	-	-	88	132	-	190	-	410
Total Centre	1,324	3,280	1,469	928	698	1,997	853	2,630	640	13,819

[1] *Musa* and coconut only.

Table 3: Capital Investments in Biotechnology by Centre 1995-2000 (US$ '000)

Centre	1995	1996	1997	1998	1999	2000[1]
CIAT	100	160	100	150	460	100
CIMMYT	115	28	76	345	175	124
CIP	42	85	62	50	519	800[2]
ICARDA	30	50	100	75	95	na
ICRISAT		3	47	15	43	674
IITA	50	75	27	10	54	50
IRRI[3]	150	180	190	235	260	na
WARDA	45	60	180	120	120	80
Total	532	641	782	1,000	1,726	...

[1] Estimate.
[2] 2000/2001 including a new biosafety facility.
[3] In addition IRRI capital investment in facilities 1995-99 US$ 2 million.
na = not available

Table 4: Value of Outsourcing in 1999 by Centre (US$ '000)

Centre	Crop	Value of Outsourcing
CIAT	Bean	74
	Cassava	13
	Rice	191
CIP	Potato	380
	Sweetpotato	42
ICARDA	Barley	130
	Wheat	110
	Chickpea	220
	Lentil	42
IITA	Cowpea	10
	Yams	54
	Musa	3
INIBAP	*Musa*	669
	Coconut	10
WARDA	Rice	141
Total outsourcing		2,089
Total biotechnology		13,819
Total crop improvement[1]		60,420

[1]Source: Centre MTPs 2001-2003: 1999 actuals (including overhead) for crop improvement output.

CGIAR-NARS INTERACTIONS IN PLANT BREEDING AND BIOTECHNOLOGY

by Derek Byerlee

A diversity of NARS

Plant breeding capacity varies greatly among NARS. Table 1 presents a highly simplified view of differences in capacity, divided into three broad groups[10]:

1. Type I NARS which consist of the advanced group, usually including India, China and Brazil for most crops, and a few other NARS depending on the crop, where capacity in applied and some strategic research is strong and often better in specific areas than that in the IARCs;
2. Type II NARS which are a group with considerable capacity in applied plant breeding research, although upstream research capacity is limited;
3. A large group of Type III NARS, with very fragile capacities, and that for the moment, depend largely on introduction and testing of varieties from abroad, especially from the CGIAR System.

Collectively NARS spend substantially on plant breeding. In the case of wheat breeding, for example, NARS, excluding China, employ over 1000 scientists and spend more than four times that in the IARCs. However, operating costs are often a major problem.

The diversity in NARS with respect to biotechnology capacity is even greater than for conventional breeding. NARS invest 5-10% of their total research expenditures in biotechnology—a share that is similar to the CGIAR System. In aggregate NARS' investment in biotechnology is several times that of the CGIAR but most of this is concentrated in Type I and a few Type II NARS. Type I NARS have strong capacity in molecular biology including capacity to develop new tools for their own specific needs. Most Type II also have capacity to apply molecular tools (markers and transformation protocols), although they depend on tools developed elsewhere. Most Type I and II NARS also have instituted a regulatory framework for testing of transgenic crops and to protect intellectual property, although capacity to evaluate risks and to manage intellectual property is inadequate. Type III NARS do not have capacity in molecular biology and most do not have a regulatory framework in place to even import and test transgenic products.

A similar diversity also exists with respect to private R&D investments in plant breeding which is growing rapidly in Type I and II NARS. The private sector already plays a lead role in research on hybrid crops such as maize, and is increasingly poised to assume research on self-pollinated crops such as wheat and rice for commercial farmers in developing countries.

[10] A fourth group not discussed here are the NARS in transition in the former Soviet Union. These NARS are often strong relative to their size in human resources and scientific quality, but institutional capacity to organize, fund and deliver final products to farmers is quite weak.

Table 1. Summary of Breeding and Biotechnology Capacities of Different NARS Types

	Type 1 NARS-- Very strong	*Type 2 NARS— Medium to strong*	*Type 3 NARS-- Fragile or weak*
Markets size	Large to very large	Medium to large	Small to medium
Plant breeding	Strong national commodity programs with comprehensive breeding programs, including some pre-breeding.	National commodity programs that are generally strong in applied breeding.	Usually small and fragile programs with success dependent on one or two individuals. Usually conduct own crosses although value added of local adaptation often low due to small market size.
Use of IARC materials	Used as parents to obtain specific traits for breeding and pre-breeding, and sometimes released directly. Also use early generation materials.	Very important as parents, and also as direct releases.	Mostly direct releases after local screening and testing.
Basic and strategic research	Often considerable capacity that can match that in IARCs.	May have capacity in specific areas.	No capacity.
Private sector	Private sector very active for hybrid crops and increasingly for non-hybrid commercial crops.	Private sector activity increasing and usually involved in hybrid crops.	Little private sector activity for food crops.
Biotechnology research	Capacity in molecular biology as great or greater than most IARCs. Marker assisted selection being incorporated into breeding programs. Considerable research on transgenics.	Usually developing capacity in molecular biology but with considerable support from donors and IARCs.	Very little capacity in molecular biology although many have capacity in tissue culture.
Regulatory framework for biosafety and IPR	Framework in place although capacity to implement is modest and untried.	Most countries have, or soon will have framework, but weak capacity to implement.	Most countries do not have regulatory framework.

These differences among NARS in capacities require very different strategies for IARCs. IRRI, for example, largely deals with Type I and II NARS in Asia, most of which have strong plant breeding programs and substantial capacity in rice biotechnology research. As a result strong collaborative partnerships in both breeding and biotechnology have been developed. IITA and WARDA on the other hand, largely deal with Type III NARS, which have no capacity in molecular biology and many do not have a breeding program for some crops. Other centres, such as CIMMYT, are challenged to work with the full range of NARS, requiring the development of a range of products to serve their diverse needs. For many of the so-called orphan crops that are included in the CGIAR mandate, there are no Type I NARS and few Type II programmes. For example, only four countries of the 60 where cowpeas are produced have a cowpea breeding program.

Plant breeding as an institutionalized success story of CGIAR-NARS collaboration

The CGIAR provides a range of products to NARS including intermediate and finished germplasm products, tools and methods for application in breeding and associated biotechnology programs, and short- and long-term training. Plant breeding research, defined to include associated efforts of other plant scientists that produce new cultivars, represents an institutionalized success story of CGIAR-NARS collaboration over the past three decades.

The IARCs have provided strategic support to Type I and II national breeding programs through the supply of advanced genetic materials, often with specific traits, such as pest resistance, which require intensive breeding efforts. These lines have served as parents in local crossing programs and have often been directly released as final products, greatly reducing the cost to NARS programs of developing and releasing improved varieties. Type III NARS have largely tested and released varieties from abroad, with IARCs as the primary source. Overall, it is estimated that for each dollar spent by the CGIAR in breeding, NARS spend three dollars in testing and release of CGIAR products, suggesting a highly integrated system (Maredia and Byerlee, 1999).

Institutional innovations in the form of nationally coordinated commodity research programs and international nurseries and networks to exchange germplasm have provided an integrated approach to highly focused crop-improvement work. Free access by NARS to a wide range of germplasm resources and finished varieties from outside the country has been a major factor in this success. These same national coordinated programs have provided a natural partner for equivalent commodity programs in the CGIAR system. Once overlapping mandates of IARCs in some commodity programs were resolved; these systems have functioned well and evolved into strong international and regional networks, with relatively low transaction costs. Some IARCs have also built close links with the private sector, especially in hybrid crops, which has greatly facilitated the uptake of their products.

All IARCs have established strong germplasm networks for testing and delivering their germplasm products, and for exchange of germplasm among NARS. In most cases, the relevant IARC sits at the hub of the network and still manages its activities. For most crops, regional germplasm networks managed by regional research associations have also assumed an important role in germplasm exchange and use of IARC products, although some of these have not been sustained.

The management of some of these networks, such as INGER for rice, is being assumed by the member NARSs, with the IARC as one member of the steering group for the network. NARS ownership is most advanced for the irrigated rice and cassava networks in Latin America (FLAR and CLAYUCA), where NARS not only manage the network but finance and carry out applied breeding through the network with each country contributing in proportion to their share in production.[11] The private sector participates in, and contributes to these networks. CIAT research complements these networks by supporting upstream research on rice, but does not carry out applied breeding research to produce finished varieties.

Many other collaborative research mechanisms exists, including shuttle breeding programs (various wheat diseases), consortia of NARS and IARCs to carry out an integrated research problem on a major problem (various rice ecologies in Asia), and competitive grants programs for funding specific research activities within NARS of regional interest (maize in West Africa).

Emerging IARC-NARS interactions in biotechnology

Although interaction in biotechnology research is more recent, there are a number of ongoing interactions in biotechnology. Several centres have set up collaborative networks for biotechnology to enhance capacity building in NARS and foster collaborative efforts. The Asian Rice Biotechnology Network (ARBN) established with Asian Development Bank (ADB) support in 1993, and now involving 13 institutes in 6 countries with IRRI at the hub, is the most advanced of these. IRRI through ARBN fosters collaborative research and provides training to NARS scientists in the use of molecular markers and other tools. In 1998, a similar network for maize, the Asian Maize Biotechnology Network (AMBIONET) was established through CIMMYT with support from the ADB. AMBIONET shares technologies, promotes communication, and provides training in use of molecular markers. Finally, a cassava biotechnology network for Latin America is currently being established.

NARS also participate in wider biotechnology networks involving the IARCs and ARIs. For example, some NARS are participating in the collaborative research on molecular genotyping through the Integrated International Molecular Breeding Programme, and China and India participate in the Global Rice Genome Collaborative Program.

IARCs also provide training for NARS scientists, both through offering opportunities to visiting scientists to work in their laboratories, and through formal training courses. In addition, ISNAR has a special International Biotechnology Service for capacity building through training and technical advice.

[11] In the case of rice, commercial farmers provide a considerable share of the funds through a levy on rice output in the member countries

Emerging issues in CGIAR-NARS interaction

Although CGIAR-NARS interaction in plant breeding has been highly successful, a number of trends are critically affecting the relevance of past models:

- Increasingly pluralistic public NARS with greater participation of universities and general scientific organizations, requiring that IARCs seek more diverse partnerships than in the past. Biotechnology capacity in NARS, for example, is often located in university faculties of science, or specialized science and technology institutes.
- The growth in the private sector in applied breeding in many NARS that will require that the public sector and IARCs redefine their role in applied breeding, and make strategic decisions about the clients that they will target.
- Growing restrictions on the free exchange of germplasm among breeding programs due to the implementation of plant varietal rights (PVRs) and/or patenting for biological processes, efforts by public organizations to off-set funding shortfalls through royalties and license fees for their products, and increasing national restrictions on export of germplasm resources[12]. Germplasm is increasingly seen by the public sector, both national and international, as a bargaining chip for accessing proprietary technologies from the private sector, and/or a source of revenue to offset funding shortfalls. However, few public sector NARS have capacity to manage intellectual property and negotiate access and exchange of materials with the private sector.
- Controversy and negative public perceptions on transgenics that will greatly increase the costs of introducing new germplasm products based on transgenics, combined with lack of capacity in most NARS to evaluate risks, and engage in participatory dialogue with producers and consumers regarding the risks and benefits of the new technologies.
- The difficulty of most IARCs to support long-term core breeding activities, given declining real budgets and the shift from core funding to project funding. This is leading to trade-offs in supplying finished varieties versus increasing strengths in upstream research activities, that supply intermediate products, tools, and knowledge.

Issues and recommendations for future IARC-NARS interactions

Maintaining core breeding capacity

A consistent theme across the centres is that core-breeding activities are being threatened by budget cuts, especially the development of finished varieties which are critical to weaker NARS. Budget cuts have been especially critical in the training and outreach activities with NARS to support germplasm evaluation and varietal release of IARC materials. Meanwhile many NARS, especially Type III NARS that use finished IARC products, are facing acute resource constraints, and it is unlikely that they will be able to take on more of their own breeding in the foreseeable future. Together these trends are likely to slow utilisation and uptake of IARC materials. Regional networks may fill part of the gap, but IARCs serving these NARS, especially in Africa, must be provided sufficient resources to maintain core-breeding programs.

[12] Thirty-five countries now have restrictions on germplasm exports (Thornström, 1999).

It is recommended that the CGIAR give priority to the following investments to ensure continued flow of germplasm products to farmers:

1. Maintenance of core breeding activities in centres to serve the smaller and weaker NARS, and support to building capacity of NARS and regional plant breeding programs, especially in Africa;
2. Exploration of additional opportunities to finance and execute applied breeding through regional consortia of public and private organizations along the lines of FLAR and CLAYUCA in Latin America, and;
3. Exploration of opportunities to outsource applied plant breeding to stronger NARS.

Development of wider NARS partnerships for plant breeding and biotechnology

Although IARCs are slowly broadening NARS partnerships to embrace universities, NGOs, and the private sector, the bulk of the effort continues to be with national research institutes. In participatory research, the major partners are likely to be NGOs, while in biotechnology, the best capacity is often in universities and general science research institutes. The IARCs should accelerate efforts to diversify their partnerships with NARS, especially in biotechnology.

Capacity building in biotechnology research

Most centres have some focused training programs for NARS in biotechnology tools, especially molecular markers. It is recommended that resources continue to be invested to train NARS scientists, but more effort be made to train breeders who are often unfamiliar with the new tools. Use of IARC developed tools in NARS can increase the payoffs to IARC efforts to develop these tools, since benefits will be spread beyond their application in the IARC breeding program. A good example, is the development of diagnostic tools for RYMV by WARDA which is now being passed to NARS, and the development of molecular markers for bacterial blight in rice in Asia which are being applied by several NARS.

Capacity building in regulatory framework

To date IARCs have provided little support to capacity building in biosafety and management of intellectual property. Although most IARCs are developing transgenics, the strategy for deployment of these products is often not well developed for a number of reasons:

- Lack of an appropriate regulatory framework in client countries for the testing and release of transgenics;
- Lack of capacity in countries to carry out risk assessment, even where a regulatory framework is in place;
- Use of proprietary tools and technologies and lack of capacity and resources in NARS to negotiate access to intellectual property;
- Lack of capacity in NARS to manage the public dialogue with respect to release of transgenics.

Some centres have worked with NARS to promote, strengthen and harmonize regulatory frameworks, and this is becoming increasingly important as finished transgenic products are developed. For example, ICARDA has worked with NARS in the region to harmonize biosafety regulations and all centres have provided support to their host country. However, it is clear NARS must take the lead in efforts to release transgenics and IARCs will have to devote more resources to development of capacity in these critical areas if transgenics are to be successfully deployed. Capacity building in public awareness activities at all levels, including policy makers, must also be part of these efforts. Costs of these activities will be initially high, but should fall as NARS' capacity increases. IARCs should develop partnerships with other centres and with donors to strengthen capacity in biosafety regulation and public dialogue in biotechnology. It is recommended that the CGIAR provide special funds for supporting IARC-NARS joint efforts to test technologies that have high potential to provide benefits for poor producers and consumers.

Collaboration and participatory priority setting for biotechnology

Much of the early work by IARCs in biotechnology has been quite supply driven, and there was little evidence that NARS had been fully consulted on priorities for tool and product development. Since NARS will have to shoulder the major responsibility for introduction of these products, and will increasingly be full collaborators in their development, high priority should be given to participatory processes for jointly setting the biotechnology research agenda, to ensure that IARC and NARS research agendas are complementary and that NARS develop a sense of ownership of the emerging products and tools from IARCs.

Intellectual property rights

Much discussion is needed to develop options for managing IPR between IARCs and NARS. In some cases, IARCs have negotiated IPR for research and commercialisation of proprietary tools and products in developing countries or at least in a subset of them. In other cases, IARCs have negotiated freedom to operate for research only, but it is not clear how products derived from these proprietary tools will be commercialized. Also IARCs are increasingly patenting their own technologies to use as bargaining chips with the private sector. Several models are possible for products from IARCs in which third parties hold IP interests (Fischer, 2000):

- The IARC negotiates the IPRs for commercialisation, on behalf of the NARS;
- Individual NARS negotiate the IPR for commercialisation; or
- A consortium of NARS negotiates the IPR, through a legal entity set up by the NARS in a region, on behalf of the member NARS. Regional networks such as ARBN might eventually assume this responsibility on behalf of NARS. For products developed by IARCs, various options for IP management are also possible;
- The IARCs might take out a defensive patent and make the product freely available;
- The NARS or a consortium of NARS hold patents on behalf of the IARCs, and license as appropriate to other public and private organizations;
- The IARCs grant the private sector in a country exclusive rights on approval by the country.

Some of the networks such as ARBN are already discussing these issues, but much more dialogue will be required. IARCs are also increasingly developing agreements with the private sector to use or exchange proprietary technologies. A number of actions are recommended to strengthen CGIAR-NARS understanding with respect to IP:

- IARCs develop a transparent communication system to inform all stakeholders, and especially NARS, of the specific of agreements that it reaches with the private sector for accessing proprietary materials, and;
- Each IARC holds a series of workshops with NARS to clearly explain the IPR status of its tools and technologies, and discuss with NARS various options for making these tools and technologies, and products derived from them, available to client countries;
- Crop-oriented IARCs work with ISNAR to strengthen training of NARS policy makers and scientists in IP issues.

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GLOSSARY OF ACRONYMS

ARBN	Asian Rice Biotechnology Network
AFLP	Amplified Fragment Length Polymorphism
AMMI	Additive Main Effects and Multiplicative Interaction
ARI	Advanced Research Institute
BAC	Bacterial Artificial Chromosome
BC	Backcross
Bt-genes	Insect resistance genes originating from *Bacillus thuringiensis*
BW	Bacterial Wilt
BYDV	Barley Yellow Dwarf Virus
CAMBIA	Centre for the Application of Molecular Biology to International Agriculture
CAPS	Cleaved Amplified Polymorphic Sequences
CAS	Central Advisory Service on Proprietary Science
CCD	Cereal Cyst Nematode
CBD	Convention on Biodiversity
cDNA	Complementary DNA
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CIP	Centro Internacional de la Papa
CLAYUCA	Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y Desarrollo de la Yuca
CMD	Cassava Mosaic Disease
CMS	Cytoplasmic Male Sterility
DAF	DNA Amplification Fingerprinting
DH	Doubled Haploid
DNA	Deoxyribonucleic Acid
EARRNET	Eastern African Roots Research Network
ELISA	Enzyme-Linked Immunosorbent Assay
EPMR	External Programme and Management Review
EST	Expressed Sequence Tag
FHIA	Fundación Hondureña de Investigación Agrícola
FISH	Fluorescence *In Situ* Hybridisation
FLAR	Fund for Latin American and Caribbean Irrigated Rice
GCA	General Combining Ability
GISS	Geographical Information Systems
GPS	Geographical Positioning Systems
GxE	Genotype x Environment interaction
HMW	High Molecular Weight
HPLC	High Performance Liquid Chromatography
IARC	International Agricultural Research Centre
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICIS	International Crop Information System
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IGM	Integrated Gene Management
IITA	International Institute of Tropical Agriculture

ILRI	International Livestock Research Institute
INGER	International Network for Genetic Evaluation of Rice
INIBAP	International Network for the Improvement of Banana and Plantain
IP	Intellectual Property
IPR	Intellectual Property Rights
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
IWIS	International Wheat Information System
KUL	Katholieke Universiteit Leuven (Catholic University of Leuven hosting The International Tropical Crop Improvement Laboratory)
LB	Late Blight
LMW	Low Molecular Weight
MAS	Marker-Assisted Selection; Marker-Aided Selection
MSV	Maize Streak Virus
MTM	Mid-Term Meeting
NARI	National Agricultural Research Institute
NARS	National Agricultural Research Systems
NGO	Non-Governmental Organization
NIL	Near Isogenic Line
NIRS	Near Infrared Diffuse Reflectance Spectroscopy
NMR	Nuclear Magnetic Resonance
NPT	New Plant Type
PCR	Polymerase Chain Reaction
PGMS	Photo-Sensitive Genic Male Sterility
PGRA	Systemwide Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation
PLRV	Potato Leafroll Virus
PPB	Participatory Plant Breeding
PRA	Pest Risk Analysis
PRINS	Primed *In Situ*
PROFRIJOL	Programa Cooperativo Regional de Frijol de Centroamérica, México y el Caribe
PROFRIZA	Proyecto Regional de Frijol para la Zona Andina
PRO*Musa*	The Global Program for *Musa* Improvement
PVP	Plant Variety Protection
PVS	Participatory Variety Selection
PVX	Potato Virus X
PVY	Potato Virus Y
QTL	Quantitative Trait Loci
R&D	Research and Development
RAPD	Randomly Amplified Polymorphic DNA
REML	Residual Maximum Likelihood
RFLP	Restriction Fragment Length Polymorphism
RGA	Rapid Generation Advance
RHBV	Rice Hoja Blanca Virus
RKN	Root Knot Nematode
RIL	Recombinant Inbred Line
RYMV	Rice Yellow Mottle Virus
SARRNET	Southern Africa Root Crop Research Network
SAS	Statistical Analysis System

SCA	Specific Combining Ability
SCAR	Sequenced Characterised Amplified Region
SDS	Sodium Dodecyl Sulfate
SINGER	Systemwide Information Network for Genetic Resources
SNP	Single Nucleotide Polymorphism
SRP	System Review Panel
SSD	Single Seed Descent
SSR	Simple Sequence Repeat
STMS	Sequence-Tagged Microsatellite Site
STS	Sequence Tagged Site
TAC	Technical Advisory Committee
TGMS	Thermosensitive Genic Male Sterility
TPS	True Potato Seed
USDA	United States Department of Agriculture
WARDA	West Africa Rice Development Association