Consultative Group on International Agricultural Research

Technical Advisory Committee

Report on the

Inter-Centre Review of

Root and Tuber Crops Research

in the CGIAR

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

This report comprises:

(a) Extract from "Summary of Proceedings and Decisions", Mid-Term Meeting 1996, Jakarta, 20-24 May 1996

(b) Letter from TAC Chairman transmitting the Report on the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR

(c) TAC Commentary on the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR

(d) Transmittal Letter from Panel Chairman to TAC Chairman

(e) Report on the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

June 1997

From: The Secretariat July 1996

Mid-Term Meeting 1996
May 20-24, 1996
Jakarta, Indonesia

Inter-Centre Review of Root and Tuber Crops[1]

The similarities and dissimilarities among root and tuber crops were noted by participants, and the lack of available production and consumption data was recognized as a constraint. The long-term potential of root and tuber crops, including sweet potato, was affirmed, as was their importance as staple crops in developing countries. TAC's recommendation to continue current investments on root and tuber crops was endorsed. It was agreed that an inter-centre consultative committee, already formed by the Centres concerned, could be a useful mechanism to facilitate cooperation, and that such a consultation process should involve NARS.

It was felt that there were opportunities for collaboration both among Centres and with other institutions outside of the CGIAR - for example, with AVRDC on sweet potato - which should be explored further to build on the complementarities which exist among the crops. However, the cost of collaboration should be kept in mind, and every effort made to collaborate through efficient and cost-effective means.

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1 Extract from "Summary of Proceedings and Decisions - Report on Parallel Session I", Mid-Term Meeting 1996, Jakarta, Indonesia.

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CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

Donald L. Winkelmann
Chair

15 April 1996

Dear Mr. Serageldin,

I am pleased to submit to you the report of the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR. The report has been prepared by an external Panel led by Dr. David MacKenzie. Accompanying the report is the TAC Commentary which was prepared at TAC 68 in December 1995 when the Committee discussed the report.

The review was commissioned by TAC to provide an input into the current deliberations on priorities and strategies. The review was timed so that it could draw on experiences gained from the external reviews of CIP, CIAT and IITA, the three CGIAR centres engaged in root and tuber crops research. The Panel is commended for employing a participatory workshop forum which was attended by representatives of five CGIAR Centres (CIP, CIAT, IITA, IPGRI and IFPRI), and outside specialists to identify key issues of importance to root and tuber crops research in the CGIAR.

The main outcome of the review has been the identification of the main issues relevant to priority setting, and to Systemwide planning, coordination and operations which would further improve coherence of CGIAR's research on root and tuber crops, and make greater use of complementarities among the three Centres concerned. In this regard, one of the recommendations is the formation of an informal Inter-Centre Committee on Root and Tuber Crops Research, and TAC is pleased to note that the three Centres have taken prompt action to set up such a committee to address the terms of reference proposed by the Panel.

I wish to draw your attention to the TAC commentary which has been offered to facilitate follow-up action on future inter-centre collaboration, including the development of a Systemwide strategy for root and tuber crops research, and of research partnership with NARS, advanced research institutions, and private sector on postharvest technology and market research needs.

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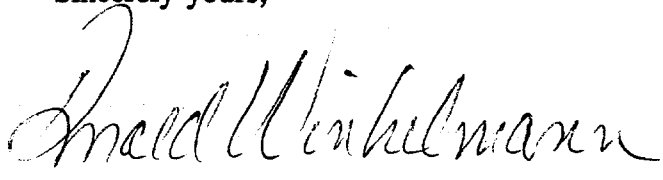
The review has pointed out the need for the three centres concerned with root and tuber crops research to engage in pre-extension technology transfer activities aimed at overcoming constraints to the dissemination of improved cultivars. TAC is of the opinion that the Centres are aware of the need to engage in such technology transfer activities, but cautions the centres not to become a provider of technical assistance for which there exist more effective international and national development agencies.

I commend the report to you and the Group. The views of the Group will be taken carefully into account in finalizing the recommendations on future strategic directions of the CGIAR's work in this area.

I would like to express sincere thanks to the Panel for the participatory and cost-effective manner by which it conducted the review. I also wish to acknowledge the cooperation that was extended to the Panel by the CGIAR Centres, and by the Chairmen of the external reviews of CIP, CIAT and IITA. Finally, I would like to express the Committee's appreciation to the TAC Secretariat for providing its full support to the Panel.

Sincerely yours,



Donald L. Winkelmann

TAC COMMENTARY ON THE INTER-CENTRE REVIEW OF ROOT AND TUBER CROPS RESEARCH IN THE CGIAR

TAC extends its appreciation to the Chairman, Dr. David MacKenzie, and members of the panel for their report. The panel completed its work within a tight time schedule and was able to draw on experiences gained from the external reviews of CIP, CIAT and IITA. The panel is commended for employing a participatory workshop forum which was attended by representatives of five centres (CIP, CIAT, IITA, IPGRI and IFPRI), and outside specialists to identify key issues of importance to root and tuber crops research in the CGIAR.

TAC considers that despite the unforeseen difficulty encountered by the panel due to the lack of generally accepted production and consumption data, the panel has done a commendable job of identifying issues relevant to priority setting, and to Systemwide planning, coordination and operations.

TAC offers the following comments to bring this review to a close, and to facilitate the follow-up action on future inter-centre collaboration as well as on TAC's work on research priorities and strategies for root and tuber crops.

Inter-Centre Committee on Root and Tuber Crops Research. The external reviews of CIP, CIAT, and IITA highlighted the positive history of collaboration among the centres, and the benefits and recognitions that have been derived from such collaboration. TAC therefore welcomes any move which would further improve the coherence of CGIAR's research on root and tuber crops, and make greater use of complementarities among the three centres concerned. TAC supports the panel's recommendation that an informal Inter-Centre Committee on Root and Tuber Crops Research be formed provided that the centres remain convinced that it adds value to root and tuber crops research in the CGIAR. TAC notes that the centres are in agreement with the recommendation and the proposed terms of reference, and considers that the Inter-Centre Committee mechanism should certainly be tried out and a genuine effort made for it to work effectively.

TAC notes the recommended agenda of work for the Inter-Centre Committee, including the development of a Systemwide strategy for root and tuber crops research. TAC looks forward to receiving reports of the recommended studies and inquiries under the aegis of the Inter-Centre Committee, and will see their effects through the normal process of annual programme and budget submissions, centre-commissioned external reviews, and external programme and management reviews.

Postharvest Technology. TAC agrees with the panel that the pattern of consumption can be altered (e.g., via price effects) through the development of new technologies in areas such as food processing. TAC considers that the recommendation regarding partnership with AROs, NARS and the private sector on the characterization of starch and flour, on food processing technology and on market research needs to be followed up through the proposed postharvest technology and market working group. TAC requests the relevant centres to interact with the broader TAC study currently being conducted on postharvest technology research in the CGIAR.

Research Partnership with the Private Sector. TAC concurs with the panel that considerable opportunity exists for the development of improved cultivars for processing and for new products based on genetically-enhanced root and tuber quality and storage potential. As the panel points out, this is not a trivial consideration, but one that demands considerable evaluation, analysis and strategy. Moreover, it is likely to require strong cooperation between the public and private sector, while at the same time the protection of the intellectual property rights of the CGIAR's investments. The committee therefore endorses the spirit of the recommendation to encourage more private sector research partnerships, and requests that the recommendation be considered by the CGIAR Private Sector Committee, as well as by the broader TAC study on postharvest technology research.

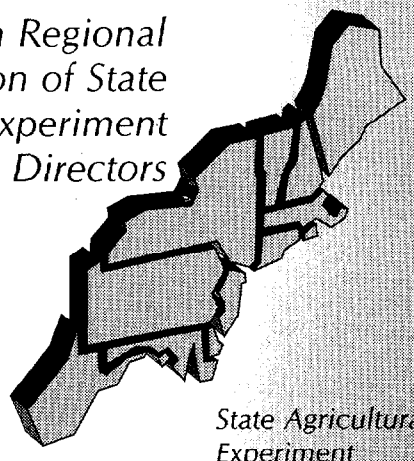
Technology Transfer Activities. TAC considers that there is a convincing case for the three centres concerned with root and tuber crops research to engage in technology transfer activities aimed at overcoming constraints to the dissemination of improved cultivars. The external reviews of CIP, CIAT and IITA have shown that such activities are needed before extension can proceed, and cannot be supplied by other sources. TAC is of the opinion that the three centres concerned are aware of the need to engage in such technology transfer activities, but would caution the centres not to become a provider of technical assistance for which there exist more effective international and national development agencies.

Passing the CGIAR Sweet Potato Programme to a Strong NARS. TAC considers that the six guideline criteria provided by the review to judge the merits and demerits of passing a particular research programme or activity to a NARS are sound and useful but incomplete (e.g., whether national systems should be expected to use national funds to generate international public goods). Moreover, the criteria apply in the context of seeking new partnerships rather than seeking alternative suppliers, and there are additional considerations such as cost efficiencies, funding availability, geographical priorities, etc. that must be taken into account before a firm decision can be reached. Nonetheless, in the case of sweet potato, CIP should continue to explore opportunities for strategic partnerships with the Chinese Agricultural Research System, based on the proposed criteria and other considerations. Such a partnership, if successful, might permit a reduction in the commitment of CIP to sweet potato research.

Biotechnology. TAC considers that the use of advanced biotechnology research on potato is currently well developed in AROs, and care needs to be taken not to duplicate this research. The Committee considers that within the CGIAR the development of technologies for safe and economically viable vegetative propagation, especially for cassava, is an important area for inter-centre cooperation.

Data. The review has highlighted the need for generally accepted data to assist in setting future priorities for root and tuber crops. This deficiency needs to be put right and TAC would request the Inter-Centre Committee to take the responsibility of reconciling the available data from the different sources. TAC is pleased to note that CIP has taken steps to reconcile its database on potato with that of FAO through a joint publication, and would request that other root and tuber crops be covered in a similar fashion.

Northeastern Regional
Association of State
Agricultural Experiment
Station Directors



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April 5, 1996

Dr. Donald L. Winkelmann
Chairman
CGIAR Technical Advisory Committee
Food and Agriculture Organization of the United Nations
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Rome 00100, Italy

Dear Dr. Winkelmann:

It is my pleasure to transmit to you the final report on the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR.

This report is the result of a multi-step process that built on the outcomes of three External Program and Management Reviews of the International Agricultural Research Centres that are engaged in root and/or tuber crops research (CIAT, CIP and IITA). Immediately following the three EPMRs a workshop was held in College Park, Maryland, U.S.A. The workshop attendees are listed in an appendix to this report, and specifically included administrators and scientists from several IARCs, technical specialists, and a professional facilitator to keep the meeting on task. The purpose of the Maryland workshop was to inventory the issues and opportunities relevant to CGIAR priorities and organization, and to explore alternative approaches for Centres carrying out research with the mandated root and tuber crops. The standing panel subsequently took this wealth of information and conducted analyses and evaluations to assemble a progress report for TAC's July 1995 meeting in Rome, Italy.

In response to the July 1995 TAC meeting commentary, a second chapter was developed by the standing panel's chair to address specific topics, and to provide more information and examples for illustrative purposes. The intent of the second stage of reporting was not to significantly modify the workshop's reported outcomes, or to change the intended recommendations of the standing panel. TAC's requests were clearly of a nature to obtain more information. The second chapter was reported to TAC at its December meeting in Nairobi, Kenya, and merely added to the information without intentionally changing the earlier consensus report.

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Following the December 1995 TAC meeting, TAC asked for a revised final report that would integrate the two chapters into one report. The final, integrated report is to have been reviewed and agreed to by the standing panel members, and submitted in time for distribution for the May 1996 Mid-Term Meeting of the Group in Jakarta, Indonesia.

This assignment is now fulfilled with the submission of this final report. The requested revisions have been made and approved by the standing panel.

In closing, I would like to express my appreciation for the opportunity to serve the CGIAR system and its Technical Advisory Committee. I wish to once again express my appreciation to the standing panel members, the participating IARCs, and the TAC Secretariat for both their cooperation and contributions.

Sincerely,

David R. MacKenzie
Chair of the Standing Panel
Inter-Centre Review of Root and Tuber Crops Research in the CGIAR

SDR/TAC:IAR/95/25.1

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

REPORT ON THE INTER-CENTRE REVIEW OF ROOT AND TUBER CROPS RESEARCH IN THE CGIAR

Panel: David R. MacKenzie (Chair)
Evert Jacobsen
Donald Plucknett
Carlos Sere

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

April 1996

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PREFACE

This is the final report of the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR. The standing panel members for this Inter-Centre Review were Drs. Evert Jacobsen, David R. MacKenzie (chair), Donald Plucknett, and Carlos Sere. Their addresses can be found in Appendix 1 of this report.

This study is one of a set of studies being conducted for the TAC priority setting process. Each of these commissioned studies will undoubtedly use different procedures, but each report is expected to provide a set of recommendations to TAC, based on the best possible information and analysis.

The detailed terms of reference for this Inter-Centre Review are shown in Appendix 2. The panel's approach to this Inter-Centre Review was been an open, participatory, issues-based investigation of the opportunities for inter-Centre research collaboration on the root and tuber crops mandated within the CG System. The timing for this Inter-Centre Review was planned to closely follow the External Program and Management Reviews (EPMR) of the International Agricultural Research Centers (IARC) engaged in root and tuber crops research (CIP, CIAT, and IITA). The process used by the standing panel was a three-and-one-half day workshop, held at the University of Maryland, in College Park, Maryland, U.S.A. May 30 - June 2, 1995, with participation from selected members of the root and tuber crops research community having experience relevant to the topics being studied. Representatives from five IARCs, several international consultants, some research management experts, and a meeting facilitator provided the panel with extraordinarily rich sources of information for the review.

The standing panel also had access to extensive documentation developed for the three EPMRs, as well as specifically drafted documents prepared by the participating Centres, entitled, "Issues and Options Papers" (see Appendix 3). In these papers the Centres provided descriptions of the purpose and the extent of collaboration by discrete activities; research collaboration mechanisms; benefits accrued to the Centre and the System as a whole from the collaborations; suggestions as to what further inter-Centre strategies might be followed in future collaborative projects; and suggestions on how best to promote and initiate more effective inter-Centre collaboration on root and tuber crops research. Centres were also asked to provide documentation on the impact and benefits of root and tuber crops research, *ex ante* and *ex post*, and to evaluate their institutional comparative advantages *vis-a-vis* non-CGIAR institutions. Other topics requested of the participating Centres were evaluations of existing structural efficiencies, and any perceived advantages and disadvantages of restructuring research staff, facilities, and services in support of current and future root and tuber crops research in the CGIAR. The primary goal of the latter point was to look at gaining greater efficiency of CGIAR investments in root and tuber crops research. Finally, the participating Centres were invited to provide expressions of program priorities, and their views on the likely consequences of reducing or eliminating some ongoing or planned program activities that they judged to be of lower priority.

Following the submission of a progress report to TAC in July 1995, the TAC Secretariat undertook: 1) a desk study, entitled "Global Production and Consumption of Root and Tubers" (October 1995) and; 2) an *aide memoire* entitled "Overview of Research on Root and Tuber Crops Conducted Outside of the Ambit of the CGIAR" (October 1995). These two documents are presented as Appendix 4 and Appendix 5, respectively.

In addition to these reports, the standing panel's Chair interviewed specialists in resource allocation and technology assessment, and reviewed scholarly literature seeking to find alternative analytical procedures that could be used to address the comments prepared by TAC in response to the July 1995 progress report.

The perspectives derived from the pre-conference documentation, from the participants in the workshop, and from the post conference papers were used to evaluate issues, analyze options, and develop recommendations for this final report. This study did not undertake any country field visits, inasmuch as these perspectives were provided through the experience of participation in the EPMRs.

One acknowledged weakness of the process was the lack of representation by National Agricultural Research System (NARS) scientists. This omission was a conscious decision, based on the following rationale.

Extensive contact with NARS scientists was provided through the previously conducted three EPMRs, with each review particularly focused by their terms of reference on opportunities for partnership and for the devolution of research programs. This information was used as a resource by the panel in evaluating various options in this Inter-Centre Review. The panel believes, therefore, that NARS perspectives have been adequately included in this study. The panel anticipates that subsequent steps to this Inter-Centre Review may include evaluation of the recommendations by NARS representatives. This would, then, "close the loop" through a broader representation of NARS than would have been possible by including a very limited number of NARS scientists in the Root and Tuber Crops Research workshop.

Collectively, this study has been able to obtain information, documentation, and perspectives sufficient to forward with confidence the analysis and recommendations contained in this final report. It is hoped that this report will be useful to TAC in evaluating the priorities and options for root and tuber crops research in the CGIAR.

OVERALL SUMMARY AND RECOMMENDATIONS

This is the final report of the standing panel commissioned by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) to conduct an Inter-Centre Review of Root and Tuber Crops Research within the CGIAR. The terms of reference provided by TAC were to assist TAC in formulating a system-wide strategy for research on root and tuber crops within the CG System to meet global and regional needs, taking into account current and projected demands. The standing panel was given specific guidance for assessing priorities and on the organization of research, giving consideration to root and tuber crops as both commodities and as components of production and farming systems. The terms of reference asked the standing panel to explore alternative approaches for carrying out this work, with special consideration to be given to major constraints on increased production and consumption of these commodities. This perspective was to include post-harvest problems, with emphasis on those topics with international research significance.

The standing panel was also asked to outline priorities and strategies for root and tuber crops research within the CGIAR, paying particular attention to system-wide aspects of research efficiency and impact potential.

The timing of the Inter-Centre Review was specifically selected to follow the External Program and Management Reviews of the three International Agricultural Research Centers with mandates to conduct research on root and tuber crops (CIP, CIAT, and IITA). The standing panel was comprised of specialists knowledgeable in the specific research activities of the three IARCs and of international activities in root and tuber crops research.

The Inter-Centre Review employed a workshop forum that was professionally facilitated and attended by representatives of five IARCs (CIP, CIAT, IITA, IPGRI, and IFPRI), research specialists in production and post harvest technology, research managers, and consultants with experience relevant to the review topics. The workshop was held on the campus of the University of Maryland in College Park, Maryland, U.S.A. May 30 - June 2, 1995, and was supplemented by substantial documentation derived from the three EPMRs, as well as reports specifically prepared for the Inter-Centre Review (see Appendix 3).

Eight issues were identified for the standing panel, based on discussions at the root and tuber crops workshop. These eight issues were:

- Global planning and organization.
- Potential inter-Centre collaborations.

- Better communication and operations.
  - Co-location of facilities.
  - International transfer of germplasm.
- Biotechnology research.
- Post-harvest and market research.
- Partnerships with research strong NARS.
- Policy research.
- Incentives for progress.

Each of these issues were explored by the standing panel, and the results of those evaluations are contained in the body of this report.

The panel summarized its findings and judgements in the form of answers to questions. These are followed by the recommendations contained in this final report.

Are the CGIAR priorities appropriate to research on root and tuber crops?

The panel separated this question into three dimensions for its analysis:

- Root and tuber crops research as a component of total CGIAR commitments,
- Individual crops as priorities within the CGIAR mandated root and tuber crops, and
- Types of research to be undertaken (e.g., post-harvest, biotechnology).

Regarding the first dimension (root and tuber crops as a component of the CG System), the panel observed that there is considerable disagreement within the CGIAR community on the types of information needed and the appropriateness of certain methods for setting System-wide research priorities. In the panel's judgement, there is a strong need to reconcile these differences of opinion.

Regarding the relative priorities of individual crops within the mandated root and tuber group, the panel concluded that modest downward adjustments in emphasis for some root and tuber crops would permit increased research activities on cassava and potato. This judgement is based on the panel's assumption that significantly greater amounts of resources will not be available for expanded research programs. However, given the clear need to expand research activities in cassava and potato, some concomitant downsizing seems appropriate, in the panel's view.

This study evaluated extensively the need for different types of research on root and tuber crops, with a perspective for inter-Centre collaborations. The similarities and dissimilarities of the mandated root and tuber crops of the CG System are identified. This distinction permitted the identification of candidate research activities for inter-Centre collaborations across root and tuber crops. The anticipated benefits of inter-Centre collaborations would be expressed as greater program efficiencies. These suggested collaborative research areas are:

- Support for the System-wide genetic resources program, with special reference to the root and tuber crops.
- Collaborative efforts on international germplasm movement strategies, with phytosanitation.
- Vegetative propagation and conservation technology.
- Biotechnology.
- Collaborative efforts in post-harvest technology and market research.
- Mechanization research[1].
- Policy analysis.
- Studies on international trade.
- Coordinated collections of statistics and surveys.
- Training.
- Concerted, collaborative efforts to strengthen national programs.

Are the current Centre mandates for root and tuber crops appropriate?

The standing panel explored this question extensively, and concluded that readjustments to the Centre's mandates are not justified at this time. Considerable discussion was given to designating a lead Centre for cassava germplasm conservation, but persuasive arguments advanced by both CIAT and IITA showed this would serve no purpose, as the existing mandates are adequate, and are working well. For this reason, the standing panel makes no recommendation for changing the existing Centre mandates for root and tuber crops research.

Are the current strategies for inter-Centre research working?

The panel was not able to identify a clearly stated inter-Centre strategy for research on root and tuber crops. However, in its analysis, the panel was able to determine that certain types of root and tuber crops research are more appropriate to inter-Centre research activities than are other types. In the panel's analysis, there are three types of root and tuber crops research that need to be accommodated in a strategy for inter-Centre research. These distinctions are related to the similarities and dissimilarities of root and tuber crops, which are not always apparent.

Type 1: The dissimilarities of root and tuber crops identified in the progress report clearly established the justification for research independence for the mandated root and tuber crops in many areas. These independent research

[1] This point was made by the conference participants, but there is reason to conclude that research-strong NARS, working with the private sector, might assume primary responsibility for mechanization research and development.

Centre research collaboration in areas of dissimilarity for the root and tuber crops would offer no benefit.

Type 2: There are, however, a considerable number of opportunities for inter-Centre research collaborations that are, or could be, based on the identified similarities of root and tuber crops. This final report provides an analysis of these similarities, with recommendations for their facilitation.

Type 3: The third identified category of research includes projects of a cross-cutting, system-wide nature, that include root and tuber crops, but also extend to other commodities as well. One example of system-wide research opportunities is Integrated Pest Management (IPM). The panel did not address this research category in its recommendations, as it clearly extends beyond the boundaries of the standing panel's terms of reference.

Are there alternative mechanisms that could be used to facilitate inter-Centre collaboration?

The standing panel gave considerable attention to alternative mechanisms that could "reengineer," "reorganize," or "reassign" research responsibilities. It was concluded that major changes to the root and tuber crops research structure of the CGIAR are not justified at this time. The standing panel's preferred strategy would be to create an Inter-Centre Consultative Committee on Root and Tuber Crops Research that would facilitate inter-Centre research activities- as a coordinating mechanism. This recommendation was formulated by the standing panel as an overarching recommendation. The standing panel prefers this "gentle hand" approach to inter-Centre collaboration, and feels that it is more appropriate to the opportunities and needs of the Centres mandated to conduct research on the root and tuber crops. This judgement is based on the example of the excellent collaboration that currently exists between IITA and CIAT for cassava research. Both Centres actively seek to bring the right people together on the right research topics in consultative approaches.

Are there opportunities for greater interactions with Advanced Research Organizations and National Agricultural Research Systems?

The panel clearly saw many opportunities for more collaborative research activities on root and tuber crops. These collaborations could take many forms: as inter-Centre collaborations; as networks of scientists and institutions; and as partnerships with other public and private institutions in both developed and developing countries. In fact, the standing panel views this set of opportunities as a highly appealing aspect of the proposed Inter-Centre Consultative Committee, which could provide facilitation for collaborative research projects of all kinds.

The panel makes two general recommendation for root and tuber crops research, upon which the remaining recommendations are based.

General Recommendations:

General Recommendation 1: Continue research investments in root and tuber crops research at least at current levels, with the expressed expectation that the participant IARCs will seek the most effective and efficient use of those resources.

General Recommendation 2: Form an "Inter-Centre Consultative Committee on Root and Tuber Crops Research" for system-wide planning, coordination, and operation.

Supplemental Recommendations:

The panel recommends that the proposed Consultative Committee convene a task force, including non-CG members, to prepare a comprehensive, documented text that sets out a vision for root and tuber research employing inter-Centre collaborations and institutional partnerships for root and tuber crops research.

The panel recommends that the Consultative Committee develop a system-wide strategy for root and tuber crops research.

The panel recommends that the proposed Inter-Centre Consultative Committee commission a task force to explore the possibility of rationalizing international phytosanitation regulations and institutional arrangements for shipments of root and tuber crops as vegetatively-propagated materials.

The panel recommends that the proposed Inter-Centre Consultative Committee commission a study to recommend inter-Centre collaborations in biotechnology research.

The panel recommends that the proposed Inter-Centre Consultative Committee sanction a post-harvest technology and market working group to explore with AROs, NARS, and the private sector root and tuber crops research partnerships on:

- **The characterization of starch and flour (antecedent to industrial processing).**
- **Food processing technology.**
- **Market research.**

The panel recommends that the proposed Inter-Centre Consultative Committee continuously explore opportunities for different types of partnerships and collaborations among IARCs, and with public and private partner institutions in both the developed and developing world.

The panel recommends that the Consultative Committee seek ways to consolidate root and tuber crops research investments through a comprehensive plan that would build the capacity of AROs as alternative suppliers of relevant knowledge.

The panel recommends that the Consultative Committee formulate policy to encourage more private sector research partnerships.

The panel recommends that the Consultative Committee work to develop strategies and resolve policies regarding technology transfer activities.

The panel recommends that the Consultative Committee remain vigilant of the environmental impacts of root and tuber crops production.

INTRODUCTION AND BACKGROUND

At International Centres Week 1993, the Consultative Group on International Agricultural Research (CGIAR) requested its Technical Advisory Committee (TAC) to initiate a critical examination of CGIAR programs in the context of a long-term vision, taking into account current and future trends with options for structural change within the system. A derivative of this examination was a paper tabled at the Mid-Term Meeting in May 1994, in New Delhi, India, entitled, "The CGIAR in the 21st Century: Options for Structural Change." In this paper, TAC noted trends in root and tuber crops production and consumption, globally and by region, and put forth the "urgent need to define a CGIAR strategy for roots and tubers research in the medium term and to explore alternative institutional mechanisms."

This conclusion was based on several assumptions stated by TAC:

- Root and tuber crops are subsistence crops of critical importance to low-income producers and consumers.
- These crops are subject to declining demands as incomes rise[2].
- Biologically, these crops have many similar characteristics, such as: vegetative propagation; their susceptibility to some pests and viral diseases; and their perishability, which makes post-harvest work important. The research disciplines that provide inputs into roots and tubers research are therefore similar.

The paper then noted, "Because of potential reduced priority of cassava, potato, and sweet potato in the future and the emergence of alternative sources of research supply, the scale of future CGIAR efforts in research on these commodities could be lower than it is today ... To this end TAC is conducting a stripe review of research on roots and tubers to further explore these issues."

TERMS OF REFERENCE

The Inter-Centre Review of Root and Tuber Crops Research (hereinafter called the Inter-Centre Review) in the CGIAR was commissioned for the purpose of assisting "TAC in formulating a system-wide strategy for research on roots and tubers in the CGIAR to meet global and regional needs, taking into account current and projected demands." The so-called "stripe review" was, by its terms of reference, specifically to address CGIAR priorities and the organization of work, and to explore alternative approaches for carrying out this work. The review was to be done in

[2] Panel's comment: This point is probably true for sweet potato, but it is believed not to be true for potato, yam, or cassava products.

consideration of major constraints in the production and consumption of root and tuber crops, and ongoing research and related activities within the CG System and elsewhere.

Consideration was also to be given to priorities and strategies within the CGIAR, with particular attention to system-wide aspects of research efficiency and impact potential. Attention was to be given to existing and preferred collaborations, impacts, and benefits of Centre activities, comparative advantages, structural efficiencies, and program priorities from an inter-Centre perspective (see Appendix 2 for the complete Terms of Reference for this review).

The Inter-Centre Review panel accepted the charge from TAC with the understanding that the timing had been selected to follow EPMRs of CIP, CIAT, and IITA which would provide a foundation of analysis and information for the Inter-Centre Review. To this end, three consultants who had directly participated in one or more of the EPMRs were asked to serve on the standing panel, with the chair of the CIP EPMR.

REVIEW OF CGIAR PRIORITIES AND STRATEGIES

The TAC Secretariat published, in December, 1994, a document entitled, "Review of CGIAR Priorities and Strategies." In this document, it was noted that the CGIAR has the ability "to continuously adapt to changing circumstances (which) should be seen as a strength ..." This statement followed the observation that "TAC's review of activity balance, regional distribution of resources, and commodity congruence suggested that the 'founding fathers' of the CGIAR and its changing membership since have charted a course that allows for evolution and change, and continues to address high priority issues."

Specific to root and tuber crops, TAC recommended maintaining current efforts in cassava, sweet potato, potato, and yam, with the last commodity being reviewed for research effectiveness in the "next external review of IITA, which has the global mandate for this commodity."

Additionally, TAC noted the divergence between modified values of production and CGIAR allocations. "Nevertheless, TAC recommends maintaining current efforts in cassava and other root and tuber crops." Later on in the document, it was stated that, "TAC reaffirmed the priority it is currently allocating to the cereal and root and tuber crops," suggesting a linkage in priority setting between cereal crops and root and tuber crops.

The preceding information is important as background in understanding the approach and process that were used for conducting this Inter-Centre Review. During the EPMRs repeated reference was made to the review panels of misunderstandings and misperceptions regarding the appropriate priority and relevant strategy for the root and tuber crops research within the CGIAR system. Given these stated concerns, it seemed appropriate for the Inter-Centre Review panel to involve appropriate IARC representation.

REVIEW PROCESS USED

With TAC Secretariat approval, the Inter-Centre Review panel invited Centre representatives (CIP, CIAT, IITA, IPGRI, and IFPRI), technical experts, and a meeting facilitator to a three-and-one-half day workshop (May 30-June 2, 1995) held at the University of Maryland's Conference Center and Inn in College Park, Maryland, U.S.A. Each of the IARCs was asked to prepare background documents, in a suggested format, that were to serve as resource papers for the workshop. Additionally, a "desk study" was prepared by the TAC Secretariat on production and consumption trends of the main root and tuber crops (cassava, potato, sweet potato, and yam; see subsequent section for a discussion of these commodities). These sources of information were supplemented by the recently complete EPMRs at CIP, CIAT, and IITA.

Donal O'Hare, of O'Hare Associates, Inc. was commissioned as the meeting's facilitator, to direct the workshop on the process of identifying the strategic issues, and for generating options appropriate to the collective needs of IARC research on root and tuber crops. Following overview presentations by the five participating IARCs on the first morning of the workshop, the participants were asked to generate issues relevant to the terms of reference presented by TAC for the "stripe review," and in successive breakout sessions, to explore those issues through analysis and the generation of options, and to share those outcomes with the workshop in plenary session.

This process provided an opportunity for the Inter-Centre Review panel to interact directly with Centre representatives, and to obtain from experts independent opinions on topics relevant to TAC's terms of reference for the Inter-Centre Review. Additionally, the process provided the Centres an opportunity to share important and valuable information with the Inter-Centre Review panel, especially in reference to strategies and priorities within the CG System, *vis-a-vis* root and tuber crops. It was, however, clearly stated to all of the participants that the recommendations from the workshop represented advisory information for the Inter-Centre Review standing panel, with explicit statements that the panel would not be bound by the workshop's outcomes.

The Inter-Centre Review panel was particularly pleased with the energetic participation by all who attended at the workshop. This opportunity to focus on strategies and priorities for root and tuber crops research generated an extensive amount of material, including pre-workshop reports from CIAT, CIP, and IITA that described current and future conditions for root and tuber crop research within the CG System, and in its partner institutions. This productivity was no doubt greatly enhanced by the excellent process facilitation of Donal O'Hare.

OVERVIEW OF ROOT AND TUBER CROPS

Commodity Perspectives:
The commodities that make up root and tuber crops in the CG System are cassava (*Manihot esculenta*), potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), yam (*Dioscorea spp.*), edible aroids (*Colocasia esculenta* and *Xanthosoma spp.*), and Andean root and tuber crops (several genera).

Root and tuber crops provide a substantial part of the world's food supply, and are also an important source of animal feed and industrial products. On a global basis, approximately 45% of root and tuber crop production is consumed as food, with the remainder used as animal feed or for industrial processing for products such as starch, distilled spirits, and a range of minor products.

The pattern of root and tuber crop utilization varies considerably among countries. In the developing countries (with the exception of China and Brazil), relatively small amounts (less than 20%) are fed to livestock. Most of the remainder is used locally as food. The relatively high cost of transportation, processing, and storage, as well as the considerable time needed in food preparation, frequently makes unprocessed root and tuber crops less attractive to urban consumers.

The consumption of root and tuber crops as food in developed countries is considerably smaller than it is in developing countries, but their use as animal feeds is relatively higher. A very small proportion of root and tuber crop production (approximately 5%) is traded internationally.
More than two-thirds (2/3) of those exports come from developing countries, with Thailand's cassava exports accounting for more than half (½) of the total. Apart from cassava, only potatoes are traded internationally in significant quantities - mainly among developed countries.

There are considerable differences in the agroclimatic conditions suitable for the production for the different root and tuber crops studied by the CG System. Cassava is grown across a broad range of agroclimatic conditions from sea level to 1,800 meters, and from areas with as little as 500 mm of rainfall, to tropical rain forest areas with more than 2,000 mm per year. Potatoes, on the other hand, are considered to be a high latitude/altitude crop, originating in the Andes, but now grown in a range of environmental conditions, from traditional ranges to warmer, drier areas, including irrigated production in Latin America, Asia, and portions of Africa.

Sweet potato is understood to have originated in the Americas (as did cassava and potato), and it too is grown over a considerable range of latitude and elevation (up to 2,500 meters). Conversely, yams have a relatively narrower range of production, being mainly confined to the tropical region throughout the world from sea level to 1,400 meters. The main production of yam is in the savannah region of West Africa, where more than 90% of the crop is grown.
Unlike cassava, potato, and sweet potato, the white and yellow yam (*Dioscorea rotundata* and *D. cayenensis [esculenta]*, respectively) are thought to be indigenous to West Africa, whereas the water yam (*D. alata*) is thought to have originated in Southeast Asia.

Most of the cultivated edible aroids are well adapted to high rainfall (and occasional flooding) and can be cultivated in temperatures ranging between 16° and 30° C, at elevations up to 1,600 meters.

The lesser-known Andean root and tuber crops, of which there are more than a dozen, vary considerably in their ranges of adaptation and tolerance to environmental conditions. They are primarily considered to be medium-to-higher elevation crops of moderate temperature regimes and water requirements, and have greater tolerance to frost than do other root and tuber crops.

According to the TAC Secretariat desk study[3], annual production growth rates to the year 2010 for root and tuber crops are expected to be positive, with the exception of modest declines in cassava in Asia (including China; -0.4%) and sweet potato and yams in Northeast and North Africa (-1.0%). TAC also predicts a decline in area for potato, cassava, aroids, sweet potato and yam in Asia (including China) over the indicated period (potato, -4.9%; cassava, -1.3%; aroids, -1.1%; sweet potato and yam, -0.2%).

Indicated changes in yield in the TAC Secretariat report are all positive, with the minor exception of a decrease in yield in Northeast and North Africa for sweet potato and yam (-0.7%). Significant yield increases are anticipated for potato in sub-Saharan Africa and Asia (including China), cassava in sub-Saharan Africa, aroids in Asia (including China), and sweet potato and yam in sub-Saharan Africa as well as in Asia (including China).

Some of the indicated changes will likely be driven by consumption demands and production opportunities as a result of technology yet-to-be-developed for root and tuber crops. Some of these technologies will no doubt entail food processing technologies and expanded feed markets, as well as current and new industrial uses for the harvested products of root and tuber crops.

The TAC Secretariat desk study traces historical changes in food, feed, and industrial uses of root and tuber crops, by commodity and region. Patterns indicate significant change is apparently taking place in the utilization of root and tuber crops, particularly with cassava and sweet potato in Asia (both in China and elsewhere), and in Asia for potato as both food and feed crops. The latter trend is primarily in China.

Total root and tuber crop consumption increased for developing countries (1980-1992) while *per capita* consumption declined over the same period, primarily with the exceptions of potato (+0.9%) and yam (+5.5%). When these patterns are examined regionally by commodity, it is clearly evident that the total consumption of root and tuber crops is increasing in Africa with annual rates of change for potato and cassava of +0.32%, and of yam a surprising +8.5%. Despite these increases in total consumption, *per capita* consumption patterns in Africa are lagging, likely as a consequence of

[3] The panel cautions the reader that the Desk Study's projections are probably linear, and based on very poor data.

increased population. The striking exception to this pattern is for yam *per capita* consumption which in Africa increased +5.2% over the fourteen-year study period.

With a few notable exceptions, *per capita* consumption of root and tuber crops in South America and Asia declined over the period of the study, with some notable changes. Declining *per capita* consumption of sweet potato in South America (-2.7% per annum) was out-paced by the change in Asia (-5.2 %).

These patterns, derived from a TAC desk study, appear to be at odds with information provided by the relevant IARCs for their mandated root and tuber crop commodities. Consider the following points:

- For the past thirty years (from 1961-63 to 1991-93), potato production in developing countries grew rapidly. Annual growth was particularly strong in Asia (+3.9 % annually), and in Africa (+4.2%). Growth in production was combined with a continuing decline in the use of potato for animal feed in developed countries. Therefore, the share of global production in developing countries rose from 10% to 30%. By the early 1990s, developing countries accounted for 36% of the area planted in potato worldwide, up from 16% at the beginning of the thirty-year period. These patterns are expected to continue into the future at a projected rate of +2.7 % per annum in developing countries, reaching 105 million tons (for 34% of world production) by the year 2000.

- During the same thirty year period, world cassava production has experienced strong growth, with an annual rate of +2.7%, although this pace has declined during the past decade to +1.8% per annum (which does not keep pace with population growth). There are also differential patterns by region, but, for the most part, increased world production of cassava during the last decade has been mainly due to an area expansion (+1.7% annually) rather than increased yields. However, survey data gathered by the Collaborative Study of Cassava in Africa (COSCA) estimate cassava yields of 12 tons per hectare, as compared with FAO estimates of 8.5 tons. This difference indicates that yield increases may have been contributing more heavily to cassava production growth than other reports suggest.

- Processed cassava for human consumption is projected to play an important role in rural and lower- to medium- income urban populations' daily energy diets. This will be especially true in Africa, where cassava continues to play an important role in food security. Future cassava production levels are projected to be consistent with patterns of the past decade, which implies that the largest share of additional cassava supplies will continue to be derived from the African continent. Predicted patterns of cassava production in Latin America and Asia indicate continued growth of production at modest rates.

- The evolution of cassava from a basic world staple crop to a diversified end-use carbohydrate source has largely been completed in Asia, and is underway in Latin America. In Africa, while traditional processing techniques were integral to the adoption of the crop, agro-industrial transformation appears only to be in the beginning stages.

- Production growth rates of yams in West and Central Africa, where they are an important food staple, are surpassed only by rice. For example, yam production increased by seven million metric tons (20 to 27 million tons) between 1988 and 1993. The demand prospects for yams appear particularly positive, given expected economic growth and rising household incomes in the region[4].

- In China, where approximately 85% of global sweet potato production is grown, multiple uses of the crop (e.g., as animal feed as well as processing of the roots into starch, noodles, and alcohol), have helped to diversify markets for what was once mostly a directly-consumed food crop. In other regions, sweet potato use has declined or stagnated over the past thirty years. There are, however, some exceptions to this general trend. In sub-Saharan Africa, sweet potato production and area planted has not declined. Globally, in the poorest developing countries, and particularly in those areas affected by civil war, sweet potato production area has substantially expanded, a testament to its attributes as a human food during periods of famine and suffering.

There are, thus, discrepancies in not only the numerics of production and consumption of root and tuber crops, but also in the interpretation of exactly what the numbers mean, and how this information ought to be used to plan research strategies and set priorities for resource allocation. The panel took this divergence of opinion as an opportunity to reassess the strategies and priorities for roots and tubers from an inter-Centre perspective.

Research Accomplishments:
To set the stage for assessing strategies and priorities for root and tuber crops research, the standing panel inventoried CGIAR's accomplishments in root and tuber research. This provided some interesting background information that pointed out the very significant contributions that the CGIAR Centres have made to these crops.

Cassava (IITA)

- Collaborative studies, through a network (COSCA) in Africa, have examined varietal needs of farmers and the potentials for production, processing, and distribution. One anticipated outcome of the studies, namely to improve the relevance of research on cassava at national and international levels, was fully realized. For example, the description across several

[4] The panel notes that projections for rising incomes in West Africa are arguable.

countries and socio-economic domains of preferred varietal characteristics at farmer, processor, and consumer levels has had a major input to priority setting in breeding programs.

- The characterization and integrated control of pests and diseases of root and tuber crops in Africa has led to a special focus on the biological control of cassava pests, including a remarkably successful Africa-wide biological control effort for the cassava mealybug.

- The genetic base of cassava has been expanded through varietal releases in a number of countries in sub-Saharan Africa. Most of these cultivars carry resistance to mosaic virus, mealybugs, cassava green mite, and cassava bacterial blight.

- Successful wide-crossing of cassava with its wild relatives has been accomplished to acquire genetic resistance to certain pests and diseases.

- Post-harvest research has solved, to a considerable extent, the riddle of cyanogenic glycosides in cassava, thus helping to reduce prussic acid problems in the leaves and roots.

- Assemblage and maintenance of a significant collection of cassava germplasm of more than 2,000 accessions, consisting mostly of African farmers' cultivars and some exotic materials from Latin America, including roughly 200 accessions of wild manihot species from Brazil.

- Diagnostic capability for reliable screening for African cassava mosaic virus (ACMV) has been developed. This has enabled routine indexing of elite materials for distribution to NARS, and has facilitated the international movement of elite ACMV resistant clones to Latin America.

- A better understanding of ACMV etiology and epidemiology has been achieved, enabling control strategies to be improved in West Africa.

Yam (IITA)

- The acquisition and maintenance of more than 2,800 accessions of yam comprising eight cultivated species and several wild relatives, with accompanying agrobotanical and biochemical characterization.

- The genetic improvement of yam became possible through the discovery of how to induce flowering, which -- for the first time -- permitted conventional plant breeding.

- The elaboration of a minisett technology appropriate for use by yam growers, which vastly improves the multiplication ratio, and therefore the supply, of vegetative planting materials. The technique has been adopted by seed yam producers in West Africa.

- Studies of little known viruses in *Dioscorea spp.* and the development of an indexing protocol for *D. rotundata* has enabled germplasm distribution regionally and internationally.

- The development of micropropagation techniques for producing virus-free minitubers which meet quarantine requirements and enable the routine transfer of elite materials to national programs.

Sweet Potato (IITA)

- From 1977 to 1988, when IITA passed responsibility for sweet potato improvement to CIP, a sizeable amount of breeding stock was developed and distributed as virus-free plantlets to national programs worldwide. By 1988, at least fifty improved clones, based on IITA germplasm, had been officially released.

Aroids (IITA)

- A treatment was identified and refined to induce flowering in the edible aroids, thus removing the bottleneck to selective hybridization and genetic improvement of this plant group.

General (IITA)

- Partner institutions have been strengthened for enhanced global and regional scientific participation, including helping to establish more than twenty national root and tuber crops research programs in Africa.

Cassava (CIAT)

- Development of cassava information services as resources for professional enrichment of cassava scientists.

- Assemblage and maintenance of a world germplasm collection, representing 80% of the total diversity of cassava, complemented with related wild species.

- Methods for the *in vitro* conservation of cassava germplasm.

- Morphological and biochemical characterization of collected cassava germplasm.

- Global germplasm conservation and distribution.

- Ecoregional approach to gene pool improvement in cassava.

- Broad-based and durable resistance to major insects, mites, and pathogens incorporated into cassava gene pools.
- Characterization of the mechanisms of drought tolerance in cassava.
- Understanding and describing the C_3-C_4 intermediate biochemical characteristics of cassava photosynthesis.
- Identification of several effective biological control agents for major pests of cassava.
- Characterization of the post-harvest physiology of cassava roots.
- Improvement and local adaptation of cassava selections for food and industrial processing.
- Co-development of cassava drying and processing plants in Central and South America.
- Research on cassava's best management practices led to an understanding of how to maintain long-term soil fertility.

Potato (CIP)

- Development of Integrated Pest Management (IPM) strategies based on biological control for the Andean potato weevil and the potato tuber moth.
- Diagnostic field kits for the serological and DNA-hybridization assay of potato tissue to determine virus status - especially useful in developing countries.
- Development of true potato seed technology, which is now deployed in a number of countries.
- Development of potato late blight resistant varieties that are being used in East Africa and portions of South America.
- Identification, cleanup and wide scale distribution of an Argentinean clone that is now grown on more than 150,000 ha. in China.
- Collaborative development of a highly saturated marker map of the potato genome and development of specific markers for virus and improved late blight resistance.
- Establishment of an R-gene-free population with durable late blight resistance.
- Development of an *in vitro* assay system for the conservation of potato germplasm.

- Completion of eight impact studies on CIP's work in varietal improvement, IPM, seed technologies, etc., identifying returns on investment ranging from 26-106% per annum.

- The acquisition and maintenance of an extensive collection of germplasm, comprising wild and weedy species, cultivars, improved varieties, and important breeding lines.

- Utilization of the "hairy potato" for resistance to potato insect pests.

- Bacterial wilt disease management strategy now being used in East Africa and Central America for effective disease control.

- Widespread utilization of CIP-released potato cultivars in Eastern Africa.

Sweet Potato (CIP)

- Production of improved sweet potato varieties now widely used in Peru.

- Development of an IPM system for sweet potato weevil that is now being used commercially in Cuba.

- An impact study of IPM of sweet potato.

- The collection and maintenance of a sweet potato germplasm bank (6,522 accessions).

- Development of methodologies to induce sweet potato flowering and seed set for germplasm conservation.

- Development of *in vitro* storage systems for sweet potato germplasm.

Lesser-known Andean Root and Tuber Species (CIP)

- Genetic conservation of nine Andean species of edible roots and tubers that are presently being evaluated for their agronomic characteristics, nutritional value, and potential for production and consumption.

The panel notes these achievements in root and tuber crops research with an appreciation of each individual Centre's success and with a view to the terms of reference of the Inter-Centre Review that asked for an evaluation of the opportunities and potential for inter-Centre collaboration. To undertake this evaluation, the panel gave focus to the similarities and dissimilarities of root and tuber crops in an attempt to find points-of-intersection that would permit synergies through inter-Centre collaboration.

SIMILARITIES AND DISSIMILARITIES

Root and tuber crops share some common **similarities**, based on their biology and agricultural production and used. However, they also have a number of **dissimilarities** that are not immediately evident to those not directly involved in research or the development of relevant technologies.

Similarities:

The similarities of the root and tuber crops are:

- Perishability of the harvested product.
- Vegetative propagation, and some related consequences.
- The need to conserve genetic resources, and some related complications.
- Labor demands for production and marketing.
- Marketing, from a farm perspective.
- Research program needs, from a national level.
- Biotechnology.
- Technologies yet-to-be-developed.

Harvested Product Perishability: The perishability of the harvested products of root and tuber crops (i.e., high water content) is a fundamental consideration that leads to a rationale for greater investments in post-harvest technology research. The suitability of the root and tuber crops to the CGIAR mission hinges on the need for technologies that will allow either extended storage or the processing of the harvested products to avoid otherwise enormous losses that can occur with these commodities. The distinct advantage of grain crops is their "storageability" and their "transportability". Root and tuber crops, in much of the developing world, need to be consumed at or near the point of production. This raises key policy issues regarding the definition of who are the intended claimants of the benefits of CGIAR research investments (e.g., rural vs. urban consumers).

Cassava and sweet potato can be "field stored" in the ground for a few months with minimal loss of quality if conditions are right. All of the root and tuber crops have the distinct disadvantage, following harvest, of limited storability, and are fairly perishable if the conditions are not suitable. This characteristic of root and tuber crops predetermines the need for post-harvest treatment of these crops to preclude very large post-harvest losses.

If the CGIAR System's research agenda of the future is to focus on rural community development exclusively, then certain crop and technology choices become evident. However, if the CGIAR's future research agenda is to include humankind's poverty needs, broadly defined it will, in turn, become necessary for the CGIAR to address the food needs of both urban and rural populations in the next decades and beyond. A post-harvest technology research strategy for the CGIAR on root and tuber crops could extend the consumption of roots and tubers beyond proximal rural settings, through enhanced processing, transportation and marketing technologies.

The TAC Secretariat desk study of root and tuber crops production and consumption trends does not (indeed cannot) accurately project what some foresee as the enormous potential impact for new post-harvest technologies for root and tuber crops that would permit better storage, transportation, and processing of these otherwise perishable commodities. How this perspective can be incorporated into a valid, quantitative assessment for TAC priority setting and resource allocations is a key issue.

Consequences of Vegetative Propagation: Another similarity of root and tuber crops is the common practice of vegetative propagation. Relative to grain crops, root and tuber crops require sophisticated technologies for their propagation. Moreover, vegetative propagation of crops increases the likelihood of transmitting many different plant pathogens. In most developed countries, this type of need is dealt with through institutional outreach programs (a.k.a. Cooperative Extension in the U.S.A.). But this solution is very costly. The expense of this type of a technology transfer system seems beyond the financial reach of many developing nations. The policies (implied or otherwise) on the IARCs' restricting allocations for "technical assistance" to NARS precludes the Centres from openly dealing with this key issue. With regard to the CGIAR mandated commodities, the problems attendant to vegetative propagation, and thus the implications for technology transfer, are unique to the root and tuber crops, and the *Musa spp.* crops.

Complications for Genetic Resource Conservation: Another similarity of root and tuber crops relates to specific requirements for the conservation of genetic resources. The requirement to propagate vegetatively, and the perishability of the vegetative organs means that root and tuber crops require substantially more resources to assure adequate reserves are 'banked' for future generations. For some of the root and tuber crops true seed can be substituted for vegetative materials, but this approach usually compromises the genetic integrity of the collections.

For each of the individual root and tuber crops a complementary approach to their genetic conservation will need to involve a mix of different methods (primarily *ex situ*), as appropriate. This would include field gene banks, *in vitro* conservation, and seed and pollen storage, along with the storage of vegetative materials.

In situ conservation, (e.g., on farm gene banks) has some limited applications for root and tuber crops. Field gene-bank conservation is costly and carries the risk of loss of the collection, when in some situations, proper safeguards cannot be provided. Moreover, the requirements, particularly for the latter approach and *with in vitro* conservation, vary significantly from crop to crop. These issues are sometimes not accommodated during the allocation of resources for this important area of science enablement.

Labor for Production and Marketing: The production, harvest and marketing of root and tuber crops are generally labor intensive. The sheer bulk of root and tuber crops, compared to cereals, is an even bigger problem than is their underground harvest. Root and tuber crops can be harvested by means other than simply digging up individual plants (e.g., ploughs, spinners, mechanical

harvesters) but the volume to be dealt with (stored or transported) remains a significant labor problem. The processing of traditional consumable products from these crops may also require high labor inputs.

In many countries, women are heavily involved in each of these tasks, and thus the role of women is worthy of special attention.

Marketing, From a Farm Perspective: Root and tuber crops share some similarities from a market perspective at the farm level. For instance, much of root and tuber crop production is consumed on-the-farm, or at distances that are relatively close to production. In these situations the similarities of the various root and tuber crops could be considered as one category, for research purposed. It seems reasonable to project that inter-Centre collaborations on these research topics could be organized. But the similarities of marketing characteristics for root and tuber crops become quite dissimilar when considered from an off-the-farm marketing perspective (see later section for off-farm market dissimilarities).

National Program Research Needs: Root and tuber crops share similarities at the national program level, wherein for most NARS the capacity for research on these commodities is small, relative to other commodities. Commonly, one researcher has responsibility for more than one crop (e.g., cassava and sweet potato). This situation places increased demand on IARCs to work on root and tuber crops in ways to assist national programs through partnerships that are oftentimes unbalanced.

Biotechnology: Biotechnology represents an area of similarity for root and tuber crops. Biotechnology can provide new research tools for the identification and elimination of viruses, the propagation and conservation of plant materials, and genetic enhancement that have application across commodities. Biotechnology illustrates the opportunities that the Centres have for organizing certain types of research collaborations among root and tuber crops.

Technologies Yet-to-be-Developed: Finally, one of the greatest similarities among root and tuber crops is unrealized yield potential that could be attained through yet-to-be-developed technologies. The standing panel chose not to use the term "yield gap" for this concept, as "yield gap" has been used to describe crop production levels that could be increased using known technology. In the case of root and tuber crops, the potential for yield is considerably higher than the actual yield, in most settings. All too frequently, this is because the needed technology is not available to deal with yield-limiting factors (water, nutrients) and yield-reducing factors (disease, pests). As a consequence, increases in farmer yields is expected to be much greater than from attempts to increase the physiological yield potential of crops already trapped on a yield plateau.

Dissimilarities:

There are, however, in addition to the similarities noted above, some dissimilarities that distinguish the individual root and tuber crops. These dissimilarities are:

- Genetic Systems of the Individual Crops
- Strategies for Genetic Improvement
- Farming Systems Perspectives
- Pest and Pathogen Systems
- Off-Farm Markets
- Starch Properties
- Policy Environment
- Available Scientific Knowledge

Genetic Systems: To scientists familiar with the biology of the root and tuber crops, the genetics of these crops are enormously dissimilar, as are the pests and pathogens that attack them and reduce yields. From a superficial inspection, it is true that the breeding of root and tuber crops is primarily done sexually, and that there are viruses, bacteria, fungi, insects, and mites that attack these crops to varying degrees. The reality is that each of the pollinating systems and different ploidy levels brings with it breeding complications, along with specific opportunities for genetic development.

Strategies for Genetic Improvement: Strategies for the genetic improvement of root and tuber crops differ significantly, since they must to take into account the various production systems and end-uses. Some crops (e.g., sweet potato, potato) may benefit from breeding cultivars adapted to shorter growing seasons, while other crops (e.g., cassava) may need to fit into different and contrasting growing cycles. Other considerations (e.g., crop and soil management practices, crop rotation schemes, rainfall patterns) mandate that decision making be done in the individual breeding programs. The needs for improvement are usually unique to the crop, rather than to the group of crops classified as root and tuber.

Farming Systems Perspectives: There are significant differences in the farming systems perspectives of root and tuber crops, ranging from contrasting systems of production for some crops, to complex systems of intercropping involving two or more root and tuber crops. All of these aspects are important considerations, inasmuch as the transfer of know-how from one crop's farming system to another is difficult, if not impossible. This means that most farming systems research must be done for each root and tuber crop, thereby giving the appearance, falsely, of duplication of effort.

Pest and Pathogen Systems: The pest and pathogen complexes of root and tuber crops are remarkably dissimilar, in that none of the viruses of one root or tuber crop can attack another. Knowledge of one pest or pathogen may be generally applicable to other situations in other root and tuber crops, but the specific information cannot be directly applied. This is an important consideration, in that the transfer of developed technology is just as difficult from cassava to potato as it is from sweet potato to wheat.

Off-Farm Marketing: Root and tuber crops produced for off-farm markets can have considerable dissimilarities in transportation, storage, processing, consumption, economics, consumer demand, and other factors. These differences need to be taken into account when inter-Centre opportunities are assessed for improving root and tuber crops, and for distinguishing among strategies for their improvement *vis-a-vis* the mission of the CG System. In fact, some individual root and tuber crops are presently experiencing a segmentation of markets that will undoubtedly require substantially different types of cultivars to meet divergent market needs. Some examples of this phenomenon are the emerging uses of cassava as an industrial raw material, as compared with its traditional uses as a food. Similar differentiation is occurring with potato and sweet potato.

Starch Properties: Another dissimilarity of root and tuber crops is the properties of the starches that are produced in the harvested roots and tubers. There has been a limited amount of work on the characterization of root and tuber crop starches (mostly for potato, and to a lesser extent for cassava and sweet potato), but work to date has shown considerable variability within and between the crops evaluated. However, the methods required to evaluate the quality characteristic and assess the product potential are similar for any starch source. In addition, the required primary processing technologies (flour/starch) are also similar for all root and tuber crops. This information gap represents a whole new area of research that needs to be addressed if post-harvest technology of root and tuber crops is to become a reality. How much of this research should be done by the public sector and/or the CG System is addressed elsewhere in this report.

Policy Environment: The policy environment for many food crops often differs by commodity. Some crops are often disadvantaged as a consequence of historical choices, political realities, and a host of other considerations that are driven by market demands, alternative foods, or substitute uses. Many of these policy factors are poorly understood for root and tuber crops. It is presumed that, for this group of commodities, the relationships are not universal, and that some unique and dissimilar factors are responsible for certain observed outcomes, for specific root or tuber crops.

Available Research Knowledge: The quantity and quality of available research generated from sources other than the IARCs is another dissimilarity between root and tuber crops. For instance, potato research at developed country institutions is quite advanced, and currently there are activities in a number of areas that are being tapped by CIP. This is not the situation for cassava and yam research. And, to a degree, there is little Advanced Research Organization (ARO) technology available for sweet potato. There is virtually no research activity of potential benefit for the aroids or for the lesser-known Andean root and tuber crops, (beyond the CG system), that Centres could adopt from alternative research suppliers.

PRIORITY SETTING EXERCISES

TAC is recognized as an international leader in processes for research priority setting and resource allocation. The innovative use of matrix analysis, and the allocation of resource "envelopes" place the CGIAR system well ahead of many other institutions in this regard.

For many of the CGIAR mandated commodities, considerable information is available on global, regional, and national production and consumption patterns. Reasonable projections can be made with some validity. This is especially true for the commodities that are of extreme importance to many nations (e.g. rice, wheat, maize), and for the commodities of significant international trade. Several sources of information are available to assist in establishing and verifying commodity production and consumption patterns over considerable periods of time.

The situation is not as convenient for the root and tuber crops. Much of the production of root and tuber crops is not captured in accessible survey literature or databases. Such information must be estimated through surrogate indicators, and the use of default assumptions. This in-and-of-itself is not a fatal flaw for making projections, but it does raise some degree of concern over the validity of the resulting estimates.

As an alternative analytical approach, a recent TAC Secretariat desk study (October 1995) looked at the value of the root and tuber commodities in terms of caloric and protein measures. This analytical approach was used because of the difficulties in establishing the monetary value of the individual root and tuber commodities. This approach does however point out the difficulty in coming up with analytical indicators that could be used to set research priorities for individual commodities. The TAC Secretariat desk study was admittedly inconclusive.

There are other some alternative analytical approaches that could be used for research priority setting.

In a landmark article published in the November 1994 issue of the American Journal of Agriculture Economics, Huffman and Just demonstrate an analytical procedure for assessing the agricultural production benefits of alternative institutional structures in the U.S.A. federal/state partnership for agricultural research. A conversation with Professor Richard Just explored the potential application of this analytical procedure to the commodities of the CGIAR system. He responded that it would be possible to analyze returns on research investments using trends in crop yields from the IARC stations, as a surrogate for missing crop production information. This would allow an analysis of the "unrealized yield potential" discussed earlier in this report.

A point of interest for this type of analysis would be in the characterization of "research plateaus" *vis-a-vis* the identification of research opportunities. The notion here is to better cross link research opportunities with research priorities. This proposed analytical approach would also be helpful for

establishing the relationships, if any, between commodity research outlays and resulting yield gains. Other analyses could be conducted on similar dependent variables that have been set out as research goals (e.g., crop market values; crop nutritional values; IPM gains) .

Professor Just responded to a request about conducting an analysis on surrogate crop yields for the IARCs' mandated root and tuber crops. He estimated that such a study would take at least a year and would require considerable financial resources to obtain the intended results. Given the time constraints on this study, the project was not pursued further. It is included here to note that there are analytical opportunities available to TAC that could be used as alternative approaches for research priority setting.

A study of the technology assessment process used by the U.S. Department of Agriculture's Agricultural Science and Technology Review Board (ASTRB) was also conducted. The ASTRB was charged in the Federal Food, Agricultural and Conservation Trade Act of 1990 (a.k.a., 1990 Farm Bill) with identifying and evaluating current and emerging technologies, and with assessing how well the research and extension programs provided by the federal government meet the purposes and needs of U.S. agriculture and the U.S. consumers..

ASTRB has developed a new method for technology assessment that has been tested against seven controversial technologies. The evaluation process completed a matrix of criteria that was then used to assess the ways in which the selected technologies are likely to affect five different segments of society. The method they developed included consideration of "issue-categories" relating to agricultural and rural life as:

- Structure, ownership, participation in, and control of U.S.A. agriculture.
- Economic opportunities in rural communities.
- Nutrition, health, and the food supply.
- Interactions between agricultural practices and the environment.
- The resilience and regenerative capacity of agriculture.
- Global agriculture.
- The relationship between agriculture and the public.
- Human capital.
- The science and education system.

The evaluation process used by ASTRB was more qualitative than quantitative, and the criteria are not necessarily appropriate to the priorities of the CGIAR system. But the outcomes of the process seem suitable for choosing among technologies in way that seem relevant to the needs of the CGIAR.

The above two approaches represent alternatives to analyzing production and consumption trends as a way of setting research priorities. These alternatives are noted with the suggestion that TAC consider broadening its analytical process to use a pluralism of methods for priority setting. This is definitely not intended as a criticism of the process that TAC has used for priority setting, but

rather as encouragement for TAC to extend its reach for information gathering, and for using diverse analytical processes, to further enhance the strength and acceptance of the recommendations derived from such activity. [5]

WORKING ASSUMPTIONS

In developing a set of strategic options for TAC's consideration, some working assumptions had to be made. These working assumptions were:

- Technology transfer constraints placed on the IARCs can and will be overcome.
- Partnerships can and will be made with the private sector.
- Technologies can and will be designed to impact consumer demand and consumption patterns.

Technology Transfer- Constraints on the deployment of new CGIAR-developed technologies must be overcome if root and tuber crops research investments are to result in intended payoffs. It is assumed, for the purposes of this analysis, that serious consideration will be given to the removal of policy constraints on IARCs that now limit technology transfer activities by IARCs. In addition to needed policy changes, it is foreseen that resources will be needed to deploy new technologies to realize their intended benefits.

It no longer seems reasonable to assume that all technologies, once developed, will become deployed without assistance from some source. In some instances, the most likely source of that assistance will be the IARCS' that developed the technology. How this expectation will be meet remains to be resolved.

The relevance of this point to TAC's priority setting processes is in the need for policy adjustments that would allow the IARCs' to conduct technology transfer activities, and indeed provide for them. Failure to address this issue raises a serious question- why initiate research in an area if there is no envisioned processes for getting the intended users to use the developed technology?

Consider a contemporary example.

In the CIP EPMR the panel recommended that the Centre refrain from technical assistance programs provided to NARS. Much of this technical assistance is directed towards creating a "critical mass" of demand for seed of newly released and named cultivars. Not reaching a "critical mass" with a new

[5] The constraints of time and resources did not allow this study to pursue these alternative analytical methods. They are referenced here as informational only.

introduction may doom the selection, because when it is in limited use, it cannot be profitability maintained private seed producers. CIP attempts to assist the "jump starting" of new selections with extension-type activities, which is then criticized as mere technical assistance. Other commodities without the complications of: vegetative propagation; bulkiness of the"seed"; and high production costs per hectare do not face these constraints. Thus the question needs to be asked... Should the different needs of CGIAR mandated commodities be factored into considerations for the desired mix of research and technical assistance performed by a Center? Traditional expectation for NARS to provide technology transfer for root and tuber crops research has proven inadequate in many instances, and for many reasons. Alternative provisions seem to be needed.

Private Partnerships- The nature of the root and tuber crops research requires that IARCs establish partnerships with the private sector in critical areas. Heretofore, there seems to have been an implied prohibition against IARCs working in collaboration with the private sector. However, as pointed out below, this constraint has greatly limit opportunities for developing necessary root and tuber crops technologies, appropriate to the expectations of the CGIAR donors. Consider the following example.

The development of low cost, high nutritive value foods with a long shelf-life using root and tuber crops as an ingredient will require extensive research investments. It is unlikely that the private sector will make such investments until a market is clearly visible, and the technology is emerging. The risks of initiating such research are often too great for private enterprises to accept. Commonly, some research results are needed from the public sector to get things started. The pre-commercial research and development responsibilities thus fall to the public sector.

The opportunities for IARCs to jointly plan with the private sector, and "pass the baton" at the appropriate stages could be done through well defined partnerships. This is an area that the IARCs will need to engage in the future, if they are to be successful in some areas of technology. Support from the CGIAR System in the form of new policies will be of critical importance, by allowing, and indeed encouraging, such public-private sector partnerships to form.

Demand Patterns- It is assumed that patterns of consumer demand and consumption can be altered through the development of new technologies, in areas such as food processing. Although some would argue otherwise, there is some evidence to suggest that markets can be created by targeting specific technologies, if they meet the needs of consumers for convenience, appeal, added value, etc. This assumption is important to TAC's priority setting process. Consider the following point.

There is an expectation that, to feed the poor of the Third World into the medium term of the next century, new types of foods will be required. The technologies to produce and process these foods is yet to be developed. It seems reasonable to assume that substantial shifts will occur in the demand for ingredients for food stuffs, thus affecting patterns of crop production and consumption. The simple projection of past consumption patterns to obtain estimates of future production needs does not take this point into account.

An alternative analytical strategy would be to anticipate those crops that are likely to play a major role in any new food technology, and plan research activities accordingly. This study assumes that resource allocation strategies can be developed that will significantly affect the technological outcomes and consequent impacts. To assume otherwise contradicts the primary purpose of research priority setting for resource allocations.

These working assumptions are critically important to developing an understanding of how to interpret projections in consumer demand and consumption patterns. The October 1995 desk study by the TAC Secretariat, although inconclusive for root and tuber crop consumer demand patterns, does forecast considerable areas of increased demand in certain regions. It can be reasonably argued that these desk study projections could be seriously affected by new technologies. This is particularly true if new technologies are developed and transferred in ways to strategically impact consumer demand and consumption patterns. Such strategies would be especially effective if done in partnership with the private sector. Could carefully selected new technologies be used to "push" markets in new and desired directions, rather than waiting for markets to "pull" new technologies? Could the anticipated food deficit problems of the next century be ameliorated by strategic resource deployments? What role would the root and tuber crops play in such a strategy? Surely, it would be different from a straight line projections of past patterns. And more assuredly, the need for a balanced portfolio of crop commodities would be of prime consideration.

ANALYSIS AND EVALUATION

It is apparent that there does not exist today an inter-Centre strategy for root and tuber crops research. The panel could find no written documentation or any claims for a clear statement on a strategy for inter-Centre root and tuber crop research beyond the considerable scientific collaborations that exist between programs within the CG System. The panel was impressed by the number and variety of apparently spontaneous, ongoing collaborative efforts between Centres in root and tuber crops research. But these appear to be informal structures based on scientific desirability rather than on a strategy for root and tuber crops research.

The present root and tuber crops research portfolio of the CGIAR System has been largely determined historically, during a period of growth in which Centres took on added responsibilities, often as decisions by their management and their boards.

Overall, the initial approach to root and tuber crops research seemed to relate to a common vision of a hungry world wherein these crops could contribute to famine relief. Nutrition and poverty considerations were introduced later. More recently has come the notion of "income generation" through root and tuber crops production and processing.

In the case of research-weak NARS, one peculiar consequence for root and tuber crops is that some of the Centres have developed a kind of autonomous research agenda, with a heavy emphasis on institutional strengthening through training and technical assistance. This is understandable, but it is a complicated and difficult strategy for the Centres that pursue it. The strategy also probably reflects the need, noted earlier, for a mechanism for technology transfer.

The perishability of the root and tuber crops has also complicated CG System research strategies by leading to greater investments in post-harvest technology, relative to cereal programs.

Similarly, the difficulties of vegetative propagation have led to relatively larger investments in "seed technology" *vis-a-vis* what is allocated to seed issues in other CGIAR commodity programs, in an apparent attempt to assist NARS in obtaining research impact.

Interestingly, in recent years the CGIAR strategy has increasingly stressed the need for inter-Centre collaboration. Such collaborations must, in the panel's opinion, be built on a clear understanding of the biological similarities of the crops, especially for the frequently misunderstood similarities and dissimilarities of root and tuber crops, if the expected benefits of collaboration are to be obtained.

It is noteworthy that each of the Centres working on root and tuber crops research has built strong upstream links with AROs as part of its institutional strategy for research with root and tuber crops. This may represent a special opportunity for interlinking AROs in an inter-Centre strategy for root and tuber crop research.

The mode of operation for root and tuber crop research within the CG System is still largely based on self-contained, independent operations, rather than as full-fledged partnerships among IARCs and with NARS.

The organizational structure (i.e., coordinating mechanism) of root and tuber crops research is "Centre oriented" and is not program-based. Any semblance of a system-wide root and tuber crops research program is simply the summation of related activities across autonomous Centres. One exception is the cassava program that is operating quite well between IITA and CIAT. This inter-Centre organization for collaboration in cassava research probably reflects to a great extent the willingness of scientists to work together to achieve a common goal, rather than some organizational structure to facilitate inter-Centre collaboration. In the panel's observation, there are no structures in place that would facilitate inter-Centre research on root and tuber crops within the CGIAR mandates.

Given the foregoing considerations, the panel (with the assistance of the workshop participants) analyzed eight overarching issues relative to Inter-Centre research on the root and tuber crops. These eight issues were:

- Global planning and organization.
- Potential inter-Centre collaborations.

- Better communication and operations.
  - Co-location of facilities.
  - International transfer of germplasm.
- Biotechnology research.
- Post-harvest and market research.
- Partnerships with research strong NARS.
- Policy research.
- Incentives for progress.

Global Planning and Organization: Discussions at the University of Maryland workshop clearly indicated that root and tuber crops research suffers because of absence of global planning and priority setting for research, especially for analyses which would build on the important similarities between the crops. Also lacking is an effective way to organize and conduct research on root and tuber crops, which often are studied by a small number of scientists located in widely dispersed locations and institutions; including IARCs, AROs, and NARS in developing countries. Because funding for support of root and tuber crops research is unlikely to increase significantly in the medium term, these crops will require new or improved approaches to global planning, coordination, and partnerships for achieving critical mass in research.

The panel evaluated, from three perspectives, new approaches that could be taken for inter-Centre collaboration and partnerships in root and tuber crops research. This analysis was undertaken to provide a perspective to the preceding recommendation, and to establish the boundaries of expectations that surround the standing panel's analysis.

From the first perspective, the panel asked, "if the system was starting all over again with root and tuber crops research, what would be the preferred strategy? This "clean slate" analysis led to the conclusion that very likely that the same root and tuber crops would be selected for research, and that the assignment of crops to Centres would remain the same. One exception might be a reassignment of mandates for cassava (see later section in this report on this topic). But the benefits of making such a total "fix" at this point might be very small. The panel concluded that a major "reengineering" of the CGIAR's root and tuber crops research organization would not necessarily provide 1) a new strategy, 2) increase efficiencies, or 3) enhance opportunities for success. The clean slate approach was thus abandoned.

The second analytical approach which the panel undertook was to examine a rearrangement of commodities to see if a reorganization through a reassignment of commodities might yield some benefit. Again, the panel's analysis showed there were no significant scientific or management benefits to be gained from the reassignment of commodities among the participating Centres.

The third analytical approach that the panel used was to ask, "Could some new structures be formed that would facilitate inter-Centre collaborations on root and tuber crops research?" Through this analysis the panel did identify opportunities for:

- Better identification of potential inter-Centre Collaborations.
- Enhanced planning, communication, and operational efficiency.

Potential Inter-Centre Collaborations: Some potential inter-Centre collaborations identified and recommended by the panel included joint projects with root and tuber crops on:

- Support for the System-wide genetic resources program, with special reference to the root and tuber crops.
- Collaborative efforts on international germplasm movement strategies, with phytosanitation.
- Vegetative propagation and conservation technology.
- Biotechnology.
- Collaborative efforts post-harvest technology and market research.
- Mechanization research.
- Policy analysis.
- Studies on international trade.
- Coordinated collections of statistics and surveys.
- Training.
- Concerted, collaborative efforts to strengthen national programs.

The panel recognized that it would be possible under existing mechanisms for individual scientists to identify and go straight to these special topics through various forms of collaboration. In fact, nothing institutional would be likely to stop them. The panel's concern, however, is that some topics might not be initiated because of a lack of recognition, or the failure of the right personalities to come together to form an initiative.

Better Communication and Operations: The panel considered two areas where better communication, and/or facilitated operations would serve the collective interests of the Centres' mandated to work on root and tuber crops. These two areas are:

- Co-location of facilities.
- International transfers of germ plasm.

Co-location of Facilities: The panel explored prospects for the co-location of Centre activities in African countries as a model. There are some significant difficulties in co-location of facilities that are not apparent at first glance. For example, IITA, CIP, and CIAT are co-located in Kampala, Uganda while CIP and IPGRI are both located in Nairobi, Kenya. A superficial evaluation of opportunities to gain efficiencies within the CG System might suggest that individual Centres could "piggyback" on another Centre's existing Memorandum of Understanding (MOU), and thus expand operations, without much additional cost or commitment. This is not the case, as the existing Centre

MOUs tend to be highly specific for intended activities, and most MOUs are not applicable to the commodity(ies) of another Centre. For instance, CIAT's MOU for Uganda is specifically for beans, and thus serves no practical use to CIP or IITA.

Nevertheless there are opportunities for Centres with existing MOU's to help other Centres, such as in the importation of a limited amount of equipment that is crucial to implementation of specific research or training programs.

International Transfer of Germplasm: The conservation, maintenance, improvement, and deployment of germplasm have traditionally been core activities of commodity- based IARCs. As noted above, vegetative propagation of root and tuber crops complicates greatly the preservation and distribution of pathogen-tested vegetative material. This is a particularly demanding requirement for a CGIAR Centre.

To conduct the panel's analysis of this issue a number of assumptions were made. Many of these assumptions reflect the biological realities of the crops being researched, and the collective experience of distributing vegetatively propagated material in a number of different settings, for each commodity. In general, although there are some exceptions, centralized governmental and public sector-organized distribution systems for vegetatively propagated crops have considerable difficulty. (Cuba is a notable positive exception.) In many instances there are limited prospects for a strong private sector that supplies planting materials, although there is a often a demand which seems not to be met. Also, there is a limited scope for enhancing the techniques and efficiencies of these supply systems. The exception to this point is the potential for the development of new methods for certifying the plant health status of vegetative materials. Methods for vegetative propagation of all of the crops are reasonably well developed.

What is the bottleneck in the multiplication and distribution of vegetatively propagated root and tuber crops? The panel evaluated this question and listed a number of options for the solution of the problem. These solutions included the development of some inter-Centre special projects perhaps involving ISNAR. The projects should be of limited duration, and in partnership with NARS and with selected private sector representatives, to address constraints to the distribution of improved root and tuber crops germplasm. The panel suggests that the setting of this research agenda should include farmer participation, both for variety selection and for research approaches, to enhance the acceptability of the resulting methods and materials.

With respect to the preservation of germplasm of root and tuber crops the panel recognizes the need for the Centres to collect, characterize, conserve, move, and use the available germplasm, recognizing the unique challenges presented by vegetative propagation. The panel evaluated this topic using a number of assumptions to develop some options leading to a recommendation.

The panel assumed that germplasm preservation activities will continue to be an important component of any IARCS' working on root and tuber crops. It would therefore be desirable to provide more effective and cheaper methods for the conservation of this germplasm through new

technologies, such as cryopreservation. Root and tuber crops are particularly difficult to store, as they are more vulnerable to loss than are other types of crops (i.e., those that can be stored as true seed). The panel also assumed that plant pathogens, especially plant viruses, will continue to be a major hazard to the international movement of plant materials intended for research. However, the panel recognized that the new biotechnologies offer considerable hope for increasing the safety of international shipment of plant materials, especially through use of biochemical and molecular diagnostic kits to identify the plant health status of material, and by enabling the culture of plant parts free of pathogens.

Given these assumptions the panel deliberated two alternatives that could be used as a strategy for inter-Centre collaboration on phytosanitation issues *vis-a-vis* germplasm. The first strategy was characterized as a higher cost/lower risk approach to obtain, through the development of a centralized facility, phytosanitary certification of germplasm as an inter-Centre effort for the CGIAR mandated root and tuber crops. The higher cost would be for the development of needed technology and for institutional support to maintain a centralized facility that would deliver lower-risk international shipments, from a plant health perspective.

The second option was characterized as a lower cost/"higher risk" strategy to speed up the exchange of materials between countries, with an emphasis on intra continental movement of materials. This strategy would entail the development of internationally acceptable, rational phytosanitary protocols based on the best possible science, and arguing for a lowering of non-tariff trade barriers which all too often complicate international phytosanitary regulations.

The panel notes that the first option (higher cost/lower risk) has been successfully accomplished by the INIBAP Transit Centre in Belgium. There are, however, some hidden costs to INIBAP. Also, the panel noted that the volume of banana and plantain moving through the Transit Centre was considerably less than the expected volume for a hypothetical root and tuber crops transit centre. A root and tuber crops partnership with the INIBAP Transit Centre seems out of the question, as the existing space and facilities at the Katholik University in Leuven, Belgium could not accommodate the anticipated volume that would be transmitted, and dealt with, in a fully operational root and tuber crops research system.

Another consideration noted by the panel is the lack of trust relative to the problems of international shipments of vegetatively-propagated material. This problem is not that widely understood, and is manifested as "double cleaning." Untrusting recipients of vegetatively- propagated materials once again clean materials already certified at the time of shipment as pathogen-tested. This lack of trust becomes an unnecessary delay in the exchange of material that would not necessarily be resolved by the creation of a root and tuber crops transit centre.

Biotechnology Research: The panel noted the opportunities for the application of the new tools of biotechnology for the genetic improvement and maintenance of healthy materials of root and tuber crops. In the panel's assessment, these applications need to be stimulated within the CGIAR system, particularly when working in partnership with non-CGIAR institutions. This effort will require,

however, adequate resolution of several outstanding issues, such as: claims to intellectual property rights; biosafety compliance; access to genetic materials; and the use of material transfer agreements. Some of the Centre mandated root and tuber crops that have received less biotechnology research attention, such as cassava, may require careful coordination of research activities to prevent double investments in this expensive area of research. Benefits should include incorporation of agronomically important genetic traits from foreign sources, marker- assisted selection, and genetic probes for plant pathogens. Inter-Centre coordination of biotechnology research on root and tuber crops should help to identify appropriate partners (e.g., AROs and NARS); share resources effectively; and better distribute advanced research methods.

Post-harvest and Market Research: The panel investigated the question, "What should be CGIAR's role and level of investment in the area of post-harvest and market research?"

The panel acknowledges some existing and significant inter-Centre collaborations in post-harvest and market research for root and tuber crops. Some important examples are:

- Product development workshops/manual (jointly by CIP, CIAT, and IITA).
- Marketing methods materials in Spanish and English (involving CIP, CIAT, and IFPRI).
- Demand studies for potato (Bangladesh, Pakistan) and sweet potatoes (Philippines) (done by CIP, and IFPRI).
- Marketing research on root and tuber crops in China (CIP and IFPRI).
- FAO expert consultation on root and tuber crops for animal feed (involving CIP and CIAT).
- Evaluation of competitive position of sweet potato versus cassava in Vietnam and Peru with national program collaborators (CIP and CIAT).

In the standing panel's view there appears to be opportunity for greater efficiency in post-harvest and market research that could be obtained through more organized collaborations among Centres--and with AROs and NARS through partnerships.

In the standing panel's opinion, considerable opportunity exists for the development of improved cultivars for processing and for new processed products based on genetically-enhanced root or tuber quality and storage potential. This is, however, not a trivial consideration but one that demands substantial evaluation, analysis, and strategy development. Moreover, it is likely that strong research partnerships with the private sector may be necessary in specific topics (e.g., post-harvest technology, market research).

In its analysis, the standing panel assumed that urbanization in the developing world will open up market opportunities for new food and non-food processed products that could be based on root and tuber crops. Significant commonalities appear to exist across root and tuber crops in the area of post- harvest technology and for research on the development of new products through post-harvest processing. This would likely lead to demand-driven root and tuber crops research that would make these crops more competitive with other crops at the farm level, and in strategies to provide income for the producers.

Strategies to pursue these research opportunities were evaluated by the panel as options by which to formulate a recommendation. Continuation of the *status quo* seems inappropriate because it would fail to capture the potential synergies that could be applied to the development of post-harvest technologies for root and tuber crops. Certain aspects of post-harvest technologies will continue to require location-specific attention (at the regional or sub-regional levels). Nevertheless, there could be gains in efficiency to be realized by conducting research on well defined topics, in a more centralized way.

Partnerships With Research-Strong NARS: In stating its priorities and strategies, TAC noted the opportunities for partnership with research-strong NARS as an approach for Centres working on root and tuber crops. It is understood that the intent of this approach would be to improve research output for root and tuber crops by drawing on the capacity of NARS to conduct such research. The panel evaluated this issue and concluded there were opportunities that could be pursued through inter-Centre strategies.

Clearly, the national programs have benefited tremendously from the CGIAR investments in root and tuber crops research. These benefits have been derived as increased incomes, greater food supplies, and enhanced capacity in national programs to conduct research on root and tuber crops. In spite of past capacity-building, many individuals at the Centres working on root and tuber crops feel that most developing country national programs lack the critical mass of scientific strength necessary to meet their own national research needs. Some have proposed that NARS research networks are a viable alternative to insufficient national "critical mass," and several positive examples of such networks exist to document the argument. It is likely that this assessment has led some IARCs to invest in networks and partnership arrangements designed to strengthen root and tuber crop research within national programs.

Many of the shared characteristics of the root and tuber crops could make them difficult to handle (vegetative propagation, phytosanitation, storage, etc.). Such factors, along with insufficient funding, appears to dissuade national research scientists from working on root and tuber crops. This presents a dilemma to the CGIAR System for the organization of research partnerships. Although there are number of very successful bilateral partnerships and networks that are operational, the expectation for the direct handing off of a commodity or disciplinary area of science to a national program seems, at this time, not straightforward.

The panel conducted its evaluation of the issues of partnership opportunities using a number of assumptions. The panel assumed that Centre budgets will remain constrained, and that funds will not be available to fully reimburse national programs for assuming major research responsibilities. It was additionally assumed that the budgets of potential partners would remain constrained. Research partnerships would therefore be based more on mutual interests, rather than on contract-for-research relationships with payment for services rendered. The panel does not expect national programs to underwrite international agricultural research projects of significant size.

The panel also assumed that developed countries are not likely to increase their interest in root and tuber crop research with the exception of potato, which is a commodity of interest to their region. The panel also assumed that the dissimilarities of root and tuber crops would contribute to the need for different types of partnership arrangements, especially with regard to research scope and coverage.

The panel's analysis led to a number of options that were evaluated for feasibility. Each of these supposed mechanisms for establishing inter-institutional linkages (such as networks or research collaborations) were evaluated by using specific examples identified as relevant to contemporary root and tuber crops research. After exploring a number of options it became apparent to the panel that the CGIAR system needs to maintain considerable flexibility in the types of relationships that are established for conducting research on crops that have a number of dissimilarities, given the fact that a considerable breadth of research activity is needed.

To illustrate this concept of partnering with a research strong NARS an example is given for sweet potato.

Produced on six (6) million hectares annually, sweet potato in China is often grown on marginal lands, by very poor farmers, and is used for food, livestock feed, and processing into starch, alcohol, and noodles, plus other minor uses and products. CIP, recognizing China's interest and research capacity in sweet potato, has included contract research with Chinese institutions as part of its core program. Similar support for potato research is handled through CIP's regional office in Beijing. The panel commends CIP for devising this research partnership approach.

The panel considers the CIP/China partnership in potato and sweet potato as a point of departure for further collaboration. This partnership approach could help Centres acquire a critical mass in international research, perhaps at a lower cost.

Partnerships with research strong NARS may have greater application when/if the CGIAR System falls on hard financial times. Given the unknown prospects for continued funding for the System, it seems reasonable to explore strategies for dealing with major or catastrophic budget cuts. Research partners with research strong NARS would be a likely strategy for maintaining vital research activities, rather than a shut-down of programs. Clearly no one advocates this outcome, but research leaders must consider the possibility, given present uncertainties.

The standing panel recognizes that there are several performance standards that should be considered when establishing partnerships with stronger NARS, either as a partnership strategy, or as a response to catastrophic financial exigency.

In response to the standing panel's comment on the need for performance standards for research partnerships with research-strong NARS, TAC requested some tentative guidelines and criteria that could be used to judge the merits and demerits of individual cases.
In response to TAC's request the standing panel outlines six standards should be met when passing a research program to a research strong NARS:

- **Science quality assurance** - mechanisms should be in place to ensure that the research undertaken will be of highest quality, and of relevance to the needs of the System. This needs to be assured through some agreed processes for:
  - merit review before the initiation of research projects;
  - subsequent evaluation of research progress and performance; and
  - the assessment of research results, outcomes, and impacts.

- **Cost effectiveness** - if the intention of passing off of a research program is to capture some cost efficiencies, these should be monitored in a way that justifies continuation of the agreement.

- **Adequate resources** - the capacity and/or sufficiency of:
  - People (senior scientists and support staff),
  - Facilities (for research), and
  - Funding (project support and financial accountability), should be continuously evaluated to assure that the intended research can be carried out.

- **Scientific leadership** - the acceptance of the research outcomes will depend on the scientific recognition of those conducting the research. Consequently, the research scientists and the institutions selected to take on the research responsibilities should have an established reputation for scientific leadership.

- **Programmatic commitment** - the long term success of a research program is often dependent upon a continued commitment to a program's activities. It is important to gain assurances for continuity of support for the program that is to be passed off.

- **Accessibility of research results** - inasmuch as the intention of passing off an IARCS' research program to a NARS is to obtain research results for the broad scientific community, agreements must be reached on the sharing of results, and the distribution of information and germplasm without encumbrances. These considerations range from intellectual property considerations, to cultural differences that could manifest themselves in an unwillingness to share research outcomes with the entire scientific community.

The standing panel also notes some complications that may occur with the continuation of research partnerships with research strong NARS. These complications are: the absolute need for sustained funding; policy to deal with intellectual property rights, especially for essentially derived materials; methods for dealing with material transfer agreements; and the inevitable need to comply with international phytosanitary regulations.

Obtaining early agreement on these issues should help to favorable implement international research partnerships for selected commodities.

Policy Research: One of the potential areas of inter-Centre collaboration that was clearly evident to the panel entailed opportunities for policy research. During the course of the University of Maryland workshop, one of the breakout groups had an opportunity to compose a list of potential collaborative research areas that could be conducted as an inter-Centre initiatives. Nine topics were identified as:

- Compare crop yield data with regional and national statistics to detect systematic biases and recommend improved methods for yield estimation in root and tuber crops.

- Fine-tuning of international projections of supply and demand for root and tuber crops.

- Study the indirect effects of distortionary sectorial policies and food aid on the production and consumption of root and tuber crops.

- Determine the role of public investments in infrastructure and transportation on production and consumption of root and tuber crops.

- Conduct analyses of resource allocations to root and tuber crops research in the NARS.

- Study the impact and implication of CGIAR-related root and tuber research.

- Evaluate the competitiveness of root and tuber crops as substitutes for internationally-traded commodities (i.e., cassava for feed versus imported feed grains; domestic production versus imported frozen foods; cassava starch *versus* imported starch), and the implications for research.

- Determine the alleged relative inferiority (or superiority) as consumer goods of root and tuber crops in time and space, and the value of root and tuber crops as food security.

- Study the economics of processing of root and tuber crops and the role of the public sector and the IARCs.

Incentives for Progress: There are some interesting incentives that could be provided that would help facilitate inter-Centre collaboration on root and tuber crops research.

The panel proposes that TAC could **clarify the linkages** of CGIAR system root and tuber crops research programs to ecoregional and system-wide activities that are now being initiated. This would help the Centres see where the opportunities in ecoregional and System-wide initiatives co-reside with root and tuber crops research priorities and potential inter-Centre collaborations.

The panel proposes that **improved information** on the present and future importance of root and tuber crops, and their contributions to the CGIAR goals of food security, poverty alleviation, and sustainability would help establish appropriate research roles and help set priorities for research on these crops. This might include the development of appropriate databases and geographic information systems to help decision makers plan strategies and set priorities.

In another dimension (and where appropriate), the Centres should **develop joint partnerships** and networks with NARS on a regional basis, and explore other arrangements with NARS, NGOs, AROs, universities, and the private sector on an inter-Centre basis.

The panel clearly sees opportunities for Centres to **work cooperatively within regions**, to share capabilities (e.g., science discipline strengths), and to jointly respond to the needs and opportunities of NARS through a more coordinated effort on root and tuber crops research and training. This might be modeled after the successful CIAT/IITA cassava coordinating mechanism, that captures opportunities for complementarity, based on each other's capabilities.

Relative to the common difficulties of **effective technology delivery systems** for improved planting materials of root and tuber crops, the panel notes that the appropriate Centres could jointly engage in activities with other institutions such as FAO, the World Bank, and research-strong NARS for a concerted action program to resolve these constraints. Failure to find appropriate solutions to these complex problems will severely restrict the potential for impact from current and future research on root and tuber crops. In the panel's view, a considerable portion of the research needed in this area must involve the social, behavioral, and economic disciplines.

Inter-Centre coordinated efforts in root and tuber crops could provide a clearer vision of how investments in research collaborations for these commodities could **pay off**, relative to other research investments. Several representatives from IARCs working on root and tuber crops noted to the panel the perceived under investments in research of tropical root and tuber crops. This under investment, it was argued, represents a missed opportunity in what one scientist called, "Phase I" technological change[6].

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[6] The notion here is one that recognizes that the early stages of technological breakthroughs often yield the greatest benefits. Root and tuber crops, being relatively late on the global scientific research agenda should be an excellent area for research investments to gain significant research payoffs.

STRATEGIC OPTIONS

Fundamentally, there appear to be four strategic options available for the allocation of resources for root and tuber crops research in the CGIAR system:

- *Status quo*
- Down-sizing
- Consolidation
- Expansion

Option One: *Status quo* - There is significant justification for maintaining the *status quo* of the current resource allocations in the CGIAR matrix for root and tuber crops research, as originally recommended by TAC. Adjusting any formula funding system through periodic evaluations may only provide marginal corrections, of little significance in terms of amounts. But, the anticipation of unspecified change may be of great consequence for the stability and integrity of a research system. Periodic calls in the U.S. for a recalculation of the Hatch Act formula funds for research inevitably leads to a decision by everyone affected to leave it alone, as the adjustments themselves, and the fear of future changes, would cause more difficulties than they would solve.

Option Two: Down-sizing - There is considerable apprehension within sectors of the IARCS' network that the current round of priority setting by TAC may lead to a decision to significantly adjust the "envelopes" to match a new set of research priorities, given projected level budgets or shortfalls in resources. This concern goes beyond any singular inter-Centre study, to a need for a balancing of considerations system wide.

Concern has been expressed for the research future of some of the commodities now mandated within the CGIAR. Care must be exercised in the process of decision-making to consider the alternative research suppliers for "orphaned" commodities that have heretofore been covered by the IARCs. This is also true for CGIAR mandated areas of science and technology, if down-sizing is implemented System-wide. Providing commentary on setting the priorities for root and tuber crops *vs.* grain crops *vs.* eco-regions, and similar considerations, exceeds the remit of this study to a considerable degree, and will not be attempted herein.

Option Three: Consolidation - Consolidation of root and tuber crops research within the CGIAR system could be accomplished in several ways:

- Reorganization
- New partnerships
- Seeking alternative suppliers

Reorganization of root and tuber crops research within the System could be attempted through a reassignment of priorities (the mandate question), or through the elimination of some types of activities, based on some set of criteria. Some of these mandate alternatives were rejected by the standing panel, as the current IARCS' mandates for root and tuber crops research seem workable, and the commodities that have been selected for CGIAR research are deemed appropriate (see earlier discussion).

Another approach for reorganization could be to provide a new focus on similarity-based topic-problems worthy of greater inter-Centre research collaboration. In the standing panel's judgement there are significant opportunities for inter-Centre research collaborations. Moving in the direction of inter-Centre research collaborations should lead to a consolidation of research efforts, hopefully with greater efficiencies. There is, however, a need for an implementation and oversight mechanism (see recommendations).

New Partnerships and expanded partnerships could be formed in areas of research with traditional (e.g., universities) and non-traditional (e.g., private companies) institutions. Done more as a strategic approach, partnerships could offer new options for organizing global efforts in root and tuber research. Alliances with research strong NARS (as noted earlier) would be one such option. Other options include collaborations with AROs, building on already successful models of several Centres, and working in partnership with the private sector, as appropriate to the mission of the CGIAR System.

Seeking alternative suppliers is the third alternative that could be used for research consolidation. As indicated in the TAC Secretariat's *aide memoir*e, there is substantial root and tuber crops research being conducted in industrialized countries. How much of this is appropriate to the research agenda of the CGIAR system was not resolved by the Secretariat's analysis. Surprisingly, these activities are neither fully inventoried, nor are they constantly monitored for developments (see TAC Secretariat's *aide memoire*). There is at present a shortfall of information needed to evaluate the opportunities in this perspective.

Regarding the extent of industrialized-country root and tuber crops research that is appropriate to the CGIAR system, a best guess would indicate that this varies by commodity, as would the amount of research investments. For instance, it is very unlikely that industrialized countries would invest much in research for cassava or yams. And, the appropriateness of much of the industrialized countries' research to tropical root and tuber crops production is of course questionable. This then raises some questions on seeking alternative suppliers. Could this be done by the responsible IARCs through strategies designed to create research interests; or by strengthen institutional capacity through research initiation grants, strategic research partnerships, or other inducements?

These strategic options clearly extend beyond the current priority setting process of TAC. Nevertheless, they should be allowed to evolve into a continuous operation that scans the horizon for research collaboration opportunities that provide optimum solutions to a stream of continuously emerging needs.

Option Four: Expansion- A fourth strategic option for the CGIAR system would be an expansion of resources provided for root and tuber crops research. Justification for this option is found in the argument that post-harvest technology research will be critically important for a research breakthrough leading to an expanded utilization of these commodities. In the judgement of many, there is at present an under-investment in the CGIAR system in post-harvest technology research for the root and tuber crops. Reallocation of CGIAR resources from existing root and tuber crops research programs sufficient to meet this technology gap would critically diminish other needed research investments. A decision not to employ other strategies (e.g. strategic partnerships with the private sector, enhanced inter-Centre collaboration) may require additional research resources.

CONSEQUENCES OF CHOICES

The TAC Secretariat desk study projects significant production increases in root and tuber crops, based on information from two sources. Surprisingly, *per capita* consumption of these commodities is expected to decrease. This is a consequences of projected population growth. Strategies for dealing with the expected food shortages of the 21st Century will no doubt be referred, in a large part, to the CGIAR System.

There is a "lag time" associated with deploying research discoveries. The current round of priority setting for the allocating of resources within the CGIAR system will affect food consumption patterns in the "out years" of one or two decades and beyond. This is expected to be the period when the world's population crisis intercepts the global capacity for food production. This is why the TAC's resource allocation decisions in this round are so important.

There is admittedly a divergence of opinion on the methods that should be used for resource allocations for agricultural research. Some argue that scientific opportunity should be given priority over identified need. Scientific opportunity, it is argued, is where the breakthroughs will occur, and those opportunities are not necessarily found where there is an identified need. Others argue that resources must be placed only on identified-need areas, and then assume that the identified need will somehow lead to scientific discovery.

Neither argument in convincing. The first argument fails to meet the prerequisite for scientific relevance for publicly financed agricultural research. The second argument fails to appreciate the requirements of a scientific breakthrough (i.e., an existing pool of knowledge, among others things).

There are international expectations for IARCs. In addition to the two expectations cited above [that is, the need to 1) provide the best quality science on 2) the most relevant topics], the CGIAR system must also maintain donor interest and support. There is also the obvious need for the system to provide for a diversity of research programs, a plurality of scientific discipline activities, and a mixed portfolio of commodities.

THE FUTURE

The panel envisions that an inter-Centre initiative on root and tuber crops research could develop strategies for enhancing research effectiveness and, as a result, increase the likelihood for their success. Some elements seem necessary to bring this about:

- Approach to Pay Offs.
- Inter-Centre Strategies.
- Strategic Choices.
- Operational Changes.
- Collaborations.
- Implementation.

Approaches to Pay Offs: In the panel's view, a clearly stated approach is needed for how research on root and tuber crops could pay off, and how the benefits will flow for the alleviation of poverty and hunger, provide better food security, and yield additional farmer income. This approach should be stated as a common, inter-Centre strategy that focuses on the similarities of root and tuber crops. This common-effort-approach should allow the development of collaborative research synergies among the IARCs, their partner institutions, including research-strong NARS, AROs, universities, NGOs, and the private sector.

Inter-Centre Strategies: Inter-Centre strategies for root and tuber crops research should provide a focus on targeted subjects that would amplify the investments of research resources by working across commodities, and thus multiply the resulting benefits. Earlier in this report, some of these common areas were mentioned, and they are repeated here for emphasis - post-harvest technology and market research; biotechnology; policy analysis; vegetative propagation and conservation technology; and international germplasm exchange with phytosanitation.

It is clear, however, that some areas of research will remain as best carried out separately by each Centre. Other areas of root and tuber crops research will be planned within a framework of an inter-Centre strategy. A third category of research will be those activities that should be promoted, but may need to be slotted into a wider strategy (e.g., biotechnology, IPM).

In establishing an inter-Centre strategy on root and tuber crops research, there will be a need to design appropriate training programs to support program priorities; provide services to supply information for global and regional efforts; and to find new ways of "doing business."

Strategic Choices: In the process of developing the concept of an inter-Centre strategy for root and tuber crops research, the panel maintained an appreciation for the present differential involvement of research activities across root and tuber crops, based on our understanding of the dissimilarities the crops, regional differences, and technological opportunities.

There is, in the panel's view, a need for the root and tuber crop-mandated Centres to increase their involvement in some areas of research. To accomplish this new level of research activity there will necessarily be a need to decrease other activities, given anticipated flat levels of funding. In the panel's judgement, these decreased levels of research activity should be strategically planned. These strategic shifts in priorities might occur as: less activity in genetic enhancement and breeding; reduced testing; or less crop management research, relative to current activities. Other forms of strategic consolidation might occur through closer integration of research efforts, mostly with other partners, both within and outside the CG system.

Operational Changes: The panel noted opportunities for streamlining the exchange of germplasm (including wild relatives), through joint efforts to improve the processes, protocols, and technologies used for cleaning vegetative material. Related to this topic is the panel's suggestion for a joint research project on root and tuber crops reproduction biology, as a way to better assure the eventual adoption of improved materials. This research direction could search for alternative technologies to be used for the conservation and exchange of root and tuber crops genetic material (e.g., cryopreservation; culture techniques; diagnostics; artificial seed).

The panel noted, from an operational perspective, that there are many opportunities for joint activities. For instance, joint projects could be used to conduct surveys in related areas of root and tuber crops. These surveys, coordinated as inter-Centre efforts, could bring savings, and yield tremendous benefit for the participating researchers by "piggybacking" questions on a common survey instrument.

The panel noted the desirability of improving operations with respect to NARS to provide a more rational and consistent process in the interaction of root and tuber crops research, than now exists. This would best be done through inter-Centre evaluation of current operations (some of which already are shared efforts), and the identification of preferred operations.

Collaborations: As noted above, there are a number of opportunities for collaborative research activities that could be conducted jointly by Centres on topics common to root and tuber crops. Such specific research problems could be jointly addressed if better operational mechanisms were put in place to enhance inter-Centre projects (e.g., biotechnology, post-harvest technology, market and trade analyses, vegetatively propagated crops, policy issues, phytosanitary constraints, starch biochemistry, germplasm collection and preservation, collection of statistics and surveys, training, and mechanization research)

Implementation: Successful implementation of strategies for root and tuber crops research through specific inter-Centre collaborations will require a suitable organization. One of the greatest needs, in the panel's view, will be for better coordination of activities among Centres. This might be done through periodic meetings to discuss preferred organizational structures, the creation of coordinating mechanisms, the development of communication systems, the training of people, and an appreciation of institutional cultures that need to be brought together in a collaborative setting.

RECOMMENDATIONS

The panel makes two general recommendation for root and tuber crops research, upon which the remaining recommendations are based.

General Recommendations:

General Recommendation 1: Continue research investments in root and tuber crops research at least at current levels, with the expressed expectation that the participant IARCs will seek the most effective and efficient use of those resources.

Given the incompleteness of quantitative data and the uncertainly of projections for root and tuber crops (see the TAC Secretariat desk study), and the lack a clear understanding on potential alternative suppliers of scientific breakthroughs (see TAC Secretariat *aide memoire*), this recommendation seems reasonable.

General Recommendation 2: Form an "Inter-Centre Consultative Committee on Root and Tuber Crops Research" for system-wide planning, coordination, and operation.

The Consultative Committee's activity should be carried out with regional and global perspectives, and assist the participating Centres to form new, strong research collaborations with one another, the private sector, AROs, and NARS, to achieve a critical mass in research to solve global or continental problems.

The panel's approach would be for this Committee to be made up of the Directors General of CIP, CIAT, IITA, and possibly ISNAR, IPGRI, and IFPRI (or their designated representative).

In response to this recommendation, TAC's July 1995 commentary requested some clarification. TAC also requested a draft terms of reference (TOR) for the proposed Inter-Centre Consultative Committee. This is provided the accompanying table.

TERMS of REFERENCE
Inter-Centre Consultative Committee on Root and Tuber Crops Research of the CGIAR System

Concept	The Consultative Committee on Root and Tuber Crops Research in the CGIAR System (hereinafter The Consultative Committee) is a network of IARCS' institutional leaders who meet periodically to explore opportunities for collaboration and consensus-building on topics of mutual interest in root and tuber crops research, within the CGIAR System and beyond.
Purpose	To obtain program efficiencies in root and tuber crops research within the CGIAR System. Efficiencies will be sought through program synergies, financial leveraging, and knowledge amplification. The Consultative Committee is not a formal, funded institution, but a consortium of leaders seeking to enhance opportunities in research through joint planning and coordination.
Objectives	• To enhance communication on root and tuber crops research within and beyond the CGIAR System. • To jointly plan system wide strategies for root and tuber crops research. • To help establish consensus on research priorities and responsibilities. • To provide information and advice on root and tuber crops research needs and priorities. • To coordinate research activities within and beyond the CGIAR System.
Strategies	The Consultative Committee will seek to accomplish its objectives indirectly through the facilitation of activities by others when possible, and by direct action when necessary. The anticipated strategies should be as collaborative networking among Centres, and with other partners as appropriate. Opportunities should be explored to optimize resource use through enhanced research and training coordination. Research team-building should be encouraged as a strategy.
Membership	The Directors General (DGs) of the root and tuber crops-mandated IARCs, including those with commodity research responsibilities, those with policy research interests, and those with training responsibilities.
Process	The Consultative Committee will scan the horizon for opportunities to enhance the potential for institutions and individual scientists within and beyond the CGIAR System to contribute to the knowledge pool serving root and tuber crops. The Consultative Committee should seek to bring together common interests and subjects to foster the purposes of the CGIAR.
Duration	The Consultative Committee is established for a period of five (5) years. The creation and renewal of The Consultative Committee is by the authority of the Chairman of the CGIAR. Renewal is subject to demonstrated benefits to the CGIAR System and its claimants.

TAC additionally asked for justification for establishing a Consultative Committee. These points follow:

- No presently stated strategy.
- Expectations for the handing off of commodities.
- The apparent need for enhanced communication.
- Significant areas for research collaboration have been recognized.

There is at present **no stated strategy** for root and tuber crops research with in the CGIAR System. The similarities of the commodities (noted earlier) do provide some opportunities for collaboration on an inter-Centre basis. Developing a research strategy for these commodities could permit the attainment of greater research efficiencies and provide opportunities to leverage resources and amplify discoveries. This would be of great benefit to the System and its claimants. The standing panel concluded that this could be done under the aegis of the Inter-Centre Consultative Committee, and this point is included in the requested draft TOR.

The system-wide interest in the **handing off of commodities** or research areas to national programs could benefit from continued study by an Inter-Centre Consultative Committee. As noted above, there are a number of performance standards and complications that need to be considered and resolved if such an approach is to be successful. This consideration should be done with a system-wide perspective, and with an understanding of the research relevant similarities and dissimilarities of root and tuber crops within the CGIAR system.

Another justification for establishing an Inter-Centre Consultative Committee is for **enhanced communication.** An Inter-Centre Consultative Committee could facilitate joint planning of inter-Centre projects, and assist in the identification of research gaps and research overlaps that could be resolved through reprogramming.

Although the dissimilarities of root and tuber crops may appear to be significantly greater than the similarities, there are **significant areas for research collaboration** to be found among the Centres. The proposed Inter-Centre Consultative Committee could coordinate these research collaborations

Supplemental Recommendations:

The panel recommends that the proposed Consultative Committee convene a task force, including non-CG members, to prepare a comprehensive, documented text that sets out a vision for root and tuber research employing inter-Centre collaborations and institutional partnerships for root and tuber crops research.

The panel believes that this approach would permit the participating Centres to provide scientifically valid information to positively assist TAC's priority setting process. The panel does not believe that

this task would be onerous on the Centres, inasmuch as much of the information is readily available in documentation prepared for the Inter-Centre Review, and from the recently-completed EPMRs of CIP, CIAT, and IITA. The panel believes that this approach would give the Centres a deserved opportunity to obtain a balance on the roles of root and tuber crops research within the total efforts of the System, through a vision statement.

The panel recommends that the Consultative Committee develop a system-wide strategy for root and tuber crops research.

There is at present no comprehensive strategy for root and tuber crops research in the CGIAR System. The development of a comprehensive strategy would help to set expectations for the System, the research partners, and the donors. The comprehensive research strategy should clarify authorities and resolve research mandate questions, both within the System and externally. Finally, the development of a comprehensive research strategy should lead to a working set of procedures that would help facilitate collaborations within the global research community.

Some of the expected benefits of a comprehensive research strategy would be a clarification of how root and tuber crops research will link to eco-regional research activities, integrate with farming systems perspectives research, and become coordinated with system-wide initiatives of all kinds. The comprehensive research strategy should also facilitate the gathering of information to help document past, current and projected trends in root and tuber crops production and utilization to assist TAC in future priority setting processes.

The comprehensive research strategy for root and tuber crops could monitor global research activities that are relevant to the research being conducted by Centres and non-Centres alike. It could also plan how to evaluate the relevance and usefulness of research results emanating from both the public and private sectors. The comprehensive research strategy could also describe how best to articulate the priorities, needs, and importance of root and tuber crops research within the CGIAR System. Other strategic choices would likely include how to:

- identify opportunities for the passing off of research programs to research-strong NARS;

- make adjustments to priority investments in root and tuber crops research; and

- design systems for the analysis of the outcomes and impacts of the technologies developed for these commodities.

The panel recommends that the proposed Inter-Centre Consultative Committee commission a task force to explore the possibility of rationalizing international phytosanitation regulations and institutional arrangements for shipments of root and tuber crops as vegetatively-propagated materials.

This activity could be done in partnership with FAO and IPGRI, which have experience in developing similar protocols for other commodities (e.g., banana). This approach should work to speed up the safe exchange of germplasm used for international research on root and tuber crops.

The panel recommends that the proposed Inter-Centre Consultative Committee commission a study to recommend inter-Centre collaborations in biotechnology research.

Biotechnology is recognized as an area of research that is both expensive and human resource limited. By comprehensively looking for areas of common interest and opportunity, the Consultative Committee could leverage relatively small research investments into significant projects that transcend individual commodities.

The panel recommends that the proposed Inter-Centre Consultative Committee sanction a post-harvest technology and market working group to explore with AROs, NARS, and the private sector root and tuber crops research partnerships on:

- **The characterization of starch and flour (antecedent to industrial processing).**
- **Food processing technology.**
- **Market research.**

This recommendation is intended to encourage the Consultative Committee to explore the needs for strategic research on specifically selected post-harvest and market topics, such as starch chemistry. This recommendation is not intended to suggest that IARCs undertake significant amounts of applied research and development work in this area. The notion of this recommendation is to work to identify bottlenecks to the expansion of root and tuber crops utilization not being addressed by either NARS or the private sector, and plan strategically to remove those barriers. Exploratory studies might best be done through information-sharing, coordinated by the Consultative Committee, and initiated by a lead Centre.

The panel recognizes that undertaking this initiative may require additional resources (or the reallocation of resources), which seems justified, given the importance of this topic.

The panel recommends that the proposed Inter-Centre Consultative Committee continuously explore opportunities for different types of partnerships and collaborations among IARCs, and with public and private partner institutions in both the developed and developing world.

This recommendation is made with the panel's acknowledgment that there is no one formula suitable for the "devolution" of research responsibility. Actions to form partnerships with "research-strong NARS" must carry with them unique considerations and organizations for programmatic needs. Also, it must be recognized that, justifiably, a NARS should receive funds to meet the marginal costs

of internationalizing a part, or parts, of its national research program. This will require considerable planning and multiple year budget commitments.

The standing panel had previously recommended that both sweet potato and yam be passed off to specific national programs. This recommendation is being revised here for the following reason.

The current expenditures on yam research by IITA is sufficiently small that passing off of the program to a NARS would yield little System-wide or Centre financial benefit. Moreover, the benefits of "devolving" sweet potato to a national program remains to be shown as feasible, beyond the current level of collaboration already initiated by CIP.

The performance standards for partnering with research-strong NARS (noted above) could serve as a framework for discussions and negotiating future agreements with national governments, if it can be demonstrated that there are true cost efficiencies and effective research to be obtained from changing. However, a research-efficiency-analysis goes beyond the remit of this study.

There are, the standing panel notes, significant questions regarding the efficiencies to be gained by having national research scientists assume global research responsibility for a CGIAR-mandated commodity.

The panel recommends that the Consultative Committee seek ways to consolidate root and tuber crops research investments through a comprehensive plan that would build the capacity of AROs as alternative suppliers of relevant knowledge.

Opportunities exist to induce AROs to commit to research activities that are relevant to the mandated root and tuber crops, through any one of several strategies. To this point CIP has very creatively used contract research to accomplish aspects of its research agenda, at selected universities.This approach draws research faculty to a Centre's priorities for relatively small amounts of funding.

Alternative strategies might include invitations to conferences, support for sabbaticals, or training programs. The intent is to share with potential research partners opportunities for collaborations and partnerships through experiences and by example.

The panel recommends that the Consultative Committee formulate policy to encourage more private sector research partnerships.

As pointed out in an earlier section of this report, there is a significant need, and justification for, Centres with mandated root and tuber crops to work with the private sector, especially in the area of post-harvest technology. The establishment of such partnerships with the private sector will require a new set of policies regarding the development and use of intellectual property, the sharing of resources, and distribution of benefits. This must be done in ways that are not now easily accommodated.

The panel recommends that the Consultative Committee work to develop strategies and resolve policies regarding technology transfer activities.

The general expectation is for any new technology to quickly find its way into production agriculture. However, some national programs often operate with insufficient resources for adequate technology transfer programs. This can doom otherwise useful agricultural research results, for lack of application. This consideration is especially relevant to the root and tuber crops, as they share the characteristics of vegetative propagation, which complicates considerably the issues of technology transfer (e.g., a new cultivar's introduction), and for some aspects of technical assistance.

The message from donors is clearly in an interest for more, not less, technology transfer. But the mission of IARCs has been one of mostly focusing on research activities that will have an international impact, often at the expense of technology transfer. This then presents a dilemma to the IARCs working on root and tuber crops, inasmuch as the deployment of new technologies is not easily done indirectly through NARS. This problem needs new strategies, and some resolution at the policy level.

The panel recommends that the Consultative Committee remain vigilant of the environmental impacts of root and tuber crops production.

Aspects of the root and tuber crop production systems lend themselves to environmental problems. These consequences need to be monitored with a research perspective, to remain aware of the need for avoiding or mitigating problems. Contributing factors are:

- the soil-structure-damaging effects of crop harvest practices that can lead to certain consequences, such as severe soil erosion;
- economic incentives that can lead to overexploited agricultural chemicals, with resulting water and soil pollution problems; and
- the physical consequences of the bulky harvest on factors such as soil compaction, mineral loss, and women-in-agriculture issues.

These environmental aggravations are oftentimes worse for root and tuber crops than for other commodities. This is not intended as an indictment of these commodities, but more as a justification for providing adequate research investments to find superior technologies, and thus avoid these environmental problems. Consider the following example:

There is today a global crisis in potato late blight management. This is a direct consequence of under investments for the past half century in breeding potato programs. Potato growers in the Northern hemisphere have come to rely on chemicals to protect the crop from potato late blight disease, and breeding programs for the past half-century, have, with very few exceptions, uniformly failed to

incorporate resistance into replacement cultivars. As a consequence, virtually all commercial potato growers today find themselves fully dependent on chemical protection practices.

The sudden worldwide occurrence of the A-2 mating type of *Phytophthora infestans,* carrying a gene for resistance for the most important fungicide, has created a crisis that has yet to be resolved. There is no doubt that had research investments been adequate to allow the development of cultivars with resistance to potato late blight, this global crisis would have been considerably dampened, if not obliterated.

The proposed Consultative Committee would be in an excellent position to constantly scan the environmental horizon for emerging issues and technological consequences that need to be avoided or mitigated through alternative technologies.[7]

ANTICIPATED REACTIONS TO CHANGE

The standing panel attempted to evaluate the likely reception of changing approaches to research on root and tuber crops within and beyond the CG System. Evaluations were done from the perspectives of donors, NARS, farmers, Centres, and non-CG entities in an attempt to anticipate how they might view the panel's recommendations.

Donors:
The panel believes that a concerted inter-Centre initiative on root and tuber crops research would provide better donor appreciation of the opportunities for research, and present a "cleaner" strategy for their evaluation. In the present climate, it is desirable for proposed research activities to have an anticipated impact. The panel believes that a clearly stated strategy for root and tuber crops research could include such *ex ante* impact assessments. Derivative statements of impact should be developed, with the anticipated eventual payoffs, especially for the intended rural and/or poor populations. A clearly stated strategy could further elevate the visibility of inter-Centre collaboration (which is already respectable), and bring into the partnership more members, including the private sector.

The panel believes that the donor community may or may not be interested in post-harvest technology research as a major topic. Consequently, this may require a policy statement from the CG System to clarify the legitimacy of this strategic approach.

The panel also anticipates that donors might ask about the propriety of post-harvest technology research being funded in the public sector, and if there are not alternative suppliers in the private sector. The panel has concluded that this area of research has suffered under invested

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[7] This again is another example of how the Inter-Centre Consultative Committee on Root and Tuber Crops Research could assist in program planning and research coordination.

for a considerable period of time, and that pre-commercial research through the CG System could initiate considerable research opportunity and derived benefit, for both the farmers as the main client, and for the private sector as a catalyst, if carefully planned and strategically developed.

The panel also anticipates that donors to the CG System may expect of this panel a statement about the appropriateness of existing mandates for root and tuber crops research. The panel's response to this expectation is that the current mandates are, for the most part, working. A reconfiguration does not seem to be justified in our judgement.

NARS:
The panel concluded that a new inter-Centre strategy for root and tuber crops research would boost the morale and enhance awareness within the NARS. This could result in closer partnerships with substantial scientific benefits. Some of these benefits might include: stronger research programs; more access to information; increased awareness of research opportunities; greater exchange of research materials; greater mobility of germplasm; better linkages to third institutions, including advanced research organizations leading to new partnerships; better training opportunities; and more exchange of research results.

The panel did not feel that an inter-Centre strategy for root and tuber crops research would be seen as a threat by the respective NARS.

Farmers:
In the panel's view, enhanced inter-Centre research on root and tuber crops would increase opportunities for farmers, especially women and children, who are engaged in the production of root and tuber crops. The results of the proposed collaborative research on root and tuber crops to provide improved "seed" systems will have direct benefits to farmers by giving them access to healthier planting materials. Research on post-harvest technologies should provide increased market absorption of harvested products, and thus produce additional income for farms; more food for consumers; increased rural employment when small-scale processing is available; and perhaps more industrial products. Greater partnerships derived from inter-Centre collaborations on root and tuber crops research should expand the use of research findings, and perhaps open new channels for feedback from the farm community, which would be useful for priority setting in areas such as germplasm preservation, variety selection, and research.

Centres:
The panel concluded that international Centres would benefit from an inter-Centre initiative on root and tuber crops through enhanced partnership opportunities and a new awareness of investments in root and tuber crops research. The proposed Consultative Committee could clarify roles among Centres, and provide increased attention to problems within and among commodities of the root and tuber crops group. Greater coordination of planning and implementation should increase the efficiency of research investments, and assist in the exchange of data and knowledge for the benefit of all.

Non-CG Entities:
A concerted inter-Centre initiative on root and tuber crops research could have ripple effects within the system and beyond. In addition to facilitated cooperation and support, there should be an increase in the strength of research, and a consequent elevation of appreciation of the opportunities for research on root and tuber crops. Through a clearly stated research strategy there should be new opportunities for partnerships with the private sector, NGOs, AROs, and others. This should go a long way towards reducing what some have criticized as the autonomy and isolation of root and tuber crops research globally.

CONCLUSIONS

The standing panel feels that its overarching recommendation to form an Inter-Centre Consultative Committee for Root and Tuber Crops Research provides a "Pareto optimal solution" for the CGIAR system's efforts. This assertion is based on the expectation that considerable synergies can be obtained from inter-Centre collaborations and new partnerships in carefully selected research areas. The operational costs should be minimal, especially when viewed relative to the anticipated research pay-offs, but this needs to be verified by more detailed study.

The standing panel was surprised by the extent of differences that apparently dominate discussions of priority setting for root and tuber crops research within the CGIAR system. Many of these differences appear to be based on different sets of assumptions, insufficient production and consumption data, and too little exchange of information about the science and technology of root and tuber crops. Individually, the Centres feel disadvantaged, and in need of defending themselves from what they perceive to be incomplete information and bias against their commodity assignments.

Even though the panel sees considerable opportunity for inter-Centre collaboration, this initiative will need the support of both TAC and the CG System if it is to succeed. The Centres appear willing to engage in specific collaborative research efforts, and they appear to be receptive to creating coordinating mechanisms to expedite these initiatives. There was true excitement at the Root and Tuber Crops Workshop for some of the specific research topics that were identified as strong candidates for inter-Centre collaboration. In some cases, there appears to be sufficient resources to begin some initiatives right away (e.g., policy analysis) but in other cases (e.g., post-harvest technology research), reallocation of existing resources, or perhaps even new resources, will be required.

ACKNOWLEDGMENTS

The standing panel for the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR expresses its sincere appreciation to the workshop participants who attended the University of Maryland meeting, May 30-June 2, 1995. The contributions of the workshop participants greatly facilitated the activities of the standing panel, and provided an enormously valuable forum for the exchange of ideas on issues, options, and recommendations to advance root and tuber crops research within the CGIAR system.

The standing panel gratefully acknowledges the excellent leadership provided by the workshop facilitator, Mr. Donal O'Hare of O'Hare Associates, Inc. in Arlington, Virginia. Mr. O'Hare's professional skills in leading the meeting contributed greatly to the broadly acknowledged success of the workshop and its value to the panel.

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APPENDIX 1

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IN THE CGIAR

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APPENDIX 2

TERMS OF REFERENCE

INTER-CENTRE REVIEW OF ROOTS AND TUBERS RESEARCH IN THE CGIAR

The purpose of the Review is to assist TAC in formulating a System wide strategy for research on roots and tubers in the CGIAR to meet global and regional needs, taking into account current and projected demands. Specifically the Review will:

(I) Assess CGIAR priorities and its organization of work with respect to roots and tubers, considering them both as commodities and as components of production and farming systems.

(ii) Explore alternative approaches for carrying out this work.

Special consideration will be given to the following:

(I) Identify the major constraints on increased production and consumption of roots and tubers, including post-harvest problems, emphasizing those that have international research significance.

(ii) Review ongoing research and related activities on roots and tubers at CGIAR and other research organizations as well as relevant advanced institutions.

(iii) Outline priorities and strategies for roots and tubers research within the CGIAR, paying particularly attention to System wide aspects of research efficiency and impact potential.

APPENDIX 3

REFERENCE DOCUMENTS

Consultative Group on International Agricultural Research (CGIAR)

Consultative Group on International Agricultural Research. Renewal of the CGIAR: From Decisions to Actions. External Program and Management Review of CIAT. Mid-term Meeting 1995: May 22-26, 1995. 61 pages.

Consultative Group on International Agricultural Research. Renewal of the CGIAR: From Decisions to Actions. External Program and Management Review of CIP. Mid-term Meeting 1995: May 22-26, 1995. 97 pages.

TAC Secretariat. Food and Agriculture Organization of the United Nations. Consultative Group on International Agricultural Research. Report of the Fourth External Programme and Management Review of the International Institute of Tropical Agriculture (IITA) April 1995. 173 pages.

Technical Advisory Committee, CGIAR

AGR/TAC Secretariat. The CGIAR in the 21st Century: Options for Structural Change. May 13, 1994. 44 pages.

TAC Secretariat. Review of CGIAR Priorities and Strategies. December 1994. 167 pages.

Desk Study, prepared by the TAC Secretariat for this review, 1995. 9 pages. Draft One.

Desk Study, prepared by the TAC Secretariat for this review, Global Production and Consumption of Roots and Tubers. 1995. 36 pages.

Aide Memoire, prepared by the TAC Secretariat for this review, Overview of Research on Root and Tuber Crops Conducted Outside the Ambit of the CGIAR. 1995, 9 pages.

International Potato Center (CIP)

International Potato Center (CIP). CIP's Issues and Options Paper. International Potato Center Apartado 5969 Lima, Peru. (No Date) 13 pages.

G. Scott, CIP. Potatoes in the 1990s: Current Status and Future Prospects of the World Potato Industry , International Potato Center, Apartado 5969, Lima, Peru. April 26, 1995, 46 pages.

International Potato Center (CIP) and the International Service for National Agricultural Research (ISNAR) Priority Setting at CIP: An Indicative Framework for Resource Allocation. International Potato Center. Apartado 5969, Lima, Peru. (Date) 56 pages.

International Potato Center (CIP) The International Potato Center's Medium-term Proposal. International Potato Center. Apartado 5969, Lima, Peru. September, 1992. 166 pages.

International Potato Center. Meeting the Challenge: The International Potato Center's Strategy for the 1990's and Beyond. International Potato Center. Apartado 5969, Lima, Peru. (Date) 91 pages.

International Potato Center (CIP). CIP's Issues and Options Paper. International Potato Center. Apartado 5969, Lima, Peru. (Date) 13 pages.

International Potato Center. CIP's Research in 1995. International Potato Center, Apartado 5969. Lima, Peru. January 12, 1995. 44 pages.

Centro Internacional de Agricultura Tropical (CIAT)

Centro Internacional de Agricultura Tropical. Research for Development: The CIAT Cassava Program. May 1995. 106 pages.

Centro Internacional de Agricultura Tropical. Inter-Centre Review on Roots and Tubers Research in the CGIAR Towards Formulating a System-wide Strategy. Issues and Options. May 1995. 47 pages.

Centro Internacional de Agricultura Tropical. The CIAT Cassava Program: Project Areas, Projects and Resource Distribution. May 1995. 13 pages.

Centro Internacional de Agricultura Tropical Cassava Program: Achievements, Constraints, and Impact. September 1994. 18 pages.

Centro Internacional de Agricultura Tropical. Global Cassava Sector Trends: Reassessing the Crop's Future. May 1995. 31 pages.

Centro Internacional de Agricultura Tropical. Global Cassava Sector Constraints and Estimated Future R&D Benefits. May 1995. 39 pages.

Centro Internacional de Agricultura Tropical. Research for Development: The CIAT Cassava Program. May, 1995. 106 pages.

Briefing Document 1 Pro's and Cons of Housing Strategic Research on Cassava at the Center of Origin and Diversity of the Crop. March 31, 1995. 4 pages.

Briefing Document 2 Cassava in a Global, Multicommodity and Ecoregional Setting: Synergies and Spillovers Commodity Mandate Benefitting New Ecoregional Responsibility. March 31, 1995. 3 pages.

Briefing Document 3 Root and Tuber Crops: Differences and SIMILARITIES March 31, 1995.3 pages.

Briefing Document 4 Institutional Capacity for Cassava R & D. March 31, 1995. 2 pages.

International Institute for Tropical Agriculture (IITA)

International Institute of Tropical Agriculture (IITA). Background Documentation: Issues and Options Paper. International Institute of Tropical Agriculture. Ibadan, Nigeria. May, 1995. 36 pages.

International Institute of Tropical Agriculture (IITA). Background Documentation: Technical Scope of Research and Institutional Support for Research and Development. International Institute of Tropical Agriculture. Ibadan, Nigeria. May 20, 1995. 86 pages.

International Institute of Tropical Agriculture (IITA). Background Documentation: Workshop on Roots and Tubers Research in the CGIAR. International Institute of Tropical Agriculture, Ibadan, Nigeria. May 20, 1995 80 pages.

International Plant Genetic Resources Institute

International Plant Genetic Resources Institute (IPGRI). Genetic Resources of Roots and Tubers in the CGIAR. 1995. 9 pages.

International Food Policy Research Institute

International Food Policy Research Institute. Roots and Tubers: Inter-Center Review on Roots and Tubers Research in the CGIAR: Issues and Options Paper. 1995. 17 pages.

Inter-Centre Review Consultants

Sere, Carlos and Don Plucknett. Sweet Potato Research in China December 14, 1994. 15 pages.

APPENDIX 4

GLOBAL PRODUCTION AND CONSUMPTION OF ROOTS AND TUBERS

A TAC Secretariat desk study prepared in support of the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR.

APPENDIX 4

GLOBAL PRODUCTION AND CONSUMPTION OF ROOTS AND TUBERS

Resume

The purpose of this paper is to provide summary statistics on production and consumption trends in root and tuber crops to support the work of the Strategic Study of CGIAR Research on root and tuber crops. Following a brief description of the principal root and tuber crops grown in the developing countries, analysis of production and consumption trends since 1980 are presented. Global (developing country) and regional growth rates in production and consumption are presented and discussed on a crop-commodity basis. Future projections of production and consumption of root and tuber crops, based on recent studies by FAO and IFPRI, are also presented. Finally, preliminary analyses of alternative approaches to establishing priorities among root and tuber crops, and between root and tuber crops and the other major staple foods, are presented and discussed in the context of CGIAR goals of poverty alleviation and the management of natural resources.

INTRODUCTION

Roots and tubers provide a substantial part of the world's food supply and are also an important source of animal feed. On a global basis, approximately 55 percent of roots and tuber production is consumed as food; the remainder is used as planting material, as animal feed or in the production of starch, distilled spirits, alcohol and a range of other minor products. The patterns of utilization vary considerably among countries. In the developing countries, with the exception of China, Vietnam, Brazil and Paraguay, only small quantities (less than 20 percent) are fed to livestock and production is largely for on-farm food consumption. The relatively high costs of transport, processing and storage and the not inconsiderable time needed in preparation as food, frequently make roots and tuber crops less attractive to urban consumers (FAO, 1994). The consumption of roots and tubers as food is considerably smaller in developed countries, but their use as animal feed is relatively higher. A very small proportion of root and tuber production (5 percent approximately) is traded internationally and more than two-thirds of the exports are from developing countries; exports of cassava from Thailand account for more than half of the total. Cassava apart, only potatoes are traded in significant quantities and mainly among developed countries.

This paper addresses five major groups of roots and tuber crops, viz., Cassava (*Manihot esculenta*), Sweet potato (*Ipomoea batatas*), Potato (*Solanum tuberosum*), Yams (*Dioscorea spp.*) and edible Aroids (*Colocasia esculenta* and *Xanthosoma spp.*) known variously as Taro (*Colocasia*) and Tannia (*Xanthosoma*), but often referred to as cocoyams.

Cassava

Cassava's source of origin is tropical America; it is unknown in the wild state and its evolution as a species is directly linked to selection by man under cultivation. The exact time and location of domestication and its direct ancestors are not known. Cassava is the most widely cultivated root crop in the tropics and because of its long growth season (8 - 24 months) production is limited to the tropics and subtropics. It is grown across a broad range of agroclimatic conditions: from sea level to almost 2,000 metres in the American tropics and in areas with as little as 500 millimetres of rainfall to areas of tropical rain forest.

Important characteristics that earmark a role for cassava in tropical agriculture include: (i) high carbohydrate yield per unit of land and labour, (ii) adaptation to poor soils (low pH) and water stress (ability to withstand dry periods of up to five months) and (iii) compatibility with a wide variety of crops in rotational farming systems. Limitations include the high water content (60 - 70%) and bulkiness of the roots and root perishability after harvest. Cassava has been widely characterized as a subsistence crop and is typically grown by small-scale farmers, generally on agriculturally marginal lands. Fertilizer is seldom used in cassava production systems (less than 10% of farms) and few growers apply fungicides, insecticides or herbicides.

Sweet Potato

The centre of origin of sweet potato is Central America, but the crop is widely grown in many tropical and subtropical countries. Sweet potatoes are ranked seventh in world staple food production (expressed on a dry matter basis), after wheat, maize, rice, potato, barley and cassava. The crop is particularly important in South-East Asia, Oceania and Latin America. China still accounts for over 90% of total production; the other major sweet potato producing countries in Asia are: Indonesia, India, Japan, Vietnam, The Philippines and The Republic of Korea. Rwanda and Uganda are Africa's largest producing countries. Sweet potato production in Latin America and The Caribbean is relatively small.

Sweet potato is a perennial crop, but it is cultivated as an annual. It is grown between 40°N and 32°S latitude and at elevations up to 2,500 m. The plant is tolerant to a wide range of soil conditions, but is sensitive to water logging. The crop is generally grown on fairly infertile soils with little inputs of fertilizer. Tubers can be left in the ground after maturity, but once harvested they have a short storage life. For these reasons, sweet potatoes are generally grown as a subsistence crop for immediate consumption. A major cause of production loss arises from infestation of the tubers with the sweet potato weevil and related pests. The continuous reproduction of the weevil throughout the year makes control difficult. A notable feature of all statistics on this crop is that sweet potato production and consumption have continued to decline over the past two decades; whereas the significant reductions in production and consumption in China dictate the global downward trends, the reductions are also manifest in developing countries outside China.

Potatoes

The potato is of highland origin; domesticated in the Andes of South America, it became a major food crop in the cool highland areas of South America, Asia (Himalayas) as well as Central and Eastern Africa. In the eighteenth century the potato gradually became an important food crop for peasants and the urban poor in Europe and North America and many varieties now grown in the tropics originated in these temperate areas. More recently, potato production has spread from its traditional high altitude environment into warmer drier areas such as Peru's coastal valleys, the plains of India, Bangladesh and Pakistan and the irrigated oases of North Africa. Potato production has also expanded into the warm humid tropics; however, the prevalence of pests and diseases in these areas calls for high levels of pesticide use and varieties that are resistant or tolerant to pests and diseases.

In highland farming systems, potatoes are generally grown on small farms in a number of distinct parcels of land that, taken together, rarely exceed one to two hectares. Typically, the crop is rainfed and subject to many hazards including droughts and excessive rain, hail, frost and typhoon damage, depending on the location. Highland farmers generally retain a substantial part of the harvest to use as seed in the following season. Potatoes have also become an attractive winter crop in many arid, irrigated areas where they are grown on relatively large commercial farms. As harvest in these areas occurs at the beginning of summer, storage and marketing problems pose severe problems for this perishable crop; refrigeration is generally required both for seed and ware potatoes in these areas.

Yams

Yams are grown in many tropical regions throughout the world, but the main production centre is the savannah region of West Africa, where more than 90 percent of the crop is grown, mainly in Nigeria. White yam (*Discorea rotundata*) is believed to be indigenous to the area stretching from Côte d'Ivoire to Cameroon and is generally considered to be the best edible yam in that region. The yellow yam (*Dioscorea cayenensis*) is also indigenous in West Africa, whereas the water yam (*Dioscorea alata*) originated in South-East Asia. Yam production in Africa is concentrated in areas within 15 degrees of the equator.

Yams, like most African crops, are generally intercropped. They are normally grown in high rainfall areas with distinct wet and dry seasons; they grow best on loose, fertile, well drained soils. Production is labour-intensive because of the need for soil mounding before planting, for staking, weeding and above all for harvesting. A major constraint on yam production is the high cost and sometimes the unavailability of planting materials. The cost of planting materials can account for up to 60 percent of production inputs. High perishability and losses during storage (up to 50 percent) are a further constraint. Yam production systems have largely evolved within a subsistence economy and are not suited to large-scale mechanized production.

Aroids

Most of the cultivated edible aroids belong to two genera: *Colocasia* (Taro) and *Xanthosoma* (Tannia). Both taro and tannia are often referred to as cocoyams. Taro originated in India and South-East Asia and spread to Egypt about 2,000 years ago. Later it was grown in Spain from where it was taken to tropical America and later to West Africa. Tannia originated in tropical South America and the Caribbean. It is thought that the Spanish and Portuguese introduced it to Europe and later to Asia. The crop is thought to have initially spread to West Africa from the Caribbean around the middle of the last century. Cocoyams are typically grown as secondary crops in Nigeria and rank far behind yams and cassava in production and consumption; however, they constitute a staple food in parts of Ghana, Cameroon and Gabon.

Cocoyams normally produce optimum yields when planted in fertile soil with a high water retention capacity. The crop is well adapted to high rainfall and occasional flooding, to temperatures between 21 and 30°C and grows best at elevations below 1,000 m. Cultivation practices vary from region to region. Traditionally cocoyams are planted along the banks of streams, but in parts of West Africa they are grown in association with tree crops, especially cocoa. For edible aroids, as for most food crops in the tropics, labour is the main production input. Corms and cormels are used for propagation. The planting material is stored in the shade and after sprouting, cormels are selected for planting, usually on low mounds or ridges.

ROOTS AND TUBERS: SIMILARITIES AND CONTRASTS

Root and tuber crops share some common characteristics but are also very dissimilar in many respects; see Table 1. Potatoes have a shorter vegetative period than most other root crops and do best under cool temperatures. They can be grown in areas with high daytime temperatures, but do not form good tubers if night-time temperatures exceed 20°C. For good yields, potatoes require high inputs of fertilizer and organic manure. While the optimum rainfall for potatoes is lower than other root crops, potatoes do require a regular watering and are highly susceptible to drought. Harvested tubers can be stored for long periods if they are free of pests and diseases and low temperatures and high humidity are maintained.

The other root crops have longer and more variable growing periods; cassava, at the extreme, requires 9 - 24 months depending on soil fertility and temperature. Other root crops also do better under higher temperatures; for example, the optimal temperature for yams is 30°C. Also by way of contrast, sweet potatoes and cassava, though responsive to fertilizer, can produce economic yields on poor unfertilized soils with little organic matter. Both crops are also highly drought-resistant. However, their harvested roots cannot be stored for longer than a few days, but they can be left, unharvested, in the ground for long periods. In contrast to cassava and sweet potatoes, yams and edible aroids require fertile soils and adequate moisture. Both yams and edible aroids can be left on the plant after maturity and harvested when needed. If care is taken to avoid damage to tubers, corms and cormels during harvesting, they store well.

Table 1. Characteristics of Root and Tuber Crops

Characteristics	Cassava	Potatoes	Sweet Potatoes	Tannia	Taro	Yam
Growth period (mo)	9-24	3-7	3-8	9-12	6-18	8-11
Annual or perennial plant	per.	ann.	per.	per.	per.	ann.
Optimal rainfall (cm)	100-150	50-75	75-100	140-200	250	115
Optimal temperature (^{0}C)	25-29	15-18	>24	13-29	21-27	30
Drought resistance	yes	no	yes	no	no	yes
Optimal pH	5-6	5.5-6.0	5.6-6.6	5.5-6.5	5.5-6.5	n.a.
Fertility requirement	low	high	low	high	high	high
Organic matter requirement	low	high	low	high	high	high
Growable on swampy, water-logged soil	no	no	no	no	yes	no
Planting material	stem	tubers cutting	vine cutting	corms/ cormels	corms/ cormels	tubers
Storage time in ground	long	short	long	long	moderate	long
Postharvest storage life	short	long	short	long	variable	long

Source: Derived from Kay, D.E., 1973. Tropical Products Institute, London, as presented in Horton 1988.
n.a. = Data not available.

Root and tuber crops also vary considerably in nutritional value. All are low in protein content ranging from 0.9 g (Cassava) to 2.1 g (Potatoes) of protein per 100 g of edible food. Energy contents are high relative to other food crops and range from 76 (potato) to 124 K cal per 100 g of edible food (cassava). In terms of dry matter production per hectare, they outyield rice (1.9 $t.ha^{-1}$), cereals (1.3 $t.ha^{-1}$) and vegetable crops (1.6 $t.ha^{-1}$) with annual dry matter production levels of 3.0, 2.4, 2.2 and 2.1 $t.h^{-1}$ for cassava, yam, potato and sweet potato respectively (Horton and Fano, 1985). However, contrary to conventional thinking, root crops are not necessarily a cheap food. In most developing countries, yams, potatoes and edible aroids are costly sources of energy relative to cereals, sweet potatoes and cassava. Perishability and high transport and marketing costs make cassava expensive, especially as an urban food; however, cassava is consumed by both low income and high income urban households in South America.

ROOT AND TUBER CROP PRODUCTION: 1980-1992

In this study, data (FAO Agrostat) on root and tuber crop production over the period 1980 to 1992 were analysed. The results show that root and tuber crops are still a major source of food across the developing countries, albeit there are significant differences between countries and regions in the levels of production and patterns of utilization of the different crops. On aggregate, close to 36 million hectares of land in the developing world are devoted to root and tuber crops and yield a production in the

region of 401 million metric tons each year (Table 2). With the exception of the potato, root and tuber crops are almost exclusively grown in the tropics albeit across a range of topographical, soil and climatic conditions. On the other hand, roughly 70% of the global potato crop is grown in the industrial countries, with Europe accounting for more than 80% of production[1]. Regional differences in root and tuber crop production across the developing world are also very pronounced (Table 3). Asia is by far the major source of root and tuber crops (226 million metric tons/16 million hectares approximately), followed by sub-Saharan Africa (108 million metric tons/15 million hectares), Latin America (46 million metric tons/4 million hectares) and the Near East/North African region (13 million metric tons/0.8 million hectares). Equally, there are very large differences between individual countries within each of the four regions. China, for example, dominates sweet potato production accounting for more than 90% of global production, whereas Nigeria is the major producer of yams. Nigeria (No. 3) is also among the top five cassava growing countries which includes Brazil (No. 1), Thailand (No. 2), Zaire (No. 4) and Indonesia (No. 5). China dominates potato production (34% approx.) within the developing countries; other major potato growing countries in order of levels of production output are India, Turkey, Iran and Colombia.

From a crop perspective, cassava production accounts for approximately 38% of the overall root and tuber crop production in the developing countries; sweet potato accounts for more than 31%, potatoes for 23%, whereas yams (6%) and aroids (2%) make relatively small contributions on a global scale. There are also quite large differences in average yields per hectare, among the crops. Sweet potato showed highest yields (13.9 $MT.ha^{-1}$) in contrast to aroids with a yield average of 4.6 $MT.ha^{-1}$. Within the four main regions studied there are also significant differences among the crops. For example, sweet potato is the dominant root crop in Asia, cassava the dominant crop in sub-Saharan Africa and Latin America, whereas the potato crop accounts for more than 97% of root and tuber crop production in the Near East/North African region.

Table 2: Root and Tuber Crop Statistics
Average annual production ('000 MT, '000 hectares and yield per hectare) in developing countries in the period 1990/92

	Production ('000 MT)	Area ('OOO Ha)	Yield (MT.Ha)
Cassava	152,181	15,563	9.8
Sweet Potato	123,769	8,928	13.9
Potato	93,157	6,988	13.3
Yams	23,524	2,526	9.3
Aroids	8,533	1,839	4.6
Total	401,164	35,844	10.2

Source: FAO Agrostat.

[1] *Trends in potato production in developed countries have recently been studied by FAO/CIP (1995) and will not be discussed in this paper.*

PRODUCTION TRENDS

A number of time-series analyses of trends in the production and utilization of root and tuber crops have been published in recent years (FAO, 1992; Scott and Suarez, 1993; FAO, 1994; Wheatley and Scott, 1994). These analyses have focused primarily on the potato, cassava and sweet potato crops with little or no attention to yams and aroids, or the much lesser know Andean roots and tubers. A comprehensive three volume publication, 'Product Development for Root and Tuber Crops', published by CIP in 1993, presented reports on individual country data and developments in the major root and tuber crops across a broad range of countries in the developing world. These publications, and in particular the review papers cited above, have examined long-term (30 year) trends in the production and utilization of these crops. The purpose of this paper is to update these analyses by examining more recent trends (1980-92, and 1986-92) and future projections for root and tuber crop production and utilization, both on a regional basis and across the developing countries as a whole. Some limited information on root and tuber crop production on an agroecological zone basis is also presented.

Cassava

Average cassava production over the three year period, 1990/92, amounted to 152.181 million tons, representing an average annual yield of 9.8 $MT.ha^{-1}$ over a total area of 15.563 million hectares, across the developing countries (see Table 3). Cassava production continued to expand at approximately 2.0% per annum over the 12-year and 6-year timeframes reviewed; approximately two-thirds of the increased production came from additional area planted with little indication of a significant expansion in crop yields. These increases in output are considerably lower than in earlier periods as reported by Scott and Suarez (1993); their analyses showed annual increases of the order of 3.5% per annum in the sixties and seventies, albeit there were signs of a reduction in output growth (2.75%) over the period 1974-1989. These reductions in output from the sixties to the nineties are characteristic of most food crops, and will be discussed later in the context of land areas planted to cereal based food crops versus root and tuber crops.

The results in Table 3 show some significant regional differences, not only in terms of cassava output but also in recent growth rates, particularly as regards area planted to cassava. For example, area planted to cassava in Latin America decreased annually (-0.3%) over the past twelve years and the very small annual increase in production (0.3%) resulted from increased yields (0.6%). By way of contrast, cassava production in sub-Saharan Africa increased at an annual rate of 3.4%, but much (65%) of the increased production came from additional area planted to the crop. Annual growth rates of cassava production in Asia over the study period averaged 1.2%, largely as a result of increased yields per hectare.

Sweet Potato

Sweet potato is second only to cassava in terms of production output (123.8 million metric tons per annum) and land area (8.928 million hectares) in the developing countries planted to this crop. However, in the period 1990-92, China accounted for more than 90% of total production. Annual yields averaged 15.7 $MT.ha^{-1}$, but in

countries other than China, yields were significantly lower; in Africa, for example, yields were as low as 4.7 $MT.ha^{-1}$, in Latin America yields averaged 7.4 $MT.ha^{-1}$ and in Asian countries other than China yields were 8.6 $MT.ha^{-1}$. Reliable statistics are not available for the Near East/North African region as sweet potato production in this region is of very minor importance.

Levels of production of sweet potato dropped (-0.6% p.a.) across the developing world during the 12-year period, 1980-92. Area planted to the crop fell by 1.2% per annum and this was only partially offset by a modest annual increase (0.6%) in yields per hectare. The largest reduction in output occurred in Asia, particularly in those countries outside China (-1.7% p.a.) and in Latin America (-1.0% p.a.). On the other hand, sweet potato production increased in Africa as a result of a significant increase (2.6% p.a.) in area planted to the crop; in fact, the data suggest that yield per hectare declined marginally over the period. The data reported by FAO (1992) and Wheatley and Scott (1994) show that a reduction in sweet potato production had already become evident in the period 1973/75 - 1988/9, and that land area planted to the crop began to fall in the late sixties; however, yield increases over the periods analysed in these statistics offset the impact of reduced plantings.

Potatoes

The results in Table 3 show that potato production continues to expand across the developing countries at a significant level (2.8 - 3.1%). A little more than half (54%) of the increased production over the period, 1980-92, arose from an increase in the area planted, albeit a significant annual increase in crop yields was also manifest. These more recent annual trends are significantly lower than growth rates over the period, 1962-89, as published by Scott and Suarez (1993); however, as in the case of cassava, their analyses show that increases in potato production had begun to slow down in the late seventies and in the eighties (1988/90 vs. 1973/75).

Potato production in Asia continued to expand at a significant pace (2.9% - 4.0% p.a.) both within and outside China (see Table 3). Whereas yield increases grew at an annual rate ranging from 1.0 to 1.9%, roughly two thirds of the increased tonnage of potatoes came from expanded planting area. At the other end of the spectrum, there was a reduction in the area of land sown to potatoes in Latin America (-0.9% p.a.) over the study period; this was partially offset by increased yields resulting in a modest growth in output of 0.7% p.a. In the same period, potato production in the Near-East/North African region expanded rapidly (4.6% p.a.), albeit from a relatively low base (714,000 hectares) and the reported high yields per hectare (largely irrigated) continued to increase; potato exports to Europe may have been a significant factor in stimulating these increases as will be discussed later. On the other hand, potato production in sub-Saharan Africa remained low, both in terms of area planted (406,000 ha.) and total output (2,414 million MT); growth in output was also modest (1.2% p.a.). Yields per hectare were significantly lower than in other regions and changed little (0.6% p.a.) over the twelve year period.

Table 3: Regional Root Crop Statistics
Average Annual Production (1990/92) and Annual Growth Rates, 1980-92 (Δ_1%) and 1986-92 (Δ_2%)

CROP	PRODUCTION (MT)			AREA ('000 Ha)			YIELD (MT.Ha^{-1})		
	MT	Δ_1	Δ_2	Ha	Δ_1	Δ_2	MT.Ha^{-1}	Δ_1	Δ_2
CASSAVA									
SS Africa	71,340.4	3.4.	3.3	9,077.5	2.2	3.5	7.9	1.2	-0.2
Latin America	30,700.3	0.3	-0.8	2,641.8	-0.3	-0.5	11.6	0.6	-0.3
N. East/N. Africa	7.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Asia incl. China	50,132.6	1.2	2.0	3,838.5	0.3	1.1	13.1	0.8	0.9
Asia minus China	46,849.3	1.3	2.2	3,608.5	0.4	1.1	13.0	0.9	1.1
Developing (93)	152,180.8	1.9	2.0	15,562.5	1.2	2.1	9.8	0.7	-0.1
SWEET POTATOES									
SS Africa	6,249.8	1.5	0.9	1,327.1	2.6	1.3	4.7	-1.1	-0.4
Latin America	1,920.5	-1.0	-3.2	259.4	-1.6	-2.5	7.4	0.6	-0.8
N. East/N. Africa	131.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Asia incl. China	115,466.9	-0.7	0.0	7,336.6	-1.7	-0.1	15.7	1.0	0.2
Asia minus China	9,146.9	-1.7	-1.4	1,069.2	-2.4	-1.1	8.6	0.8	-0.3
Developing (93)	123,769.4	-0.6	0.0	8,927.9	-1.2	0.0	13.9	0.6	0.0
POTATOES									
SS Africa	2,414.4	1.2	1.0	405.9	0.6	1.0	5.9	0.6	0.0
Latin America	11,784.6	0.7	0.3	967.4	-0.9	-1.4	12.2	1.6	1.8
N. East/N. Africa	12,662.8	4.6	2.7	713.9	2.4	1.6	17.7	2.1	1.1
Asia incl. China	57,576.4	2.9	4.0	4,469.7	2.0	2.0	12.9	0.9	2.0
Asia minus China	25,509.8	3.7	3.6	1,651.7	2.1	1.9	15.4	1.5	1.7
Developing (93)	93,156.6	2.8	3.1	6,988.3	1.5	1.3	13.3	1.3	1.8
YAMS									
SS Africa	22,552.1	7.7	15.6	2,382.2	4.5	7.6	9.5	3.0	7.5
Latin America	631.8	-0.2	-1.5	83.2	-1.1	-3.6	7.6	0.9	2.2
N. East/N. Africa	117.2	0.2	1.4	44.3	1.3	2.2	2.6	-1.1	-0.8
Asia incl. China	223.3	3.5	4.6	16.7	0.5	3.1	13.3	2.9	1.5
Asia minus China	223.3	3.5	4.6	16.7	0.5	3.1	13.3	2.9	1.5
Developing (93)	23,524.4	7.3	14.7	2,526.4	4.2	7.0	9.3	3.0	7.2
AROIDS									
SS Africa	5,315.4	1.0	0.5	1,435.5	0.9	0.7	3.7	0.0	-0.2
Latin America	832.4	1.5	0.9	160.2	1.5	0.2	5.2	0.0	0.7
N. East/N. Africa	122.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Asia incl. China	2,257.2	-1.0	-1.9	238.9	-1.4	-2.7	9.4	0.5	0.9
Asia minus China	1,082.8	-1.1	-2.7	156.5	-1.2	-2.8	6.9	0.1	0.1
Developing (93)	8,533.1	0.5	-0.1	1,838.8	0.6	0.2	4.6	-0.1	-0.2

Source: FAO Agrostat.
n.a. = Statistics based on few data, and consequently not reliable/available.

Yams

The growing of yams can be said to be almost exclusively confined to Africa which accounted for 96% of total production; the relatively small levels of production in Latin America (3%) and Asia (1%) have very little impact on the aggregate developing country statistics. Indeed, within Africa yam production is largely confined to a few countries, principally Nigeria (15.9 MT p.a.), Côte d'Ivoire (2.7 MT p.a.), Benin (1.1 MT p.a.) and Ghana (1.0 MT p.a.).

Perhaps, of greatest note is the comparatively rapid expansion in yam production over the period, 1980-92. The data in Table 3 show that global production expanded on average by 7.4% (sub-Saharan Africa 7.7%) each year, largely as a result of a significant increase (4.2%) in the area planted to yams, but also because of a sustained annual increase (3.0%) in crop yield per hectare over the twelve-year study period. Trends over the six-year period, 1986-92, if such short series data can be interpreted with confidence, suggest that yam production continued to expand even more rapidly in recent years, both in terms of area planted (7.0% p.a.) and yield per hectare (7.2% p.a.). China does not report yam production statistics and consequently the expansion of yam production in Asia relates solely to countries outside China; much of the expansion in production arose from increased (2.9% p.a.) yields per hectare. On the other hand, yam production in Latin America remained relatively static over the study period; the slight reduction in area planted to yams (-1.1% p.a.) was largely offset by an annual increase (0.9% p.a.) in crop yield. As few data have been published on yam production, hitherto, it has not been possible to adequately compare these recent production trends with earlier time-series data. Data published by Dorosh (1988) indicated that yam production *per capita* in West and Central Africa was declining by -0.3% and -1.2% respectively over the period 1964-74, and by -1.1% and -1.98% over the period 1974-84. To the extent that population growth in these areas was expanding rapidly in the sixties and seventies, it can be deduced that yam production was also expanding at a significant rate over the two decades in question.

Aroids

Edible aroids as defined in this paper, based on the FAO Agrostat aggregations, include Yautia/Tannia (*Xanthosoma spp.*) and Taro (*Colocasia esculenta*) commonly termed cocoyams, together with a grouping of very minor root and tuber crops (e.g., *Arracacoa xanthorrhiza*) not individually specified because of their relatively minor importance in international food production. Most of these and other minor crops (e.g, *Alucasia, Cyrtosperma* and *Amorphophallus*) are cultivated globally to a very limited extent, but are important food crops in certain communities in India, south-east Asia and the Pacific Islands. Much more important and more extensive in their cultivation, are *Colocasia* (Taro) and *Xanthosoma* (Tannia); these crops heavily dictate the edible aroid statistics reported in this section.

Edible aroid production across the developing countries averaged 8.533 million tons per annum in the period, 1990/92, and changed little (0.5% p.a.) over the previous decade; the slight increase reported arose largely from increased plantings with little change in crop yields. Sub-Saharan Africa (5.315 million MT) and Asia (2.257 million

MT) dominated global production. Production increases (1.0% p.a.) in sub-Saharan Africa were offset by comparable decreases (-1.0%) in Asia, both changes principally due to fluctuations in land areas planted to these crops. Edible aroid crop production in Latin America, albeit very modest in quantity (832,000 MT p.a.), expanded at 1.5% per annum over the twelve-year study period as a result of increased plantings. As little has been published on production trends of these edible aroid crops, comparisons with earlier patterns of production are difficult.

ROOT AND TUBER CROP UTILIZATION: 1980-1992

Traditionally, root and tuber crops have been considered primarily as food crops with some by-products and wastes used for animal feed. In reality, these crops are applied to a wide variety of uses which vary considerably across countries and regions, and indeed among the individual crops. Over the past three decades, some notable changes in the utilization of these crops have occurred in individual countries. However, on a global basis (developing countries), the data published by Scott and Suarez (1993), show that, in general, the patterns of utilization of cassava, potato and sweet potato changed little over the timespan 1961/63 to 1988/90. In this paper the utilization of root and tuber crops over the period 1980-92 has been analysed; the results are shown in Table 4.

The table shows that, across the developing countries, food accounted for the highest share of all crops, averaging 68.9%, 50%, 62.8%, 58.6% and 84.9% for cassava, sweet potato, potato, yams and aroids. Little change occurred in these global food shares over the study period, with the exception of sweet potato, which decreased by 2.9% p.a.; Asia accounted for much of this change, not only through a reduction in sweet potato consumption in China, but also throughout the region.

The utilization of root and tuber crops as animal feed also changed little on a developing country basis, over the twelve-year period; the average shares for cassava, sweet potato, potato, yams and aroids were 14.8%, 40.3%, 13.2%, 1.0% and 3.0% respectively. The only noticeable change was a significant increase (5.7%) in sweet potato use as animal feed corresponding to a reduction in the food share referred to above; again almost exclusively originating in China and the rest of Asia. Another noticeable regional change was the reduction in yam consumption in Asia and the corresponding increase in use of the crop as animal feed; however, it should be recalled that yam production in Asia is only of very minor importance.

Looking across the different root and tuber crops, it is clear that little diversification has occurred in the use of yams and edible aroids; they continue to be grown essentially for food, at least on a regional basis. At the other end of the spectrum, both cassava and sweet potato utilization is more diversified across food, feed and industrial uses. These diversified utilization patterns are most obvious in Asia and Latin America. It should be noted that significant proportions of the potato crop are also used for livestock feed and in industrial use in China.

Table 4: Utilization of Root and Tuber Crops as Food, Feed and in Industrial Use: Average Percentage Shares (S%) 1990/92, and Annual Change 1980-92 (Δ%)

CROP	FOOD		FEED		INDUSTRIAL	
	S%	Δ	S%	Δ	S%	Δ
CASSAVA						
SS Africa	82.7	0.1	2.3	-0.8	0.2	-0.6
Latin America	37.1	-0.1	47.0	0.1	6.0	0.1
N. East/N. Africa	7.9	n.a.	0.0	n.a.	0.0	n.a.
Asia incl. China	70.8	-1.5	9.2	3.7	10.6	13.8
Asia minus China	75.2	-1.3	2.8	0.4	11.8	14.6
Developing (93)	68.9	-0.1	14.8	-0.7	3.8	4.7
SWEET POTATO						
SS Africa	58.3	n.a.	1.7	0.7	n.a.	n.a.
Latin America	48.3	0.1	10.6	-0.6	n.a.	n.a.
N. East/N. Africa	60.9	0.2	n.a.	n.a.	n.a.	n.a.
Asia incl. China	49.1	-3.0	41.2	5.7	4.6	-0.4
Asia minus China	40.3	-5.7	44.5	6.6	8.2	3.8
Developing (93)	50.0	-2.9	40.3	5.7	4.4	-0.3
POTATO						
SS Africa	75.5	0.2	1.1	1.2	0.0	n.a.
Latin America	77.0	0.2	2.8	-2.1	0.9	n.a.
N. East/N. Africa	79.9	0.1	1.9	2.0	0.4	n.a.
Asia incl. China	53.9	0.4	21.2	-1.3	0.0	n.a.
Asia minus China	73.3	0.2	1.9	-2.2	0.1	n.a.
Developing (93)	62.0	0.3	14.8	-1.1	0.2'	n.a.
YAMS						
SS Africa	57.8	0.6	0.6	4.2	0.0	n.a.
Latin America	72.8	3.3	14.9	-3.9	0.0	n.a.
N. East/N. Africa	90.0	n.a.	0.0	n.a.	0.0	n.a.
Asia incl. China	82.3	-0.3	5.0	-8.3	0.0	n.a.
Asia minus China	82.3	-0.3	5.0	-8.3	0.0	n.a.
Developing (93)	58.6	0.4	1.0	-4.6	0.0	n.a.
AROIDS						
SS Africa	83.5	0.3	2.1	0.9	0.0	n.a.
Latin America	79.9	-0.1	0.9	3.6	0.0	n.a.
N. East/N. Africa	62.0	-1.2	0.0	n.a.	0.0.	n.a.
Asia incl. China	90.9	-0.1	4.0	0.6	0.0	n.a.
Asia minus China	85.2	-0.5	4.9	-0.1	0.0	n.a.
Developing (93)	84.9	0.1	3.0	1.2	0.0	n.a.

Source: FAO Agrostat.
n.a. = Statistics based on few data, and consequently not reliable/available.

Per capita consumption

Levels and changes in *per capita* consumption of the different root crops are shown in Table 5. Large differences emerged across the different regions and among the crops. At the global level, *per capita* consumption of cassava averaged 22.1 kilograms per person *per annum* in marked contrast with a *per capita* consumption of 1.8 kilograms *per annum* of edible aroids. Large regional differences in the *per capita* consumption of all crops were also manifest. With the exception of potatoes, the data showed a reduction in *per capita* consumption of all root and tuber crops over the 12-year timeframe. This essentially indicates that production levels did not match increases in population growth, possibly as a result of changes in dietary preferences, urbanization trends and the relative prices of alternative foods.

FUTURE PROJECTIONS OF ROOT AND TUBER CROP PRODUCTION

In recent years a number of studies have attempted to project future trends in the demand for and supply of the major food crops. These include two FAO studies, viz., (i) 'Medium-Term Prospects for Agricultural Commodities - Projections to the Year 2000' and (ii) 'Agriculture: Toward 2010', and a recent IFPRI study, 'Global Food Projections to 2020: Implications for Investment'. In all three studies the projections are based on past and current production trends tempered by assumptions relating to future population growth, changes in economic development patterns, food demand and anticipated dietary changes in the context of growing urbanization. A synopsis of the three studies is presented below.

Projections to the Year 2000

Production: This study projects that output of root and tuber crops in the developing countries will increase by 1.3% per annum, resulting in the production of 455,452 MT by the year 2000 (see Table 6). The bulk of this increase is forecast to occur in the Far Eastern countries, particularly in some of the major root crop producing countries such as India, Indonesia, the Philippines and Vietnam. Strong growth in potato and sweet potato production is anticipated in India and Indonesia, whereas growth in cassava is expected to be strongest in Vietnam. In contrast, it is projected that growth in root and tuber production in China will be modest (less than 1% p.a.) and will depend entirely on increased yields, due to the continued replacement of sweet potatoes by cereals.

Growth rates of root and tuber crops in Africa (2.6% p.a.) are expected to result in a production of 150 million tons (approx.) by the year 2000, largely due to increased planting of potatoes, sweet potatoes and cassava. Regional output in Latin America is also projected to increase particularly in Brazil, Colombia and Peru. However, expansion of root and tuber crop production in the Near East countries is expected to slow down in comparison with the growth rates witnessed in the eighties.

Table 5: Annual *Per Capita* Consumption ($Kg.c^{-1}.a^{-1}$) in the period 1989/91 and Annual Change over the period, 1980-91 (Δ%)

CROP	$Kg.c^{-1}.a^{-1}$	Δ%
CASSAVA		
SS Africa	116.6	0.4
Latin America	26.6	-1.7
N. East/N. Africa	n.a.	n.a.
Asia incl. China	7.3	-2.6
Asia minus China	11.6	-2.9
Developing (93)	22.1	-0.2
POTATO		
SS Africa	3.8	-1.5
Latin America	21.5	-1.0
N. East/N. Africa	31.3	1.8
Asia incl. China	10.3	1.6
Asia minus China	9.7	2.5
Developing (93)	12.4	1.0
SWEET POTATO/YAMS		
SS Africa	34.2	2.1
Latin America	4.2	-2.6
N. East/N. Africa	0.3	-0.6
Asia incl. China	21.0	-5.6
Asia minus China	4.2	-3.8
Developing (93)	19.1	-4.4
AROIDS		
SS Africa	9.1	-1.8
Latin America	1.3	-0.7
N. East/N. Africa	0.3	-1.4
Asia incl. China	0.8	-2.5
Asia minus China	0.3	-2.5
Developing (93)	1.8	-1.4

Source: FAO Agrostat.
n.a. = Statistics based on few data, and consequently not reliable/available.

Consumption: The FAO Year 2000 study projects that consumption of root and tuber crops in the developing countries will increase by 1.8% p.a., but consumption *per capita* is expected to decline. The study suggests that this decline will reflect a movement towards more readily available and easily prepared cereal staples. In this context, mention is made of the high marketing and processing costs of roots and tubers coupled with inadequate storage. Urbanization in Africa is calculated to curtail consumption, particularly for cassava and yams, but will only have a small effect on potato consumption. Consumption in Latin America and the Caribbean is projected to increase

by 1.8% p.a., mainly reflecting population growth (and in the case of cassava, increasing industrial use), but on a *per capita* basis a long-term decline in root and tuber consumption is anticipated.

In the Far East, consumption of roots and tubers is projected to rise at 1% p.a. Highest growth is expected in Thailand where a major shift of supply from export to domestic markets is foreseen as a consequence of the reforms in the European Community marketing policies. In contrast, the domestic market for roots and tubers and in particular for sweet potatoes in China is expected to fall as higher incomes encourage a shift in patterns of consumption.

Table 6: Root and Tuber Crop Production - Projections to the Year 2000

Area	Projected Production ('000 MT)	Growth Rates (%)
Africa	149,882	2.6
Latin America	57,217	1.7
Near East	12,215	2.0
Far East	234,101	0.6
Other developing	2,037	2.0
Total developing	**455,452**	**1.3**

Source: FAO Medium-term prospects for agricultural commodities - projections to the year 2000.

The study questions further expansion in use of roots and tubers as animal feed, mainly as a result of change in government policies. In the developed countries, the demand for roots and tubers as animal feed is expected to fall. Lower domestic grain prices and the slowing down of livestock production in the EC, as a result of the CAP reform, are expected to reduce import demand; this is expected to significantly effect cassava imports to the EC. These trends will be further aggravated by the Uruguay trade agreement, albeit the impact of these new arrangements was not considered in the study.

Trade: Only a very limited amount of roots and tubers is traded internationally. The vast majority of production in developing countries is utilized on-farm, because the inherent high degree of perishability and bulkiness of the product results in high transport costs. In the 80s, however, there was a noteworthy increase in international trade, largely, because of an expansion in the export of processed cassava from Thailand to the EC. By the late 80s, trade in cassava accounted for 75% of total trade in roots and tubers and reached 30 million tons, whereas trade in potatoes accounted for the remaining

25%. The FAO Year 2000 study projects a significant fall in cassava chips trade, but that trade in potatoes and cassava starch will increase substantially.

'Agriculture: Towards 2010'

The FAO study, 'Agriculture: Towards 2010', makes projections on root and tuber crop production over a 20-year horizon. A summary of the projections is shown in Table 7. In general, the projections anticipate significant growth in root and tuber production (more than cereals) with much of the expansion coming from increased yields. It is tacitly assumed that the application of existing technologies can dramatically increase yields, particularly in regions such as sub-Saharan Africa.

Potato yields across the developing countries are expected to grow by as much as 3.9% p.a., but a projected reduction of 1.9% in the area of land planted to the crop is expected to result in an overall production increase of the order of 1.9% p.a. However, the study anticipates significant regional differences in the growth of potato production, with an expected high growth in sub-Saharan Africa (3.4% p.a.) and a modest growth in Asia (1.6% p.a.), largely because of a reduction in the cultivation of potatoes in China. Annual production growth rates of 2.7% and 1.9% p.a. are anticipated in Latin America and the Near East/North African regions.

Cassava production is expected to grow at an even faster rate (2.1%), again with about half of the increase coming from increased productivity per hectare. Little change in output is anticipated in Asia (a negative 0.4% p.a. in fact), whereas rapid expansion (3.4% p.a.) is projected for Africa, much of it (62%) dependent on increasing the current low yields per hectare across the region. The study also projects significant increases in cassava production in Latin America (2% p.a.), arising, in near equal proportions, from increases in crop yields and in area planted to the crop.

The projections for yams and sweet potatoes were aggregated as a single crop group, in the FAO 2010 study. Given the diverse trends in the recent production histories of these crops (increased growth in yams vs. reduced sweet potato production), it is difficult to interpret the study's projections on these crops. Suffice to say that, on aggregate, the two crops are projected to increase by 1.5% p.a. across the developing world, with the largest increases anticipated in sub-Saharan Africa (3.7%) and Latin America (3.0%). Noticeably, the study projects a significant reduction in land area planted to these crops (-2.4% p.a.) and a rapid annual increase (4.0 % p.a.) in crop yields! This contrasts sharply with recent trends as reported in this study (Table 3). The edible aroid crops are also anticipated to increase at an annual rate of 1.9% p.a., arising from increased plantings and crop yields in nearly equal proportions.

Projection across Agroecological Zones

Of interest, in the context of ecoregional research and development programmes, the FAO 2010 study examined roots and tuber crop production on an agroecological basis and made projections across the different agroecological zones. The projections are based on average output and yields reported in the period, 1988-90, and arrived at through a process of objective and subjective appraisals of the growth potentials of the different land classes coupled with subjective expert opinion on likely advances in and application of production technologies. The projections suggest that, across the developing countries as

a whole, cassava production will expand most rapidly in the moist semi-arid, humid and subhumid zones, whereas highest growth rates in potatoes are anticipated in the irrigated and moist semi-arid zones. The largest percentage growth rates for sweet potato/yam and edible aroids are projected on the fluvisol/gleysol soil classes and in the humid regions.

Table 7: Root and Tuber Crop Production: Projected Annual Growth Rates to 2010

CROP	PRODUCTION Δ %	AREA Δ %	YIELD Δ %
CASSAVA			
S.S. Africa	3.4	1.5	1.8
Latin America	2.0	0.9	1.0
N.East/N. Africa	0.0	0.0	0.0
Asia incl. China	-0.4	-1.3	0.9
Asia minus China	-0.3	-1.0	0.7
Developing (93)	2.1	0.9	1.2
SWEET POTATO/YAMS			
S.S. Africa	3.7	1.8	1.9
Latin America	3.0	2.0	0.9
N.East/N. Africa	-1.0	-0.2	-0.7
Asia incl. China	0.7	-8.3	9.8
Asia minus China	2.9	1.8	1.2
Developing (93)	1.5	-2.4	4.0
POTATOES			
S.S. Africa	3.4	1.3	2.1
Latin America	2.7	1.8	0.9
N.East/N. Africa	1.9	1.0	0.8
Asia incl. China	1.6	-4.9	6.7
Asia minus China	2.2	0.5	1.7
Developing (93)	1.9	-1.9	3.9
AROIDS			
S.S. Africa	2.4	1.3	1.1
Latin America	1.2	1.1	0.1
N.East/N. Africa	1.1	1.1	0.0
Asia incl. China	0.8	-1.1	1.9
Asia minus China	2.7	1.7	1.0
Developing (93)	1.9	1.0	0.9

Source: FAO Year 2010 Study

By and large, the regional projections mirror the global trends with some notable exceptions. The study projects a reduction in both potato and cassava production in the subhumid and humid tropics of Asia when China is excluded. Within this region, cassava production is also projected to fall in the moist semi-arid zone. Projections on cassava, sweet potato/yams and edible aroids for the Near East/North African region are not discussed as the levels of output of these crops are of very minor significance in the region.

Finally, the IFPRI Study, 'Global Food Projections to 2020: Implications for Investment', has published aggregate projections on root and tuber crop production (all crops) to the year 2020 (Rosegrant *et al* 1995). The study suggests that production will grow at a rate of 1.64% p.a., of which 37% will come from increased area planted and the balance of 63% from increased yields. With the exception of rice, the study projects that roots and tubers will fail to match the productivity increases anticipated in the cereal crops; this projection is not consistent with the FAO 2010 Study, but the differences in the projected growth rates are not very great.

DISCUSSION

Statistical parameters on root and tuber crops in the developing countries are difficult to estimate with any degree of precision (Horton, 1988). The difficulty arises from the very nature of the crop (subterranean root and tuber growth), the extended planting and harvesting seasons, and the predominance of traditional production and harvesting systems and storage practices associated with resource-poor farmers and isolated marginal land areas where the crops are normally cultivated. In many developing countries and particularly in Africa, root crop statistics are based on extrapolations from small, often dated surveys (Dorosh, 1988). It is also suggested that government agencies tend to underestimate root crop production and consumption, because root crops are grown in isolated areas on small, irregular plots, frequently as intercrops, relay crops, secondary crops or backyard garden crops. (Horton, 1988) A further difficulty arises when time series analyses are undertaken. The FAO Production Yearbook publications are the commonly used reference source. However, it should be remembered that FAO continually revises and updates its estimates and does so retrospectively; consequently, recently updated Agrostat data are most accurate in time series analyses. This also implies that short timespan series analyses probably reflect trends more accurately than do long span analyses. However, in general, time series analyses should be interpreted with caution.

By and large, the trends reported in this study are consistent with most earlier studies, if not in the absolute levels of change, certainly in the direction of the changes indicated. The main trends may be summarized as follows:

Production:

(i) Root and tuber crops continue to be a major staple food across the developing world, yielding a total production in excess of 400 million metric tons of product, which in addition to its main use as human food, alternatively is used as animal feed or as a base material for a wide range of industrial processing.

(ii) In order of global production output per annum across the developing countries, the crops ranked as follows: 1. Cassava (152,181 MT), 2. Sweet Potato (123,769 MT), 3. Potato (93,157 MT), 4. Yams (23,524 MT), and 5. Edible Aroids (8,533 MT).

(iii) With the exception of sweet potato production, output of the major root and tuber crops expanded over the past decade, at moderate (cassava: 2%) to intermediate (potato: 3.1%) and at very high (yams: 7.3%) rates of annual growth.

(iv) Growth rates over the past decade were considerably lower than in the sixties and seventies (cf. Scott and Suarez, 1993), but the fall-off in production growth rates is in line with the general reduction in agricultural output of all agricultural crops over the period in question. The increase in yam production is a notable exception.

(v) Crop yields changed very little over the twelve-year period (1980-92) with the exception of yams (3% p.a. increase) and to a lesser extent potatoes (1.3% p.a. growth).

(vi) Expansion in area planted to roots and tubers was the main component of increased production.

(vii) Strong regional differences in production output and annual growth rates, and to a lesser extent in land area changes and crop yields, were evident in the study period. Asia was the major producer of root and tuber crops, and in particular of sweet potato and the potato crop, whereas cassava production was the most important root crop in Africa. Yams, and to a lesser extent edible aroid crops, all be they minority crops on a global basis all made important contributions to food production in Africa, and particularly in Nigeria. Asia headed the list in terms of improvements in crop yields.

Utilization:

(viii) Root crops continue to be predominantly used as a source of food; on a global basis the sweet potato crop is most prominent as regards the extent and range of its utilization as animal feed and in industrial processing, in addition to its use as a staple food. However, cassava and potatoes also make important contributions to the animal feed industry, and in the case of cassava to industrial processing. Yams and the edible aroid crops continue to be almost exclusively used as food for human consumption.

(ix) Globally, across the developing countries, the only major shifts in root crop utilization patterns appear to be in Asia, principally with regard to diversification in cassava use. However, global and regional statistics can mask developments at the level of individual countries; this will be discussed later.

(x) Annual *per capita* consumption of root crops averaged 55 kilograms in the period 1980/91. Large differences in consumption levels were evident not only among the crops, but also between the regions across the developing world. The consumption of roots and tubers is particularly prominent in Africa.

(xi) In general, *per capita* consumption levels fell over the study period with the exception of the potato, indicating that production level increases are not matching population growth. However, the effects of urbanization coupled with possible changes in dietary preferences (convenience foods) may also have had a significant bearing on the reduction in *per capita* consumption levels.

Projected Growth:

(xii) The three projection studies reviewed in this paper envisage modest to fairly significant expansion in root and tuber crop production in the future, albeit the three studies encompassed quite different time horizons. On a global basis, the growth projections averaged 1.3% p.a., 1.8% p.a. and 1.6% p.a. in the FAO Year 2000, FAO Year 2010 and IFPRI Year 2020 studies, respectively. Implicit in all three studies is the projection that crop yield increases will grow significantly in the future, an assumption that has clear implications for the development and/or transfer of production technologies.

(xiii) The FAO 2010 Study implies that root and tuber crop production growth rates will marginally outpace growth in cereals, whereas the FAO Year 2000 and IFPRI Year 2020 studies indicate growth rates somewhat less than cereals, rice not included.

Another major observation that is evident in this study is that aggregate analyses, such as those presented here, can mask significant developments at the level of individual countries. Firstly, it is obvious in the data presented that aggregated global (developing country) statistics do not reflect the wide variation that exists from region to region. Perusal of the data on the individual countries within the regions studied further emphasizes this point. In the context of capturing the dynamics and embryonic development of any given industry, particularly as they relate to future research needs and priorities, global and regional analyses such as those presented here, have considerable limitations. Evidence to support this point emerges strongly in the studies published by Scott and Suarez (1993), Wheatley and Scott (1994), Henry and Gottnet (1995) and indeed in several of the papers presented in the CIP publication, 'Product Development for Root and Tuber Crops', volumes I, II and III. A review paper, 'Potatoes in the 1990s', currently being prepared by FAO and CIP, further exemplifies this point in the context of developments in international trade in potatoes.

Whereas international trade in cassava peaked in the early nineties, and is currently facing a nose dive in the exports of cassava pellets to Europe as animal feed, growth in cassava based extracts and in particular in starch is expanding. For example,

starch production in Thailand has been increasing in recent years at a rate of 8% p.a. and a considerable amount of research on the development of modified starches for a variety of industrial uses is being undertaken both in the public and private sectors (Cenpukdee et. al. 1992). Several countries (e.g., Indonesia, Vietnam, Colombia and Nigeria) are researching the use of root crop flours as a substitute for cereal flours and starches and a number of successes have been reported (Berrios and Beavogui, 1992; Odaga and Wanzie, 1992; Damardjati et. al. 1994 and Gitomer, 1994).

Starch extraction from root crops expanded rapidly in some individual countries (Thailand, Brazil and Indonesia) during the 1980s (Wheatley and Scott, 1994). However, seasonal variation in product supply and lack of storage are major bottlenecks in the development of this industry. It highlights the need for R & D on primary processing and cost-effective storage systems. More fundamentally, sustained or expanded root and tuber crop consumption will increasingly demand research on postharvest technologies to meet the growing trends in diet diversification which follow economic growth and urbanization. Wheatley and Scott (1994) have discussed this subject at some length; they report interesting case studies and development examples from Indonesia, China, Hong Kong and Singapore in Asia and from Colombia, Guatemala, Costa Rica and Panama in South America. All of these examples of embryonic developments in the processing and diversification of root and tuber crops, have clear implications for the importance of postharvest research, not only to secure a future niche for roots and tubers in the food chain, but also for the long-term competitiveness of this group of crops in future land use systems.

Assessing the Priority of Root and Tuber Crop Research

In the context of establishing priorities for national and/or international agricultural research, several and indeed contradictory arguments can be advanced to support and/or to undermine support for research on roots and tubers. Some of the arguments will be briefly discussed, all in the context of the major goals of the CGIAR, viz., improving sustainable food security through the alleviation of poverty and the conservation of natural resources.

The research priority of root and tuber crops as a source of human food, as animal feed or as industrial raw material may be described in terms of output parameters, measures of utilization and demand, and productivity indices (input/output ratios). The discussion which follows will focus primarily on the utilization of root crops for human consumption and animal feed in that, to date, the use of root crop products (principally starch) in industrial processing is of very minor significance on a global basis. *Crop output parameters* include: (i) Gross output of harvested material (metric tons), (ii) Dry matter percentage (% DM), and (iii) Output expressed in terms of food/feed energy (Kcals) and protein (Kg); ideally crop by-products (vines, stalks, etc.) should be included in these measurements but few reliable data are available. *Utilization parameters* include: (i) Total consumption (metric tons), (ii) Food and feed utilization shares (%), (iii) Per-capita consumption ($Kg.C^{-1}$), and (iv) Proportion of dietary calorie supply (%). *Productivity indices* ideally should include output per unit area of land, labour and capital, taking into account input costs such as seed, fertilizer and biocides, to facilitate gross and

net margin profit analyses; however as the economics of root crop production in the tropics are very poorly documented, few estimates of these measures of productivity are available.

Each of these parameters has merit in projecting the relative importance of each crop from a particular perspective. However in making comparisons among crops, or as between root and tuber crops and cereals for example, some common value denominators are needed. A widely used congruent in priority analysis of agricultural research is the economic value of production expressed in a standard currency; it is the starting point of the 1992 CGIAR Priorities and Strategies analysis which expressed the gross value of production of the major food commodities in US dollar terms. One of the limitations of this approach, as cited in the CGIAR Priorities and Strategies study, is the difficulty in getting comparable information on crop prices that reflects the *true value* of each commodity to the consumer across so many diverse socio-economic environments within the developing countries. This is particularly difficult for root and tuber crops which for the most part are consumed on-site by the producer; consequently, international trade in these commodities is non-existent (yams and edible aroids) or very limited (cassava, potatoes and sweet potatoes). As a result, relevant and reliable price data are very difficult to obtain.

An alternative approach would be to compare the crops in terms of energy and protein production relative to human dietary needs. However, this approach also has its limitations in that no single crop adequately meets the balanced requirements of the human diet, which in addition to protein and energy includes specific essential amino acids, minerals, trace elements and vitamins. Root and tuber crops vary considerably in these different components and in turn are markedly different from other staples, most noticeably in terms of protein content. Food protein is particularly important for the poor as their choice of food is often limited to one or two staple crops. Consequently, priority ranking of food crops is arguably better based on an index which takes into account the energy content of the protein fraction of the crop.

Output Parameters. Rankings of root and tuber crops on edible energy, edible protein, protein adjusted energy and economic value of production (VOP) are shown in Table 8. Values for rice and wheat are also listed for comparison. The economic values of production are based on the commodity prices being used in the current CGIAR Priorities and Strategies Study[2]. The estimated VOP figures rank the five crops in the order: cassava (30%), potato (30%), sweet potato (27%), yam (9%) and aroids (3%). Ranking on edible energy places cassava first (40%), followed by sweet potato (35%), potato (17%), yam (6%) and aroids (2%). However, when the energy values are adjusted for protein and indexed to cassava, sweet potato moves to the top of the list; in this ranking the value for edible aroids, albeit retaining the lowest rank, increases significantly.

Table 8: Edible Energy, Edible Protein, Edible Energy Adjusted for Protein[3] and Value of Production (VOP) of Root Tuber Crops, Rice and Wheat (1990/92)

	Edible Energy (Trillion Kcal)	Edible Protein (Million Tons)	Edible Energy Adjusted for Protein	VOP[4] (US $ Million)
Cassava	130,617	594	130,617	10,348,308
Sweet Potato	114,511	1,733	187,798	9,406,444
Potato	57,944	1,593	148,916	10,247,270
Yam	20,584	393	40,756	3,222,788
Aroids	6,826	171	32,628	1,169,021
Root Crops	**330,482**	**4,484**	**540,706**	**34,393,831**
		Cereals		
Wheat	**587,221**	**23,422**	**3,270,821**	**33,526,224**
Rice	**805,750**	**14,851**	**1,756,353**	**96,794,788**
		Rice indexed Comparisons		
Rice	**1.0**	**1.0**	**1.0**	**1.0**
Wheat	**0.73**	**1.58**	**1.86**	**0.35**
Root Crops	**0.41**	**0.30**	**0.31**	**0.36**

[2] **Based on the prices being used in the current CGIAR Priorities and Strategies Study, viz.: Wheat US$ 144 per ton; Rice US$ 292 per ton; Cassava (fresh) US$ 68 per ton; Potato US$ 110 per ton; Sweet potato US$ 76 per ton; Yam US$ 137 per ton. In the absence of published price data on edible aroids this group of crops has been assigned the same value as yam, viz., US$ 137 per ton.**

[3] **Edible Energy Adjusted for Protein (EAP): EAP = α E, where E = Edible energy (Kcal) and α = 4p/e; p and e = grams of protein (p) and food energy (e) per 100 grams of edible portion.**

[4] **The value of production data should be interpreted with caution as there is some uncertainty about the prices used.**

Of wider interest, perhaps, is the comparison of root and tuber crops as a commodity group with other staple foods such as rice and wheat. In terms of value of production (VOP), Table 8 shows that root and tuber crops on aggregate sum to 36% of the value of rice whereas wheat has a rice indexed value of 35%. In food energy terms, roots and tubers are marginally higher in relative value (41%) whereas wheat because of its higher protein content increases to 73% of the value of rice. As might be expected these differences are much more noticeable when the crops are compared on a protein adjusted energy basis. On this basis the rice indexed value of root and tuber crops drops to 31% whereas wheat increases to 186%. It is interesting to note that the estimated values of root crops relative to rice fall within a very narrow range (31-41%) irrespective of the congruent used in the comparisons.

Productivity indices. As stated earlier, priority ranking on output criteria only captures one perspective of the production process. Input costs are also critically

important, particularly in the context of a priority setting exercise which has as one of its major goals the alleviation of poverty. Comparable input costs from Africa (FAO, 1985) and South America (FAO, 1989), based on IITA and CIAT data, suggest the following average cost differentials relative to cassava, viz., cassava 1.0, potato 2.74, sweet potato 1.25, yam 3.34, and edible aroids 0.73; the South America study did not include input costs for edible aroids, but did provide estimates for rice production which would suggest a weighting of 1.5 relative to cassava costs. Applying these weights to the output data in Table 8 results in the rankings listed in Table 9.

As would be expected cassava heads the list on cost adjusted value of production and energy output terms, whereas sweet potato has highest rank on protein adjusted energy output; this simply reflects its relatively high protein content. It should be noted that, adjusting for input costs does change the relative values of the crops significantly. The aggregate cost adjusted values for root and tubers relative to rice are 0.48, 0.35 and 0.38 for Energy, Protein adjusted Energy and Value of Production respectively; these are not greatly different from the respective values in Table 8, and suggest that root and tuber crops have a value somewhere between 30 to 48% of the value of rice depending on which index is chosen for comparison. The proximity of the rice-indexed cost-adjusted

Table 9: Ranking of Root and Tuber Crops on Cost Adjusted Edible Energy, Protein Adjusted Energy and VOP (1990/92)

	Edible Energy (Trillion Kcal)	Protein Adjusted Energy (Trillion Kcal)	VOP[4] (US $ Million)
Cassava	130,617	130,617	10,348,308
Sweet Potato	91,609	150,238	7,525,155
Potato	21,148	54,349	3,739,880
Yam	6,163	12,202	964,907
Edible Aroids	9,351	44,696	1,601,399
Roots and Tubers	**258,888**	**392,102**	**24,179,649**
Rice	**537,167**	**1,170,902**	**64,529,858**
R&T/Rice	**0.48**	**0.35**	**0.38**

[4] **The value of production data should be interpreted with caution as there is some uncertainty about the prices used.**

edible energy and protein-adjusted energy values relative to value of production in dollar terms would seem to suggest that market price does reflect the nutritional value of the crops. However, it should be borne in mind that the part-whole correlations among these indices will intrinsically engender some degree of proximity between the values. It may be argued that the cost adjusted rankings, and in particular the cost adjusted energy

ranking, have greatest relevance to the poor, who on the one hand don't have the resources to engage in high input farming systems, and on the other hand have most urgent food energy and protein needs. On the other hand, value of production (VOP) as it relates to economic development also has relevance for the poor, particularly in countries where there is an equal distribution of wealth across the different sectors of society.

In addition to the costs considered above, productivity returns to land and labour should also be taken into account. Availability of land and labour are often major constraints of the poor; labour to the extent that family labour demands need to be abated to accommodate needed improvements in education standards. In this context, published rankings of some of the major food crops on Edible Energy per hectare per day (Horton, 1984), and FAO estimates of the labour demands of different food crops (FAO, 1994), are interesting. However, the basis of these calculations is not described and consequently it is difficult to decide how to use the estimates appropriately.

Another productivity parameter which may well become increasingly important in priority analysis in the future is the energy balance ratio of crop production systems, particularly in the context of the sustainable management of natural resources. Food crop production systems differ markedly in their energy balances. Leach (1976) has reported energy balance ratios (Er = $Mj.ha^{-1}$ OUT/$Mj.ha^{-1}$ IN) for a range of farming systems in the tropics and in temperate regions. Subsistence cassava (Er = 62) and rice (Er = 17.3) production systems are shown to be far more efficient in energy terms than, for example, main crop potato production in lowland Britain which has an estimated energy ratio of 1.57. Typically, energy balance ratios for tropical crop production systems involving some fertilizer inputs and machinery, range from 5 to 10. This energy balance perspective has relevance to long-term research priorities, which in the context of sustaining natural resources may dictate greater emphasis on the photosynthetic capture of C_4 crops and the genetic manipulation of germplasm to enhance pest and disease resistant capacity, thereby reducing the need for pesticide and herbicide inputs.

Demand perspectives: Finally, demand side perspectives should also be considered in priority setting judgements. In this context, it must be recognized that root and tuber crops do not make a major contribution to the human diet on a global (developing countries) basis. Horton (1988), calculated that root and tuber crops collectively contribute 6.7% of total dietary calorie intake in the developing countries. Sweet potato (2.7%), cassava (2.1%) and potato (1.3%) contributed more than 90% of root and tuber sourced calorie intake. However, regional differences were quite large. For example, cassava accounted for 9.6% of total calorie intake in Africa and 3.7% in South America, whereas the potato contributed 2.9% of total calorie intake in Asia.

These regional differences not only reflect consumer preferences, but also agroecological and soil suitability to grow different crops. However, traditional consumer preferences strongly influence demand for foods and particularly for foods of root and tuber origin. Of important relevance to future research priorities in this context is the extent to which the continuous expansion of urbanization will effect the demand for root and tuber crops. It is argued that research and development of postharvest technologies will open up new urban markets for convenience foods based on root and tuber crops;

reference to recent developments in Asia is cited by Scott and Suarez (1993) to advance this view. On the other hand, there are a number of studies (FAO 1985) which show that the storage and marketing costs of root and tuber crops are very high compared to staple foods such as rice. At issue therefore, is the question - can postharvest research on the storage and processing of root and tubers commercially enhance these crops to more effectively compete on the urban markets. Of more immediate interest are the questions - should the CGIAR Centres expand their activities in postharvest technology; and how should this work be facilitated in partnership with the private sector which ultimately must become involved in commercial development and marketing?

The foregoing analyses and discussion provides a starting point and some instrumental perspectives on the task of determining the research priorities of root and tuber crops. Several additional judgements need to be made in the context of the CGIAR Priorities and Strategies exercise. These include considerations such as (i) Technology gap potentials, (ii) Application of existing technologies, (iii) Strength of NARS in root and tuber crop research, (iv) Comparative advantage of the CGIAR Centres, and (v) Alternative sources of technology supply. All of these considerations raise important questions that are very difficult to answer with relevant and conclusive evidence.

Further, a dimension not easily captured in a global approach to the setting of agricultural research priorities is the development dynamics of the production-consumption chain, the starting point of most priorities and strategies market research in industry. Post-factum regional statistics may capture some of the fluxes; e.g., growth in use of root crops for animal feed in China. However, emerging developments usually have their origin in localized initiatives which as they evolve develop appropriate momentum and change. Given that agricultural research priorities are all about likely future change, perhaps they are best identified in the market place, viz., from the bottom up. In this context and in hindsight, it may have been better to have undertaken this analysis on a country basis, selecting those countries that grow most and are exploiting more fully alternative uses of root and tuber crops, and sequentially develop appropriately weighted aggregate regional and global parameters and perspectives from that basis. Certainly, growth projections developed from a selected country perspective may provide better insights to potential and likely changes. On the other hand, the global projections in the FAO and IFPRI studies do not anticipate significant growth differentials among the major food crops, other than what might be expected from past trends.

REFERENCES

Berrios, D. and M. Beavogui. 1992. Trials for the Introduction of Sweetpotato in Bread Making in Burundi. *In:* Scott, G., P.I. Ferguson and J.E. Herrera (eds.) 1992. Product Development for Root and Tuber Crops. Vol. III - Africa. Proceedings of the Workshop on Processing, Marketing, and Utilization of root and Tuber Crops in Africa, held October 26 - November 2, 1991 at International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. CIP, Lima, Peru. 506p. + xxiii. pp. 373-376.

Cenpuykdee, U., C. Thiraporn, and S. Sinthuprama. 1992. Cassava Processing and Utilization in Thailand. *In:* Scott, G., S. Wiersema and P.I. Ferguson (eds.) 1992. Product Development for Root and Tuber Crops. Vol. I - Asia. Proceedings of the International Workshop held April 22 - May 1, 1991 at Visayas State College of Agriculture (VISCA), Baybay, Leyte, Philippines, sponsored by the International Potato Centre (CIP), the Centro Internacional de Agricultura Tropical (CIAT), and the International Institute for Tropical Agriculture (IITA), CIP, Lima, Peru. 384p. + xxii. pp. 51-60.

CIP. 1993. Product Development for Root and Tuber Crops. Volumes I, II and III. Edited by Scott, G.J., S. Wiersema and P.I. Ferguson. CIP, Lima, Peru.

Damardjati, D.S., S. Widowati, T. Bottema and G. Henry. 1994. Study on Cassava Flour Processing and Marketing in Indonesia. Paper presented at International meeting on cassava flour and starch, CIAT, Cali, Colombia 11-15 January 1994.

Dorosh, P. 1988. The economics of root and tuber crops in Africa. RCMP Research Monograph, IITA, Ibadan, Nigeria.

FAO, 1985. Report of the Workshop on Production and Marketing constraints on Roots, Tubers and Plantains, Kinshasa, Zaire, 1985.

FAO, 1989. Roots, tubers and plantains in food security. FAO Economic and Social Development Paper No. 79.

FAO, 1990. Roots, Tubers, Plantains and Bananas in Human Nutrition. FAO Food and Nutrition Series: No. 24.

FAO, 1992. The World Sweet Potato Economy. Published by the Commodities and Trade Division, FAO, Rome.

FAO, 1993. Agriculture: Towards 2010. FAO, Rome.

FAO, 1994. Medium-Term Prospects for Agricultural Commodities Projections to the year 2000.

FAO, 1994. Tropical root and tuber crops: Production perspectives and future prospects. FAO Plant Production and Protection Paper, No. 126. FAO, Rome.

FAO/CIP, 1995. Potatoes in the 1990s: Current Status and Future Prospects of the World Potato Industry. (In press).

Gitomer, C. 1994. Potato and Sweetpotato Production in China: Systems, Constraints, and Potential. (In press).

Henry, G. and V. Gottnet. 1995. Global cassava sector trends: Reassessing the crops future. CIAT internal cassava programme paper, 1995.

Horton, D. 1988. Underground Crops: Long-term trends in production of roots and tubers. Winrock International, Morrilton, AR, USA.

Horton, D. and H. Fano. 1985. Potato Atlas. International Potato Center (CIP). Lima. Peru.

Kay, D.E. 1973. Root Crops. Tropical Products Institute, London.

Leach, G. 1976. Industrial energy in human food chains. In Food Production and Consumption: the efficiency of human food chains and nutrient cycles. Ed. by A.N. Duckham, J.G.W. Jones and E.H. Roberts. North Holland Publishing Company. 1976.

Odaga, A. and R. Wanzie. 1992. The Use of Sweetpotato in Bakery Products in Cameroon. *In:* Scott, G. P.I. Ferguson and J.E. Herrera (eds.) 1992. Product Development for Root and Tuber Crops. Vol. III - Africa. Proceedings of the Workshop on Processing, Marketing, Utilization of Root and Tuber Crops in Africa, held October 26 - November 2, 1991 at International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. CIP. Lima, Peru. 506p. + xxiii.

Rosegrant, M.W., Mercedita Agcaoili - Sombill and Nicostrato, D. Perez (1995). Global Food Projections to 2020: Implications for Investment. IFPRI Draft Food Agriculture and the Environment Discussion Paper, 2020 Vision.

Scott, J.S. and V. Suarez, 1993. Transforming Traditional Food Crops: Product Development for Roots and Tubers. Proceedings of an International Workshop on Root and Tuber Crop Processing, Marketing and Utilization in Africa. Published by the International Potato Centre (CIP), Lima, Peru. 1993

Wheatley, C.C. and G.J. Scott, 1994. Global Markets for Roots and Tubers in the 21st Century. Proceedings of the Tenth Symposium of the International Society for Tropical Root Crops (ISTRC)l, Brazil. November 1994.

APPENDIX 5

AIDE-MEMOIRE

OVERVIEW OF RESEARCH ON ROOT AND TUBER CROPS CONDUCTED OUTSIDE THE AMBIT OF THE CGIAR

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The CGIAR centres are but one set of international Institutes engaged in research on root and tuber crop production and processing. Perusual of the Annual Reports of CIAT, CIP and IITA immediately identifies a set of Advanced Research Institutes and University Departments (both in industrial and developing countries) that are actively collaborating with the Centre in the conduct of joint and/or contract research programmes; these programmes are usually focused on strategic research topics which require advanced laboratory skills and equipment in the fields of genome mapping, gene expression, virus studies and other biotechnology developments.

However, it is also widely evident and recognized in the scientific literature that the root and tuber crop research 'campus' embraces a broad range of national research institutes across the developing world, working in collaboration with (via networks) or independently of the CGIAR centres. Many of these institutes seek support from bilateral funding agencies and very often develop research partnerships with advanced research organizations in the donor country.

An attempt has been made to 'survey' the nature and scope of research on tropical roots and tuber crops being undertaken by various agencies outside the CGIAR. Two approaches have been followed. Firstly, the major donor agencies, known to support agricultural research, were requested to provide summary information on the tropical root and tuber crop research programmes which they support and/or collaborate in. A summary of their responses is presented below. Additionally, searches were made in four project inventory data bases as available in the FAO Library, viz., the CRIS, ARRIP, SPAAR and AGREP research inventories of current research projects. The results of these searches are also summarized below.

BILATERAL RESEARCH SUPPORT TO ROOT AND TUBER CROP RESEARCH

Seven funding agencies prominently recognized to be engaged in bilateral support to agricultural research were requested to provide information on their involvement in root and tuber crops research[1/]. Additionally, five relevant regional research organizations, viz., AVRDC, CARDI, CATIE, CGPRT and ICOMOD were also convassed for information on their involvement in root and tuber crop research. Seven responses were received and are summarized below:

ACIAR

The Australian Centre for International Agricultural Research (ACIAR) supports a limited amount of research on root and tuber crop production, largely in the Asia/Pacific region.

1/ The bilateral agencies contacted include: ACIAR, CIRAD, IDRC, GTZ, JICA, ODA and US-AID.

Current and recent projects include: (i) Sweet potato pathogen tested germplasm for the South Pacific (Aus$ 205 065: 3 years); (ii) Sweet potato improvement (Aus$ 527 309: 3 years); (iii) The cause and control of Kava wilt disease in the South Pacific (Aus$ 221 578: 3 years); (iv) Cassava Cyanide: improved techniques for estimation and influence of environment on concentration (Aus$ 137 252: 2 years); (v) The cause and control of Kava die back in the South Pacific (Aus$ 404 500: 3 years) and (vi) Diagnosis and correction of mineral nutrient disorders of root crops in the Pacific (Aus$ 443 224: 3 years).

Four of the six research projects are focused on root crop production in the island countries of the Pacific (eg., Fuji, Tonga, Papa New Guinea, Solomon Islands), whereas the Cassava (Nigera, Philippines and Indonesia) and sweet potato improvement (Philippines, Thailand, Indonesia and Sri Lanka) projects have broader geographical relevance. All six projects are implemented in collaborative partnerships involving Advanced Research Institutes/University departments in the host country and National Research Institutes/Universities in the target countries. IITA is named as a collaborator in the Cassava cyanide project, and CIP in the sweet potato improvement project.

CIRAD

Since the 1970's CIRAD has been working on yam, taro cassava and potato research, embracing agronomy, mechanization and post harvest technology studies. It's roots and tuber research programmes extend to West Africa, Asia and Latin America. CIRAD has quite an extensive research programme in West Africa embracing varietal improvement, crop protection and agronomy; it collaborates with IITA and IIRSDA on yam and with IDESSA on cassava research. CIRAD's work on yam has been intensified due to the expanding cultivation of yam with industrial crops (coffee and cocoa). It's research on yam harvesting in collaboration with CIMA (Centre Ivoirien due machinisme agricole) has resulted in the development of yam harvesting and residue filtering machines. CIRAD is also active in cassava processing and in the biochemistry of cassava flour and starches. CIRAD is a member of the CORAF cassava network and of the steering committee of the West African Yam Network.

In Latin America, CIRAD is active in the fields of mechanization and post harvest technology and has developed close collaboration with CIAT, University del Valle (Colombia), UNESP (Brazil) and UBA (Argentina).

CIRAD is also active in root and tuber research in Asia, particularly in cassava processing (Thailand) in collaboration with private industry. It sponsors a large programme on yam, taro, sweet potato and cassava in New Caledonia embracing germplasm enhancement and production systems research.

CIRAD research on tropical root and tuber crops is conducted within the Annual Crops Department which has a budget of more than 210 million F Fr (CIRAD, AR 1992). Its research activities on roots and tubers as summarized above involved a total of 23 scientists over the past five years. Clearly CIRAD devotes significant resources to research on root and tuber crops.

ODA

ODA sponsors a significant programme of research on tropical roots and tubers, principally via its research arm NRI, the Natural Resources Institute. NRI directly supports fundamental strategic research on roots and tuber crops through contracts with advanced research organizations. Current contracts include: (i) Gene transfer and expression in cassava (Long Ashton Research Station, £ 43 625); (ii) Incorporation of insect resistance genes into potato (Agricultural Genetics Company, £ 219 111); (iii) Transformation of sweet potato with combinations of cowpea trypsin inhibitor, wheat alpha-amylase inhibitor, snowdrop lectin and bean chitinase genes. (Agricultural Genetics Company, £ 276 189); (iv) Invitro Plant Regeneration in Cassava. (Bath University, £ 236 052); and (v) Restriction Fragment Length Polymorphisms in Cassava. (New Castle University, £ 183 369). NRI also directly supports joint ARO/CGIAR strategic research projects (hold back projects) involving CIP, IITA and CIAT, which over the past five years involved NRI support in the order of £ 1.2 million pounds sterling. The research foci of these projects included Bacterial wilt and Leafroll virus control in potatoes (CIP/Rothanstead/SCRI), Conservation of pathogen free yams (IITA/Wye College), Somatic Embryogenesis in Potato (CIP/SCRI), Yellow Vein, Sago and Kully Ongoy diseases of potato (CIP/Columbia NARs and PROINPA) and virus diseases in sweet potato (CIP/Uganda NARs).

NRI also supports applied/adaptive research and network activities in Africa and Latin America. A total of 24 research projects have been supported in recent years, largely in collaboration with NARs. The bulk of these projects address post harvest technology research issues. NRI funding inputs are not specified in the project protocols; NRI annual scientific staff inputs are listed and total 375 m/m over the 24 projects.

AVRDC

The Asian Vegetable Research and Development Centre (AVRDC) no longer engages in root and tuber crop research following the transfer of its mandates on white potato research to CIP in 1979 and sweet potato research to CIP in 1991. AVRDC transferred its sweep potato germplasm collection to CIP in 1993. Its root crop research is now confined to the bulb Allium (onion, garlic and scallot) which is not included in the CGIAR portfolio of root and tuber crops.

CARDI

CARDI attaches high priority to root and tuber crop research, largely because of the resistance of these crops to withstand tropical storms and hurricane damage in the Carribbean regions. Major research trusts, as outlined in CARDI's MTP, focus on yam, sweet potato, cassava and edible aroids and embrace: (i) Characterization and evaluation of germplasm; (ii) Maintenance, multiplication and distribution of elite germplasm; (iii) Pest and disease management; (iv) Production systems research and (v) Product development.

Current research projects are listed as follows: (i) Development of an efficient, internationally competitive yam production and marketing system (172 SSM: 4 years); (ii) Improvement of production and marketing systems of sweet potato in the region (135

SSM: 4 years), and (iii) Improvement of quality and availability of Aroids (Tannia, Dasheen and Eddoe) in the region (97 SSM: 4 years). The budgeted cost of these three projects is $ 104 000 p.a. approximately. Projects on cassava and sweet potato germplasm conservation, yam virus diseases, sweet potato weevil and tissue culture studies are also reported, but it is difficult to gauge the scale of this work.

CARDI's work programme and estimates of expenditure for 1993/94 shows an annual expenditure of US$ 392 845 on root crops research.

CATIE

CATIE's work on root and tuber crops is limited both in scale (US$ 10 000 p.a. approximately) and focus (clonal evaluation and germplasm conservation). The research programme objective is to evaluate different varieties within the cropping systems of the major agro-ecologies of its member countries. Most of its work in this area is undertaken in close collaboration with CIAT and CIP. The centre also collaborates with national programmes in research on the management and establishment of germplasm multiplication and distribution systems.

CGPRT

The Regional Co-ordination Centre for Research and Development of Coarse Grains, Pulses, Roots and Tuber crops (CGPRT) in the humid tropics of Asia and the Pacific supports a range of information dissemination and research activities in the Asian region. Currently, the centre supports one large research project, viz., Market development of root crops in Asia and the Pacific (ROTMA). This project involves China, Indonesia, Papua New Guinea and Vietnam and has stated objectives, viz., (i) To increase, on a pilot basis, efficiency of root crop markets through the effective flow of market information, and the introduction and transfer of appropriate post-harvest technologies, (ii) Promoting small and medium-scale processing industries, by providing information on markets and investment opportunities regarding root crop products and their uses, and (iii) Improved income of the rural population dependent on production, processing and trade in root crops. CIAT and CIP are mentioned as collaborators in this project which has a budget of US$ 1 450 000. The project is scheduled to commence in 1995.

ROOT AND TUBER RESEARCH PROJECTS LISTED IN AGREP, ARRIP, CRIS AND SPAAR

Based on the keywords tropical root and tuber crops, searches of four project inventories in the FAO David Luben Memorial Library, listed a total of 266 research projects. These inventories provide information on project title, name and address of the senior author together with a brief description of the projects aims and objectives; information on funding source and/or involvement of international research agency support is indicated, but without reference to the scale of funding involved. The projects are not classified and were listed in country sequence order.

Perusual of the project titles and stated objectives facilitated a categorization of the projects by commodity and research activity. The classification is summarized in Table 1.

Table 1: Classification of Research Projects Listed in the AGREP, ARRIP, CRIS and SPAAR Project Inventories, by Commodity and Research Activity.

Crop	Number of Projects
Cassava	82
Potato	52
Sweet Potato	105
Yam	27
Total	**266**
Research Activity	
Germplasm Conservation	11
Germplasm Enhancement	57
Biotechnology	26
Plant Protection	47
Crop Production	58
Post Harvest Technology	64
Economics	3
Total	**266**

Across the four inventories sweet potato projects featured most prominently and yam research was least evident. The dominance of sweet potato research emerged almost exclusively from the North American CRIS inventory. A close look at the entries shows that practically all of the Southern and Mid-Western State Universities in the USA report research activities on sweet potato; the most prominent being the Universities of Louisiana, Georgia, Arkansas, Florida, Texas and North Carolina; research on post-harvest technology was dominant among the research themes reported.

In contrast, research on cassava and yam was most prominent in the SPAAR data base. A closer look at the entries showed that many of these research projects were conducted by scientists at the National Research Institutes and all were externally funded. The International Science Foundation featured strongly as a donor. As would be expected the AGREP and ARRIP inventories featured European and Australian support to research on tropical roots and tubers, respectively.

Perhaps, of greatest note is the dominance of post harvest technology research which accounted for 24% of all entries. Within this subset of research projects, activities ranged from mechanization of root crop harvesting to problems of root crop storage to product development and marketing. A high proportion of the projects reported

addressed problems of root crop storage. As might be expected germplasm enhancement (22%), crop production (22%) and plant protection (17%) also accounted for large shares of the database entries. Surprisingly, very few of the projects related to the economics of root crop production.

OVERALL COMMENT

What does this information tell us as regards research on tropical root and tuber crop production, and more importantly, is it of any benefit to the Inter-Centre Review Panel as it attempts to plot a prioritized agenda for roots and tubers research in the CGIAR? In brief, the information summarized above is not of great benefit to this exercise. On the one hand, the information is incomplete; it certainly does not reflect the extent and range of research on root and tuber crops being conducted across the developing countries. A quick glance at the literature references in publications such as the recent CIP Compendum "Product Development for Root and Tuber Crops", Vols I, II and III, confirms this view. A second limitation is that the information extracted from this type of exercise gives little or no indication of the scale or depth of research reported. A more serious limitation is that it does not convey any impression of the status or "state of the art" of the research being conducted in each of the fields of study. This type of information requires a thorough and systematic review of the literature across each of the relevant research activities. Most likely the CGIAR centres have this information in their archives, in that it is the "norm" in the development of research initiatives to firstly review work already published.

It nothing else, these exercise prompts one suggestion. That is, that the centres might be requested to formally develop global data bases of all on-going research on roots and tubers and to periodically synthesise this information in terms of "state of the art" review papers in each of the relevant fields of research. In the context of current developments in information technology and database management it is now relatively easy to "tap into" existing databases and globalize the information. Perhaps the CGIAR centres should take the first step in this direction by defining regional and global database configurations that would serve not only their own needs, but also those of their NARs partners. It is quite evident from this overview that a lot of research on tropical root and tuber crops is being conducted outside the CGIAR. If research on potato production in the temporate regions were included the magnitude of the research base would increase dramatically. Clearly there is a need to capture this information more comprehensively so as to better plot the CGIAR research agenda in the context of what other researchers are doing. The development of a global project inventory would be a good beginning in this direction.

APPENDIX 6

LIST OF ACRONYMS

ACMV	African Cassava Mosaic Virus
ARO	Advanced Research Organization
CIAT	Centro Internacional de Agricultural Tropical
CGIAR (CG)	Consultative Group on International Agricultura Research
CIP	Centro Internacional de la Papa
COSCA	Collaborative Study of Cassava in Africa
DNA	Deoxyribonucleic Acid
EPMR	External Program and Management Review
FAO	Food and Agricultural Organization of the United Nations
IARC	International Agricultural Research Center
ICRT	Inter-Centre Review of Root and Tuber Crops Research
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
INIBAP	International Network for Improvement of Banana and Plantain
IPM	Integrated Pest Management
IPGRI	International Plant Genetic Resources Institute
IPR	Intellectual Property Rights

ISNAR	International Service for National Agricultural Research
MOU	Memorandum of Understanding
NARS	National Agricultural Research System(s)
NGO	Non-Governmental Organization
TAC	Technical Advisory Committee, CGIAR
U.S.A.	United States of America

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